Effective asset management meeting future challenges

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SABARIS
Stakeholder benefits and road intervention strategies

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Executive Summary

The project “Stakeholder Benefits and Road Intervention Strategies” (SABARIS) is a two years project conducted between September 2010 and August 2012 for the ENR2 programme “Effective Asset Management Meeting Future Challenges”. SABARIS addresses the challenge of road agencies of selecting an intervention strategy for a particular link of a road network that is optimal taking into consideration the varying and sometimes conflicting values of road impacts for the stakeholders of this road link. The main objective of SABARIS is to support this decision making at road agencies by:

- identifying the stakeholders of road links,
- determining the road impacts on stakeholders,
- determining ways of engaging the stakeholders in impact determination,
- analysing the valuation of road impacts by stakeholders,
- assessing the impact of the valuation of impacts on the optimality of intervention strategies for roads, and
- providing a guideline and tools for the stakeholder oriented optimisation of road intervention strategies.

Based on a comprehensive literature study and two in-depth case studies in the Netherlands and Belgium SABARIS achieved its objective by producing a number of results that will be of immediate use to infrastructure managers in European road agencies:

- **Guideline for stakeholder oriented optimisation of road intervention strategies**
  The guideline describes a 7-step process road agencies should follow when determining the optimal intervention strategy for a road link taking the valuation of road impacts by stakeholders into account.
- **List of road stakeholders**
  The list of road stakeholders helps road agencies in identifying critical stakeholders of a particular road link. It categorizes road stakeholders into four groups: directly affected stakeholders, indirectly affected stakeholders, directly affecting stakeholders, and indirectly affecting stakeholders.
- **Impact hierarchy**
  The impact hierarchy helps road agencies in defining the impacts to be considered when defining intervention strategies and can assist in determining the information needed for the valuation of the impacts. It subdivides road impacts on stakeholders (e.g. safety, travel time, comfort) at increasingly fine levels until impacts can be reasonably and objectively quantified and modelled.
- **Stakeholder survey**
  The stakeholder survey helps road agencies in revealing the importance of road impacts to stakeholders and the expectations, experiences and satisfaction of stakeholders related to an intervention project.
- **Importance-satisfaction rating/matrix**
  Importance-satisfaction rating and matrix help road agencies in determining the intervention priorities of road impacts by relating the importance of road

impacts to stakeholders and the satisfaction of stakeholders with these impacts.

- **Expectancy (dis)confirmation diagram**
  The expectancy (dis)confirmation diagram helps road agencies in determining the combined influence of stakeholder expectations and experience on the satisfaction of stakeholders with intervention projects.
- **List of engagement strategies**
  The list of engagement strategies provides road agencies with an overview of possible ways to influence stakeholder expectations about and experience of intervention projects and, by doing so, to attain satisfied stakeholders.
- **Optimisation tool**
  The optimisation tool is a simple prototype of an user-friendly interface which allows to estimate the optimal intervention strategy for a road link based on a deterministic optimisation model. Results of estimation can be recorded on screen or into flat files and being used in other software for graphical demonstration.

The two case studies in the Netherlands and Belgium were used to develop and test the aforementioned guideline and tools. Important insights generated by the case studies are:

- There are road impacts that can be important to all stakeholders such as safety, travel time, economy and comfort,
- The importance of road impacts between stakeholder groups can differ, for example emissions is particularly important to residents,
- Stakeholder experiences are more important for the satisfaction with an intervention project than expectations,
- Satisfaction with the outcomes of an intervention project determines the overall satisfaction with the project,
- The stakeholder management strategy has an effect on the satisfaction of road stakeholders with an intervention project,
- An optimal intervention strategy does not guarantee satisfied stakeholders,
- An intervention strategy that is optimal during intervention is not necessarily the optimal intervention strategy over the whole infrastructure life cycle, and
- The optimal intervention strategy depends on impact values and model parameters used.

Although SABARIS was able to address the stakeholder-oriented optimisation of road intervention strategies in a comprehensive way, a number of recommendations can be made for future activities:

- Allow road agencies to experience the possibilities of guideline and tools,
- Refine the questionnaire for revealing the satisfaction with road impacts,
- Collect more data on the expectation, experience and satisfaction of road stakeholders,
- Determine the effectiveness of stakeholder engagement strategies,
- Improve the reliability of the input parameter for the optimisation model, and
- Develop a sophisticated user interface for the optimisation tool.

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1 Introduction

1.1 Background

Road networks are essential to the functioning of modern society. The levels of service they provide strongly affect the distribution of resources and goods, the accessibility and economic development of regions and the mobility of citizens. Since roads, including all of the objects of which they are composed (e.g. pavement, bridges, and tunnels) deteriorate over time due to environmental factors and use, and the required levels of service, in general, either increase or remain constant, the road sections must be maintained by executing interventions (e.g. asphalt crack sealing and chip sealing of pavement, painting or replacing the girders of a steel bridge).

There are an extensive number of possible intervention strategies (e.g. the types of interventions to be executed and the time of execution) that road agencies may use to ensure that roads continue to provide an adequate level of service. The decision of the intervention strategy to be followed is often based solely on owner costs, i.e. it is determined to be the one that results in the lowest costs for the owner of the road (e.g. national government). An illustrative example of the owner costs of two possible intervention strategies is shown in Figure 1, where the first strategy consists of more frequent less expensive interventions and the second strategy consists of less frequent more expensive interventions.

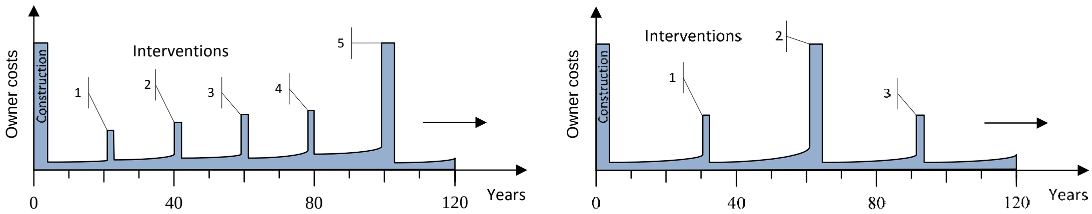


Figure 1 Two example intervention strategies

Road owner costs, of course, are not the only impact that need to be taken into consideration when determining optimal strategies. Almost every intervention on a road affects the amount with which society benefits from the transportation network to which the road belongs. Normally, benefits decrease during the intervention and increase after interventions. For example, during the intervention there may be an increase in travel time due to the traffic jams resulting from closing two lanes on a four-lane highway, or an increase in noise to those living next to the road section, or an increase in CO_2 emissions that may negatively impact the climate or the health of persons in the immediate vicinity of the road section. Between interventions there may be lower routine maintenance costs and a decrease in vehicle operating costs. The impact of a road link on stakeholders, both during and between interventions, should be taken into consideration when determining optimal intervention strategies to ensure the maximal societal benefit from the transportation network.

Since the consideration of all of the road impacts in the determination of optimal intervention strategies requires the valuation of many impacts that are not naturally in monetary units (e.g. noise costs, CO_2 emission costs, and accident costs), the value of these units depends greatly on the utility functions of the affected stakeholders (individuals and organisations). It is expected that the variations in these values, especially in the cases of conflicting values, have a significant effect on the optimality of intervention strategies, and that the variations are significant between road types (e.g. motorways, rural roads) and between stakeholders (e.g. road users, road neighbours). As public-oriented network managers road agencies need to know the varying and conflicting valuation of stakeholders' requirements and consider them when deciding on the optimal intervention strategies. Central questions in this regard are:

- *Who are the stakeholders of a particular road link?*
- *How do stakeholders affect and are affected by a road link?*
- *How do stakeholders value the impacts of a road link?*
- *Which intervention strategies are optimal for the likely values of these impacts?*
- *How can optimal intervention strategies be selected taking into consideration the variation in of these values, especially in the case of conflicting values?*

1.2 Objectives

The research project "Stakeholder Benefits and Road Intervention Strategies (SABARIS)" contributes to the objective A) "Meeting stakeholders' requirements and expectations" of the ENR2 research programme "Effective Asset Management Meeting Future Challenges". It addresses the challenge of road agencies of selecting an intervention strategy for a particular link of a road network that is optimal taking into consideration the varying and sometimes conflicting values of road impacts for the stakeholders of this road link.

The objective of the project SABARIS is to support this decision making at road agencies and provide answers to the aforementioned questions by:

- identifying the stakeholders of road links,
- determining the road impacts on stakeholders,
- determining ways of engaging the stakeholders in impact determination and in the communication to them that their concerns are being considered and managed,
- analysing the valuation of road impacts by stakeholders,
- assessing the impact of the valuation of impacts on the optimality of intervention strategies for roads, and
- providing a guideline and tools for the stakeholder oriented optimisation of road intervention strategies.

Although the determination of optimal intervention strategies has been studied extensively by others, the total impact of a road link and its effect on the optimality of interventions has not been investigated. Moreover, the differences and possible variations in the valuations of the impacts that are not naturally in monetary units have not been included. The innovativeness of this research project lies in the optimisation of intervention strategies taking into consideration the varying valuation of the individual and overall impacts for multiple stakeholders of road links.

1.3 Methodology

For the collection of data and the development of tools the SABARIS project makes use of a number of methods:

Literature study

A comprehensive literature review is conducted including scientific as well as professional literature. The literature review aims at:

- Identifying stakeholders of road networks,
- Developing an overview of road impacts and stakeholder engagement strategies,
- Investigating the relationship between stakeholder expectation, experience and satisfaction, and
- Studying and comparing existing models used in optimisation of road intervention strategies.

Case studies

Two case studies are an important data source of the SABARIS project. The cases comprise intervention projects carried out in 2011 on the highway A20 in the Netherlands and on the highway E17 in Belgium. In both cases the intervention took place on a highway link located in an urban area (Rotterdam and Gent) with a number of stakeholders affected by the intervention project. The case studies are used to:

- Collect information about the valuation of road impacts by stakeholders,
- Determine the project expectations, experiences and satisfaction of stakeholders,
- Reveal the engagement strategies applied by the road agencies,
- Determine the optimal intervention strategy for the two highway links based on the interventions carried out, and
- Develop and test guideline and tools developed.

During the case studies the SABARIS consortium worked very closely with the project teams of the agencies responsible for the intervention. That did not only include the collection of project information but also the presentation and discussion of the case study results. The Dutch case study was presented on 22 November 2011 at the Dutch Road Agency (Rijkswaterstaat) in Rotterdam. The Belgian case study was presented on 02 March 2012 at the Flemish Road Agency in Brussels.

Workshop

The SABARIS project is striving for a guideline and tools that are applicable in daily practice and processes of road agencies. On 13 September 2012 a workshop with 12 practitioners from the Dutch Road Agency (Rijkswaterstaat) was held in Den Haag to present and discuss the results of the SABARIS project (see APPENDIX 26). Practitioners were asked to evaluate the project results in terms of the value for their daily work and the possibility to implement the results at a road agency like Rijkswaterstaat.

Project meetings

The SABARIS consortium had 5 project meetings approximately every 5 months. At the two days meetings the consortium discussed the progress of the project, brought results together, developed ideas for guideline and tools, and planned the work for the upcoming period. Between meetings the consortium had contact via e-mail, telephone and video conference.

1.4 Scope

The SABARIS project focusses on the stakeholder oriented optimisation of road intervention strategies. Although the project provides general overviews of stakeholders, road impacts and optimisation models, it is not feasible to investigate all possible stakeholders, road impacts and optimisation models in the case studies. In addition, it is not possible to include all road and intervention types in the research. The main focus of SABARIS is on the development of guideline and tools and their application is exemplified in two cases. The following delineations are made:

- Guideline and tools are developed for the stakeholder oriented optimisation of intervention strategies for a road link. A road link is considered as a connection between two intersections of a road network consisting of at least two different types of assets (e.g. pavement and bridge).
- The optimisation includes all interventions that influence the valuation of road impacts by re-establishing the function or performance of a road link without fundamentally changing the structure and traffic pattern of the road link. This includes interventions such as the resurfacing of pavement or the replacement of crash barriers. It does not include, for example, road lane extensions.
- The two case studies focus on highway links in urban areas. Both highway links are located in densely populated areas and are highly frequented. That allows the consideration of different types of stakeholders such as road user, residents and companies. Moreover, by investigating two similar cases it is possible to draw more general conclusions and reveal those factors that may explain differences between the two cases. Of course, with only two cases the generalisation to other road contexts (e.g. rural areas) remains limited.

1.5 Structure of the report

In chapter 2 of the report the guideline for stakeholder oriented optimisation of road intervention strategies is presented. The guideline describes the steps road agencies should follow when optimising intervention strategies based on the valuation of road impacts by stakeholders. It also refers to the tools road agencies can use while optimising interventions strategies. In chapter 3, 4, 5 and 6 steps and tools and their application are further elaborated. Chapter 3 discusses the identification of stakeholders and presents a list of road stakeholders. Chapter 4 concentrates on stakeholder analysis, provides a hierarchy of road impacts and explains importance-satisfaction rating and matrix and expectancy (dis)confirmation diagram. Chapter 5 deals with stakeholder management and offers a number of strategies to engage with road stakeholders. In chapter 6 the optimisation model is developed and the optimisation tool is introduced. Chapter 7 and 8 present the results of the two case studies. In chapter 9 both cases are compared and the main insights generated by the cases are discussed. Chapter 10 draws general conclusions of the SABARIS project and gives recommendation for future research activities.

2 Guideline for Stakeholder Oriented Optimisation of Road Intervention Strategies

The SABARIS project developed a guideline for stakeholder oriented optimisation of road intervention strategies (Figure 2). This guideline describes the process steps road agencies should follow when determining the optimal intervention strategy for a road link taking the valuation of road impacts by stakeholders into account.

An optimal intervention strategy is applied if road stakeholders experience the lowest impact or the highest benefit from a road link. That includes that (1) the total costs incurred to stakeholders are the lowest compared to other strategies and that (2) stakeholders perceive benefits from the execution of the strategy, or that they are satisfied with the interventions applied to the road link.

The different process steps are guided by main questions and supported by a number of tools helping in answering these questions. This chapter briefly describes process steps and tools which are further elaborated in chapter 3-6 and applied in two case studies in chapter 7-8 of the report.

Step 1: Stakeholder Identification

The starting point of the process is the identification of stakeholders of a particular road link. Knowing the stakeholders of a road link is the prerequisite for defining an intervention strategy that considers the impact of the road link on these stakeholders. Each road link can have different stakeholders (e.g. road users, residents) depending on the location of the road link (e.g. urban or rural area) and the importance of the road link in the entire network (e.g. primary or secondary road). The guiding questions is: Which individuals and/or organisations affect or are affected by the road link? Our list of road stakeholders can help in revealing critical stakeholders of a particular road link (Chapter 3).

Step 2: Stakeholder Analysis I

After knowing the stakeholders of a road link the next step is analysing the valuation of road impacts by these stakeholders and the satisfaction of stakeholders with road impacts. That requires the definition of road impacts and the level of impact detail that will be included in the analysis. To support this decision the SABARIS project provides an impact hierarchy which shows the main impacts a road can have on stakeholders (e.g. safety, travel time, comfort) and which offers a further break down of the impacts (e.g. impact of an accident on vehicle damage, injuries, fatalities) (Chapter 4). A stakeholder survey can be used to answer the questions: How important are impacts of the road link to stakeholders? How satisfied/dissatisfied are stakeholders with road impacts? Such a survey will reveal those road impacts that are important to stakeholders but that stakeholders are dissatisfied with. These impacts should get high priority during optimisation of the intervention strategy. The importance-satisfaction rating and the importance-satisfaction matrix are tools that can help in determining the priority of road impacts (Chapter 4).

Process Steps	Guiding Questions	Supporting Tools	Reference
Road link: 1.Stakeholder identification	Which individuals and/or organisations affect or are affected by the road link?	List of road stakeholders	Chapter 3
2.Stakeholder analysis I	How important are impacts of the road link to stakeholders? How satisfied/dissatisfied are stakeholders with road impacts?	Stakeholder survey Impact hierarchy Importance-satisfaction rating Importance-satisfaction matrix	Chapter 4
3.Intervention optimisation I	Which intervention strategy creates the maximum net positive impact to stakeholders of the road link?	Intervention optimisation tool	Chapter 6
Intervention project: Planning: 4.Stakeholder analysis II	What are expectations of stakeholders about the specific intervention project on the road link?	Stakeholder survey Stakeholder map	Chapter 4
Execution: 5.Stakeholder engagement	What are appropriate measures to influence stakeholders' expectations and experiences about the specific intervention project?	List of engagement strategies	Chapter 5
Evaluation: 6.Stakeholder analysis III	What are the experiences of stakeholders with the intervention project? How satisfied/ dissatisfied are stakeholders with the specific intervention project?	Stakeholder survey Expectancy (dis)confirmation diagram	Chapter 4
7.Intervention optimisation II	Which intervention strategy creates the maximum net positive impact to stakeholders of the road link?	Intervention optimisation tool	Chapter 6

Figure 2 Guideline for stakeholder oriented optimisation of road intervention strategies

Step 3: Intervention Optimisation I

With the information about impact valuation and satisfaction the following question can be answered: Which intervention strategy creates the maximum net positive impact to stakeholders of the road link? The identification of the optimal intervention strategy for a specific road link requires a number of inputs such as:

- the current condition of the road link objects (e.g. pavement, bridges),
- the condition of the objects when interventions are needed,
- the type of interventions that are applied to improve the condition of the objects,
- the condition of the objects after interventions are applied,
- the costs of executing the interventions,
- the traffic management measures taken during interventions (e.g. rerouting, lane reduction),
- the traffic situation on the road link between and during interventions, and
- the unit costs for road impacts (e.g. the costs per accident).

Different combinations of interventions and traffic management measures will lead to different intervention strategies. The strategies can be compared with each other by using the developed optimisation model/tool (Chapter 6) which determines the time of interventions that incurs the lowest total costs or provides the highest benefit for stakeholders over a certain period (e.g. 30 years). The priority of road impacts can be addressed either by including only impacts with high priority or by adjusting the unit costs for road impacts. The prototype optimisation tool can take into consideration a number of constraints such as the available budget or failure norms (e.g. the safety level).

Step 4: Stakeholder Analysis II

According to the chosen intervention strategy there are interventions to be executed at certain points in time on the road link. An intervention project temporarily reduces the performance of the road link, but with the promise of an improved performance after the intervention. In other words, stakeholders affect and are affected by the intervention project and managing the stakeholders during the project will ensure that the project can be successfully carried out. Thus, when planning an intervention project the questions should be answered: What are expectations of stakeholders about the specific intervention project on the road link? Expectations will relate to process, outcome and information provision of the project and in case of large projects they should be measured by using stakeholder surveys. For smaller projects experiences from previous projects under similar conditions can be used (Chapter 4).

Step 5: Stakeholder Engagement

Based on stakeholder expectations appropriate measures for engaging with stakeholders in the project can be identified and applied (e.g. information, participation). Expectations but also experiences of the stakeholders should be influenced in a way that stakeholders are satisfied with outcome, process and information provision of the project. Our list of engagement strategies can help in finding a suitable level of engagement and answering the question: What are appropriate measures to influence stakeholders' expectations and experiences about the specific intervention project? (Chapter 5)

Step 6: Stakeholder Analysis III

Whether stakeholders are satisfied with the intervention project should be analysed after finishing the project. The level of satisfaction indicates the appropriateness of the interventions implemented and the success of the stakeholder management. A stakeholder survey can elicit the level of satisfaction with the project. Since both expectations and experiences can have an influence on satisfaction, an expectancy (dis)confirmation diagram should relate expectations, experiences and satisfaction and reveal the extent to which expectation and experiences play a role in forming satisfaction (Chapter 4). On the one hand, this helps in confirming the applied stakeholder management measures. On the other hand, it informs future projects in similar contexts about the most effective way of engaging with stakeholders to ensure that the projects will be successful.

Step 7: Intervention Optimisation II

It is always possible and very likely that assumptions made when determining the optimal intervention strategy change. That may happen directly as an outcome of an intervention project; for example another material is used, the condition of the assets is at an unexpected level or the stakeholders are not satisfied with the project. Changes may also occur between interventions when an object deteriorates faster than expected, the available budget decreases, or road impacts get other priorities. In these cases the intervention strategy should be revised by answering the question: What is the maximum net positive to stakeholders of the road link? (Chapter 6)

In the following chapters we discuss the development and application of the process and the tools to be used in the process more in detail.

3 Identification of Road Stakeholders

3.1 What are stakeholders?

The term "stakeholder" emerged in the 1960s with the insight that the business success of an organisation depends on different individuals and groups "who can affect or are affected by the achievement of the organisation's objectives." (Freeman, 1984, p. 46). Since then a wide variety of individuals and groups have been labelled stakeholders, since their interests and relationships have been recognized as an important aspect in business decisions (Freeman et al., 2010). Figure 1 depicts typical stakeholders with which an organisation can have relationships.

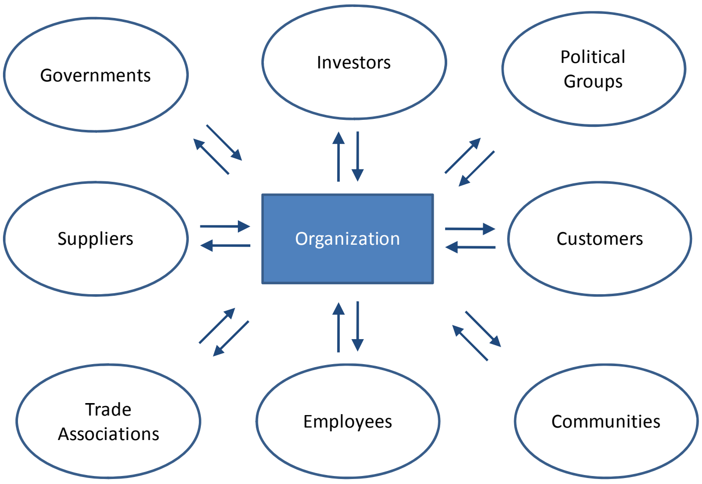


Figure 3 Typical stakeholders of an organisation (adapted from Donaldson and Preston, 1995)

However, identifying the stakeholders to be considered in the decision making seems to remain a difficult task, since the commonly used definitions are viewed as being broad and including virtually anyone (Mitchell et al., 1997). It is argued that the impact on and benefits for organisations may be of different orders of dimension among stakeholder groups, and a clear categorization may help to reduce complexity (i.e. players, conflict among players, benefit or cost components etc.). Not surprisingly, different attributes for the categorization of stakeholders are proposed. For example, Mitchell et al. (1997) suggest three stakeholder attributes for identifying stakeholders and assessing potential stakeholder influence: power, legitimacy and urgency. They define power and legitimacy as core attributes in a comprehensive stakeholder identification model and add a dynamic attribute of urgency to complete that model. A stakeholder can have the power to impose its will on the relationship. The power of stakeholders may arise from their ability to mobilise social and political forces, as well as from their ability to withdraw resources from the relationship. Legitimacy can be defined in terms of stakeholders who bear some sort of risk in relation to the organisation, be it beneficial or harmful. The dynamic character of stakeholder influence is covered by the term urgency, which is defined as the degree to which claims (or stakes) call for immediate attention. According to Mitchell et al. (1997) urgency is based on two attributes: time sensitivity or the degree to which managerial delay in attending to the claim or relationship is unacceptable to the stakeholder; and criticality or the importance of the claim or the relationship to the stakeholder. The dynamic part of urgency is that at any given time, some stakeholders will be more important than others. Concerns and priorities change over time, new classes and configurations of stakeholders appearing in response to changing circumstances (Olander, 2005).

Although such categories as suggested by Mitchell et al. (1997) might be also useful for the identification of stakeholders in road maintenance, we suggest a different perspective which puts road infrastructure as the central concept. We argue that several individuals and groups can have a stake in road infrastructure, since they are affected by and can affect the performance level of a road. The rational for taking the road as starting point for stakeholder identification is that stakeholders are roles individuals or groups play. An individual or group can take on different roles with different, even conflicting interests in road infrastructure. For example, an individual living nearby a road but also using this road combines two stakeholder roles: road neighbour and road user. Another example is a road agency which can play the role of the road owner, road manager and/or service provider. Following this perspective and on the basis of the work done by the PIARC D1 Committee work, we identified a list of four groups of road stakeholders: directly affected stakeholders, indirectly affected stakeholders, directly affecting stakeholders, and indirectly affecting stakeholders. The list can help in identifying road stakeholders of a particular road link. The four groups are further divided in several subcategories and more elaborated in the next sections.

3.2 Stakeholder groups

3.2.1 Directly affected stakeholders

The first group involves stakeholders which directly experience impacts of road infrastructure. These stakeholders benefit from an improvement of the road system, but will also immediately exposed to any performance loss. Two main categories of directly affected stakeholders can be distinguished: road users and road neighbours.

- **Road users**
  Individuals or organisations who make use of road infrastructure. They can be further subdivided into the following categories:
  - Road users related to the travel mode such as:
    - Car drivers and passengers
    - Truck drivers and passengers
    - Bus drivers and passengers
    - Cyclists
    - Motor-cyclists
    - Pedestrians
  - Road users related to the travel frequency such as:
    - Frequent users
    - Occasional users
  - Road users related to the travel purpose such as:
    - Commercial users
    - Leisure users

- **Road neighbours**
  Individuals or organisations who live or are located along or nearby a road and have direct connection (entrances, exits) to a road network. Categories of road neighbours include:
  - Residents
  - Commercial organisations such as:
    - o Retailers
    - o Industrial enterprises
    - o Farms
    - o Restaurants
  - Public communities such as:
    - o Schools
    - o Hospitals
    - o Sport clubs
    - o Administrative organisations

3.2.2 Indirectly affected stakeholders

The second group involves those stakeholders which indirectly benefit from improvements of road infrastructure, but also indirectly face any performance decrease. A general category of an indirectly affected stakeholder is the human **society** as a whole. The societal interests are often represented by different organisations such as:

- National and local governments
- Non-profit organisations
- Political parties
- Advocacy groups

3.2.3 Directly affecting stakeholders

The third group involves those stakeholders which have a direct influence on the performance of road infrastructure through their decisions and activities. Categories of directly affecting stakeholders include:

- **Road management organisations**
  Private and/or public organisations which set the policies and procedures and take decisions regarding the construction, extension, development, maintenance and/or operation of road infrastructure. They decide how and where money is spent. Road management organisations include:
  - National and local road authorities
  - Road concessionaires
- **Road service providers**
  Private and/or public organisations which schedule manpower to implement road interventions effectively and efficiently to meet defined service levels. Depending on the services that are delivered service providers include:
  - Maintenance contractors
  - Engineering firms
  - Inspection firms

3.2.4 Indirectly affecting stakeholders

The fourth group involves those stakeholders which have an indirect influence on the impacts of road infrastructure through their decisions and activities. Categories of indirectly affecting stakeholders involve:

- **Road owners**
  Public or private entities which endorses the primary responsibility for road infrastructure. They are responsible for the strategic management of the infrastructure and the allocation of budgets. Road owners include:
  - National and local government
  - Private individuals and organisations
- **Development banks**
  Financial organisations which provide the (generally developing) countries with loans to develop their economy. A part of these loans are allocated to the improvement and reconstruction of road networks, considered as an effective tool for the economic development. Loan decisions are based on feasibility studies demonstrating the relevance of the investments.
- **Shareholders**
  Private and public organisations gathering financial resources and investing them in road infrastructure. Two categories of road shareholders can be identified:
  - Those who are only expecting a financial return on their investment and manage this asset as any other investment;
  - Those who also expect an economic return, especially the large public works companies which are looking for some synergy between their financial and economic activities.
- **Insurance companies**
  Organisations which insure risks that emerge from using, owning, building, operating, and maintaining road infrastructure.

4 Analysis of Road Stakeholders

4.1 What is stakeholder analysis?

Stakeholder analysis is a common management method to understand the interest and relevance of individuals, groups and organisations for an action, project or policy.

In the context of road asset management stakeholder analysis aims at understanding the impacts of road infrastructure on stakeholders and determining the satisfaction of stakeholders with these impacts. Based on that understanding it is possible to define appropriate intervention strategies which maximize the net positive impacts (or benefits) of road infrastructure on stakeholders and eventually lead to satisfied stakeholders. Here, it should be noted that any road intervention temporarily decreases the road benefits by imposing for example traffic disturbance to the network. Why then do road interventions if road benefits cannot be fully reaped while interventions are executed? Roads deteriorate over time, which continuously reduces the benefits, for example through a reduction of speed or uncomfortable rides. Road interventions such as resurfacing asphalt layers intend to increase the net positive impact of a road on stakeholders.

Road may have a diverse and disparate set of social, economic and environmental impacts on stakeholders during and between interventions. In addition, the importance of these impacts may vary between stakeholders. In order to determine the most relevant impacts of a particular road infrastructure, the procedure in Table 1 is proposed:

Table 1 Steps and tools in stakeholder analysis

Step	Tool
1. Compiling possible impacts of the road infrastructure on identified stakeholders	Impact hierarchy
2. Collecting information about the importance of and satisfaction with road impacts among stakeholders	Stakeholder survey
3. Identifying the road impacts that need to get priority for improvement through interventions	Importance-satisfaction rating Importance-satisfaction matrix
4. Collecting information about the expectations of the stakeholders before the intervention	Stakeholder survey
5. Collecting information about the experiences and satisfaction of the stakeholders with the intervention	Stakeholder survey
6. Identifying the road impacts that need to be improved during interventions	Expectancy (dis)confirmation diagram

4.2 Understanding road impacts on stakeholders

4.2.1 Road impacts

Road infrastructure can have several impacts on stakeholders which can be either positive or negative. The main direct positive impact emerges from the function of road infrastructure which is transportation. Road infrastructure facilitates the distribution of goods and persons, the accessibility and economic development of regions and the mobility of citizens. However, with the existence of road infrastructure some unwanted side effects are generated such as the risks of accidents or the emission of noise. These negative impacts increase with the deterioration of a road and intervention projects aim at reducing them. An overall net positive impact or benefit is achieved, if the gains in terms of impact reduction exceed the costs of the intervention.

Although there are different conceptualizations of road impacts, widely accepted impacts include (Baird and Stammer, 2000; Sinha and Labi, 2007; PIARC, 2008; Adey et al., 2010):

- **Safety**

  Safety refers to the effect of road infrastructure on the risk of getting involved in an accident involving at least one vehicle and causing fatal injuries and vehicle damage.

  Safety is a main concern of directly affected stakeholders as they are the potential victims of accidents. Road users face the risk of getting involved in an accident when using a road. For residents a road can constitute a danger particularly in cases of disabled and old people getting in and out of their home or children playing along the road.

  Safety is also a concern of directly affecting stakeholders such as road management organisations, since they are in the position and have the responsibility to reduce the risks of accident. They are exposed to the public opinion expressed in media, by politics, or through advocacy groups, if not complying with their responsibility.

- **Travel time**

  Travel time refers to the effect of road infrastructure on the time spent traveling.

  Time directly relates to speed. The speed of motorized vehicles on a road is influenced by a number of factors including vehicle characteristics, road characteristics (alignment, section pavement, etc.), motorized and non-motorized traffic volume, roadside friction (e.g. bus stop, access point, etc.).

  Travel time is important to road users who may experience delays due to accidents, road works or capacity limits. As a consequence, the available time for doing business or leisure activities is lost. Users consider the road system reliable if actually experienced travel time confirms expected travel time. Travel time reliability is: “the consistency or dependability in travel times, as measured from day-to-day and/or across different times of the day” (FHWA 2006).

A direct effect on travel time is exerted by road management organisations which try to ensure a constant traffic flow and a reliable journey by looking constantly after traffic management measures to maintain the traffic flow at the optimal level in any place at any time.

- **Comfort**

  Comfort refers to the effect of road infrastructure on the quality of traveling and includes the quality of the traffic information system and the road condition.

  Comfort is an important impact to road users who physically and psychologically experience the condition of a road and the available information. Travel information deals for example with weather forecast, congestion, accidents, on-going interventions. It also includes guiding information which helps road users to find their way in an unknown or unfamiliar environment. Road neighbours also benefit from guiding information in the sense that it helps users to reach them. Quality of travel information depends on circulation, reliability, clearness and usefulness which are much influenced by road management organisations and service providers.

- **Vehicle operation cost**

  Vehicle operation cost refers to effect of road infrastructure on the consumption of fuel, lubricating oil, tires, spare parts and other material for using a vehicle, as well as the repair and maintenance of a vehicle including maintenance labour hours.

  First of all, vehicle operation and the associated costs are incurred to road users. Road management organizations and service providers directly affect vehicle costs by maintaining road infrastructure.

- **Visual quality**

  Visual quality refers to the effect of road infrastructure on the perception of its aesthetics and architectural look as well as its cleanness and integration into its surrounding.

  The quality of road landscape describes the extent to which the architectural appearance of road infrastructure fits into the surrounding as being part of our cultural identity. Cleanliness of roads can have an impact on the psychological situation of road users, both motorized and non-motorized expressed, for example, in their anxiety being involved in an accident. In towns, road neighbours are also sensitive to the aesthetic and cleanness of the street they are using several times a day or they can see from their windows.

- **Economy**

  Economy refers to the effect of road infrastructure on the economic activities in an area/region by allowing for freight transport, accessibility of firms and emergence of new business.

  Economy is one of the main reasons for building road infrastructure and it is a strong impact for commercial road users and road neighbours. Roads allow for access to premises and factories, support the transportation of goods and persons and stimulate the settlement of businesses in regions. Public institutions such as hospitals and schools take advantage of roads as well.

For financial institutions economy can also represent an important impact if they are investing in road networks to generate direct financial benefits (toll incomes) but also indirect returns, for instance due to a growth in the industrial business financed by the institution, or due to a more cost-effective industrial activity. Financial institutions expect that their investment in road infrastructure will maximize their overall profit.

- **Emissions**

Emissions refer to the effect of road infrastructure on the consequences of road traffic on the environment and include noise and particle emissions.

A rather general definition of environment is provided by the PIARC dictionary: “The circumstances, objects, or conditions by which one is surrounded”. Preserving the natural context consisting of avoiding that road transport modifies air, water, noise, fauna, and flora in a negative and (quasi-) irreversible way. In other words, it aims at limiting the direct and negative influence of human activity on the environment.

It should be noted that the term “environment” tends to be perceived differently. Administrations often associate with it technical aspects (water, air, waste, nuisance, ecosystems). The society at large tends to think of the quality of life and nature. The word often means living environment for executives and professionals, towns and traffic for artisans and traders, nature for salaried workers, pollution for industrialists, and neighbourhood for farmers.

- **Resource consumption**

Resource consumption refers to the effect of road infrastructure on the absorption of material, energy, labour for constructing, maintaining and operating road infrastructure. It can be also regarded as the required costs to have a functioning road infrastructure in place.

Resource consumption is strongly related to sustainable development which means meeting the needs of the present without compromising the ability of future generations to meet their own needs. That particular includes the preservation of (natural) resources such as quality aggregates, bitumen, but also water. Resource consumption becomes an impact which is important for the society as a whole.

Resource consumption is also related to the efficiency of an investment which is calculated as the benefit (return) of an investment divided by the cost of the investment. The benefit of the investment is the sum of the dividends produced by the investment and the profits obtained from selling the investment. This last term is in direct relation with the infrastructure value, which is partially related with the condition of the infrastructure. The amount of benefit is a probabilistic estimate. This benefit risk is depending upon the reliability of the predicted traffic, infrastructure life, and occurrence of hazardous natural events (e.g. earthquakes, flooding).

An impact hierarchy is suggested showing how impacts should be broken down at different levels (Table 2). The impacts are subdivided at increasingly fine levels until the impact of each type can be reasonably and objectively quantified and modelled. To help to ensure orthogonality in the impact hierarchy, each impact, on the lowest defined level, is explained and classified as contributing to one of the pillars of sustainability (economic, societal, environmental).

Rather than seeing the presented hierarchy as comprehensive, it should be regarded as a first attempt to systematically structure road impacts at different levels of detail. Although we intended to provide a very complete and non-redundant structure, it is possible to add further impacts or substructure existing impacts. More importantly, however, the hierarchy can help in defining the impacts to be considered when defining intervention strategies and can assist in determining the information needed for the valuation of the impacts. By estimating the impact values over time, and attributing monetary values to each unit change in the impacts, it is possible to evaluate the impacts. In addition, depending on the stakeholders identified the impacts can be grouped and related to the different stakeholders. An example of how impacts can be associated to stakeholders (based on the categorisation proposed in section 3.2) is given in APPENDIX 7.

Table 2 Impact hierarchy

Impact Level 1		Sublevel 1.1		Impact Level 2	
Label	Description	Label	Description	Label	Description
Safety	The impact of accidents			Vehicle damages	the economic impact of vehicle damages
				Injuries	the societal impact of injuries
					the economic impact of injuries
				Deaths	the societal impact of deaths
					the economic impact of deaths
Travel time	The impact of time spent traveling			Work time	the economic impact on work time availability
				Leisure time	the economic impact on leisure time availability
Comfort	The impact of travelling quality	Road quality	The impact of road quality	Physical situation	the societal impact of obtaining for example, bruises from an extremely bumpy ride
				Psychological situation	the societal impact of having, for example, anxiety due to a perceived increase in the probability of being involved in an accident
		Information quality	The impact of information quality	Psychological situation	the societal impact of having, for example, anxiety due to a perceived increase in the probability of getting lost
Vehicle operation cost	The impact of vehicle operation cost			Operation cost	the of economic impact consuming fuel lubricating oil, tires, spare parts and other material
				Maintenance cost	the economic impact of repairing vehicles and ensuring that materials, e.g. tires and brake pads, are available for use
Visual Quality	The impact of visual quality	Architectural appearance	The impact of architectural appearance	Cultural identity	the societal impact of changing things important to our identity (of which heritage is part)
		Cleanliness	The impact of cleanliness	Psychological situation	the societal impact of having, for example, anxiety due to a perceived increase in the probability of being involved in an accident

Table 2 Impact hierarchy contd.

Impact Level 1		Sublevel 1.1		Impact Level 2	
Label	Description	Label	Description	Label	Description
Economy	The impact of economic activities	Person transport	The impact of transporting people	Productiveness	the economic impact of travelling e.g. to work
				Health	the societal impact of medical care
		Good transport	The impact of moving goods	Productiveness	the economic impact of production material availability
				Health	the societal impact of medical supply
		Business settlement	The impact of new business	Employment	the economic impact of creating jobs
Emissions	The impact of emissions	Noise	The impact of being exposed to noise emissions.	Environment	the environmental impact of noise emissions emitted during travel
				Health	the societal impact of noise emissions (human health)
		Particle (e.g. CO_2, NO_x, SO_2)	The impact of being exposed to particle emissions	Environment	the environmental impact of particle emissions emitted during travel
				Health	the societal impact of particle emissions (human health)
Resource consumption	The impact of resource consumption	Energy	The impact of energy consumption	Environment	the environmental impact of energy consumption, e.g. depletion of finite amounts of non-renewable energy sources
				Intervention cost	the economic impact of energy consumption due to road interventions
		Material	The impact of material consumption	Environment	the environmental impact of consuming materials, e.g. the consumption of wood has an impact on woodland areas.
				Intervention cost	the economic impact of material consumption due to road interventions
		Labour	The impact of labour consumption	Intervention cost	the economic impact of labour consumption due to road interventions
		Land	The impact of land consumption	Environment	the environmental impact of land consumption, e.g. increased environmental damages due to floods

4.2.2 Importance-satisfaction analysis

A next step is analysing the importance of road impacts for stakeholders and the satisfaction of stakeholders with the impacts road infrastructure has on them. This information can be obtained by regular surveys among stakeholders (e.g. yearly) and will serve as input for the decision on the appropriate intervention strategy for a particular road link.

Depending on the identified stakeholders and the importance of impacts for the stakeholders the impacts can be assigned to different stakeholders. Table 3 shows a possible assignment of impacts to stakeholders.

Table 3 Expected importance of road impacts

	Directly affected stakeholders		Indirectly affected stakeholders	Directly affecting stakeholders	
	Users	Residents	Society	Road Management	Service provider
Safety	***	**	**	**	***
Travel time	***	*	**	**	*
Comfort	***	*	*	**	*
Vehicle operation cost	***	*	*	**	*
Economy	*	**	***	**	**
Emission	*	***	**	**	*
Resource consumption	*	*	**	***	***

*** very important   **important   *less important

Although road impacts can be important to several stakeholders, they are often conceptualized from different points of view. For example, safety is an impact expectation for many stakeholders, but each of them considers it differently:

- Road users regard safety as risk of accident mainly with other users.
- Residents are more concerned with the risk that they, or theirs relatives (especially their children), are injured by a vehicle.
- Society is mainly concerned by the overall safety on the networks, since higher risks mean more accidents and therefore, higher social and political costs.
- Road management is worrying about the image of their networks, and their own responsibilities for preventing accidents on these networks.
- Service providers are mainly concerned with safety of their employees working on a road while the traffic is passing the construction site.

The importance of road impacts to stakeholders can already indicate which impacts need attention when deciding on intervention strategies. However, important impacts stakeholders are satisfied with need less priority than important impacts they are complaining about. Besides importance of road impacts stakeholder surveys should also collect information about the satisfaction of stakeholders with the impacts. We propose two tools to determine the intervention priority of impacts: the importance-satisfaction rating and the importance-satisfaction matrix.

Importance-satisfaction rating

The importance-satisfaction rating is calculated by summing the percentage of stakeholders who select an impact as one of the most important. This sum is then multiplied by 1 minus the percentage of stakeholders who indicate they are satisfied with the impacts (the sum of the ratings of 4 and 5 on a 5-point Likert scale with 1-very dissatisfied and 5-very satisfied).

IS Rating = Importance Rating · (1-Satisfaction Rating) (1)

The maximum rating is 1.00 and would be achieved when 100% of the stakeholders select an impact as one of the most important ones and 0% indicates that they are satisfied with the impact. The lowest rating is 0.00 and would be achieved if either 100% of the stakeholders are satisfied or 0% of the stakeholders selected an impact as one of the most important ones. Ratings that are greater than or equal to 0.20 identify impacts that stakeholders think should give the highest priority. Ratings from 0.10 to 0.20 identify impacts that should also receive more attention than currently done. Ratings less than 0.10 should continue to receive the current level of emphasis.

Example: In a survey stakeholders were asked to rate importance of and satisfaction with road impacts. 35% selected comfort and 50% selected travel time as most important impacts. With regard to satisfaction, 80% of stakeholders rated their satisfaction with comfort of the road as a "4" or a "5" on a 5-point Likert scale (where "5" means "very satisfied") whereas only 30% were satisfied with travel time. The importance-satisfaction rating is then calculated by multiplying the sum of the most important percentages by 1 minus the sum of the satisfaction percentages. In this example, 0.35 is multiplied by 0.20 (1-0.80) for comfort and 0.50 is multiplied by 0.70 (1-0.30) for travel time. This calculation yields an importance-satisfaction rating of 0.07 for comfort and 0.35 for travel time. That suggests that travel time should give the highest priority when deciding on intervention strategies whereas the attention for comfort can be kept on the current level.

Importance-satisfaction matrix

A two-dimensional matrix can be created with satisfaction depicted along the x-axis and importance along the y-axis (Martilla and James, 1977). The four quadrants that emerge suggest specific recommendation for giving priority to road impacts (Figure 4). Impacts in Quadrant I score high on both satisfaction and importance. They are appropriately addressed and the attention they receive should be kept on the same level. Immediate action is required for impacts in Quadrant II which are important to stakeholders but score low on satisfaction. Impacts with both a low importance and satisfaction are placed in Quadrant III. These impacts can be given low priority. If impacts possess a low importance to stakeholders but are associated with high satisfaction, they are located in Quadrant IV and indicate an overspending. Resources committed to interventions related to these impacts should be redirected to the improvement of other impacts.

For the location of impacts in the matrix and the interpretation of the results the scaling of the axis becomes critical. Since impacts are quite often compared with each other to decide on which impact should receive the highest priority, the means for importance and satisfaction obtained from the survey are used to divide the matrix.

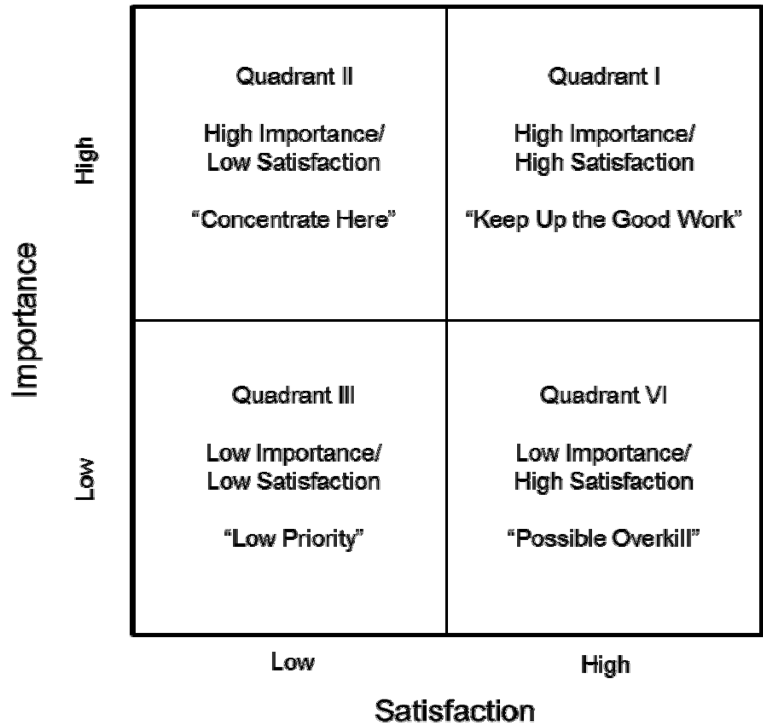


Figure 4 Importance-satisfaction matrix (adapted from Martilla and James (1977))

Example: Taking the results of the survey mentioned above, the importance rating of comfort has a mean of 4.15 and the mean of the satisfaction rating is 4.78. The mean of the importance of travel time is 4.65. The satisfaction rating for travel time shows a mean of 3.63. Placing both impacts in the importance-satisfaction matrix yields a high priority for travel time whereas comfort can remain on the current level of emphasis.

Figure 5 Importance-satisfaction matrix - example

4.3 *Understanding the impact of road intervention projects on stakeholders*

In the previous sections we addressed the importance of and satisfaction with road impacts and proposed steps and tools which can be used to identify those impacts that should be given high priority when defining appropriate intervention strategies. However, stakeholder surveys often cover broader road networks. Thus, they draw a more general and average picture which may change when it comes to a particular road link and intervention project. The contextual setting of a road (e.g. urban or rural area) can lead to different stakeholder judgements in terms of importance and satisfaction. Moreover, any intervention project aiming at improving these impacts will temporarily reduce the benefits of this road. It is also essential to understand the impact of a specific road link and the impact of road intervention projects on stakeholders in particular.

4.3.1 Expectations and experiences about intervention projects

In order to explore the impact of road intervention projects a further specification of the aspects of road interventions are needed which can have an effect on stakeholders. The notion of value as being adopted by service-dominant logic (Vargo and Lusch, 2004) seems particularly fruitful in this regard, since intervention projects usually try to increase the benefits of a road to stakeholders. From a service-dominant logic perspective we argue that value does not reside in road infrastructure but rather is created through the interplay of expectations and experience of road stakeholders. As a consequence, a road cannot provide value to the stakeholders. It can only offer value which stakeholders make use of in a given context and by doing so they determine and co-create the actual value. Stakeholders may have expectations about the value offer, but certainly experience the offer, for example through a safe and reliable journey, which then creates actual value. Intervention projects temporarily reduce the value offering of a road by imposing traffic disturbance to the network, decreasing road capacity and increasing the probability of accidents. The benefit of road intervention projects lies in improving and enhancing the value offering of a road. The deterioration of roads diminishes the value that can emerge, for example through a reduction of speed or uncomfortable rides. Resurfacing asphalt layers, placing traffic management devices, or renewing the drainage system are interventions that intend to increase the value proposition. It is this conflict between the temporary loss of proposed value during an intervention project and the intended increase of offered value after the project which suggests two aspects of road intervention projects that play an important role in forming expectations and experiences of stakeholders: the outcome and the process of an intervention project.

The outcome of an intervention project relates to the improvement of a road's value proposition; stakeholders can have certain expectations about this improvement before the maintenance, and they will experience the extent of this improvement after the maintenance. The process of an intervention project addresses the downgrade of the proposed value during maintenance, and again stakeholders can have expectation about the extent of the decline and can experience its actual reduction. For both intervention outcome and intervention process we can argue that a certain interplay of expectation and experience will determine (dis)satisfaction of stakeholders with the value proposition of the road. In addition, while forming expectation about an intervention project as well as while experiencing the outcome and process of the intervention, stakeholders will heavily rely on information. It is posited that satisfaction depends on accurate information regarding realistic expectations and accurate depiction of actual performance (Strong et al., 2001). Since information received by road stakeholders will be used to make decisions about, for example, the routes taken during maintenance or the time of traveling after maintenance, we consider the information provision to be the third aspect in the formation of satisfaction with the value proposition of a road in intervention projects, and again the interplay of expectation and experience will yield a certain level of satisfaction.

4.3.2 Expectancy (dis)confirmation analysis

As mentioned before, the satisfaction of stakeholders with the value proposition of a road in intervention projects will depend on the interplay of the stakeholders' expectations about and experiences of project outcome, process and information provision. Expectancy (dis)confirmation analysis (EDA) is a tool which can be used to determine the satisfaction of stakeholders and provide information for the optimal intervention strategy and stakeholder management in intervention projects. The starting point of EDA is that satisfaction is a function of prior expectations and the discrepancy between expectations and actual experiences (Oliver, 1980). When forming judgments about road impacts that will emerge from a particular road, stakeholders may already possess a set of expectations with respect to these impacts. Expectations are stakeholders' predictions or anticipations of road impacts. Upon experiencing the actual impacts, the expectations then serve as a comparative reference for the formation of satisfaction judgments. The discrepancy or gap between prior expectations and actual experiences is called expectancy disconfirmation. Size and direction of the disconfirmation determine the level of (dis)satisfaction. The results of the EDA show this combined influence of a priori expectation and a posteriori experience on satisfaction in an expectancy (dis)confirmation diagram. Depending on the combined influence different recommendations for stakeholder management can be given. According to Brown et al. (2007), who summarized the literature around EDA, there are six generic models of the interplay of expectations, experiences and satisfaction: the contrast model, the assimilation model, assimilation-contrast model, the ideal point model, the expectation-only model and the experience-only model.

Contrast model

The first model is known as the contrast model and suggests that when experiences fall short of expectations, the satisfaction will be lower – i.e. a disappointment effect. When experiences exceed expectations, expectations exert a positive influence on satisfaction – i.e. a surprise effect (Figure 6). From this perspective, stakeholder expectations about road impacts during and after intervention projects should be understated in order to maximize the extent to which experiences of the impacts exceed expectations.

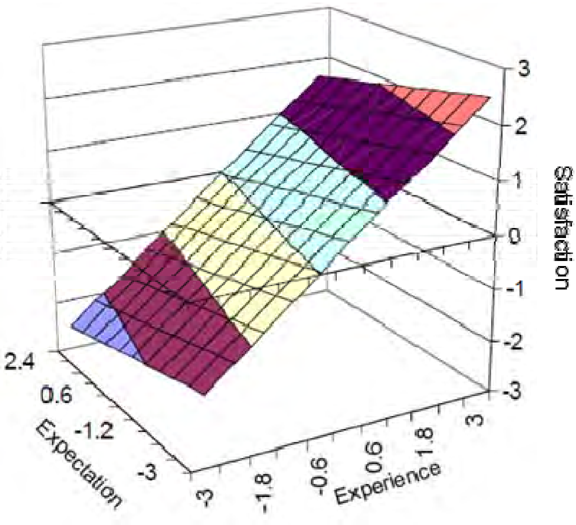


Figure 6 Expectancy (dis)confirmation diagram of the contrast model (Brown et al., 2007)

Assimilation model

The second model is the assimilation model which suggests that experiences are adjusted to expectations in order to prevent cognitive dissonance (Figure 7). As a consequence, individuals use expectations as an anchor for their experiences which are then adjusted to be more consistent with the expectations. This reduction of dissonance would suggest that the higher the expectation, the higher the satisfaction and that an overstatement of expectations of road impacts increases satisfaction.

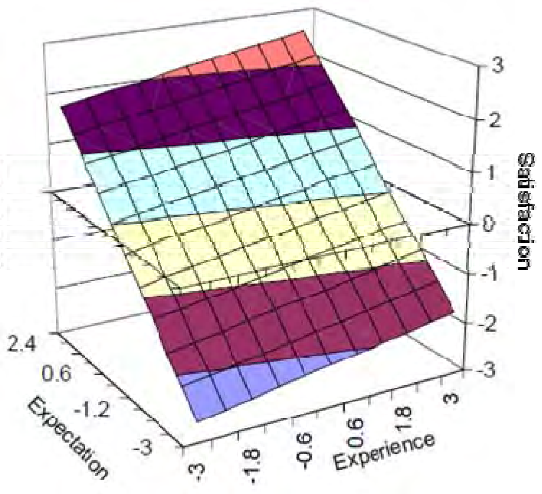


Figure 7 Expectancy (dis)confirmation diagram of the assimilation model (Brown et al., 2007)

Contrast-assimilation model

The third model is a combination of the contrast and assimilation model. It proposes a different effect of deviations from expectations depending on the magnitude of the deviation. If there is a small disconfirmation experiences will assimilate toward expectations, whereas large contrasts between expectations and experiences will lead to either a disappointment effect or a surprise effect (

Figure 8). It is additionally suggested that negative disconfirmation will have a greater negative impact on satisfaction than positive disconfirmation will have in the positive direction because losses are weighted more than gains.

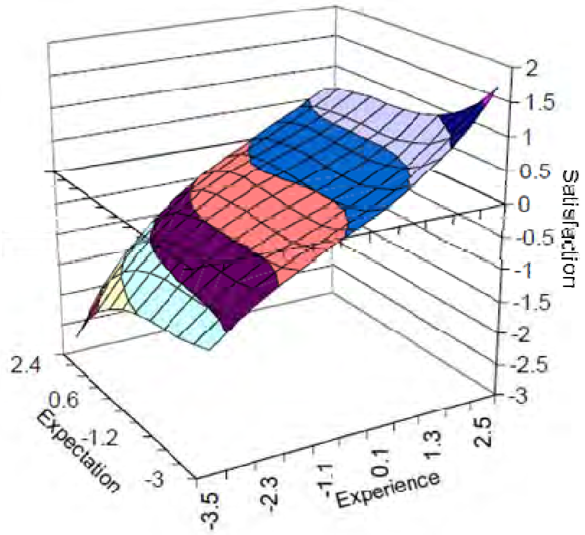


Figure 8 Expectancy (dis)confirmation diagram of the contrast-assimilation model (Brown et al., 2007)

Ideal point model

The fourth model is labelled the ideal point model. This model proposes that any difference between expectations and experiences, regardless of the direction, will result in a lowered evaluation (Figure 9). In contrast to the disconfirmation model, the ideal point model anticipates negative outcomes when expectations are both not attained and when they are exceeded. It is argued that the dissatisfaction stems from physiological tension created by an unfair perceived mismatch between what someone received and what someone expects to get. The implication is that raised expectations about the road impacts should be closely met and experiences should not deviate from expectations in order to attain stakeholder satisfaction.

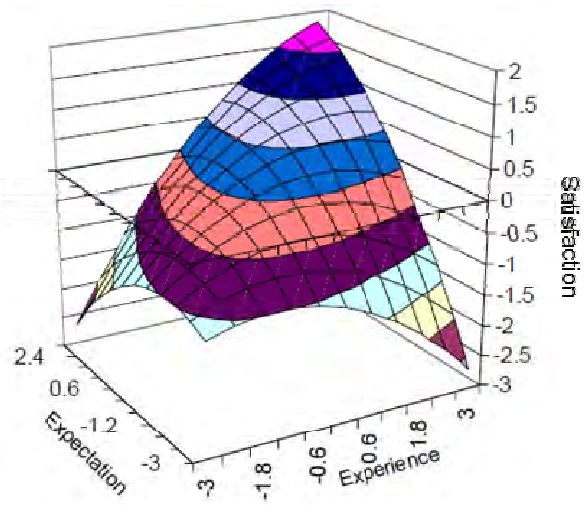


Figure 9 Expectancy (dis)confirmation diagram of the ideal point model (Brown et al., 2007)

Expectation-only model

In the fifth model expectations directly predict satisfaction, thus representing a perfect assimilation toward stakeholders' a priori beliefs (Figure 10). That would suggest that high expectations about road impacts of an interventions project should be raised to satisfy stakeholders.

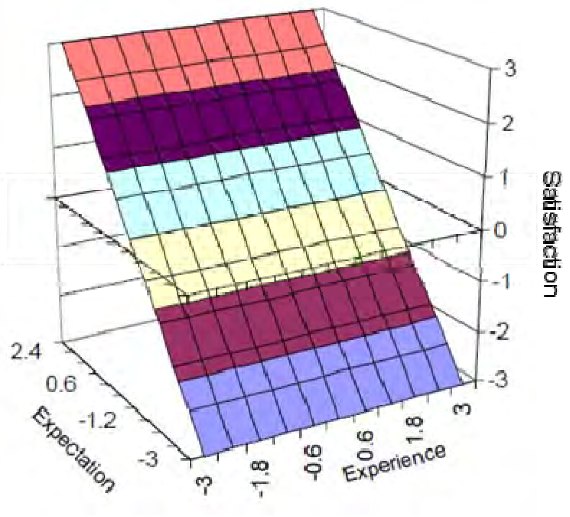


Figure 10 Expectancy (dis)confirmation diagram of the expectation-only model (Brown et al., 2007)

Experience-only model

The sixth model is the experience-only model. This model suggests that experiences are most influential in determining satisfaction, because they are more recent than expectations when evaluations are done (Figure 11). Compared to the expectation-only model most attention should be paid towards the experience of road impacts during and after intervention projects through which value for stakeholders emerges.

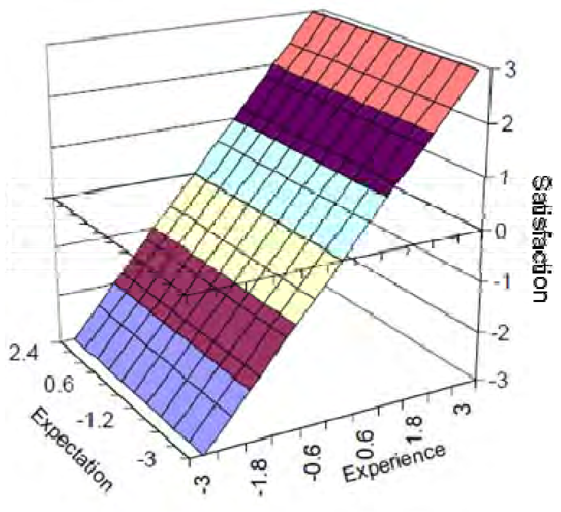


Figure 11 Expectancy (dis)confirmation diagram of the experience-only model (Brown et al., 2007)

In order to analyse expectancy disconfirmation and determine the appropriate model for a particular intervention project, data on the expectations, experiences and satisfaction of stakeholders needs to be collected. There are two ways of collecting the data. First, expectations, experiences and satisfaction are measured after finishing the intervention project. The main advantage is that only one questionnaire is administered. The main disadvantage is the risk of biased results, since respondents have to recall their pre-exposure expectations after gaining experiences which are far more salient and available. That may not only lead to guesses when people are not able to recall expectations, but also to a disproportional influence of the current and prevailing experiences. Therefore the second way of collecting data for the EDA is recommended (Figure 12). Here, data on the expectation is collected before an intervention project is executed (questionnaire 1) asking stakeholders about the expected project outcomes in terms of road impact improvements, the expected project process in terms of the temporary road impact reductions, and the expected information provision during the intervention project. Data on the experiences and satisfaction are obtained after the intervention project is finished (questionnaire 2) asking stakeholders about the experienced road impacts and the extent to which they are satisfied with project outcome, process and information provision.

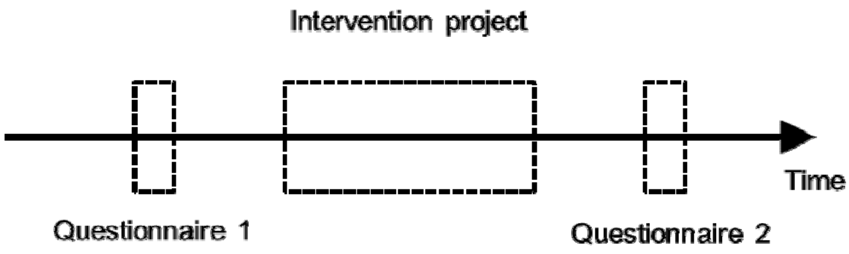


Figure 12 Data collection for EDA

It should be noted that only after the second questionnaire the EDA can be done, but this would mean that the results of the analysis cannot be used for managing the intervention project the data was collected about. Thus, EDA should be seen as a tool that will improve the management of intervention projects in the long term. After a series of applications it will reveal which of the presented models above are most suitable in which context (e.g. type of road, stakeholder group, region). Then the results of the first questionnaire can be used to decide on the appropriate management measures and the results of the second questionnaire can confirm the appropriateness of the taken measures. Examples of both questionnaires as being used in the case studies can be found in APPENDIX 11 and APPENDIX 12.

5 Engagement of Road Stakeholders

5.1 What is stakeholder engagement?

As described before, the level of satisfaction of stakeholders with an intervention project will arise from the interplay of stakeholder expectations about and experience of the project. In other words, by influencing stakeholder expectations and experiences a certain level of satisfaction can be accomplished.

Stakeholder engagement is the process of forming and maintaining constructive relationships with stakeholders, in order to influence stakeholder expectations about and experiences of intervention projects. There are many different ways of engaging stakeholders in a project which may have different effects on expectations and experiences. Interacting with stakeholders before the intervention can help in shaping expectations whereas engagement during a project will have an influence on experiences. In either case, creating meaningful interactions with various stakeholders enables the identification of shared objectives, the design of solutions that account for various perspectives, and the creation of projects valuable for individuals and organisations affected by the project.

5.2 Ways of stakeholder engagement

There are four different strategies to engage with stakeholders in projects:

- Information: Distribution of information about the project to stakeholders
- Communication: Exchange of information about the project with stakeholders
- Participation: Involvement in decisions on planning and executing the project
- Compensation: Compensating for inconveniences caused by the project

These engagement strategies can have a different influence on expectations and experiences of stakeholders (Table 4). Informing about a project is an useful way for shaping expectations but the interaction with stakeholders is limited and it is not possible to take the perspective of stakeholders into account. Communicating with stakeholders appears to be a more effective way, since it allows the exchange of views on the project and to understand and form expectations about the project through a direct discussion. The same holds for participation, but here stakeholders paly a much more active role in the project which will also affect their experience of the project. Compensating for the inconveniences caused by a project, first of all, will have an influence on the experiences of stakeholders.

Table 4 Influence of engagement strategies on stakeholder expectation and experience

	Expectation	Experience
Information	**	*
Communication	***	**
Participation	***	***
Compensation	*	**

*** great influence **moderate influence *less influence

The next section explains the four different strategies with some example measures. Where possible, the limitations and strengths of the measures are also mentioned (based on Yang et al., 2011; AUSTROADS, 2006).

5.2.1 Information

The (one way) distribution of information can be applied in many ways. Examples are the standard measures of providing information via printed newsletter or newspaper. But with the advent of the digital age, there are more possibilities to distribute information for example via websites, videos on YouTube or e-mail. A requirement of information distribution is that it happens timely and frequent. Also the detail of information should be in line with the purpose of informing a certain stakeholder group. Examples of information measures are:

- **Letters**

  A direct way of informing stakeholders is by means of information letters. The strength of this approach is that it enables to keep stakeholders particularly informed about important details, for example, dates and deliveries of the works can be directly communicated. Limitations are that it can be time consuming and that letters cannot be sent to all stakeholders due to information scarcity.

- **Non-digital media**

  Non-digital information measures include press releases in national/regional newspapers and commercial/short documentary for television or radio. These are possible ways of gaining attention for and giving regular updates about a project. Limitations are that probably not all stakeholders will be reached and it can be time consuming and costly to prepare it well on a regular basis.

- **Digital media**

  Digital media to distribute project information are websites of the own organisation or websites of others (e.g. hospitals, schools). A strength of websites is that it provides an access point for information that can be revisited and is a platform for regular updates for those who want to know more. Limitations are that it may not be accessed by all stakeholders and can be time consuming to set up. In order to keep credibility, it needs regular maintenance. Other information channels are social media like Twitter which are very quick ways of spreading information. A limitation of this approach is that the project team needs a specialist to monitor all the messages, which can be time consuming. In addition, not all stakeholders may use these new forms of information sources.

- **Information points**

  Information points (e.g. boards, posters) can be useful to provide information to a large number of stakeholders. It is an opportunity for stakeholders to get familiar with project issues and can give positive impressions of the desire to keep stakeholders informed. It can provide regular updates on the project progress, but can be time consuming to prepare well on a regular basis.

5.2.2 Communication

Communication with stakeholders is a good way to exchange information. For the project team it is possible to explain the project, but it is also possible for the stakeholders to respond and explain their concerns. Effective communication often takes place via personal contact during information sessions or focus group meetings. Nowadays, digital media also allow for more information exchange via impersonal contact for example in web forums or Facebook.

Communication can be supported by visualizations. This may be maps or sketches, but also 3D and 4D visualizations. Visualizations can be important in a project, because very often it is difficult for stakeholders to read a construction sketch. Visualizations also help to gain an idea of the stakeholders' expectations. It is important that these tools are used to start a conversation with stakeholders. Examples of communication measures are:

- **Personal contact**

  Visiting residents or companies situated near the road is a possible way of face-to-face contact and discussing the expectations of the stakeholders and their wishes and needs. A strength of this approach is that it allows an comprehensive exchange of opinions and viewpoints and, thus, a mutual understanding of important issues. Although the location of the meeting is flexible, personal talks with stakeholders can be time consuming and expensive. In addition, it requires skilled interviewers and there might not be enough time to interview all stakeholders.

  Periodic meetings with selected stakeholders from different groups (e.g. road users, residents) are an alternative measure. These focus groups (5-10 persons) provide the opportunity for obtaining and discussing a wide range of comments and identifying the reasons behind stakeholders' opinion. A limitation is that it requires a careful selection to get a representative sample. There might be the risk that the group does not represent the majority opinion. Moreover, it can be costly, and requires a skilled facilitator.

  For larger projects guided tours in the project area is another measure. This is very useful when a large number of stakeholders can be reached. It allows team members to explain project and approach and to answer difficult questions. It is necessary to advertise in a number of ways about a tour and to prepare it properly, which can be time consuming and costly.

- **Impersonal contact**

  An impersonal way of communication is a phone line for questions, answers and complaints which is an inexpensive and simple measure for the project team to answer questions about the project and for stakeholders to give direct feedback to the project team. A limitation is that it must be adequately advertised to be successful and the contact must have sufficient knowledge about the project to be able to answer questions quickly and accurately.

  Forums on websites can also be used for the impersonal communication between project team and stakeholders. It is an useful measure for discussing specific topics over a longer period. However, to be effective answers to questions should be given on a timely basis, which may be time consuming.

5.2.3 Participation

Giving stakeholders the opportunity to co-produce the content of a project is possible on small points. Major decisions are often made which are reflected in the preferred alternative. There is, however, the possibility to engage stakeholders in the further detailing of the project and transform their wishes, needs, and views in direct project outcomes. Stakeholders can also play an active role in designing parts of the project. Here it is necessary to create some flexibility within the design boundaries to allow for stakeholder contribution. An example of creating some flexibility in the design is the look and feel of a noise barrier. Instead of deciding that it will become just a concrete wall, the project team might make some budget available for residents to decorate the noise barrier. Stakeholders can participate in projects through workshops, with interactive design mechanisms or with questionnaires. It is important that the project team has some additional budget available, is well prepared for the meetings and understands that concessions need to be made. Results will be a high commitment and credibility of the project. A possible disadvantage is that it can be expensive in preparing and implementing the consultation of and negotiation with stakeholders. It may also entail the risk of generating and aggravating conflicts.

5.2.4 Compensation

It is also possible to compensate stakeholders for inconvenience they may face during an intervention project. Compensation measures may include overnight stays for residents in a hotel during the intervention project or the opportunity for road users to have free access to the public transport during the project. Here it is important that stakeholders are aware of the urgency of an intervention and that the compensation is meant to reimburse for any inconvenience caused by the project. Examples of compensation measures are:

- Overnight stays in hotels during short intervention work,
- Holiday in bungalow park during long maintenance,
- Sponsoring of local events in the neighbourhood,
- Provision of extra busses in the area, and
- Provision of special facilities for certain companies in the area.

6 Determination of Optimal Intervention Strategies

6.1 What is an intervention strategy?

Road infrastructure deteriorates over time due to anthropogenic and non-anthropogenic processes and interventions are executed to re-establish the function or performance of roads. Different road assets or objects deteriorate at different rates and, therefore, often require interventions at different times. For example, in Figure 13, a discrete scale of 5 condition states is used for two road infrastructure objects, a pavement section (A) and a bridge (B). After a period of time t_1^A, the pavement section A reaches condition state 4, and an intervention is executed that brings it back to condition state 1. After a period of time t_1^B, the bridge B reaches condition state 3, and an intervention is executed that brings it back to condition state 1.

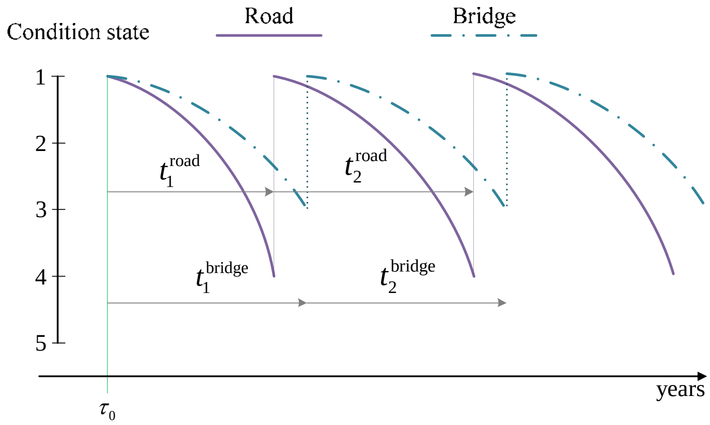


Figure 13 An illustration of the deterioration and improvement on a road link

However, one may ask the question: Would it be better to execute interventions simultaneously on the pavement sections and the bridges rather than executing interventions at different points in time? The intervention strategy gives an answer to this question. It determines the time, kind and extent of infrastructure interventions for a certain period (e.g. 30 years) as an outcome of a decision making process that balances trade-offs between road impacts. An optimal intervention strategy (OIS) is achieved if interventions are executed at times which lead to a maximum net positive impact for stakeholders.

6.2 Modelling physical changes of roads

In order to determine the unit quantities of the impacts, it is necessary to construct a model of what is expected to happen throughout the time period to be investigated. The main components of the model are the physical changes to the road link, i.e. deterioration and improvement, and the physical changes to the system surrounding the road link.

For the estimation of impacts it is convenient to consider the road link in two fundamental states: the state between interventions and the state during interventions. The assumption of two states includes that:

- while the road link is between interventions, it is fully operational, and
- while interventions are being executed on the road link, it is partially operational.

In general, the physical changes of infrastructure objects are modelled either deterministically or probabilistically. The decision of which model to use depends on numerous factors including the amount of data available, the time available for the analysis, and the accuracy required. The advantages and disadvantages of each model are briefly discussed in this section.

6.2.1 Deterministic models

When using deterministic models it is assumed that for each investigated intervention strategy the condition of an object is known with certainty at each moment of time in the future. For example, in Figure 14 the roughness of a road section increases over time and every 20 years an intervention is executed which improves the roughness.

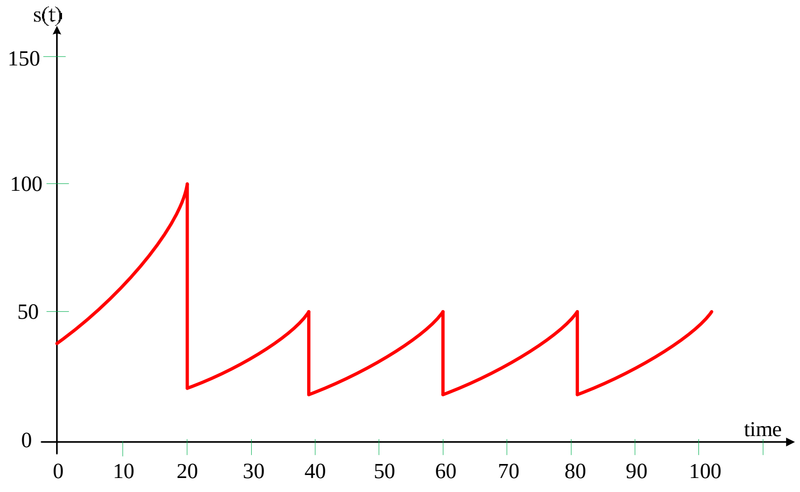


Figure 14 Physical change of a road section modelled deterministically

Deterministic models are often used (e.g. Tsunokawa & Schofer, 1994; Ouyang & Madanat, 2004; Ouyang & Madanat, 2006) and can be found in numerous infrastructure management systems such as HDM-4 (Morgosiuk & Riley, 2004) and RoSy PMS (PPC, 1998)[1]. In deterministic models, the physical deterioration of an object is modelled as a deterministic function, and the values of the parameters of the function are determined by performing tests in a laboratory, in the field, or by polling experts. The physical improvement of an object is often modelled as a deterministic jump to a specified value.

An advantage of deterministic models is their ease of use. Disadvantages include their calibration, i.e. being representative for the deterioration over an entire time period, and their inability to capture the uncertainty in estimating future condition related to factors such as the fluctuation of traffic volume, ambient temperature, and rainfall.

[1] See APPENDIX 1 for examples.

6.2.2 Probabilistic models

When using probabilistic models it is assumed that deterioration and improvement of a road object are stochastic, i.e. the states of the object or system in the future are not known for certain. Popular probabilistic deterioration models include Poisson models (Madanat & Ibrahim, 1995), Weibull models (Lethanh, 2009), Exponential models (Tsuda et al., 2006) and Markov models[2]. The values of the model parameters are often determined by using existing data, regression analysis and the maximum likelihood estimation approach. For example, with a Markov model the condition of an object at some time in future is only known with a certain probability (see Figure 15 for an object with 5 condition states). In addition, when an intervention is executed the condition of the object at the beginning of the next analysis interval is known with a certain probability, e.g. there is an 80% chance that the object will be in condition state 1 and a 20% chance that the object will be in condition state 2.

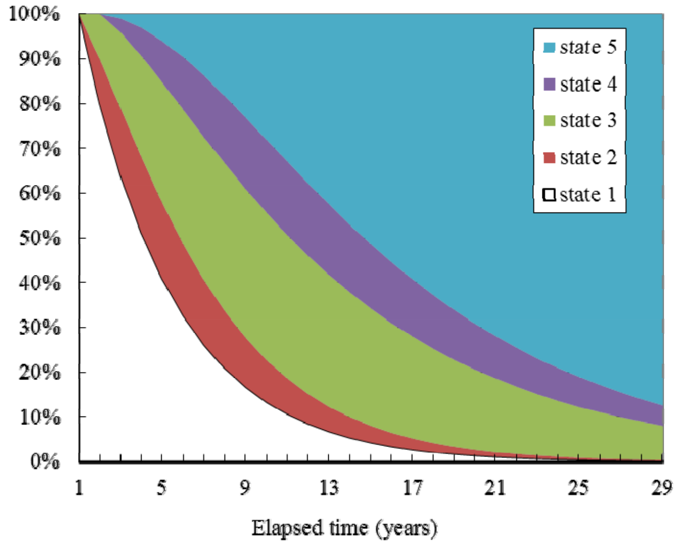


Figure 15 Physical change of a road section modelled probabilistically

An advantage of probabilistic models is that they allow for the consideration of uncertainty. They also allow for automatic updates when new data becomes available (Kobayashi et al., 2009; Jeff, 2006). Some of the disadvantages of probabilistic models are the little more complicated usage, and the significant amount of historical data to calibrate them correctly. A specific disadvantage of the Markov models is the combinatorial explosion when the deterioration of multiple objects is modelled simultaneously. An advantage is that is convenient for situations where general statements with respect to budget and condition are required for large numbers of structures, and where it is not necessary to make statements on budget and condition for specific objects.

6.3 Investigated models

In order to determine the OIS for an object, it is necessary to develop appropriate mathematical models that include the possible physical changes of the object, allow the evaluation of all intervention strategies to be investigated, and facilitate the

[2] See APPENDIX 2 for a short description of the Markov model. This has been added as the Markov model is perhaps the most widely used probabilistic model in infrastructure management systems.

identification of the strategy that maximizes the net positive impact. In operation research, this is referred as the optimal control problem (Bertsekas, 2007).

Numerous deterministic models using mixed-integer mathematical programs have been used for solving the optimal control problem. At the beginning the use of these programs often required the representation of a linear deterioration to overcome the numerical challenges in solving the problem (e.g. Al-Subhi & Johnston, 1990; Jacobs, 1992; Mitchell. et al., 1997). Later this restriction has been overcome through the development of nonlinear programming optimisation techniques (Ferreira et al., 2002b) and the use of mixed-integer nonlinear programs (MINLP) (Ouyang & Madanat, 2004; Ouyang & Madanat, 2006).

The most popular probabilistic models is the Markov Decision Process (MDP) model. The optimal control problem is formulated as dynamic programing which employs Bell-man equations (Golabi & Shepard, 1997; Camahan et al., 1987), to determine OISs. Markovian models are sometimes labelled as a top-down approach while other models with nonlinear programing optimisation are considered as a bottom-up approaches (Sathaye & Madanat, 2011).

Based upon the review of the state-of-the-art models two models were developed to address the specific problem of determining the OIS for a road link consisting of multiple objects (illustrated in Figure 16). One model is deterministic and one is probabilistic. The models were developed to determine OISs based on the impact hierarchy presented in APPENDIX 7 .

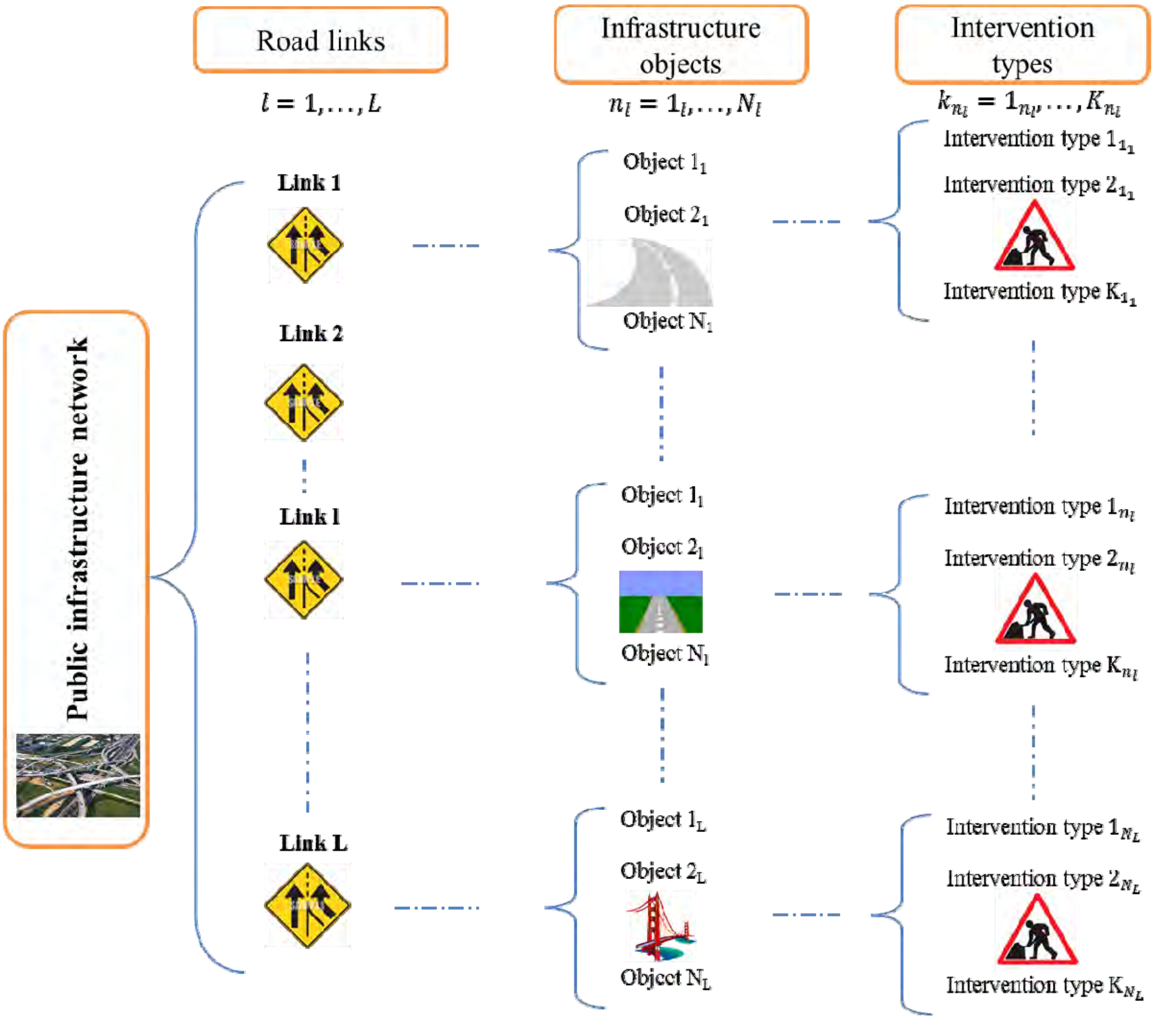


Figure 16 Combination of intervention types for respective infrastructure objects in different road links

6.3.1 Deterministic model

The investigated deterministic model is a MINLP model. It evaluates a subset of the intervention strategies that could be considered with the overarching deterministic model presented in APPENDIX 5. The formulated model enables the determination of the optimal time for the execution of an intervention on a road link and is similar to those models often used to solve optimal control problems in production process at plants (Jain & Grossmann, 1998). The formulated model only allows the evaluation of single stage intervention strategies, i.e. intervention strategies where interventions of the same type are repeated at constant time intervals.

6.3.1.1 Objective function

The objective function of the model is:

$$Min\ \mathrm{TC} = \sum_{l=1}^{L} \sum_{n_l=1}^{N_l} \left[\int_0^T \sum_{x=1}^{X} f_{n_l}^{k_{n_l}}(t,x) \cdot e^{-r \cdot t} dt + e^{-r \cdot t} \cdot \sum_{x=1}^{X} g_{n_l}^{k_{n_l}}(d,x) \right] \quad (2)$$

Where:

$f_{n_l}^{k_{n_l}}(t,x)$ is given by:

$$f_{n_l}^{k_{n_l}}(t,x) = a_{n_l}^{x,k_{n_l}} + b_{n_l}^{x,k_{n_l}} \cdot exp(\beta_{n_l}^{x,k_{n_l}} \cdot t) \tag{3}$$

$$g_{n_l}^{k_{n_l}}(d_{n_l}^{k_{n_l}},x) = \overline{a}_{n_l}^{x,k_{n_l}} + \overline{b}_{n_l}^{x,k_{n_l}} \cdot exp(\overline{\beta}_{n_l}^{x,k_{n_l}} \cdot d_{n_l}^{k_{n_l}}) \tag{4}$$

Eq. (2) deals with only one intervention type k_{n_l}.

T is the time between interventions plus the intervention time.

a, b, and β are parameters whose values are to be estimated for each type of impact indicator x and for both between and during interventions.

$^{-}$ indicate the values of a, b, and β to be used to model the increase of impacts during interventions.

With the suppression of the summation signs over L and N and indexes l, n, k in Eq. (2), the objective function reduces to that for a single object:

$$TC = \int_0^T (a + b \cdot \mathrm{e}^{\beta \cdot t}) \cdot e^{-r \cdot t} dt + e^{-r \cdot t} \cdot g(d) \tag{5}$$

Eq. (5) can be elaborated as:

$$TC = \left[\frac{a}{r}(1 - e^{-rT})\right] + \left[\frac{b}{\beta - r}(e^{(\beta - r)T} - 1)\right] + e^{-r.T} \cdot g(d) \tag{6}$$

If there is w times of intervention, the duration of each intervention cycle, intervention duration plus time between interventions, is given by t/w, where t is the total investigated time period. By introducing a new variable concerning intervention times w. Eq. (6) becomes

$$TC = w \cdot \left[\frac{a}{r}(1 - e^{-r\, t/w})\right] + w \cdot \left[\frac{b}{\beta - r}(e^{(\beta - r)\, t/w} - 1)\right] + w \cdot e^{-r.\, t/w} \cdot g(d) \tag{7}$$

The objective function for a road link composed of multiple infrastructure objects now becomes:

$$Min\ TC(t_n^k, w_n^k) = \sum_{n=1}^{N} w_n^k \left[\frac{a_n^k}{r}(1 - e^{-r\, t_n^k / w_n^k}) + \frac{b_n^k}{\beta_n^k - r}(e^{(\beta_n^k - r)\, t_n^k / w_n^k} - 1) + w_n^k \cdot e^{-r.\, t_n^k / w_n^k} \cdot g_n^k(d)\right] \tag{8}$$

i.e. determine the value of t and w so as to minimize total costs.

6.3.1.2 Constraints

The objective function is subject to a number of constraints.

Integrality constraint

The integrality of w_n^k is enforced by introducing the following constraint.

$$w_n^k = \sum_{m=\varepsilon,1}^{M} m \cdot y_{n,m}^k \quad (9)$$

$$\sum_{m=\varepsilon,1}^{M} y_{n,m}^k = 1 \quad \forall m \quad (10)$$

$$\varepsilon = 0.0001 \quad (11)$$

where

$y_{n,m}^k$: is a binary variable,

ε : is a constant with a value close to zero,

M: is a variable whose value is selected to be the upper bound on the number of intervention w_n^k

The binary variable $y_{n,m}^k$ is introduced to enforce that w_n^k is an integer. The value of ε is a constant with its value close to zero, and it is introduced so that the value of m is either ε or an integer greater or equal to 1, and the denominator in Eq. (8) cannot be 0.

Time balance constraints

Time balance constraints are introduced to ensure that the total time allocated (time between intervention + intervention time) for any object cannot be more than the cycle time

$$\Delta t_n^k \le T_{total} \quad \forall n \quad (12)$$

Where:

$$\Delta t_n^k = w_n^k \cdot d_n^k + t_n^k \quad (13)$$

$$\varepsilon \le w_n^k \le K, \ \ \Delta t_n^k \ge 0, \ \ t_n^k \ge 0, \qquad \forall \ \text{n} \quad (14)$$

$$T_{total} > 0$$

$$y_{n,m}^k \in \{0,1\} \qquad \forall \ \text{n}, m$$

T_{total} is the length of the investigated time period.

d is the duration of intervention.

t_n^k the total time during the investigated period when no intervention is being executed.

The constraints in Eq. (14) imply that values of variables are nonnegative, and the number of intervention cannot be outside of the lower bound ε and upper bound K for their values.

Intervention constraints

An additional constraint is added to force that there is at least one intervention for each infrastructure object in the network within the finite planning horizon. This constraint does not affect the optimal values of parameters; but accelerates the numerical calculation.

$$\sum_{n=1}^{N} w_n^k \geq 1 \tag{15}$$

Impact constraint

The following constraint is imposed to ensure that no maximum (or minimum) amount for a specified impact type is exceeded annually (e.g. the yearly budget).

$$\sum_{n=1}^{N} g_n^k(d,x) \leq B^k(t,x) \tag{16}$$

Where:

B(t): is the restriction for impact type k for year t.

Budget constraint

For the deterministic model it is necessary to determine on which objects interventions should be executed, if there is not enough funding to execute all interventions to be executed and the optimal intervention strategies are followed. The following priority rule is used.

If the summation of all impacts incurred through interventions on an object in a certain time interval

- is less than or equal to the summation of the impacts associated with the impact constraint (here refer as allowed impact), then all possible interventions are executed. The remaining impacts, when applicable (e.g. budget), are transferred to the following year, thus, the restricted impacts in the following year will be equal to the remaining impact of last year plus the new allowed impact (e.g. new allocated budget).
- is greater than the allowed impact, the infrastructure objects having the highest reduction in negative impacts within the investigated year is selected for intervention.
  - if the impact of the intervention is still greater than the allowed impact, the intervention will be rejected and the candidate intervention with the next highest reduction in total negative impact in the investigated year will be selected. All the non-selected infrastructure objects for intervention will be deferred to the following year.
  - a similar procedure is repeated at each year to determine the potential infrastructure objects for intervention.

6.3.2 Probabilistic model

The probabilistic model is formulated assuming that the failure probability of an object follows a specific probability density function, and that the value of the parameter of the probability density function can be estimated using statistical regression analysis and historical data. The model can be applied to determine the optimal intervention times for one or more objects in a road link.

To model deterioration it is assumed that

- an object can be in only one of two condition states; 1) fully operational or 2) not fully operational,
- the transition of the object between states can be described by a stochastic variable $\tau \in [0, \infty]$ that represents the time to depart from condition state 1,
- the transition probability of an object from state 1 to 2 can be represented by a Weibull distribution function.

The Weibull distribution function is used because it is not memoryless, overcomes some of the criticisms of the widely used exponential distribution, and has been found to be a good representation of certain manifest deterioration processes in the past (Kobayashi et al., 2010, Kobayashi & Kaito, 2011). The probability density function $f(\tau)$ and survival function $\tilde{F}(\tau)$ in the form of Weibull hazard function can be expressed as:

$$f(\tau) = \alpha m \tau^{m-1} \exp(-\alpha \tau^{m}) \quad (17)$$

$$\tilde{F}(\tau) = \exp(-\alpha \tau^{m}). \quad (18)$$

Where:

α is arrival density parameter, and

m is the acceleration or shape parameter.

In order to obtain the values of the parameters α and m, the maximum likelihood estimation method can be used, where the parameter values $(\theta_1 = \alpha, \theta_2 = m)$, which maximize the logarithmic likelihood function (9) $\hat{\theta} = (\hat{\theta}_1, \hat{\theta}_2)$, i.e. satisfy:

$$\frac{\partial \ln L(\Xi, \hat{\theta})}{\partial \theta_i} = 0, (i = 1, 2). \quad (19)$$

where L is the maximum likelihood function, Ξ is the set of observed data, and the most likely values of $\hat{\theta} = (\hat{\theta}_1, \hat{\theta}_2)$ are estimated by using numerical iterative procedures such as Newton method[3] for simultaneous equations (Eq. (8)) (Dennis, 1996; Kelley, 1999). In order to test these values for statistical significance, the probabilistic $t-test$ and the asymptotic covariance matrix (Eq. (8)) [4] can be used (Cramer, 1946).

[3]Newton method is a method to find the successively better approximations to the roots of a real-valued function

[4]values of $t-test$ should be greater than 1.96 for 95% confidence and the covariance matrix should be non-singular

$$\hat{\sum}(\hat{\theta}) = \left[\frac{\partial \ln L(\Xi, \theta)}{\partial \theta \partial \theta'} \right]^{-1}. \tag{20}$$

To be clear about the maximum likelihood estimation method, the likelihood of the values of the model parameters, given the set of observed data Ξ, e.g. condition states, time to failure of all similar object, $s(s = 1, \cdots, S)$ and assuming that the deterioration of each object is independent from all other objects, is given by:

$$\ln L(\alpha, m : t_s) = \sum_{s}^{S} \begin{bmatrix} (1-\delta_s)(-\alpha t_s^m) \\ +\delta_s \left\{ \ln \alpha + \ln m + (m-1)\ln t_s - \alpha t_s^m \right\} \end{bmatrix}. \tag{21}$$

Where :

δ_s is a binary variable that has the value of 1 when the object is in state 2 and 0 otherwise.

The values of the parameters α and m can be estimated using either a maximum likelihood or Bayesian approach and existing data.

The net present expected values of the impacts on the owner, IC, and those on the user and general public, SC over time period z, are estimated as:

$$ESC(z) = \int_0^z SC \cdot f(t) \exp(-\rho t) dt. \tag{22}$$

$$EIC(z) = \int_0^z IC \cdot f(t) \exp(-\rho t) dt + \tilde{F}(z) \cdot IC \exp(-\rho z). \tag{23}$$

Where the values of IC and SC are given by

$$IC = \sum_{l=1}^{L} ic_l \tag{24}$$

$$SC = \sum_{l=1}^{L} sc_l \tag{25}$$

where l represents the index of each stakeholder group.

IC and SC can be further explained by following figure.

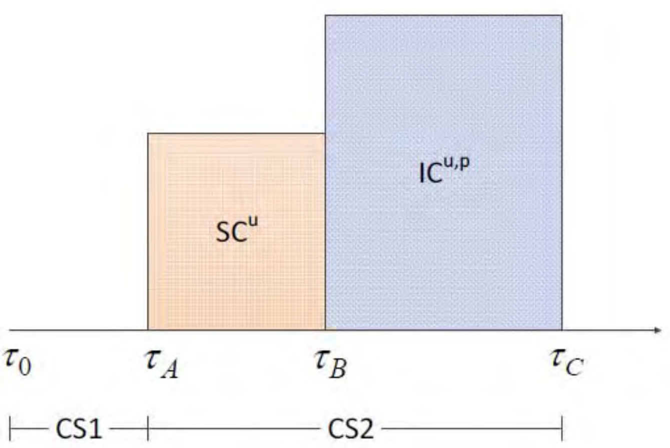


Figure 17 Graphical representation of impacts IC and SC.

When following this IS one can envision that impacts are incurred by stakeholders in two ways:

- During the execution of interventions ($IC^{u,p}$)5: e.g. the owner has to pay for the manual labour required to execute the intervention, and the user has additional travel time due to the required detours.
- When the object is in CS2 but the execution of the intervention has not yet begun (SC^{u}): e.g. the owner has to pay for the manual labour required to erect signs to reduce the number of lanes in use on a bridge, and the user has additional travel time due to the congestion that this restriction would cause.

This is illustrated in Fig. 2, where τ_A is the time the object enters CS2, τ_B denotes the start of the intervention, and τ_C denotes the end of the intervention, where the object is restored to CS1, where $ic_l^{u,p}$ and sc_l^{u} are the impacts incurred by each stakeholder group $l = (1,..,L)$. The superscripts u and p are referred as for "unplanned" and "planned". As a same type of intervention is applied in both two cases, it is $ic^{u,p} = ic^{u} = ic^{p}$.

Impacts incurred by each stakeholder group l can be estimated by use of empirical models (Kumares, 2007; Adey, 2012). For example, vehicle cost during the execution of an intervention can be estimated as a function of daily traffic volume, gasoline unit price, type of vehicle, condition of road, etc. (Kumares, 2007). Values of $ic_l^{u,p}$ and sc_l^{u} can be either positive or negative.

In order to formulate the model to determine the OIS for a road link the following additional assumptions were made:

- an intervention is executed when an object arrives in state 2, and
- the executed intervention restores the object with 100% certainty to state 1.

[5]The superscripts u and p refers to ``unplanned'' and ``planned'', respectively. As a same type of intervention is selected for both preventive and corrective intervention, it is $IC^{u,p} = IC^{u} = IC^{p}$.

It also requires special attention to:

- the interdependency of the execution of interventions, e.g. executing two interventions at the same time is less expensive than executing the same two interventions separately (Adey & Hajdin, 2005); and
- the constraints on impacts, e.g. limits on the maximum financial resources that can be allocated to all objects or the maximum travel time that can be occurred due to interventions on all objects in a specific time period.

6.3.2.1 Objective function

The objective function of the model is:

$$\Phi(0) = \min_z\{TC(0:z)\}. \quad (26)$$

Where:

ρ is the discount rate.

TC is the net present value of the total expected impacts, which is defined in following equations.

$$TC^a(z) = \Omega(z) + \sum_{z^*}\left[\int f(t)TC^a(z^*)e^{-\rho \cdot t}dt\right] + \exp(-\rho z)\sum_{z^*}\tilde{F}(z)\cdot TC^a(z^*) \quad (27)$$

Where is $\Omega(z) = ESC(z) + EIC(z)$, a is intervention type to be followed. The second and the third polynomials of Eq. ((27) represent the recursive form of Bell man equation in dynamic programming (Bachmann & Konik, 1984, Howard 1960, Howard 1971) and represent the expected total impact from the next investigated time interval. As the same type of intervention a will be repeated over an infinite time horizon and expected impact in each interval is considered to be equivalent, it is approximated that $TC^a(z) = TC^a(z^*)$., and therefore, Eq. (27) can be expressed as:

$$TC(z) = \int_0^z f(t)\{SC^u + IC^u + TC(z)\}\exp(-\rho t)dt \\ + \tilde{F}(z)\{IC^p + TC_{t+1}(0:z)\}\exp(-\rho z). \quad (28)$$

In order to obtain an explicit form of TC , $\Gamma(z)$ and $\Lambda(z)$ are defined as:

$$\Gamma(z) = \int_0^z f(t)\exp(-\rho t)dt = \int_0^z \alpha m\tau^{m-1}\exp(-\alpha\tau^m - \rho t)dt, \quad (29)$$

$$\Lambda(z) = \tilde{F}(z)\exp(-\rho z) = \exp(-\alpha z^m - \rho z). \quad (30)$$

And substituting these equations into Eq. (28)

$$TC(z) = \frac{(SC^u + IC^u)\Gamma(z) + IC^p \cdot \Lambda(z)}{1 - \Gamma(z) - \Lambda(z)}. \quad (31)$$

6.3.2.2 Constraints

The determination of the OIS for the road link requires special attention to the constraints on impacts, e.g. limits on the maximum financial resources that can be allocated to all objects or the maximum travel time that can be incurred due to interventions on all objects in a specific time period. These constraints are dealt with in this methodology by implementing a priority rule that selects some interventions to be postponed to future time periods if their simultaneous execution results in the exceedence of an impact constraint. To determine if the value of an impact is exceeded in a time period, the summation over the investigated time period is made of the probabilities of the object being in each condition state at each instant of time multiplied with the impact if the object were in that condition state over the specific time period. as shown in the following equation for the impacts on the stakeholders:

$$\Delta_k^{u,*}(\overline{t_k}) = \int_t^{t_k - t} \sum_{l=1}^{L} \left(ic_k^{u,l} + sc_k^{u,l} \right) f_k(\zeta) \exp(-\rho\zeta) d\zeta. \quad (32)$$

Where is $f_k(\zeta)$ expected failure probability of object k in an elapsed time of ζ ($\zeta \in [t, t_k - t]$). t is the start time of the investigation and t_k is the time of intervention for object k. The terms $ic_k^{u,l}$ and $sc_k^{u,l}$ are impacts incurred by stakeholder group l if object k enterring CS2 (unplanned).

The steps used to implement this priority rule are shown in Table 5.

Table 5 Steps to determine the OIS for a road link

Step	Description
1	Calculate the impacts when each object is in CS2 and no intervention is being executed, SC^{u}, and the impacts when an intervention is being executed, IC^{u}.
2	Determine the OIS for each object, e.g. every t_k^* an intervention should be executed.
3	Determine the time to intervention for each object taking into consideration its actual condition (e.g. optimal intervention time is 10 years, but the object has already been in operation 6 years, then the time to intervention is 4 years).
4	Determine the types of ISs to be investigated
5	Determine the values of the reduction factors to be used for each investigated type of intervention strategy.
6	Select a type of intervention strategy
7	Determine the time of the next intervention to be executed on the road link, t
8	Estimate the total impact from time t to the time when the execution of the next intervention.
9	Check $\sum_{k=1}^{\overline{K}} ic_k^{p,l}(t_k)$, if $\leq$ $B^{p,l}(t_k)$, then all impacts for planned interventions in t_k are within the set limits and therefore all proposed interventions are executed, then move to step 11. Otherwise, move to step 8.
10	Use priority rule to identify the interventions to be executed.
10.1	Order the objects that are candidates for intervention in decreasing order of contribution to impact incurred due to arriving in CS2 in year t_k
10.2	Select first object, $k=1$, $IC^{p,l}=0$
10.3	Check $IC_k^{p,l} < B^{p,l}(t_k)$, if yes, object k is selected, go to 10.4. if no, object k is not selected and deferred to next intervention time, go to 10.5
10.4	Set $IC_k^{p,l} = IC_k^{p,l} + IC^{p,l}$, $B^{p,l}(t_k) = B^{p,l}(t_k) - IC_k^{p,l}$, and $k = k+1$ and then go to 10.3
10.5	Set $k = k+1$ and then go to 10.3
11	Go to step 7 if the end of the investigated time period has not been reached, otherwise go to step 12.
12	If all types of intervention strategies have been analysed select strategy with lowest total impacts as the OIS and go to Step 13. If not all types of intervention strategies have been analysed select another type of intervention strategy and for to Step 7
13	Stop.

Note: t_k^* is referred as optimal intervention time for object k, corresponding to z^* in Eq. (17). It is also noted that the notation k for object in this section is different from S in section 2.1, e.g. k can be road section or bridge, while S refers to objects with similar structural characteristics.

6.4 Model comparison

6.4.1 General

The two models were tested using a fictive road link composed of three objects: one reinforced concrete bridge, with a surface area of 162.5m^2 (6.5 m x 25 m) and two road sections with surface areas of 1'653 m^2 (5.7 m x 290 m) and 912 m^2 (5.7m x 160m), respectively. The concrete bridge is affected by chloride induced corrosion of the reinforcement and the road sections are affected by soil settlement under the wearing surface resulting in cracking. It is assumed that the daily traffic volume is 600 vehicles per day, and the populations in the vicinity of the link are 500 people. The stakeholders are divided into four groups: owners, users, neighbours, indirectly affected public (APPENDIX 7).

The intervention considered for the concrete bridge is the removal of the concrete cover without exposing the reinforcement and the addition of a new chloride free concrete cover layer of the same thickness. The intervention considered for the road sections is the removal of the first 5 cm of pavement and the addition of a new 5 cm layer. Although a bit optimistic it is assumed that these interventions restore their respective objects to a like new condition. Table 6 summarises the information on infrastructure objects and the stakeholders of the road link.

In order to demonstrate the use of the proposed impact hierarchy and to evaluate two optimisation models an example is done where the OIS with respect to pavement roughness is determined for a road link composed of 3 objects (Table 6). The three models investigated are deterministic model 2 and probabilistic models 1 and 2. Deterministic model 1 is not investigated due to the programming complexity. The OISs were determined over an infinite time period with repeating the same type of intervention. A discount rate of 2%, was used.

Table 6 Information of infrastructure objects and their stakeholders

Descriptions	Object 1	Object 2	Object 3
Object name	Road section 1	Overpass RC bridge	Road section 2
Structure type	Asphalt concrete	Reinforced concrete	Asphalt concrete
Length (m)	290	25	160
Width (m)	5.7	6.5	5.7
DTV (vehicles)	600	600	600
Numbers of users	1000	1000	1000
Numbers of household	200	200	200
Numbers of residents	500	500	500

Five types of intervention strategies were investigated are summarized in Table 7. The interventions of which the intervention strategies are comprised are renewal interventions. For the road objects (object 1 and object 3), a renewal interventions is defined as the resurfacing the top asphalt layer. For the reinforced concrete bridge a renewal intervention is defined as replacing the top asphalt layer and the deteriorated concrete deck.

Table 7 The investigated intervention strategy types.

Intervention strategy type	Description
1	interventions are executed independently on the three objects
2	interventions are always executed simultaneously on objects 1 and 2, but independently on object 3
3	interventions are executed simultaneously on objects 1 and 3
4	interventions are always executed simultaneously on objects 2 and 3
5	interventions are executed simultaneously on all three objects

Two budget scenarios were investigated:

- an unlimited budget, i.e. there were sufficient financial resources available to execute all required interventions and
- a limited budget, i.e. there were not sufficient financial resources available to execute all required interventions.

6.4.2 Deterministic model

6.4.2.1 Deterioration

A representation of how the objects deteriorate over time is shown in Figure 18. The deterioration curves of road sections (object 1 and 3) are drawn according to the assumption of deterioration parameters γ in Eq. (41) to be 0.01 and 0.02, respectively. The initial roughness is s(t0)=20 mm/m and the value of parameter $\overline{f}^*$ equal to 2 for both two objects since we assume in Table 6 that they are under same traffic volume. The deterioration curve of the concrete bridge (Figure 18) is determined with:

$$I = e^{\lambda \cdot t} - 1 \qquad (33)$$

$$\lambda = (\ln 2) / T_c \qquad (34)$$

Where

I is a representation of the physical condition of the bridge

λ is rating coefficient determined for the concrete bridge on the basic of boundary condition. Tc is a standard average life of the bridge.

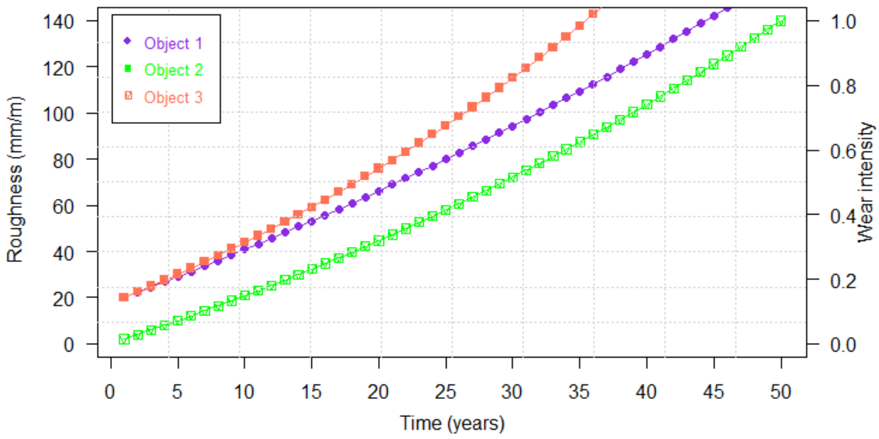


Figure 18 Deterministic model of condition evolution

6.4.2.2 Improvement

It is assumed that when an intervention is executed that the object is restored to condition state 1, i.e. a like new condition. Immediately after the execution of an intervention it is assumed that:

- for the road section, the roughness will be restored to $s(t_0)$=20 mm/m (see Figure 5-a) and all cracking will be eliminated
- for the concrete bridge, the value I will equal to 0 (see Figure 5-b).

6.4.2.3 Impacts

Impacts on each of the four stakeholder groups during the interventions and in between interventions are modelled using Eq. (3) and (4), i.e. the impacts during interventions and between interventions, were modelled using the functions $f_{n_l}^{k_{nl}}(t,x)$ and $g_{n_l}^{k_{nl}}(d,x)$. The values of the parameters $a,b,$ and β (the indexes associated with each parameter are omitted here for ease of reading) were estimated based on given impact indicators (BIs) in respective periods. For example, the expected vehicle costs associated to object 1 in condition state 1 between interventions is estimated, using Eq. (99) and Eq. (100) as:

Total VoC (year) = 290*365*600*[7*60/100*0.58]*[1/60000] = 2'579 MU/year since object 1 has a length of 290 m, the daily traffic volume is 600 vehicles, the average speed is 60 km per hour, the average amount of gasoline consumed for 100 km is about 7 litres, and the cost for 1 litre of gasoline is 0.58 MU.

This value is the value of parameter a of function $f_{n_l}^{k_{nl}}(t,x)$ where x represents the impact of vehicle costs attributed to the user. It was assumed that $b=1.2$ and $\beta=0.06$[6]. The expected variation of the vehicle costs between, and during, interventions related to each of three objects over time is shown in Figure 19 and Figure 20, respectively.

[6] These values are normally determined from actual data.

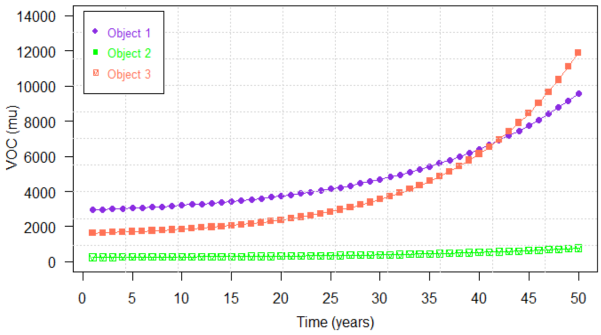


Figure 19 Evolution of VCs over time (in between interventions)

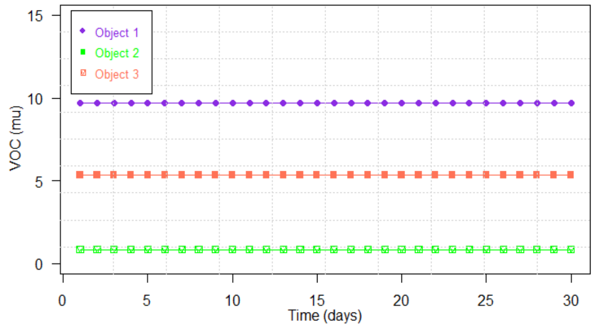


Figure 20 Evolution of VCs over time (during intervention)

The values of parameters (*a*,*b*, and *β*) of functions *f* and *g* for respective stakeholder groups are given in Table 8. During the execution of interventions, it is assumed that:

- the values of *b* and *β* are equal to 0, meaning that the impacts on each stakeholder groups are estimated as lump-sum values, i.e. they do not vary with the condition of the object, and
- the values of *a* for neighbours and DAP are equal to 0, meaning that the impacts of on neighbours and IAP during the execution of intervention are relatively small and assumed to be negligible[7].
- between interventions, it is assumed that the values of parameters are non-negative, meaning that impacts incurred to stakeholder groups are increasing functions. The values of *a*, *b* for the owner are set to be 0, meaning that the variation in costs of routine maintenance with condition are ignored[8].

Table 8 Values of parameters functions *f* and *g*

Infrastructure objects	Stakeholder groups	During interventions (g)			In between interventions (f)		
		a	b	β	a	b	β
Object 1	(1) Owner	66'947	0	0	0	0	0.060
	(2) User	5'271	0	0	0.260	0.250	0.060
	(3) DAP	0	0	0	0.090	0.080	0.060
	(4) IAP	0	0	0	0.030	0.005	0.060
Object 2	(1) Owner	9'982	0	0	0	0	0.060
	(2) User	394	0	0	0.022	0.032	0.060
	(3) DAP	0	0	0	0.008	0.008	0.060
	(4) IAP	0	0	0	0.003	0.000	0.060
Object 3	(1) Owner	36'936	0	0	0	0	0.080
	(2) User	2'520	0	0	0.103	0.138	0.080
	(3) DAP	0	0	0	0.030	0.041	0.080
	(4) IAP	0	0	0	0.010	0.003	0.080

Note: IAP stands for indirectly affected public. a, b, and β are fixed cost (MU), cost rate, initial performance index, and deterioration related parameter respectively. Value of money unit is 10^3 MU.

The decrease in the impacts on the owner and user during the execution of an intervention if more than one intervention is simultaneously executed is estimated by

[7] Although in reality perhaps not true, this assumption simplifies the presentation of the methodology.
[8] Again, although in reality perhaps not true, this assumption simplifies the presentation of the methodology.

multiplying the cost of executing each intervention if it was executed alone with a reduction factor (shown in Table 9). The decrease of impact is due to the savings of setup cost, e.g. only one worksite needs to be made, and any costs due to the deviation of traffic is only incurred once, if multiple interventions are executed simultaneously.

Table 9 Impact reduction factor

Description	Objects			
When interventions are executed simultaneously	1, 2	1, 3	2, 3	1, 2, 3
The intervention costs will be x% of costs if executed independently	84	90	85	90

The reduced impacts during interventions for each of the intervention strategy types are given in Table 10. There is no reduction of the impact between interventions.

The impacts of the interventions for strategy type 1 are the highest, e.g. 66,967 MU for object 1 when compared to 56,905 MU under strategy type 2, 60,252 MU under strategy type 3, and 60,252 MU under strategy type 5. This reduction is due to the simultaneous execution of interventions on object 1 and 2, which can, for example, be executed substantially faster than executing the interventions in series, reducing such impact as excess travel time due to detours. By executing two interventions simultaneously it is also possible to significantly reduce the set-up costs when compared to executing two interventions simultaneously.

Table 10 The impacts during interventions associated with each intervention type

Infrastructure objects	Stakeholder groups	During interventions (g)				
		Strategy type 1	Strategy type 2	Strategy type 3	Strategy type 4	Strategy type 5
		a	a	a	a	a
Object 1	(1) Owner	66’947	56’905	60’252	66’947	60’252
	(2) User	5’271	4’217	4’744	5’271	4’744
	(3) DAP	0.00	0.00	0.00	0.00	0.00
	(4) IAP	0.00	0.00	0.00	0.00	0.00
Object 2	(1) Owner	9’982	8’484	9’982	8’484	8’983
	(2) User	394	315	394	315	354
	(3) DAP	0.00	0.00	0.00	0.00	0.00
	(4) IAP	0.00	0.00	0.00	0.00	0.00
Object 3	(1) Owner	36’936	36’936	33’242	31’396	33’242
	(2) User	2’520	2’520	2’268	2’016	2’268
	(3) DAP	0.00	0.00	0.00	0.00	0.00
	(4) IAP	0.00	0.00	0.00	0.00	0.00

Only the values of a are shown as the values of b and B are 0.
The shaded areas show the changes in the values under each intervention strategy.

6.4.2.4 Results

The total impacts over the investigated time period for the five investigated intervention strategy types and each of the two budget scenarios are given in Table 11.

In the case of the unlimited budget, the OIS:

- is to execute interventions on all 3 objects every 23 years for an average cost of 4’102 MU/year.
- is of type 5, and
- results in a savings of 1’879 MU/year when compared to the OIS type 1.

In the case of a limited budget of 3’500 MU/year, the OIS

- is of type 5.
- has an average cost of 4’864 MU/year, and
- results in a savings of 1’353 MU/year when compared to the OIS of type 1.

The budget constraint, results in:

- an increase of the average costs by more than 18.8% in comparison with OIS type 5 with an unlimited budget and
- in the postponement of the intervention on object 1, 2, and 3 from year 23 to year 26.

Table 11 Total impacts determined using the deterministic model for each scenario

Strategy type	Unlimited budget					Budget constraint of 3’500 MU/year				
	Intervention duration (d) (days)	Time between interventions (years)	Number of interventions (w)	Annual cost (MU)	Reduction in annual impact	Intervention duration (d) (days)	Time between interventions (years)	Number of interventions (w)	Annual cost (MU)	Reduction in annual impact
1				5’981	0				6’217	0
+ Object 1	30	19	3	3’417		30	29	2	3’653	
+ Object 2	8	25	2	346		8	25	2	346	
+ Object 3	15	16	3	2’218		15	16	3	2’218	
2				5’146	835				5’507	710
+ Object 1+2	30	21	2	2’928		30	26	2	3’289	
+ Object 3	15	16	3	2’218		15	16	3	2’218	
3				5’436	545				5’740	477
+ Object 1+3	30	18	3	5’090		30	23	2	5’128	
+ Object 2	8	25	2	346		8	26	2	612	
4				5’076	905				5’623	595
+ Object 1	30	19	3	3’417		30	19	3	3’417	
+ Object 2+3	15	22	2	1’659		15	28	2	2’206	
5				4’102	1’879				4’864	1’353
+ Object 1+2+3	30	23	2	4’102		30	26	2	4’864	

The evolutions of impacts over time for the deterministic model under 5 intervention strategy types are shown in (Figure 21-Figure 25). For example, in Figure 21, it can be seen that there are interventions on object 3 at year 16, on object 1 at year 19, and on object 2 in year 25. The interventions of respective objects are repeated with the same interval during the period of 60 years. In year 16, 19, and 25, it can also be seen that in the years where interventions are executed that there is a large increase in owner costs due to the interventions. After interventions are implemented, impacts incurred to stakeholders in between interventions reduce sharply and continues to increase over time until the next interventions. It can also be seen that in between interventions the impact incurred to users is the dominant one (~72%) among impacts incurred to users, neighbours, and IAP.

The differences in the evolution of impacts under 5 intervention strategy types can also be comparable from these figures. For example, under intervention strategy types 1, 2, 3 and 4 (Figure 21 to Figure 24), the intervention times are scattered along the horizontal axis. However, under intervention strategy type 5 (Figure 25), intervention is concentrated in a single years, which shows the bundling all 3 objects at one.

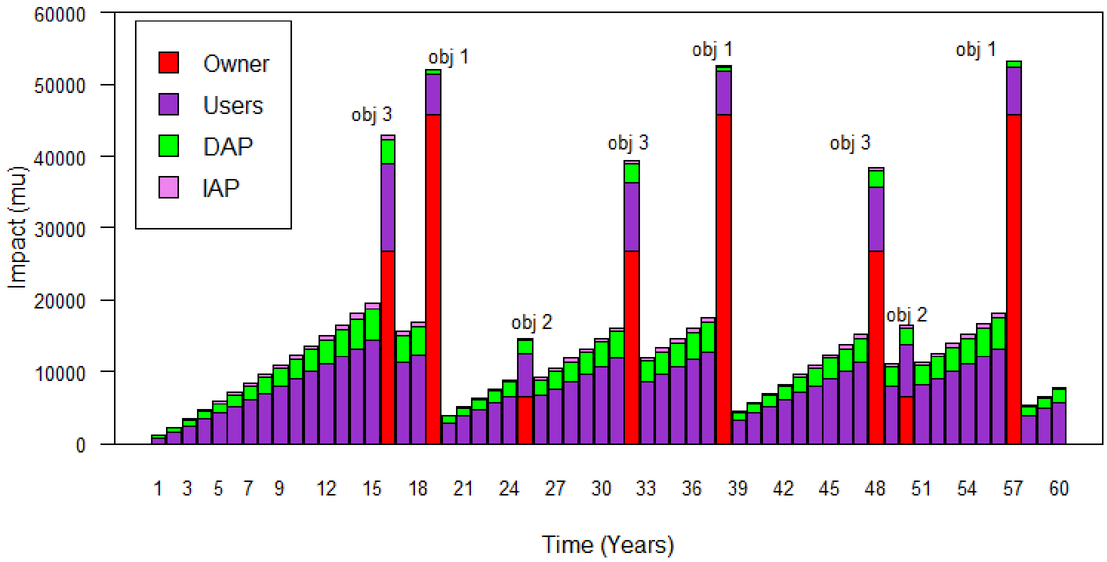


Figure 21 Evolution of impacts over time for the OIS of type 1-deterministic model

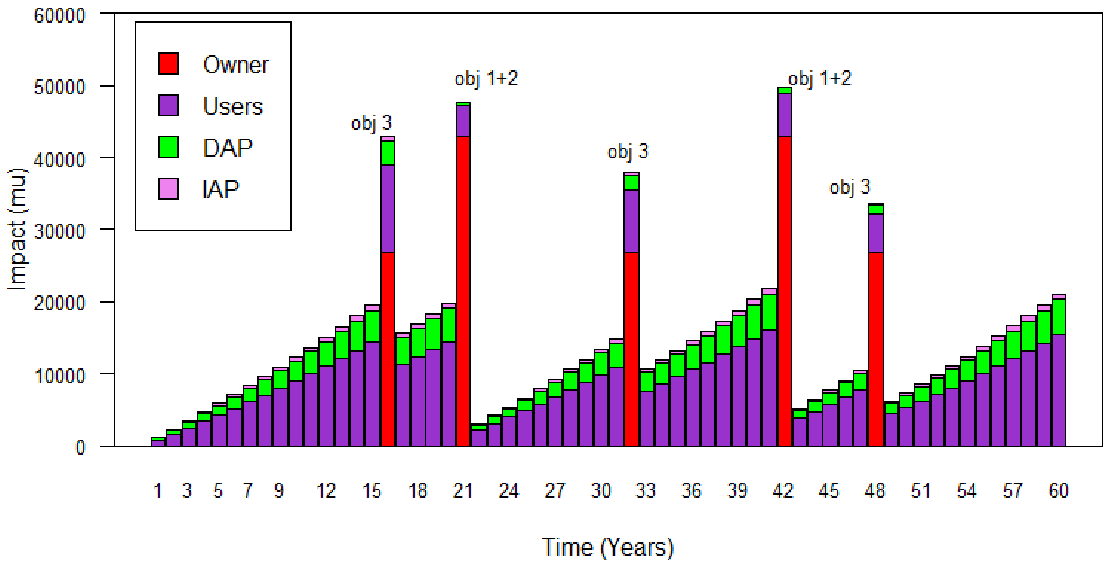


Figure 22 Evolution of impacts over time for the OIS of type 2-deterministic model

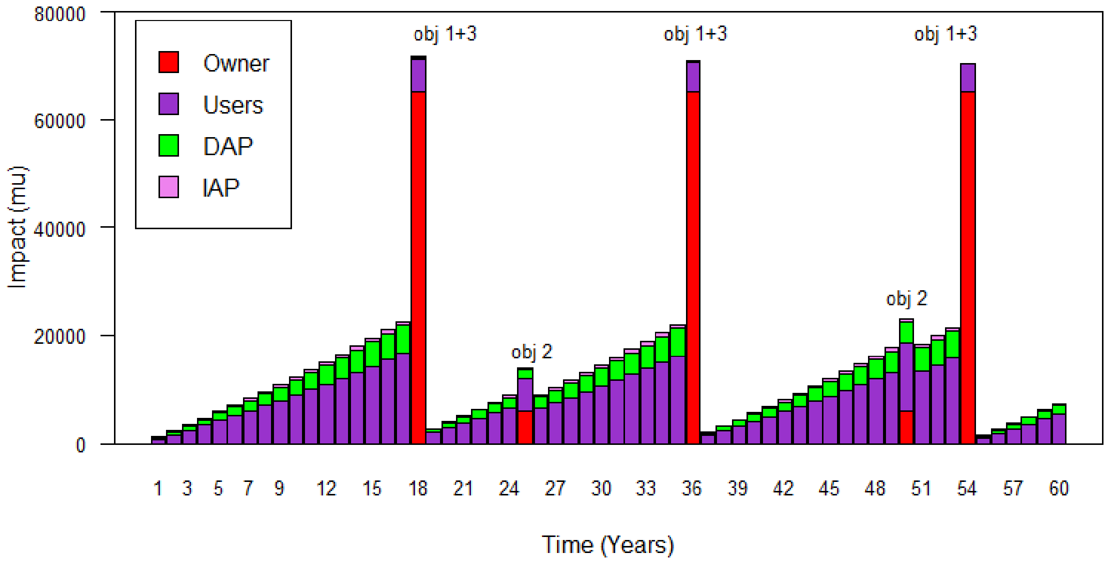


Figure 23 Evolution of impacts over time for the OIS of type 3-deterministic model

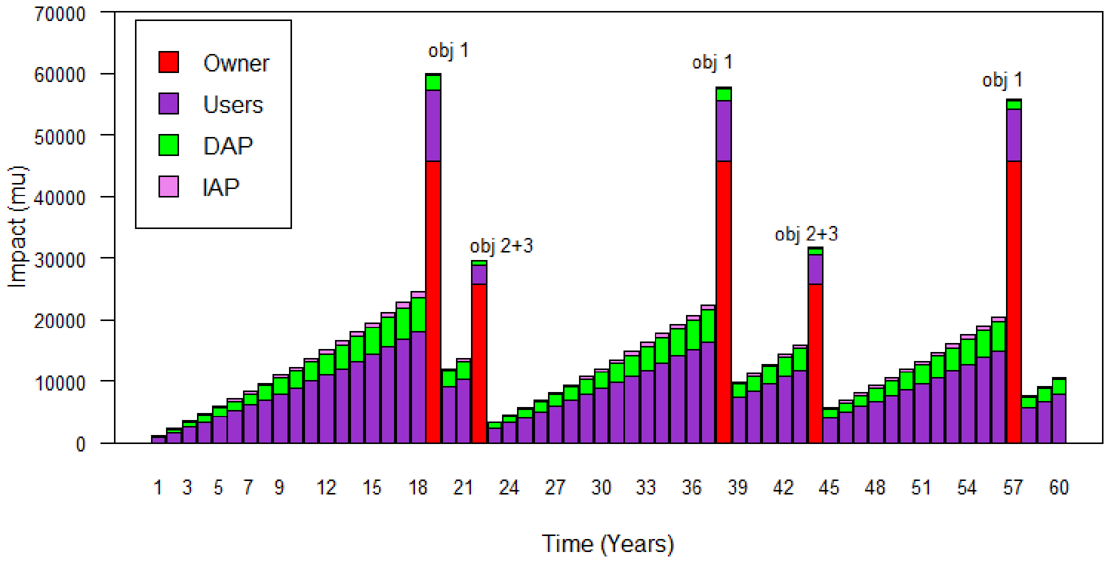


Figure 24 Evolution of impacts over time for the OIS of type 4-deterministic model

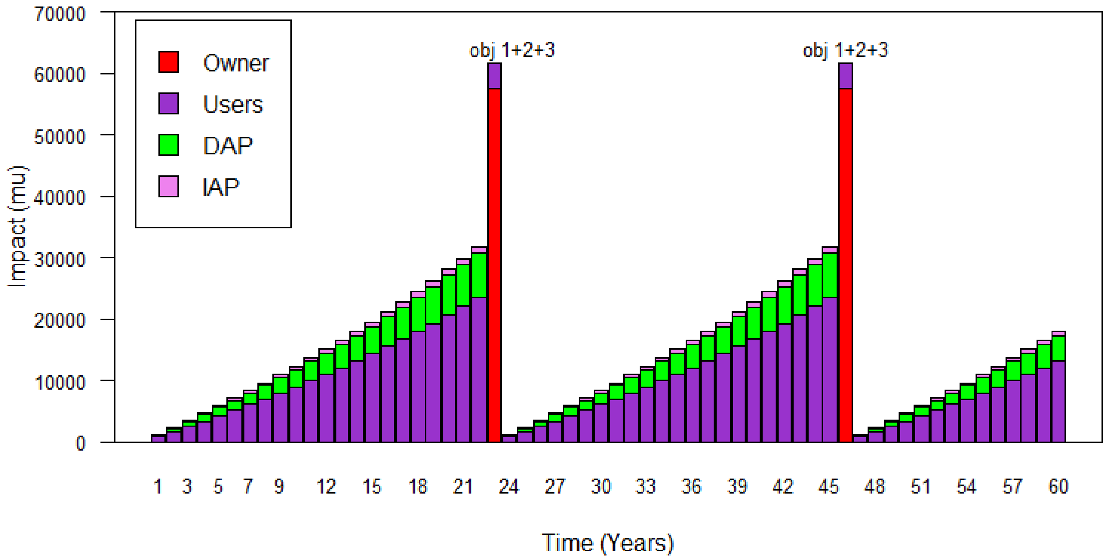


Figure 25 Evolution of impacts over time for the OIS of type 5-deterministic model

6.4.3 Probabilistic model

6.4.3.1 Deterioration

The deterioration processes of objects 1, 2, 3 are modelled as a continuous process, and assuming that the probability of being at a point along the curve can be modelled using the Weibull hazard function. The parameters of the model (refer to Eq.(17) and Eq.(18)) for the example problem are given in Table 6. The probability of reaching the predefined threshold states (condition state 4 or roughness reach more than 60) over time for each infrastructure objects is given in Table 12.

Table 12 Values of Weibull's parameters

Infrastructure objects	Parameter values	
	m	α
Object 1	2.010	0.010
Object 2	2.130	0.003
Object 3	2.120	0.010

The deterministic and probabilistic models (Figure 18 and Figure 26) are considered to be the same since:

- For road sections, after 20 years objects 1 and 3,
  - in the deterministic model have a roughness value of ~65 mm/m and ~80 mm/m respectively, and
  - in the probabilistic model have survival probabilities of being in condition state 1 of ~3% and ~2% respectively.

  It is assumed that survival probabilities of 3% and 2% are correlated to a roughness value of 65 mm/m and 80 mm/m respectively. This means, if the average roughness values are 65mm/m and 80 mm/m for road sections 1 and 3, and the thresholds for condition state 2 are 100 mm/m (equivalent to 30 years and 27 years life expectancy of object 1 and 3 respectively), and the uncertainty related to deterioration can be modelled as described above, than there is a 3% and 2% value of the road sections have lower roughness values.

- For concrete bridge, after 30 years
    - in the deterministic model has a condition value of 0.5, and
    - in the probabilistic model has a survival probability of being in condition state 1 of ~2%,

  It is assumed that a survival probability of 2% is correlated to a condition value of 0.5. This means, if the condition value is 0.5, and the threshold for condition state 2 is 0.75 (equivalent to about 40 years life expectancy)

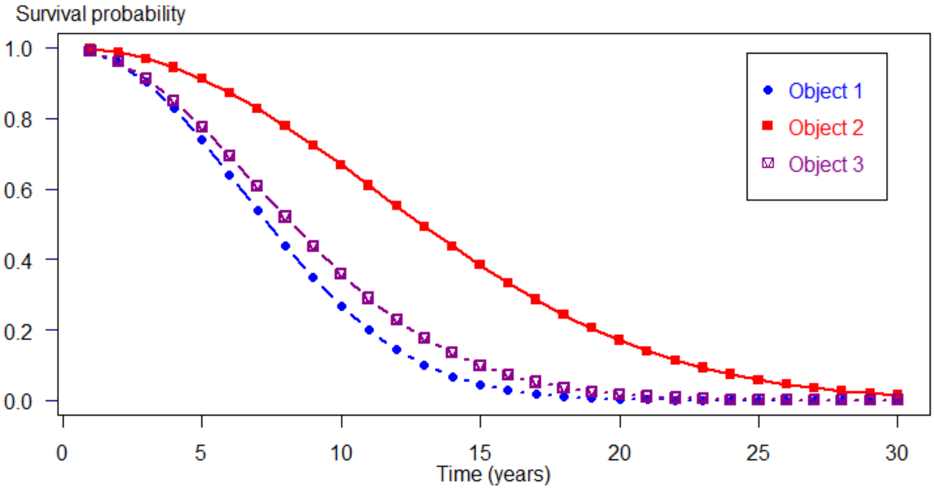


Figure 26 Probabilistic model of condition evolution

6.4.3.2 Improvement

The physical improvement on each object when an intervention is executed, it is assumed that the object is restored to a perfect condition. The threshold values of the roughness index for the road sections (object 1 and 3) were taken as 60 mm/m. The threshold value for the bridge was taken as 0.7 (value of wear intensity).

6.4.3.3 Impacts

The impacts were determined by estimating an average fixed impact associated with condition state 2, (Table 13) which are correlated to the impacts on users and the public used in the deterministic model (Table 8).

Table 13 Parameter values and expected impact of interventions (MU)

Infrastructure object	m	α	Impact on owner (IC)	Impact on user and society (SC)
Object 1	2.010	0.010	69,947	25,271
Object 2	2.130	0.003	9,982	5,394
Object 3	2.120	0.010	36,936	12,520

For example, for vehicle costs

- the probability that object 1 will survive year 1 is 0.990 ($\exp(-0.01*1^{2.01})$) (Eq. (14), and
- by assuming an average fixed vehicle costs of
    - o 2,700 MU/year when the object is in condition state 1, and
    - o 4,000 MU/year when the object is in condition state 2,

- the expected vehicle costs in year 1 are 2,712 ((2,700*0.99+4,000*(1-0.99))), which correlate nicely, albeit not perfectly, with the impacts used in deterministic model ((2,579+1.2*exp(0.06*1)*290)*exp(-0.02-1) ~2,800 MU).

The correlation between the vehicle costs predicted using the deterministic and probabilistic models over time, if no interventions are executed, can be seen in Table 27. It can be seen that the vehicle costs predicted using the probabilistic model are slightly different than those predicted using the deterministic model. It has been assumed that these two curves are the same as the average value over 30 years for both is ~3,700 MU. 30 years has been selected as it is expected to be the maximum time between interventions and therefore the correlation between the two curves before 30 years is the most important.

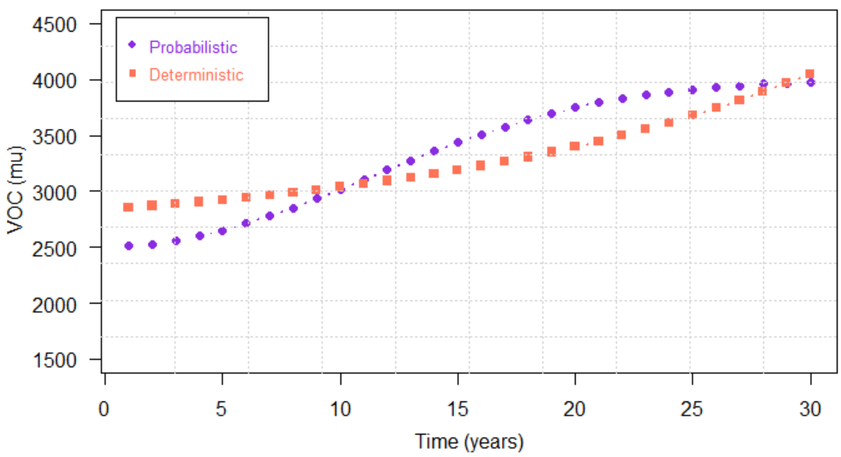


Figure 27 Evolution of VCs over time in Weibull model

6.4.3.4 Results

The total impacts over the investigated time period for the five investigated intervention strategy types and each of the two budget scenarios are given in Table 14.

Table 14 Total impacts determined using the probabilistic model for each scenario

Strategy type	Unlimited budget					Budget constraint of 3'500 mu/year				
	Intervention duration (d) (days)	Time between interventions (years)	Number of interventions (w)	Annual cost (mu)	Reduction in annual impact	Intervention duration (d) (days)	Time between interventions (t)(years)	Number of interventions (w)	Annual cost (mu)	Reduction in annual impact
1				6,587	0				7,100	0
+ Object 1	30	19	3	3,738		30	29	2	4,251	
+ Object 2	8	25	2	205		8	25	2	205	
+ Object 3	15	16	3	2,644		15	16	3	2,644	
2				5,560	1,027				6,085	1,015
+ Object 1+2	30	23	2	2,916		30	26	2	3,441	
+ Object 3	15	16	3	2,644		15	16	3	2,644	
3				6,345	241				7,220	-120
+ Object 1+3	30	17	3	6,140		30	23	2	6,492	
+ Object 2	8	25	2	205		8	26	2	728	
4				5,552	1,034				5,858	1,242
+ Object 1	30	19	3	3,739		30	19	3	3,739	
+ Object 2+3	15	23	2	1,813		15	28	2	2,119	
5				4,548	2,038				5,152	1,948
+ Object 1+2+3	30	24	2	4,548		30	25	2	5,152	

In the case of the unlimited budget, the OIS:

- is to execute interventions on all 3 objects every 24 years for an average cost of 4,548 MU/year.
- is of type 5, and
- results in a savings of 2,038 MU/year when compared to the OIS type 1.

In the case of a limited budget of 3,500 MU/year, the OIS

- is of type 5,
- has an average cost of 5,152 MU/year, and
- results in a savings of 1,948 MU/year when compared to the OIS of type 1.

The budget constraint, results in an increase of the average costs by more than 13% in comparison with OIS type 5.

The evolutions of impacts over time for the probabilistic model under 5 intervention strategy types are shown in (Figure 28 to Figure 32). For example, in Figure 28, it can be seen that there are interventions on object 3 at year 16, on object 1 at year 19, and on object 2 in year 25. The interventions of respective objects are repeated with the same interval during the period of 60 years. In year 16, 19, and 25, it can also be seen that in the years where interventions are executed that there is a large increase in owner costs due to the intervention activities. After interventions are implemented, impacts incurred to stakeholders in between interventions reduce sharply and continues to increase over time until the next interventions. It can also be seen that in between interventions the impact incurred to users is the dominant one (~72%) among impacts incurred to users, DAP, and IAP.

The differences in the evolution of impacts under 5 intervention strategy types can also be comparable from these figures. For example, under intervention strategy types 1, 2, 3 and 4 (Figure 28 to Figure 31), the intervention times are scattered along the horizontal axis. However, under intervention strategy type 5 (Figure 32), intervention is concentrated in a single years, which shows the bundling all 3 objects at one.

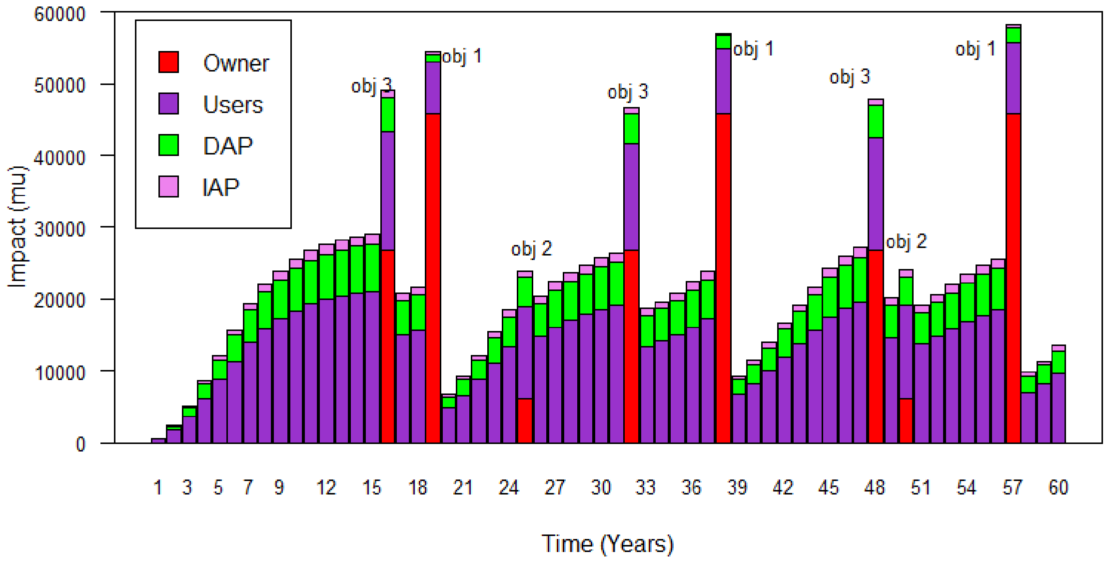


Figure 28 Evolution of impacts over time for the OIS of type 1-probabilistic model

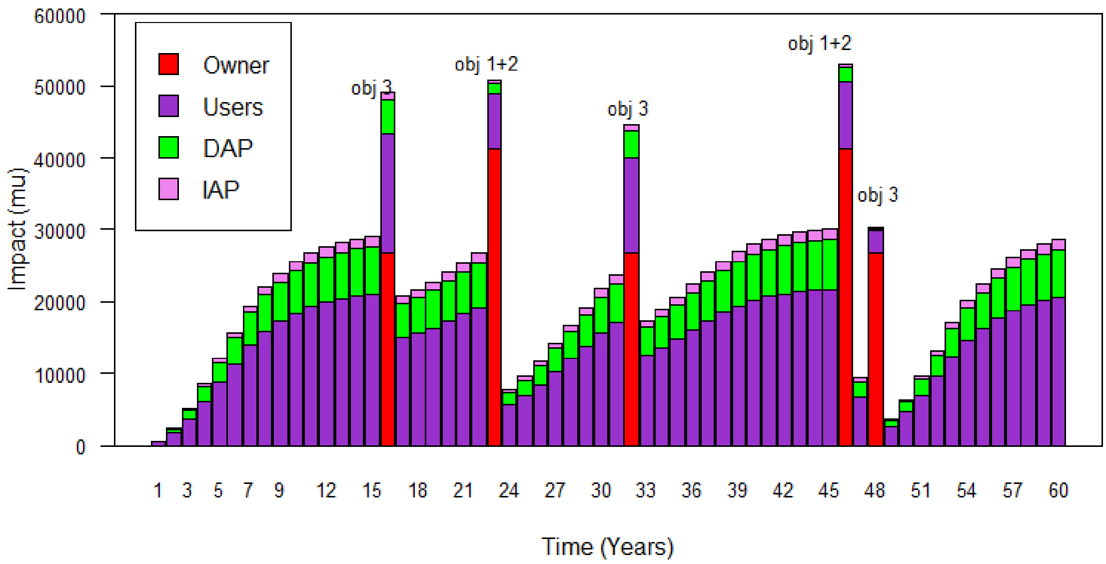


Figure 29 Evolution of impacts over time for the OIS of type 2-probabilistic model

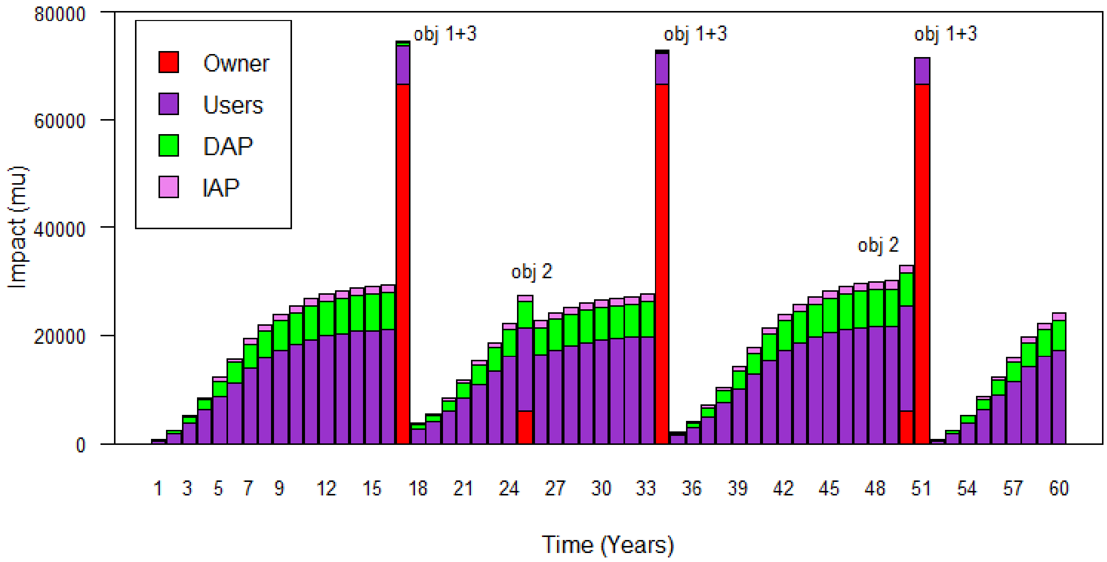


Figure 30 Evolution of impacts over time for the OIS of type 3-probabilistic model

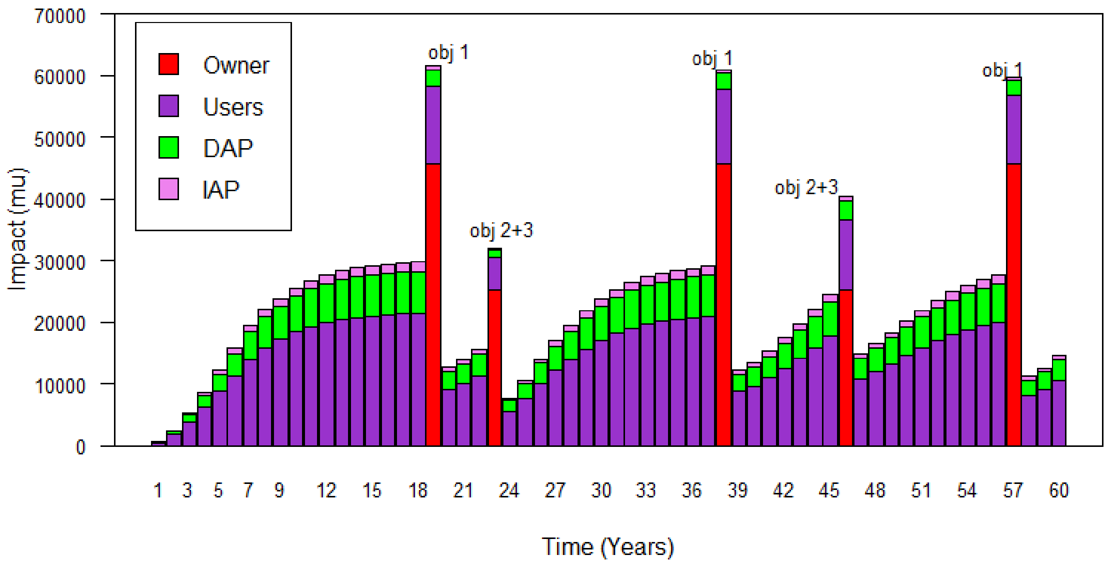


Figure 31 Evolution of impacts over time for the OIS of type 4-probabilistic model

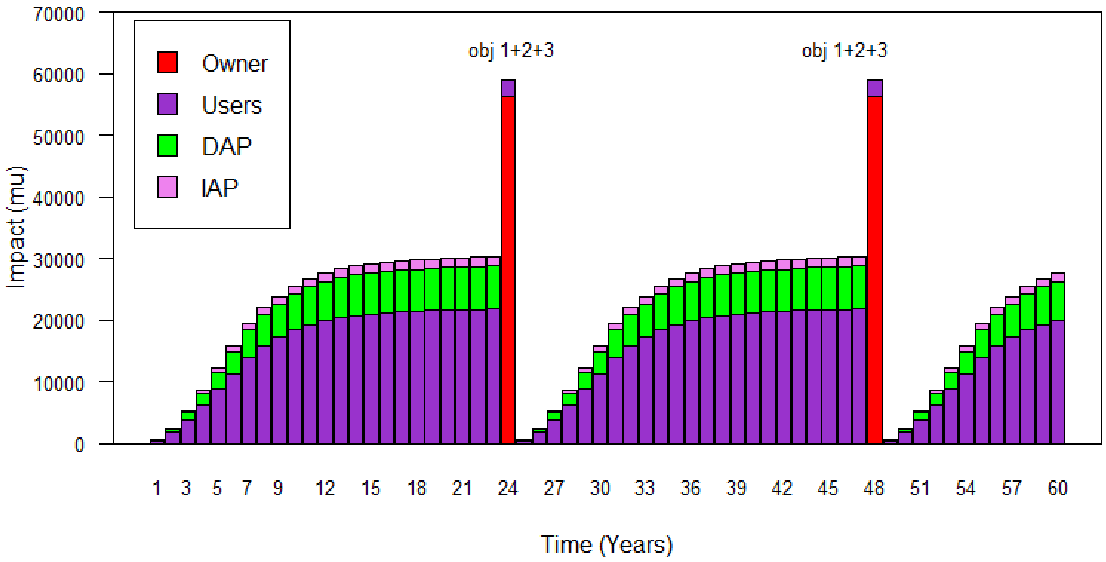


Figure 32 Evolution of impacts over time for the OIS of type 5-probabilistic model

6.4.4 Model comparison and selection

By comparing the results of the two models (Table 11 and Table 14), it can be seen that:

- the OISs determined by the two models are of the same type under both unconstrained and constrained budgets.
- the OISs of each strategy type, are similar under both unconstrained and constrained budgets.
- the probabilistic model yields higher annual costs than the deterministic model. The reason for this difference is attributable to the imperfect correlation between the assumed deterioration curves.

The deterministic model can be used to determine the OIS for a road link composed of multiple infrastructure objects that have the same intervention types over a finite planning horizon. The advantage of this model is that it offers easier and faster computational efforts than the MINLP model. However, it can only be applied for a special case of repeating the same intervention types within a finite planning horizon.

When the probabilistic model is used it is assumed that the failure probability of objects can be modelled using a Weibull density distribution function. As the probability of failure increases with the increase of time, the expected incurred costs to stakeholders also increase. Given a set of interventions, this formulation allows the determination of the optimal times to execute interventions so as to minimize the expected total impacts over a finite horizon. The numerical solution can be found using dynamic programing techniques.

Although the OISs of the two models are similar, the shapes of the curves concerning impacts evolution are different (Figure 25 and Figure 32). When the deterministic model is used the shape of the impact curves is assumed to follow an exponential function, while when the probabilistic model is used the shape of the impact curves is assumed to follow a logarithmic function. This difference is due to the assumptions related to the deterioration of the objects. With the deterministic model it was assumed that deterioration could be approximated by an exponential function, and thus the evolution of impact also follows exponential function and with the probabilistic model it was assumed that deterioration could be approximated with a logarithmic function. Ideally before using each model a goodness of fit with how the object changes over time would be performed. This information would help to select the model most suitable for a specific road link.

An evaluation of both models with respect to a number of important criteria is given in Table 15.

Table 15 Evaluation of investigated models

	Evaluation criteria							
	Type of intervention strategies considered	Programmability	Ease of determination of model parameters	Consideration of uncertainties	use of historical data for deterioration prediction	Number of condition states considered	Memory	Dimensionality
Det. model	Only single stage	difficult	moderate	No	Yes	Infinite – continuous	Yes	No
Prob. model	Only single stage	moderate	moderate	Yes	Yes	Two discrete condition states	Yes	No

The choice of whether or not to use the deterministic or the probabilistic model for the case studies is largely dependent on the uncertainty related to the deterioration processes that govern the evolution of impacts.

It is concluded that the deterministic model is most appropriate for determining the OISs for road links composed of multiple objects where multiple stakeholders are affected because of its:

- use of continuous infrastructure indicators from which to estimate impacts. In deterministic model, the deterioration progress of the infrastructure object is modelled with continuous indicators (e.g. roughness index, cracking, bridge condition indicator) which reflect the nature of deterioration. In the probabilistic model, only two condition states are considered. The use of binary condition states oversimplifies the deterioration of an infrastructure object, and therefore the modelling of impacts. In other words, it is not possible to model impacts sufficiently accurately.

- ease of determination of model parameters (e.g. parameter of impact models). The deterministic model can directly incorporate existing empirical impact models (e.g. models on travel time, vehicle cost, and environmental assessment). It is not always possible to incorporate impact models in probabilistic model.

- ease of programming. It is more challenging to program with probabilistic model. For instance, in order to compute the cost function in Eq.(31), it is required to come up with an explicit mathematical form of that function.

However, an explicit form is not possible, since a gamma function is embedded, making a direct solving of the integral challenging. In order to overcome that, we have to use an approximation algorithm to compute the value of the integral. For the deterministic model we can make use of optimisation solvers. Furthermore, the use of intermediate programing languages such as AMPL, GAMS, or LINGO is also an advantage.

6.5 Optimisation tool

In order to make the selected deterministic model applicable for the case studies (section 7 and 8), a simple prototype optimisation tool was developed. The tool was coded in R with embedded AMPL[9] syntax. Results of estimation can be recorded on screen or into flat files and being used in other software for graphical demonstration (e.g. R, Excel, etc.).

The tool includes three main components:

- Inventory (data input and data conversion)
- The model (syntax of the program to be used with optimization solvers such as CPLEX, BOMMIN)
- Illustration (Graphical presentation of the results)

The inventory component is simply made in Excel via a number of spread sheets:

- Front page: This sheet briefly describes the general information of the project.
- Historical information: The sheet is used to record the historical information concerning the physical deterioration of the infrastructure object and some basic information on the impacts of deterioration to stakeholders (e.g. traffic volume, accident rate, etc.)
- Intervention information: This sheet is designed to capture the information concerning intervention strategy. The change of impacts incurred to each stakeholders during intervention period and in between intervention period can be read from this sheet.
- Cost information: This sheet record basic cost information, which has to be entered directly by the users.

The Excel spread sheets are included in APPENDIX 9.

The model component includes the code and syntax in R and AMPL that read the input file from the inventory component and send the information to optimization solvers.

The illustration component can be done in various software supporting graphical demonstration such as Excel, R, etc.

[9] AMPL is a modeling language for mathematical programing. It was developed by Bell laboratories (the USA) http://www.ampl.com/

7 Dutch Case Study

7.1 Case description

7.1.1 Context and intervention

We choose a road intervention project on the A20, an arterial highway at the ring of Rotterdam in the Netherlands, as empirical setting for the first case study. The project was particularly appropriate for exploring stakeholder benefits and intervention strategies because of its location and organisation. The project was executed in a densely populated area. Besides residential houses, the area includes three industrial zones mostly used by spin-offs from the Rotterdam harbour, such as logistics firms and food chain companies (Figure 33). Before the intervention, the highway caused noise due to deteriorated bridge joints but also problems of accessibility due to regular traffic jams during rush hours.

Figure 33 Case study area

The maintained section of the A20 is a four-lane highway with a length of 7km and 7 overpass bridges. In APPENDIX 10 general information about the section (e.g. year of construction, length of objects), the traffic situation (e.g. daily traffic intensity), and the deterioration of the objects (e.g. condition states, survival rate) can be found. APPENDIX 10 also includes a drawing of the section.

In the period between July 30 and August 14, 2011 both directions of the highway section from the intersection Kleinpolderplein to the intersection Terbregseplein were closed one week after each other. The intervention included renewing the top asphalt layer, repairing the bridge joints and replacing the road furniture (Figure 34).

Figure 34 Maintenance activities on the A20

Due to existing capacity limits of the highway during rush hours, closing an entire direction for maintenance was expected to cause additional traffic problems, even though the work would be executed during the school holidays. Moreover, the Dutch highways agency expected that during the project, highway residents would suffer from noise and air pollution induced by the intervention work and would also have reduced accessibility to the highway network and the area. However, the intervention strategy of a complete highway closure for a short time was preferred over a lane-based maintenance which would have had a longer impact on the traffic. The expected and actual effects of the intervention on the traffic intensity are shown in Figure 35 and Figure 36.

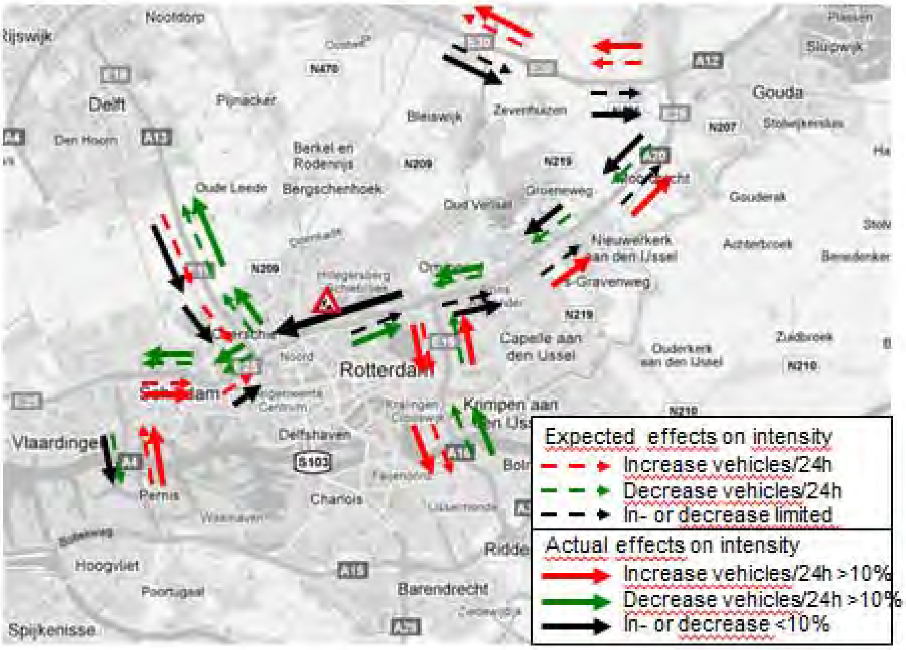


Figure 35 Expected and actual effect on traffic intensity in week 1

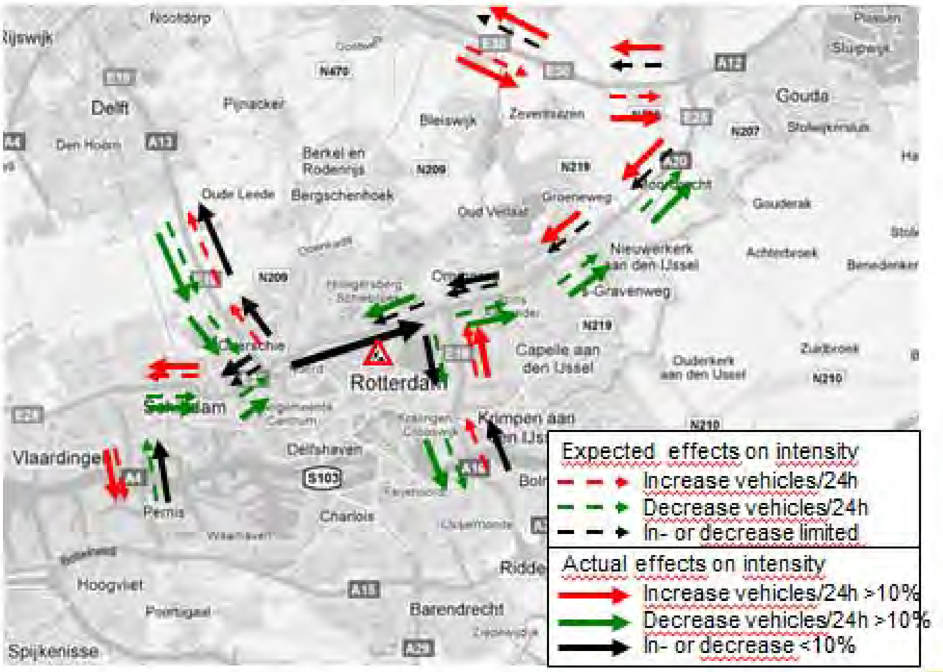


Figure 36 Expected and actual effect on traffic intensity in week 2

7.1.2 Data collection

The collected data comprised:

- Description of the highway section,
- Description of the intervention work,

- Importance of road impacts to stakeholders,
- Expectations and experiences of stakeholders about the intervention project,
- Satisfaction of the stakeholders with the project.

The stakeholder perception data was collected at two points in time. By using a questionnaire survey importance of road impacts and expectations were measured prior to the maintenance of the A20 and stakeholder experiences and satisfaction were measured after the intervention project was finished. One month before the intervention project, we administered the first questionnaire, while the second questionnaire was sent out approximately one month after the project was completed. Before the intervention project we sent 700 questionnaires to residents and 300 questionnaires to companies. Only companies and residents within 200 meters of the intervention project were selected. Each questionnaire was accompanied by a cover letter from the university and the Dutch Highways Agency. 85 road users were interviewed at a gas station and 43 road users filled in the questionnaire via the website of the road agency. In total, 244 stakeholders (128 road users, 85 residents and 31 companies) returned the first questionnaire. We asked respondents to report on the following road impacts (see also 4.2.1):

- Safety,
- Travel time,
- Comfort,
- Economy,
- Visual quality,
- Emission,
- Vehicle cost,
- Resource consumption.

For our analysis, the questionnaire was divided into four parts:

- In the first part respondents reported on certain characteristics (e.g. age, gender, user of the road), since different expectation may be assumed depending on these characteristics. The characteristics were collected to analyse group heterogeneity and eventually identify relevant sub-groups.[10]
- In the second part respondents were asked to give an indication of the importance of the above eight impacts independently from the intervention project.
- The third part focused on the stakeholders' expectations of how the road impacts will change because of the intervention project. More specifically:
  - How will the impacts change during maintenance (process).
  - How will the impacts improve after maintenance (result).
- The last part of the survey was dedicated to the expectation about type and quality of information received about the intervention project.

[10] It should be noted that the same characteristics have been collected for both road users and residents. Note also that the characteristics asked to the respondents of a company are mainly on the characteristic of the company itself, not of the employee. Apart from questions about stakeholder characteristics the questionnaire did not differ significantly for each stakeholders group. This guaranteed that differences solely depend on the intrinsic stakeholders' characteristics and not on the specific survey design.

The first questionnaire as it was prepared for road users can be found in APPENDIX 11.

To obtain individual expectation (dis)confirmation it was important during the second measurement to get responses from the individuals who already participated in the first questionnaire. Therefore we asked respondents to fill in their e-mail address on the first questionnaire. From the respondents who provided their e-mail address and were approached for the second questionnaire, 81 respondents (33%) returned the questionnaire. The second questionnaire also consisted of four parts:

- In the first part we asked the respondents once more about the importance of the road impacts, in order to check the consistency in their evaluation.
- In the second part respondents were asked about their experiences of the intervention process related to the road impacts.
- In the third part the respondents reported about their experiences of the maintenance result related to the road impacts.
- The last part of the questionnaire asked about the experiences with the information provision and the satisfaction with the intervention project. We asked about the satisfaction with the process, the outcome, the information provision and the overall project.

The second questionnaire as it was prepared for road users can be found in APPENDIX 12. The responses to the two questionnaires are summarized per stakeholder group in Table 16.

Table 16 Response to questionnaire 1 and 2

	Questionnaire 1	Questionnaire 2
Road Users	134 (10%)	32 (24%)
Residents	85 (12%)	36 (42%)
Companies	31 (10%)	13 (42%)
Total	**250 (11%)**	**81 (36%)**

7.2 Stakeholder identification

Before the intervention project stakeholders of the project were identified by the Dutch Highways Agency and mapped in a diagram (Figure 37). The more important stakeholders are, the closer they are positioned to the middle of the circle. The stakeholders marked in red have a negative position to the project, the orange stakeholders are critical about the project, the green stakeholders are positive, and the light yellow stakeholders are neutral about the project.

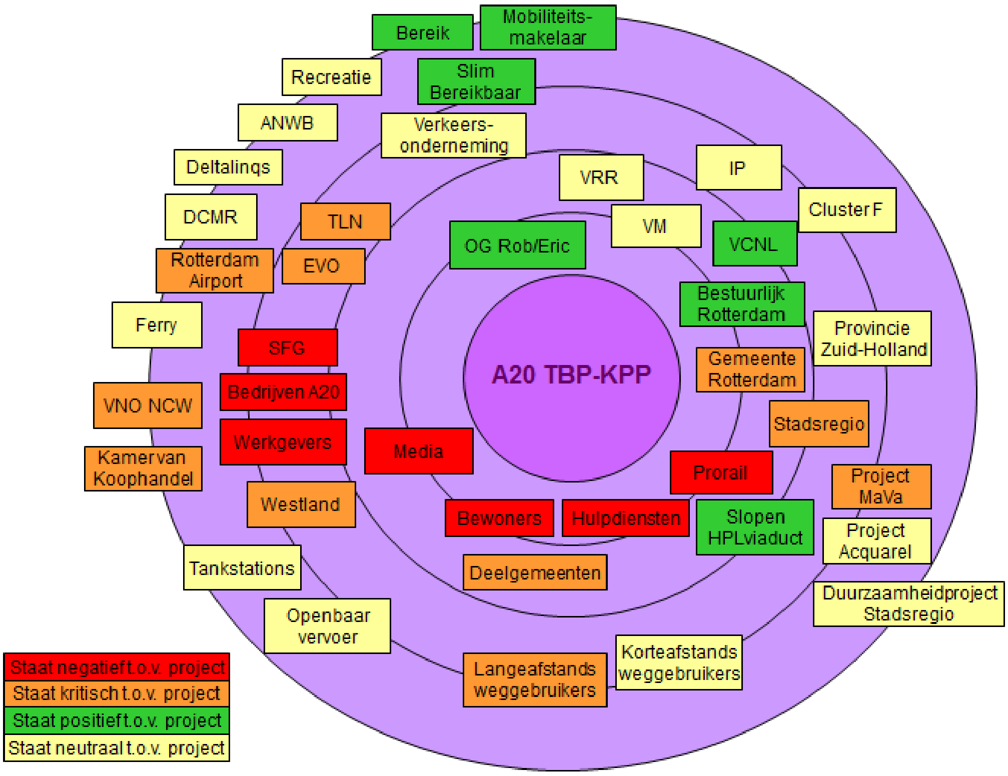


Figure 37 Stakeholder map of the Dutch Highways Agency

Although a wide number of stakeholders such as the port and the municipality of Rotterdam, gas stations, and public transport was identified, the analysis of SABARIS focused on those stakeholders which were directly affected by the road section and the intervention project:

- Road users – directly affected by the reduced capacity and speed limit of the road, the eventual increase of traffic jams and denser flows, with consequently higher travel times, discomfort, etc.
- Residents – live alongside the highway and suffer of a reduced accessibility of their environment, longer distances travelled to access the highway, air and acoustic pollution, etc.
- Companies – facing higher costs for delays, more fuel consumed, eventual losses of costumers and contracts etc.

The Dutch Highways Agency classified residents and companies as important stakeholders that have a negative view on the project. Road users were seen as less important stakeholders with a critical to neutral view on the project.

7.3 Stakeholder analysis before the intervention project

7.3.1 Respondent characteristics

225 respondents to questionnaire 1 were included in the analysis and can be characterized as follows:

- 55% are road users and 45% are road neighbours. The road neighbours can be further divided into residents (36%) and companies (10%).

- The majority of road users and residents are male (80%) and at an age between 26-65 years (85%). Only 8% are younger than 26 years and only 7% are older than 65 years.
- 64% of road users make use of the A20 2-7 days per week. 62% of the residents also use the A20 2-7 days per week, which indicates that residents switch stakeholder roles.
- 35% of the road users travel on the A20 for commuting purpose and 41% for business purpose. 51% of the residents travel for private purpose on the A20.
- 55% of the companies are of small and medium size (not more than 50 employees)
- For 91% of the companies the A20 plays an important role for doing business. 41% use the A20 for good transport and for 56% the main purpose of the A20 is the transportation of employees.

A graphical representation of the respondent characteristics can be found in APPENDIX 13.

7.3.2 Importance of road impacts

When asking all stakeholders about the importance of road impacts, the ranking of road impacts as depicted in Figure 38 was obtained.[11] Safety and travel time are the most important impacts to road stakeholders. Their importance significantly differs from the other impacts.[12] Visual quality and resource consumption are the least important impacts. Their importance also significantly differs from the other impacts.[13]

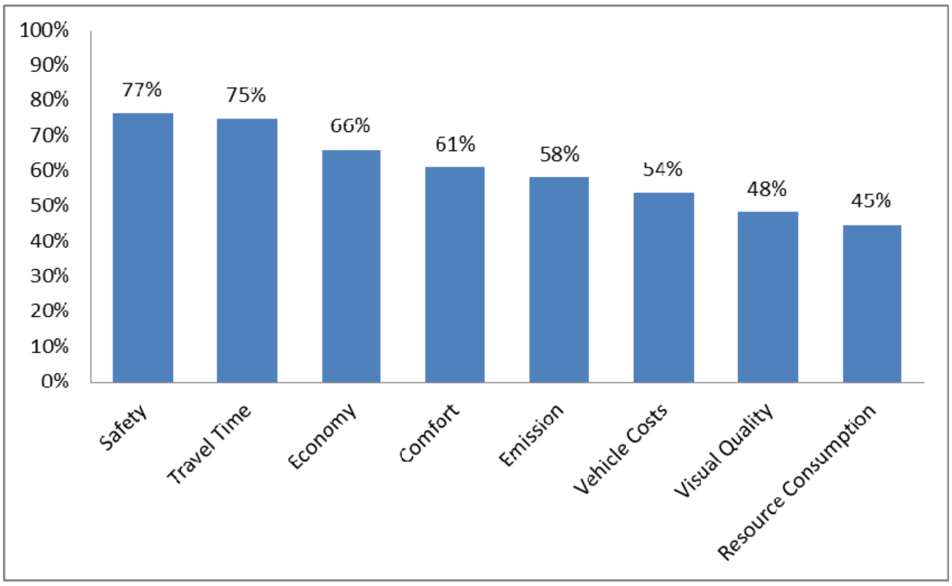
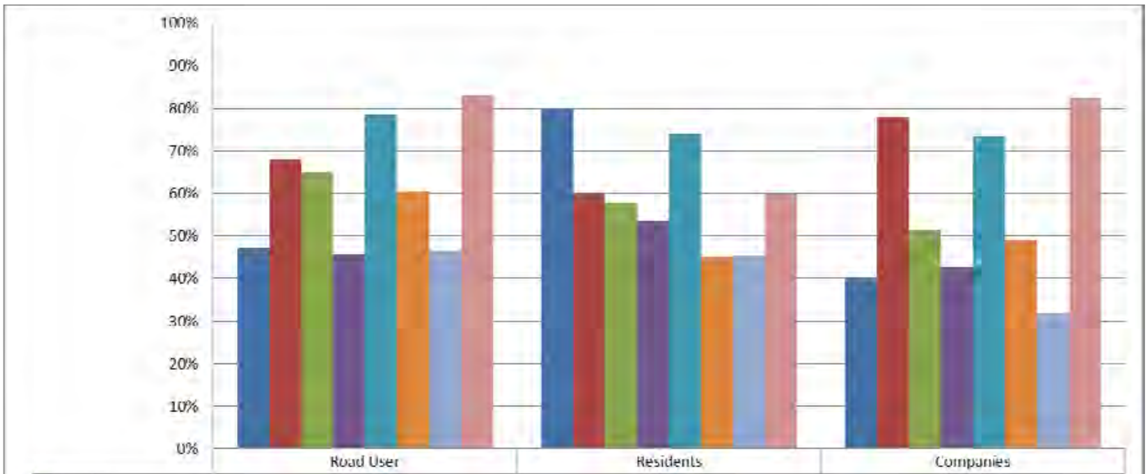


Figure 38 Overall importance of road impacts to stakeholders

The separate analysis of the importance of road impacts for the three stakeholder groups could reveal the following significant differences (Figure 39):

[11] The scale used ranges from 0% (very unimportant) to 100% (very important).
[12] It should be noted that the difference between the importance of safety and the importance of travel time is not significant.
[13] It should be noted that the difference between the importance of visual quality and the importance of resource consumption is not significant.

- Road users perceive travel time and vehicle cost more important than residents.
- Residents perceive emission more important than road users and companies.
- Companies perceive travel time and economy more important than residents.



	Road User	Residents	Companies
Emission	47%	80%	40%
Economy	68%	60%	78%
Comfort	65%	58%	51%
Visual Quality	46%	54%	43%
Safety	79%	74%	74%
Vehicle Costs	60%	45%	49%
Resource Consumption	47%	45%	32%
Travel Time	83%	60%	83%

Figure 39 Importance of road impacts per stakeholder group

Safety remains an important impact for all three stakeholder groups.

We also analysed whether there are significant differences in the importance judgement depending on respondent characteristics. The analysis showed that:

- Males perceive travel time more important than females.
- Stakeholders who use the road once per month or less perceive travel time less important than stakeholders who use the road more often.
- Stakeholders who are 66 and older perceive emissions more important than stakeholders who are younger.
- Stakeholders who are 18-25 years old perceive visual quality more important than stakeholders who are 26-65 years old.

In order to limit the length of the questionnaire it was decided to not include questions about the satisfaction with the different road impacts. However, the importance of road impacts to stakeholders indicates that safety and travel time are two impacts the Dutch Highways Agency should concentrate on when deciding on interventions. If it is assumed that both impacts already receive high attention, this attention should be kept. Emission and economy are two other impacts which are particular important in the context of the A20 and should get attention as well. If it is assumed that these impacts have been neglected in the past, interventions which take both impacts into account should receive high priority.

7.3.3 Expectations about the intervention project

The respondents were asked to report about their expectation regarding the intervention project. This included expectations about the intervention process, intervention outcome, and the information provision. Only respondents who filled in questionnaire 1 and 2 were considered in the analysis, in order to allow comparison between expectation and experience.

7.3.3.1 Process expectation

Overall 53% of the stakeholders expected a strong to very strong influence of the intervention project on them (Figure 40). Only 4% expected a very low influence. It is obvious that the road intervention project raised the expectation of stakeholders of being affected by the project.

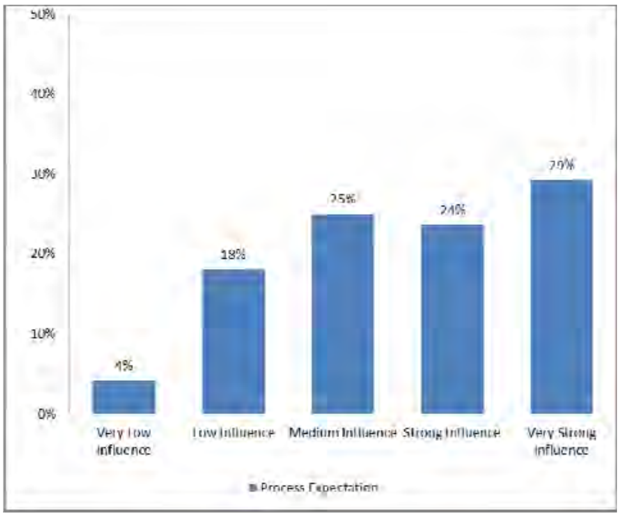


Figure 40 Overall expectation about the project influence on stakeholders

A closer look at the overall expectations of stakeholders about the influence of the intervention project on the road impacts show that first of all travel time, economy, comfort and emission were expected to be affected (Figure 41).[14] The expected impact on travel time can be explained with the importance of the highway section for the entire road network. Reducing the capacity of a traffic intense highway is expected to have effects on the capacity of other parts of the network. The expected impact on economy can be explained by the importance of the highway section for the neighbouring companies and the effect a closed highway section might have on the accessibility of premises and the transportation of goods and employees. The expected impact on emission can be explained in two ways. On the one hand, there might be the expectation that less traffic is on the highway which will lower the emissions. On the other hand, intervention work can also produce noise and dust and traffic which takes other routes can increase emissions in other areas as well.

[14] The scale used ranges from 1 (very small influence) to 5 (very strong influence). Travel time is significantly different from all other impacts. Comfort, economy and emission are also significantly different from the other impacts. The differences between comfort, economy and emission are not significantly different.

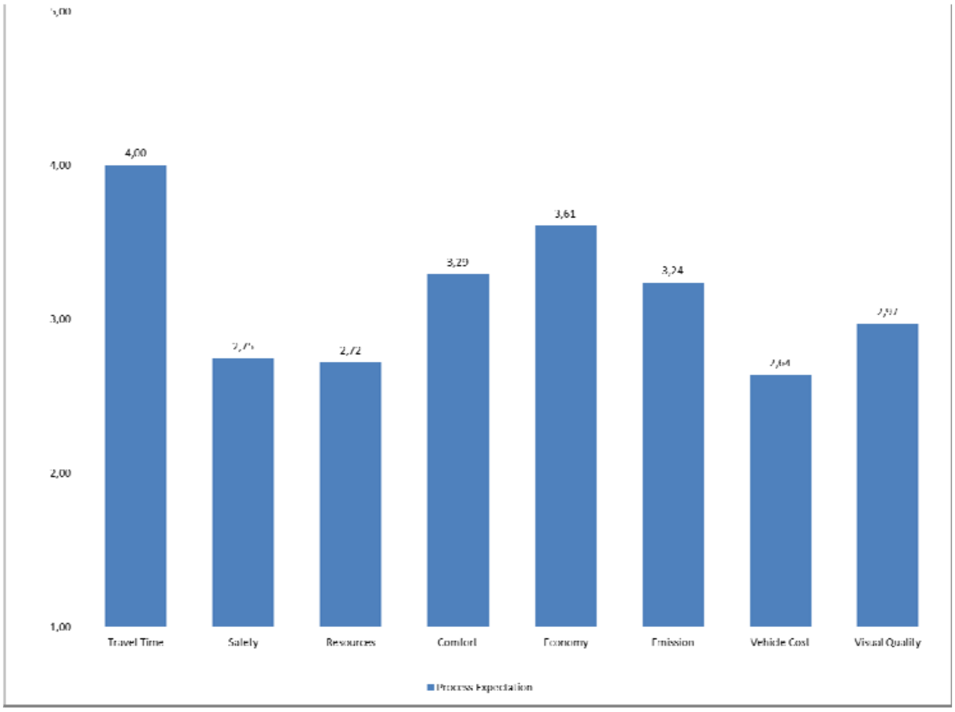


Figure 41 Overall expectations about the project influence on road impacts

A differentiation of process expectations per stakeholder group shows that:

- Road users and companies expected a stronger influence on travel time than residents.
- Companies expected a stronger influence on economy than residents and road users.
- Residents expected a stronger influence on emission than road users and companies.

These differences are in line with the importance of road impacts to stakeholders. In other words, stakeholders expected an influence on those road impacts during the intervention project which they regarded as important.

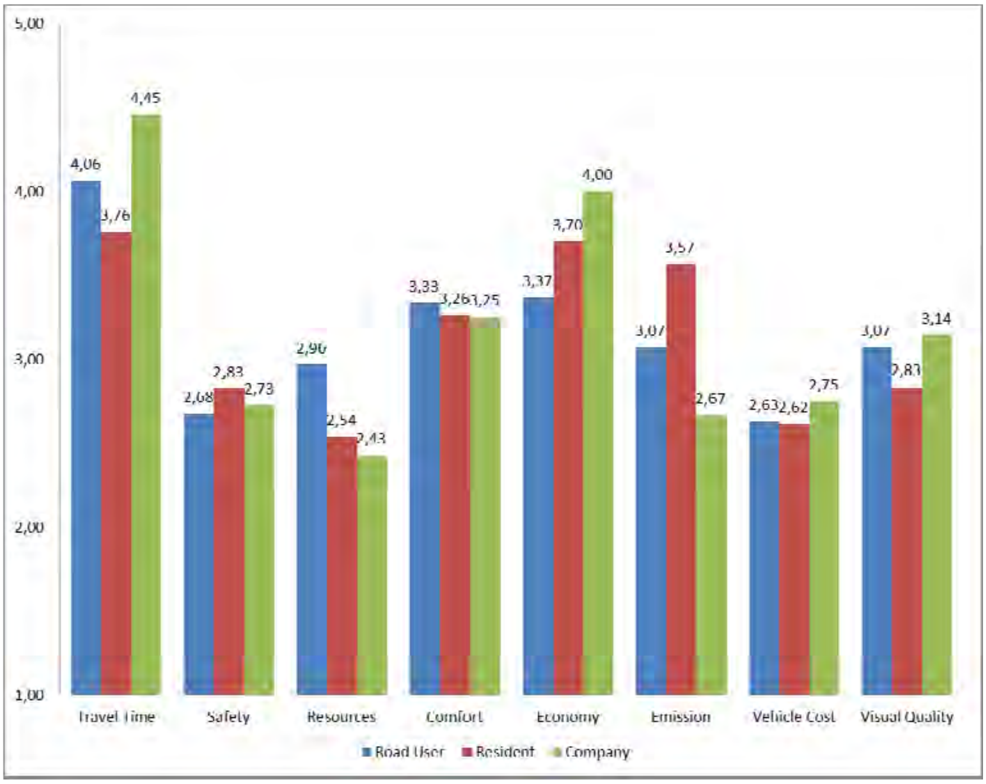


Figure 42 Expectations about the project influence on road impacts per stakeholder group

7.3.3.2 Outcome expectation

If it comes to the overall expectations about the outcomes of the intervention project, 40% of the stakeholders expected a strong to very strong improvement of the highway (Figure **43**). That suggests that before the intervention the stakeholder experienced a highway in a bad condition.

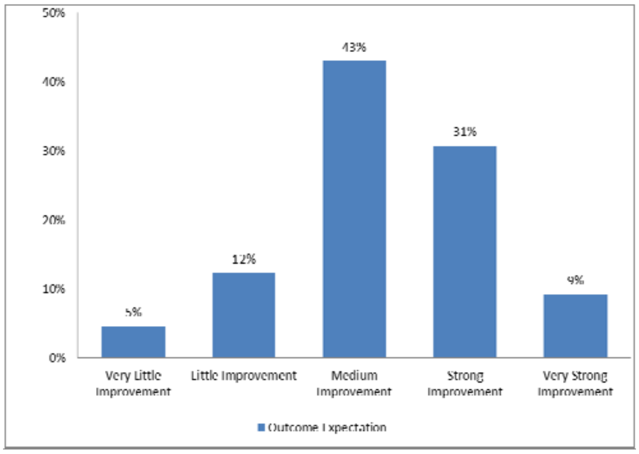


Figure 43 Overall expectations about the highway improvement after the project

The questions about the expected improvement of road impacts after the intervention project revealed that stakeholders expected comfort to be improved after the intervention (Figure 44). [15] That can be explained with the bad condition of the joints of the overpass bridges which caused noise and a bumpy ride on this link.

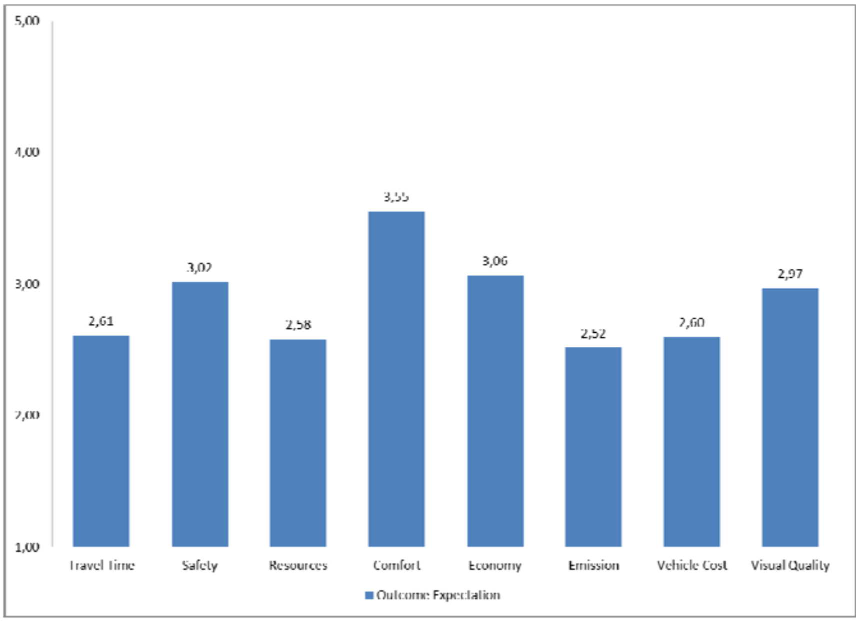


Figure 44 Overall expectations about the improvement of road impacts after the project

The three stakeholder groups expected a slightly different outcome from the project (Figure 45). Road users and residents expected a stronger improvement of comfort than companies. Compared to process expectations outcome expectations are not in line with the importance of road impacts. It seems that rather the experience of the highway link before the intervention raised certain expectations about the improvement after the intervention.

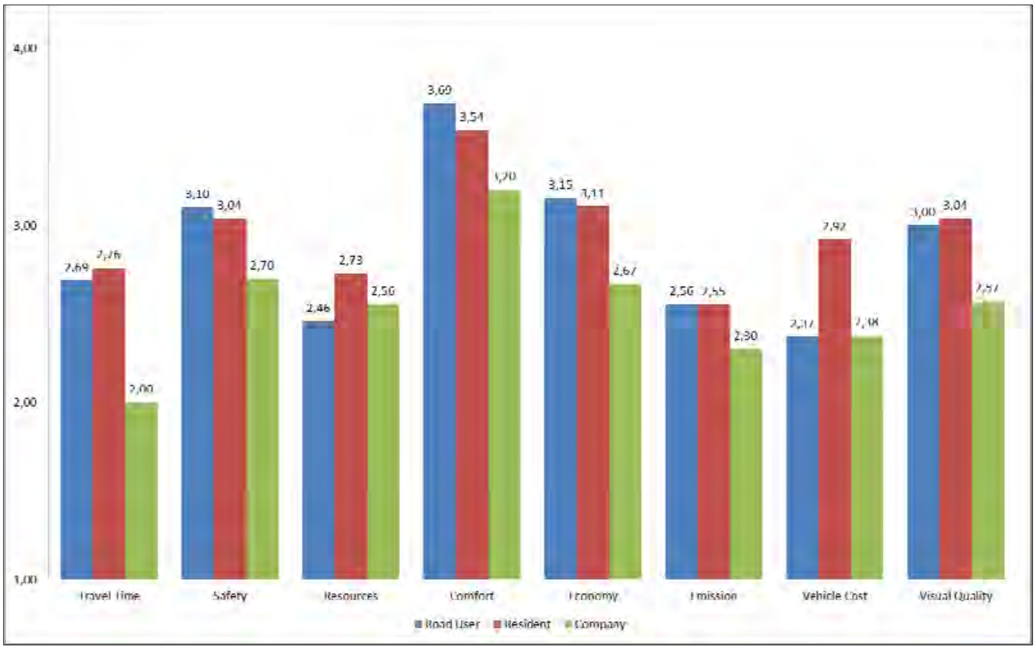


Figure 45 Expectations about the improvement of road impacts per stakeholder group

[15] The scale used ranges from 1 (very small improvement) to 5 (very strong improvement). Comfort is significantly different from all other impacts.

7.3.3.3 Information expectation

57% of the respondents expected to be informed about the road intervention much or very much (Figure 46).[16] That suggests that stakeholders rely on such information to make decisions regarding their travel behaviour or the organisational processes.

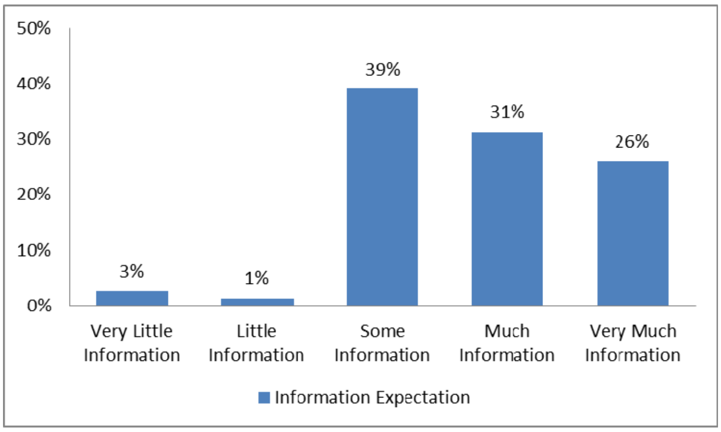


Figure 46 Overall expectations about the information provision

The expectations of the three stakeholder groups show some differences (Figure 47). Companies expect more information than residents and road users. That underlines the importance of this highway section to the companies located in the area and the expected effect of the intervention on the companies processes.

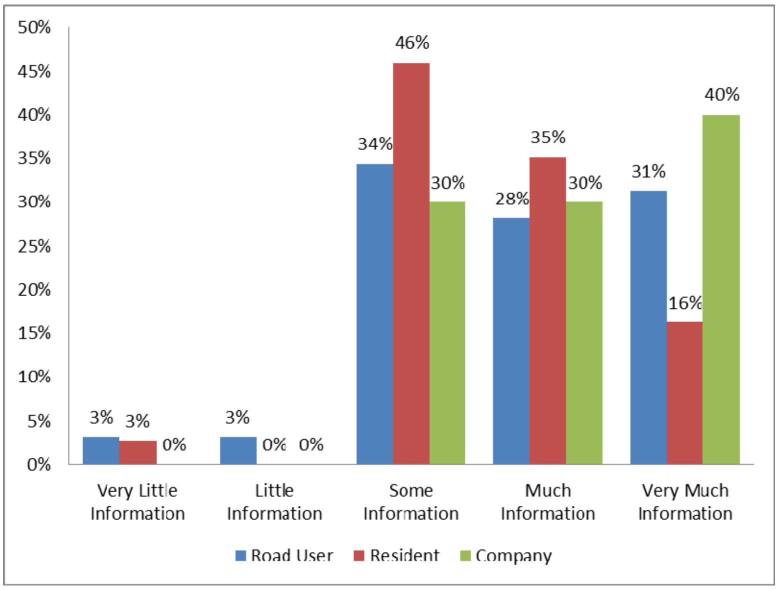


Figure 47 Expectations about the information provision per stakeholder group

[16] The scale used ranges from 1 (very little information) to 5 (very much information).

7.4 Stakeholder management

The Dutch Highways Agency tried to get every stakeholder on its stakeholder map (see section 7.2) 'green', meaning that all stakeholders have a positive view on the project. To achieve this, the stakeholder management strategy of the Dutch Highways Agency consisted of different ways of engaging with the stakeholders.

In order to decrease the traffic problems and complaints during and after the intervention, the Dutch Highways Agency communicated about the project to road users, residents, and companies before the intervention started. The companies situated near the road got letters and were visited by people from the intervention project and were asked to cooperate with the agency by providing ways for the employees to work at home or travel by public transport. The residents received two letters in which they were informed about the intervention project and possible hindrance. The road users received information through signs near the roads before the intervention. Information about the project including advice to use other routes, transportation modes or times for travelling were additionally provided via websites, newspapers, and social media. The Dutch Highways Agency also offered free tickets for the public transport.

The rationale behind this strategy was to:

- Get support from stakeholders for the intervention project,
- Convince the stakeholder that the intervention, closing of the road, and alternative routes are necessary,
- Convince stakeholder that the project team is taking enough measures to lower the inconvenience,
- Combine communication of project with stakeholders' communication,
- Convince stakeholders to use alternative travel modes, and
- Involve and invite the stakeholder to think with the project.

7.5 Stakeholder analysis after the intervention project

After the intervention project road users, residents and companies were asked about their experiences and satisfaction with the process, the outcome and the services provision of the project. The experiences are contrasted with the expectations, in order to reveal differences.

7.5.1.1 Process experiences

Only 24% of the respondents experienced a strong or very strong influence of the project (Figure 48). [17] That is in contrast with the 53% of stakeholders who expected a strong or very strong influence. That suggests that the project had a less strong effect on stakeholders. The difference between process expectation and experience is significant.

[17] The scale used ranges from 1 (very low influence) to 5 (very strong influence). Apart from comfort and resource consumption experiences are significantly different from expectations.

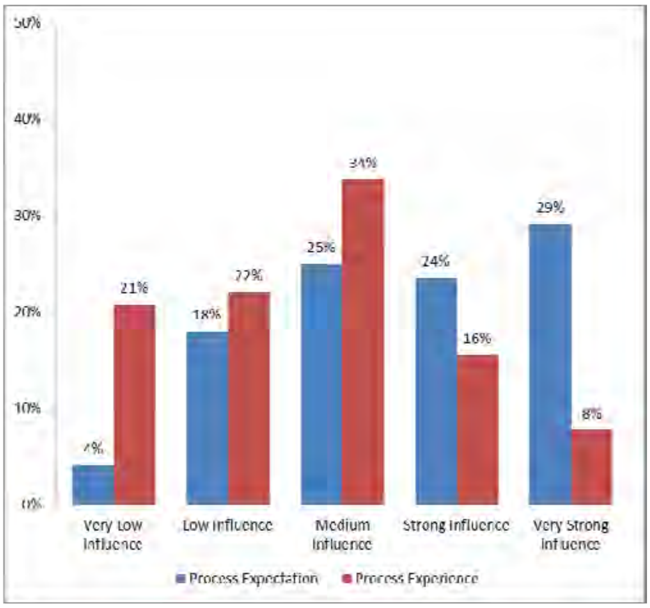


Figure 48 Overall experiences of the project influence on stakeholders

The picture of a lower influence than expected is confirmed when looking at the influences on the road impacts experienced by stakeholders (Figure 49). For all road impacts a lower influence is experienced than expected. Particularly the expected effect on travel time was lower. That is supported by the work of an engineering firm that was appointed by the Dutch Highways Agency to determine the effect of measures of the stakeholder management strategy, like the free train tickets and the public campaign, on the basis of traffic intensity during the intervention. The engineering firm concluded that there was less traffic hindrance than expected on forehand and that the stakeholder management strategy of the Dutch Highways Agency had some effect on the traffic.

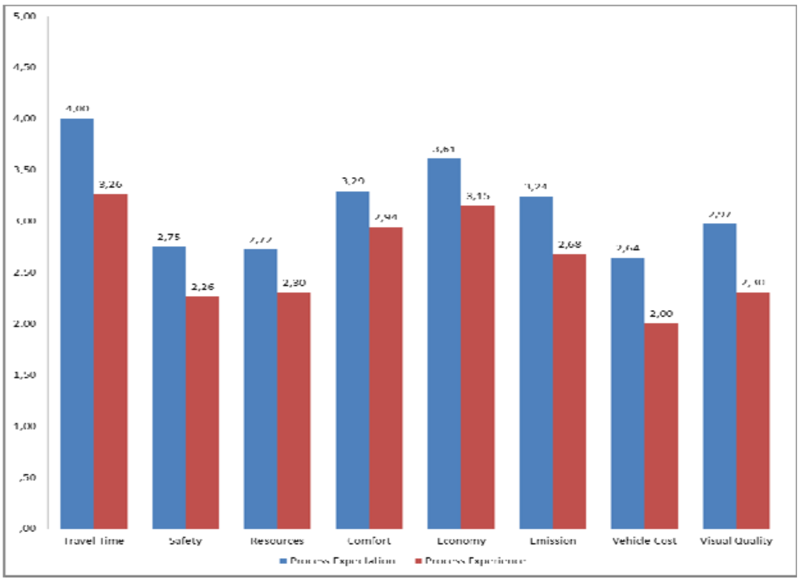


Figure 49 Overall experiences of the project influence on road impacts

Companies experienced the greatest influence on the road impacts during the intervention project (Figure 50).[18] They especially experienced influences on travel time and economy. That suggests a reduced accessibility to the companies' premises and longer routes for the transportation of goods and employees during the intervention.

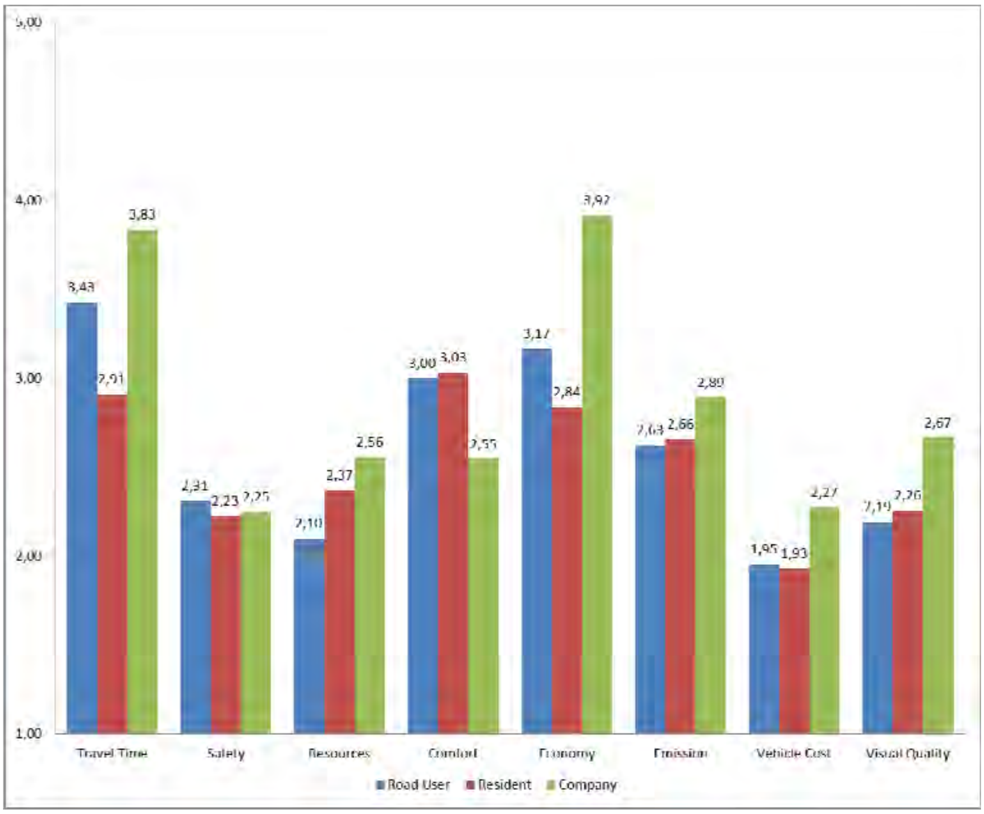


Figure 50 Experiences of the project influence on road impacts per stakeholder group

7.5.1.2 Outcome experiences

38% of all respondents experienced a strong or very strong improvement of the highway section after the intervention (Figure 51)[19]. There is no significant difference between outcome expectation and experience.

[18] It should be noted that all stakeholder groups including companies experienced less influence than expected.
[19] The scale used ranges from 1 (very low improvement) to 5 (very strong improvement).

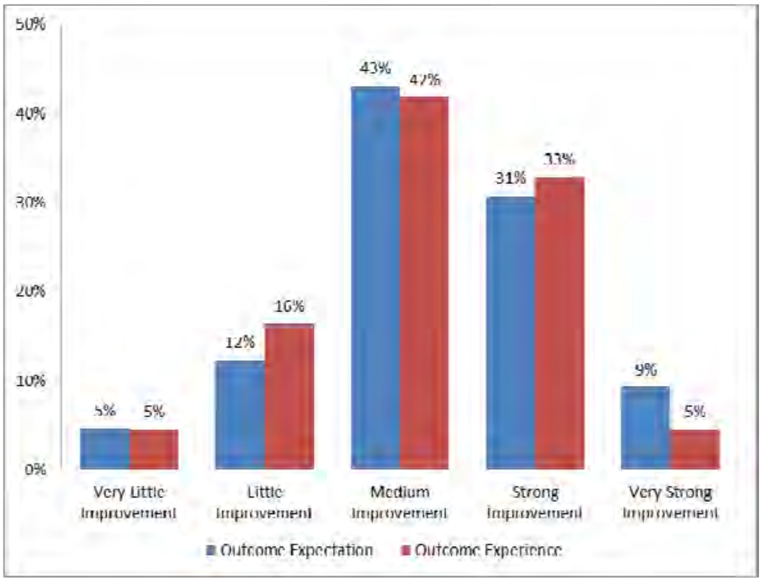


Figure 51 Overall experiences of the highway improvement after the project

Similar to process experiences, the outcome experiences related to the road impacts are lower than the expectations (Figure 52). The only exception is comfort. Respondents experienced a higher comfort than expected. That can be explained with the new asphalt layer and the renovated bridge joints. Travel time and economy show significant differences between experiences and expectations. For both impacts stakeholder expected more than they actually experienced.

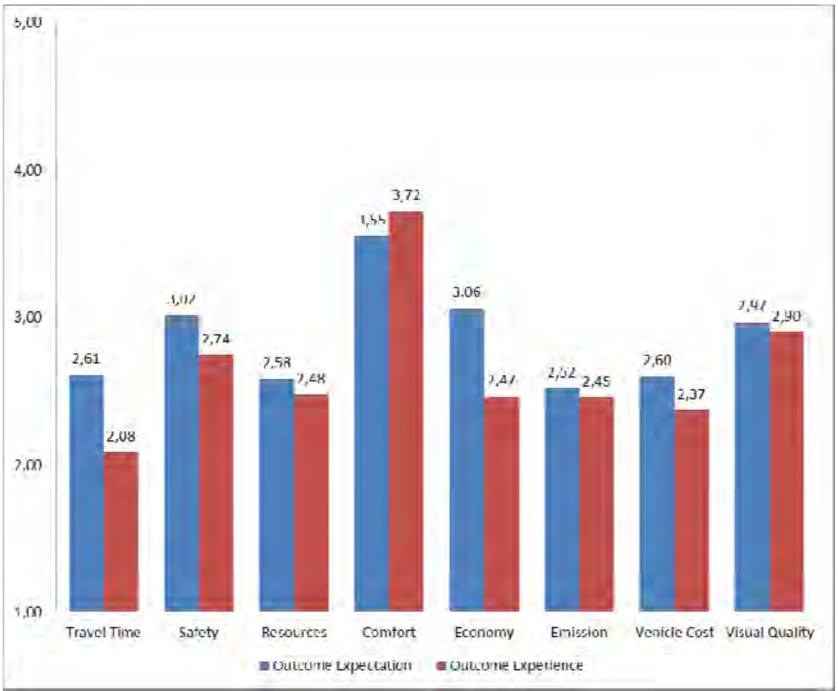


Figure 52 Overall experiences of the improvement of road impacts after the project

The improved comfort of the highway section is experienced by all stakeholder groups (Figure 53).

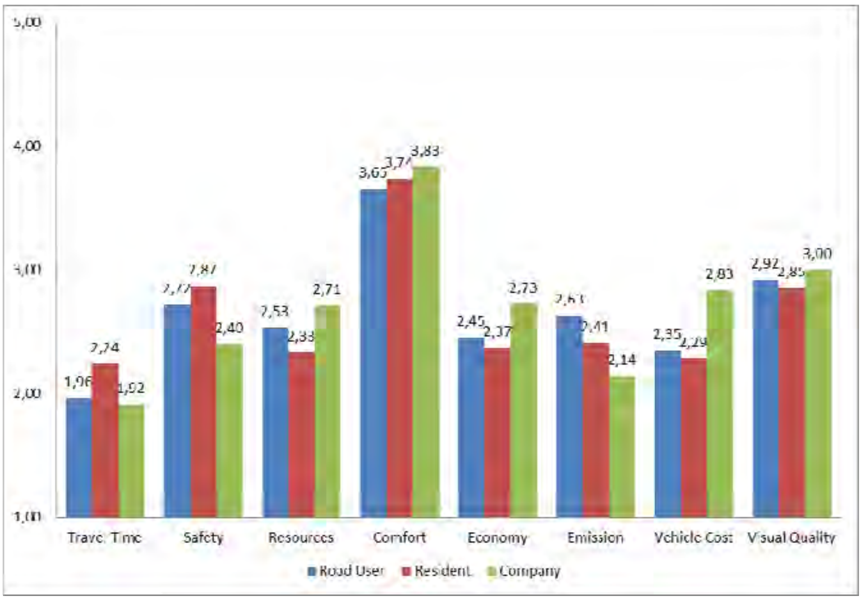


Figure 53 Experiences of the improvement of road impacts per stakeholder group

7.5.1.3 Information experiences

The majority of respondents (63%) received much or very much information about the maintenance (Figure 54).[20] That indicates that the information provision of the Dutch Highways Agency was successful in terms of reaching stakeholders. However, the difference between information expectation and experience is not significant.

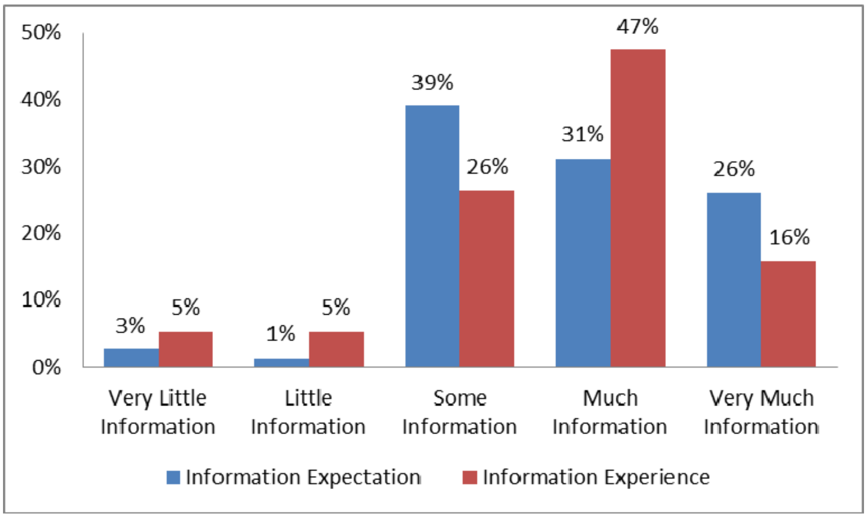


Figure 54 Overall experience with the information provision

Companies and residents experienced a comprehensive information provision of the Dutch Highways Agency (Figure 56). That is in line with the stakeholder management strategy of the agency which paid particular attention to these two groups.

[20] The scale used ranges from 1 (very little information) to 5 (very much information).

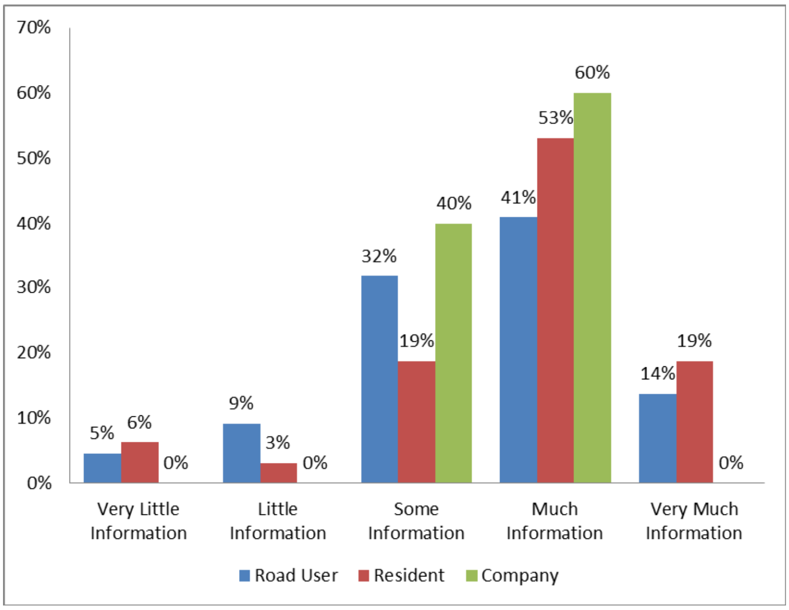


Figure 55 Experiences of the information provision per stakeholder group

7.5.2 Satisfaction with the intervention project

7.5.2.1 Process satisfaction

48% of the respondents are satisfied of very satisfied with the intervention process (Figure 56).[21] Only 15% are dissatisfied or very dissatisfied. Given the fact that road intervention is always related to traffic disruptions and other hindrance for stakeholders, the level of satisfaction points to an effective intervention and stakeholder management strategy of the Dutch Highways Agency.

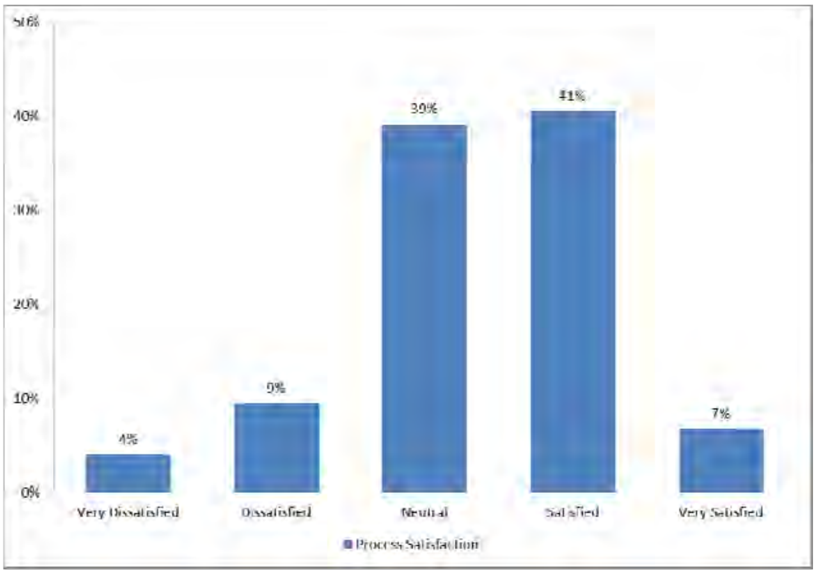


Figure 56 Satisfaction with the intervention process

The satisfaction with the intervention process per stakeholder group reflects the influence that was experienced by the respondents. The companies experienced the

[21] The scale used ranges from 1 (very dissatisfied) to 5 (very satisfied).

greatest influence and were least satisfied with the process (Figure 57). 56% of the road users and 49% of the residents were satisfied or very satisfied with the process.

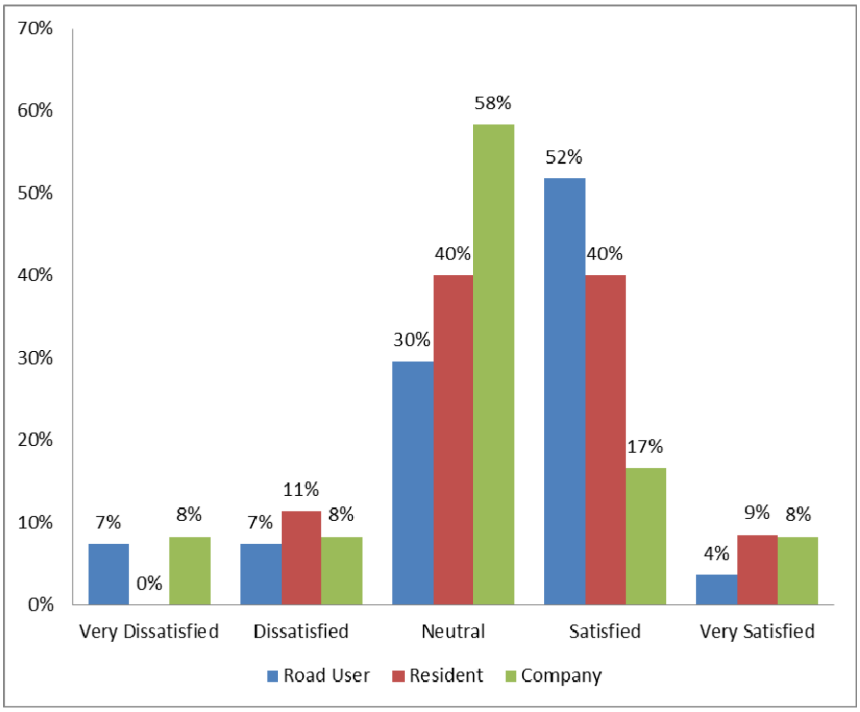


Figure 57 Satisfaction with the intervention process per stakeholder group

7.5.2.2 Outcome satisfaction

The majority of respondents (70%) was satisfied or very satisfied with the outcome of the maintenance (Figure 58). Since stakeholders experienced less improvement of all road impacts than expected (except from comfort), the level of satisfaction appears to be achieved, first of all, through the comfort experience.

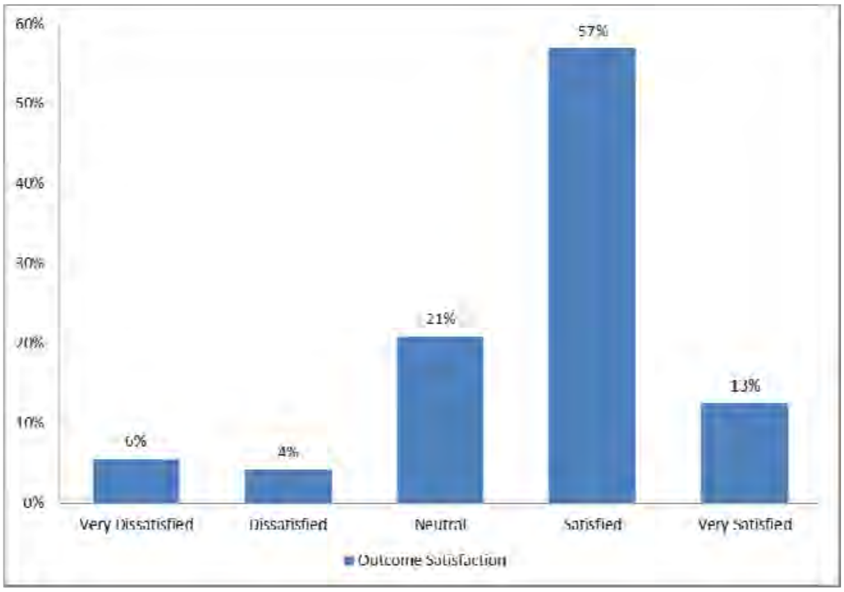


Figure 58 Satisfaction with the intervention outcome

The majority of respondents from all stakeholder groups are satisfied or very satisfied with the outcome of the maintenance (Figure 59). Only a group of road users (20%) was dissatisfied or very dissatisfied with the outcomes. A possible explanation is that their experiences did not match their expectations. Another explanation could be that they did not see the hindrance during the maintenance outweighed by the outcomes of the project.

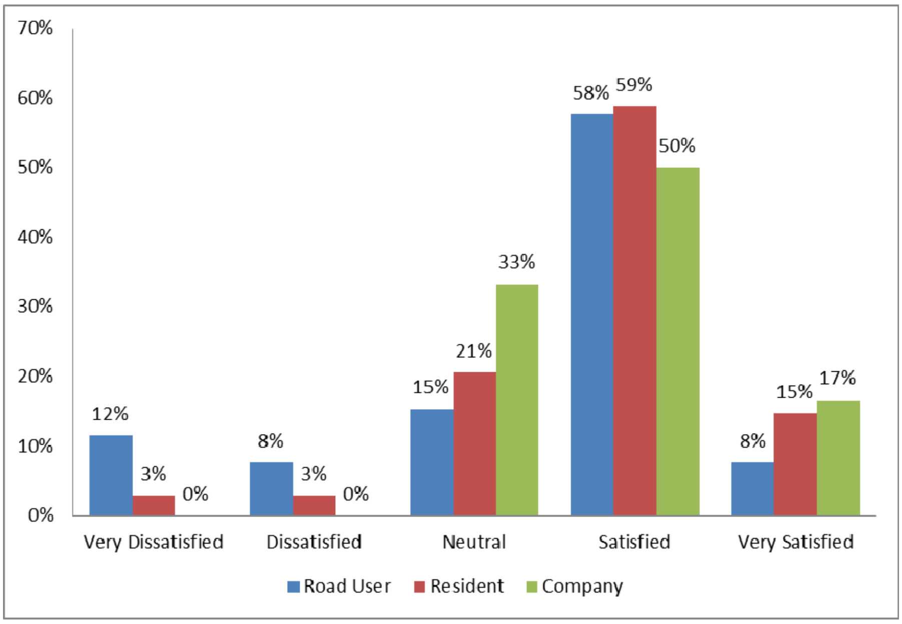


Figure 59 Satisfaction with the intervention outcome per stakeholder group

7.5.2.3 Information satisfaction

84% of the respondents were satisfied or very satisfied with the information provision (Figure 60). That indicates that they received sufficient information to be informed about the intervention project and to make informed decisions regarding their travel behaviour etc.

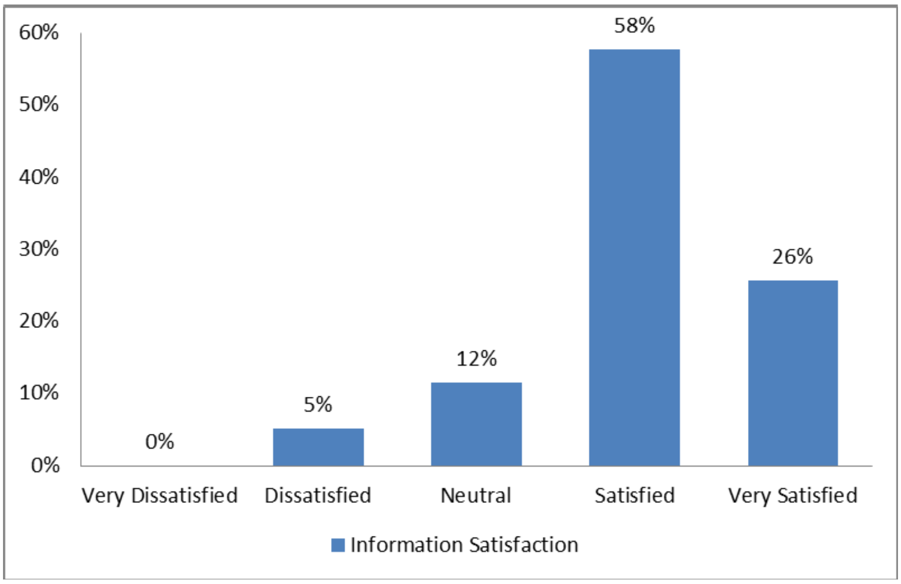


Figure 60 Satisfaction with the information provision

All stakeholder groups show a high level of satisfaction with the information provision (Figure 61). This is another indication for the success of the stakeholder management strategy of the Dutch Highways Agency.

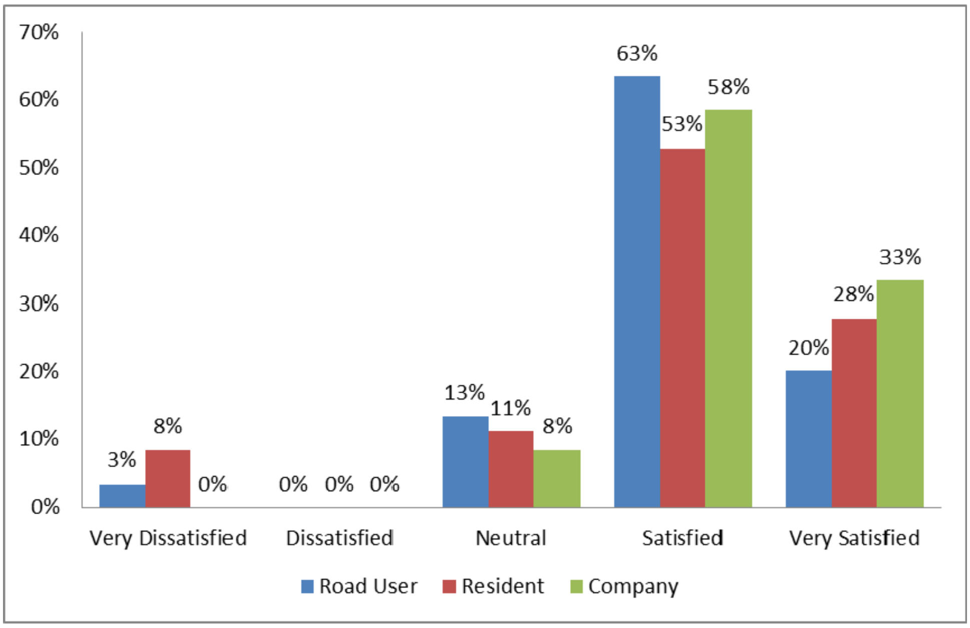


Figure 61 Satisfaction with the information provision per stakeholder group

7.5.2.4 Overall satisfaction

Besides the satisfaction with outcome, process and information provision, we also included a question about the overall satisfaction with the intervention project which was conceptualized as an aggregated assessment of the three intervention aspects and as such is an indicator for the relative importance of intervention outcome, process and information provision for the formation of satisfaction. Regarding the overall satisfaction with the intervention project 61% of the respondents were satisfied or very satisfied (Figure 62).

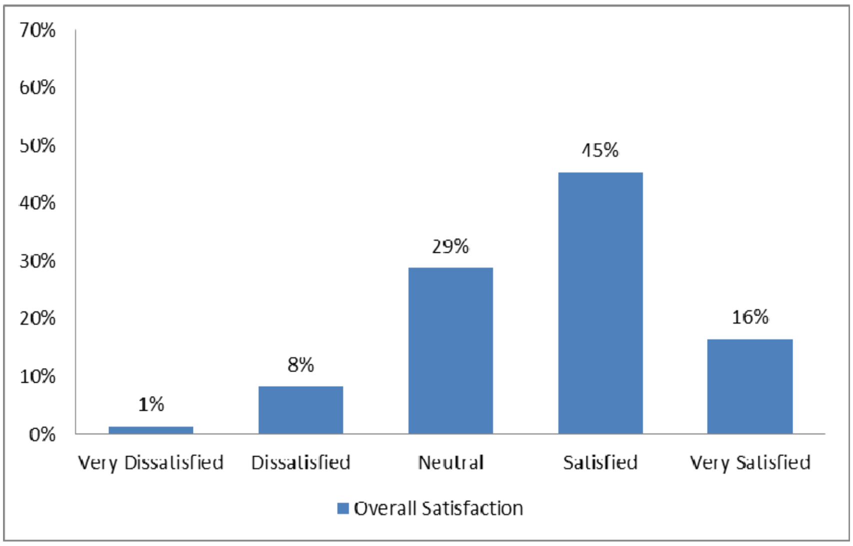


Figure 62 Overall satisfaction with the intervention project

The majority of respondents of all three stakeholder groups was satisfied or very satisfied with the project (Figure 63). Only a few residents were very dissatisfied. These stakeholders were also dissatisfied with intervention outcome and the information provision.

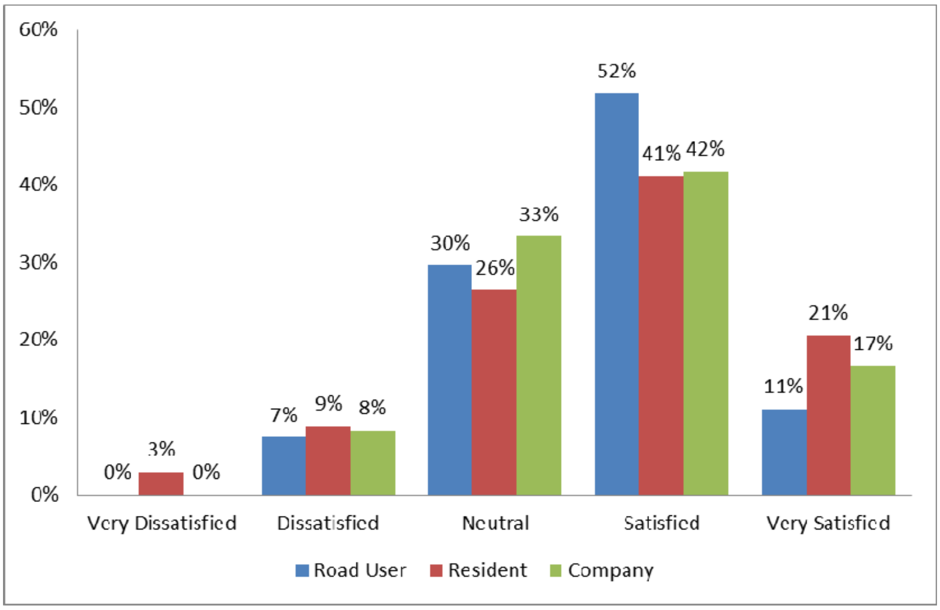
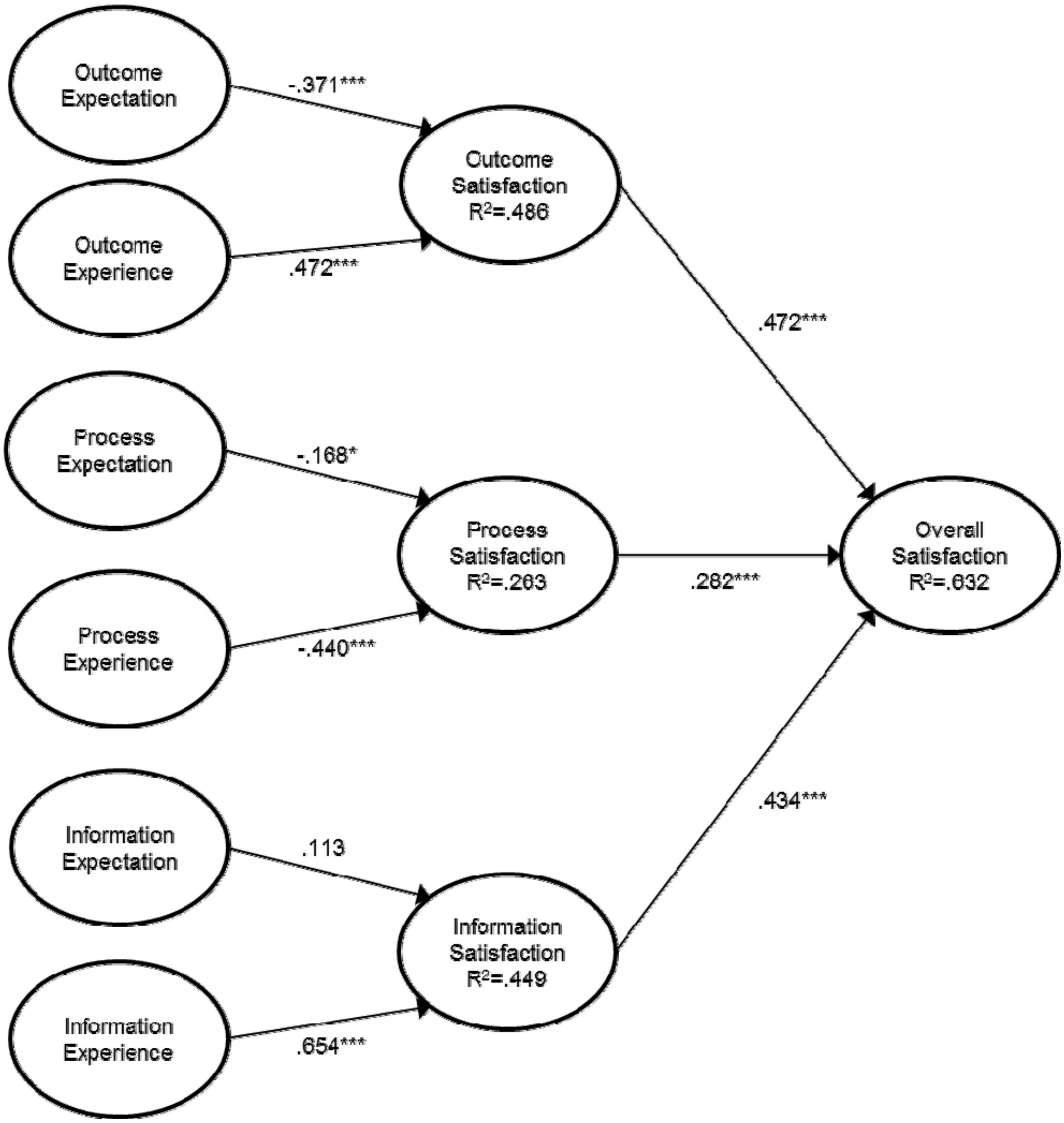


Figure 63 Overall satisfaction with the intervention project per stakeholder group

7.5.3 Expectancy (dis)confirmation analysis

We further analysed the relationship between expectation, experience and satisfaction to determine which interplay of expectation and experience explains stakeholder satisfaction. In addition, we analysed the contribution of process, outcome and information satisfaction to the overall satisfaction with the intervention project. [22] The results of the analysis are depicted in Figure 64.

[22] The analysis was done with the programme SmartPLS 2.0 (Ringle et al., 2005)



***significant at .001 level, **significant at .05 level, * significant at .10 level

Figure 64 Relationship between expectation, experience and satisfaction

The central criterion for the assessment of the relationship between the three aspects is the coefficient of determination R^2, which is used to characterize the ability of expectation and experience to explain and predict satisfaction and the ability of outcome, process and information satisfaction to explain and predict overall satisfaction. The R^2 values of outcome satisfaction (.486), information satisfaction (.449) and overall satisfaction (.632) are satisfactory. With a R^2 value of .263 the explained variance of process satisfaction is lower, but is still sufficient.

The analysis revealed a positive influence of outcome experience (.472) on outcome satisfaction whereas outcome expectation exhibits a slightly less, but negative influence (-.371). The influence of expectation shows a negative sign whereas the sign of the experience coefficient is positive. That suggests a disconfirmation mechanism in forming satisfaction with the intervention outcome, yet with a bias towards experiences. Stakeholders were most satisfied when they had low outcome expectations and experienced a strong improvement of the highway impacts. They were least satisfied when they had high outcome expectations and experienced a low impact improvement. With the experience bias in mind this is partly in line with the disconfirmation model which suggests that in order to achieve a high level of satisfaction stakeholder expectations need to be met or even exceeded. The relationship between outcome expectation, experience and satisfaction is graphically shown in Figure 65.

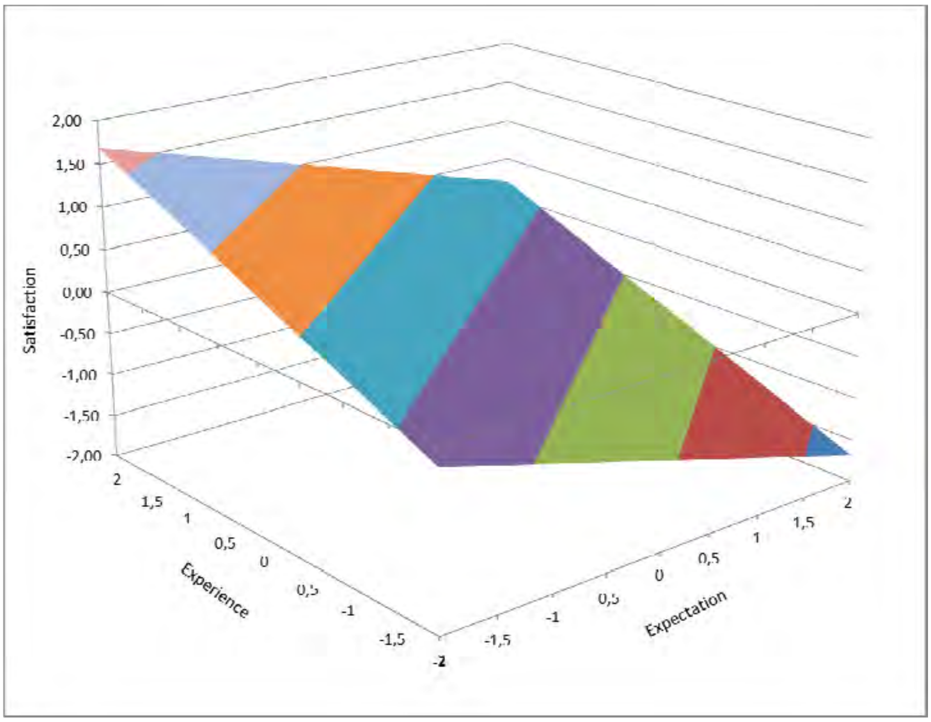


Figure 65 Outcome expectation, experience and satisfaction

The influence of process experience (-.440) and information experience (.654) on process satisfaction and information satisfaction respectively is much stronger than the influence of process expectation (-.168) and information expectation (.113). Process and information expectations are less important and only have a marginal influence on satisfaction with the intervention project. This stands in sharp contrast to the generally assumed necessity of meeting stakeholder expectations. Stakeholders were most satisfied if they experienced sufficient information provision and acceptable impact during the maintenance. The influence of process expectation and experience have negative signs suggesting a reversed effect of both variables on process satisfaction. The higher the expected or experienced impact of the project on the stakeholders, the less satisfied the stakeholders were with the intervention process. The findings also suggest that the information provision throughout the intervention project facilitated the acceptance forming of the stakeholders rather than their expectation forming. In this sense the information strategy adopted by the road agency for the maintenance of the A20 was appropriate, which included substantial effort to inform road users, residents and companies about the intervention work, the intervention duration, and alternative traffic routes and modes and to keep them informed during the maintenance. The process strategy of the agency could not clearly address the results. This can be ascribed to the nature of road maintenance which always will impact stakeholders. A process strategy should aim at keeping maintenance impacts on a level which is for the stakeholders acceptable. In the case of the A20 the agency tried to ensure this level by minimizing the duration of the maintenance and scheduling the maintenance for the holiday period. For the intervention process the relationship of expectation, experience and satisfaction is graphically shown in Figure 66 and for the information provision the relationship is depicted in Figure 67.

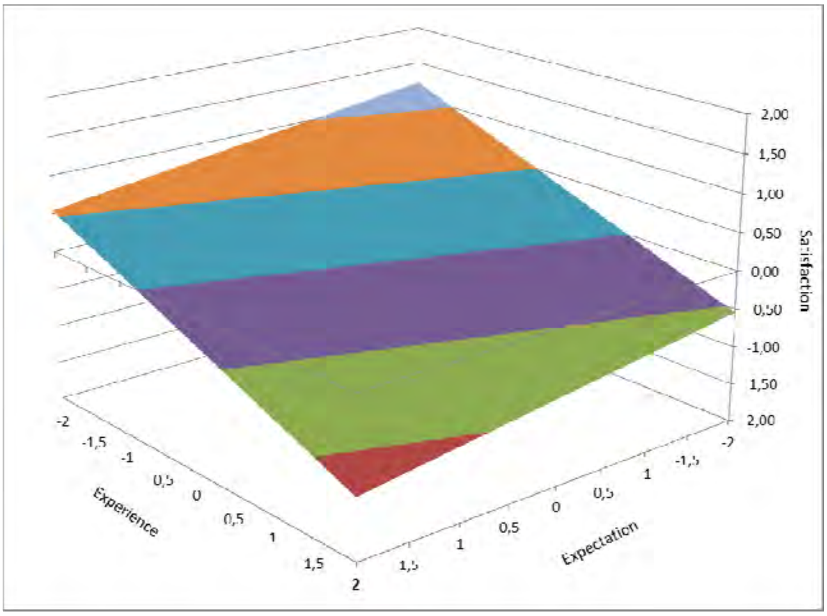


Figure 66 Process expectation, experience and satisfaction

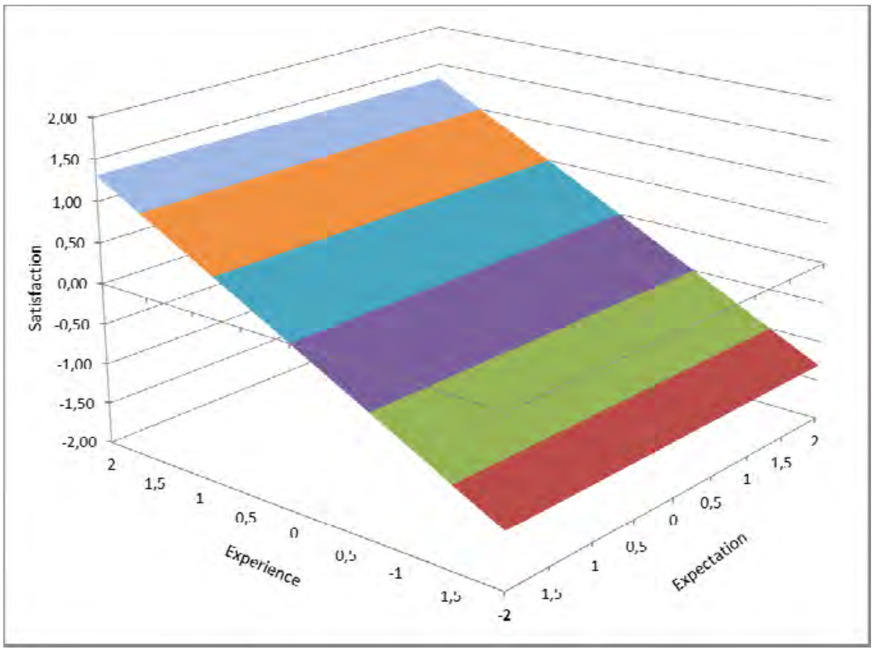


Figure 67 Information expectation, experience and satisfaction

Another result of the analysis is that outcome satisfaction exerts the strongest influence on the overall satisfaction followed by information satisfaction and process satisfaction. A main implication is that the main emphasis should be on allowing stakeholders to experience the improvements of an intervention project. That includes sufficient information provision before and during the project and an intervention strategy that takes the peculiarities of the road section into account. These peculiarities will also determine whether the Dutch Highways Agency should not raise high but realistic expectations about certain road impacts or should overstate what can be expected from the maintenance in order to gain satisfied stakeholders. In either case, intervention projects should lead to noticeably improved highway infrastructure, since the value of a highway section will emerge at the moment of its usage. The duration of an intervention project will lead to a decrease of the initial importance of expectations over time and the importance of the immediate experience of the highway during and after the maintenance. We argue it is this time effect which finally accounts for the limited role of expectations in forming stakeholder satisfaction.

7.6 Optimisation of intervention strategy

7.6.1 Intervention strategy types

The case study included an analysis of the optimal intervention strategy (OIS) for the maintained highway section of the A20. The investigated strategies differ in the way the interventions are executed for the 8 objects of the highway section (pavement and 7 overpass bridges) and thus in the duration and timing of the intervention projects. The strategic decisions concern the bundling of objects and the traffic measures.

Interventions on different objects can be bundled or done separately. We consider the following bundling options:

- **Intervention bundle 1 (IB-1)**
  All objects are maintained separately.
- **Intervention bundle 2 (IB-2)**
  All bridges are combined. The top asphalt layer is done separately.
- **Intervention bundle 3 (IB-3)**
  All objects are maintained in one intervention project. This option was applied for the actual intervention project.

Another intervention strategy decision concerns the traffic configuration during the intervention project. We consider the following options:

- **4-0 system (TC-1)**
  Weekends: both directions closed
  Weekdays: both directions open - 4 narrow lanes
- **Closed in weekends (TC-2)**
  Weekends: 1 direction closed – 1 direction open
  Weekdays: both directions open
- **Closed for multiple days (TC-3)**
  Weekends: 1 direction closed – 1 direction open
  Weekdays: 1 direction closed – 1 direction open
  This option was applied for the actual intervention project.

- **Combination of closing multiple days and in weekends (TC-4)**
  Weekends:
    Direction a closed – direction b open
    Direction b closed – direction a open
  Weekdays:
    Direction a closed – direction b open

This will result in 12 possible intervention strategy types (Table 17).

Table 17 Investigated intervention strategy types (IST)

		Intervention Bundle		
		IB-1	**IB-2**	**IB-3**
Traffic Configuration	**TC-1**	IST-1	IST-5	IST-9
	TC-2	IST-2	IST-6	IST-10
	TC-3	IST-3	IST-7	IST-11
	TC-4	IST-4	IST-8	IST-12

The kind of intervention remains the same for all strategies and comprises renewing the top asphalt layer, repairing the bridge joints and replacing the road furniture. The time needed for the actual intervention on all 8 objects is also the same for all strategies (34 days). However, due to the traffic measures there are changes in the traffic volume of these strategies. The traffic volume on the highway section is different before intervention and during intervention.

7.6.2 Simulation of traffic configurations

To reproduce the effects of the traffic configuration on the road network we used a simplified traffic model, shown on top of the geographical map of Rotterdam in Figure 68. We argue that the extracted graph contains the most relevant changes in traffic patterns caused by the road works.

Model description

The graph represented in Figure 68 represents an ordered sequence of road sections (links, or arcs in technical terms) and road junctions (nodes). Origins and destinations of the traffic demand are also represented by nodes in this network (centroids). These centroids are assumed to concentrate the demand for traveling of a complete zone (e.g. a town nearby Rotterdam, or a city quarter). Each link contains traffic flows and at each node these flows are redistributed according to the route choice of the road users, or extra demand is generated or disappears if this node is a centroid. Interconnection with the other cities external to the study area is also included in the model. Also trips between cities outside that study area but that use part of the modelled network are considered (e.g. trips from Delft/The Hague to Dordrecht).

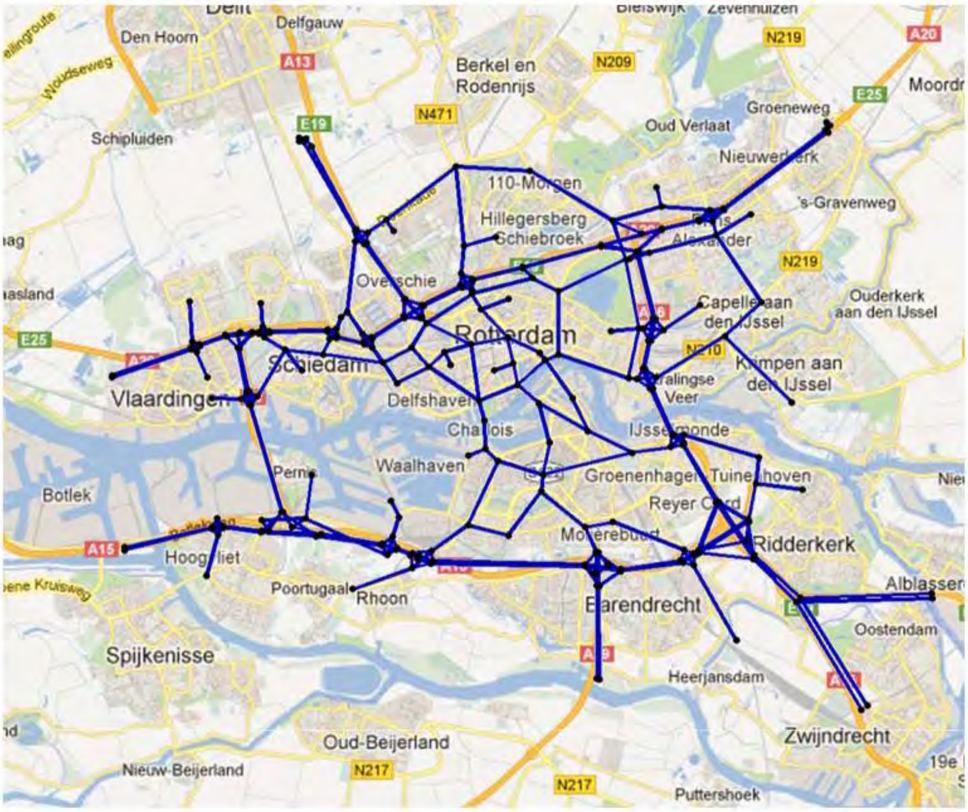


Figure 68 Graph representation of the Rotterdam network around the working zone

In this study we used a static traffic assignment model, which means that the traffic propagation from one link to the other is not a function of time and it is not explicitly modelled with its actual space-time propagation, but it is assumed in steady-state conditions. This is common assumption in planning and design problems, or in cases where the precise emergence and distribution of congestion is not fundamental. In our study we are interested in the macroscopic changes of the flows and, more importantly, in the calculation of the extra delay in the whole network. Therefore this simplification is reasonable.

The cost function used for this study is the one suggested by the Bureau of Public Roads (BPR, 1964) in US, and also very common in planning analysis:

$$S_a(v_a) = t_a\left(1 + 0.15\left(\frac{v_a}{c_a}\right)^4\right) \quad (35)$$

Where:

t_a = free flow travel time on link a per unit of time

v_a = volume of traffic on link a per unit of time (somewhat more accurately: flow attempting to use link a).

c_a = capacity of link a per unit of time

$S_a(v_a)$ is the average travel time for a vehicle on link a

This function consists of two components. The first component takes care of the minimum travel time in uncongested states (or free-flow travel time) while the second considers the non-linear increase of travel time due to queuing and reductions of the speeds. The advantage of this method in static assignment problems is that it allows for very large flows, which can occur when searching for the solution of the assignment process. Disadvantage is that the propagation of queues from one link to those connected upstream is not modelled realistically.

The assignment process on the other hand consists of the calculation of the flows in each link. These flows are a linear combination of the flows on each route using that link. These route flows are in turn determined using the demand generated by each origin and towards each destination, and assigned to each route alternative following some transport-economical function and assuming the users to make this choice in a rational and optimal way.

A popular principle governing the assignment process is the Wardrop's first principle (Wardrop, 1958), which translates in the transportation problem the concept of Nash equilibrium (Nash, 1951). This principle states that the users will distribute on the routes having the same total costs, which means that they will choose longer routes only when on the fastest routes they will experience a delay that is equal to the extra time needed on the alternative routes.

To account for the perception distortion and heterogeneity of the road users, the cost differences among the different route alternatives calculated by the BPR function are translated into stochastic choices, which mean that not all users will actually perceive in the same way the costs of each route. In practice, a part of the road users will be loaded on more costly routes. This stochastic choice is regulated in this study by the well-known Logit function (see e.g. Cascetta, 1998):

$$P^w(k) = \frac{\exp(U^w(k)/\theta_d)}{\sum_{k' \in K} \exp(U^w(k')/\theta_d)} \qquad (36)$$

Where U^w represents the cost of a certain route, which is the sum of the deterministic cost calculated with the BPR function, and an error term component, while θ_d is a parameter regulating the impact of the error term on the deterministic component in the choice of the users, or equivalently it indicates the importance the users find for a certain cost difference between route alternatives. In practice, the bigger the θ_d, the less important is for the users that there is a (deterministic) cost difference between routes and the will distribute more evenly between routes.

Despite the simplicity of the Wardrop first principle and the functions determining travel times and route flows, the solution of the assignment process, i.e. the equilibrium link flows, are not easily found, since the costs on the links may depend on several routes and several origin-destination pairs that use the same links. An iterative process is therefore used to find consistent flows and costs. This is normally referred to as 'fixed-point' problem. These types of problems, under the simplified conditions used in this study, are solved by simply assigning the flows to the fastest routes at the first iteration; once the costs are calculated using the BPR function then new route alternatives become attractive for a certain origin-destination demand and the flows are distributed according to the Logit function. This process repeats over and over until no flow changes in the system, and obviously costs become also invariant. This will be the equilibrium solution.

As one can see, and as expected, apart from the links and routes directly affected by the road intervention, the flows on the rest of the network did not change significantly. The extra delay caused by the rerouting of the travellers affected for the four traffic measures is (compared to the base scenario without any measures):

- TC-1: 0.96 minutes per trip (6.99% increase).
- TC-2: 1.39 min/trip (11.40% increase)
- TC-3: 1.00 min/trip (7.05% increase)
- TC-4: 0.81 min/trip (3.62% increase)

The graphical representation of the traffic flow generated in the Rotterdam network around the A20 can be found in APPENDIX 14.

7.6.3 Unit costs and model input parameter values

In order to determine the OIS the impacts incurred to each stakeholder during interventions and in between intervention from each object are calculated based on empirical models and following the unit costs shown in Table 18. According to APPENDIX 7 The stakeholders were grouped into:

- Owner
- Road user
- Directly affected public (DAP) which include residents and companies
- Indirectly affected public (IAP) which includes the society in general

Table 18 Unit costs[23]

No.	Cost item	Unit cost (€)	Unit
1	Operation cost per light-weight vehicle	1.65	/hour
2	Operation cost per medium-weight vehicle	2.67	/hour
3	Operation cost per heavy-weight vehicle	5.32	/hour
4	Operation cost per bus	5.32	/hour
5	Average maintenance cost	0.86	/vehicle/year
6	Petrol price (gasoline)[1]	0.46	/l
7	Diesel price[1]	0.51	/l
8	Travel time saving (commuting)	9.55	/hour
9	Travel time saving (business)	33.07	/hour
10	Cost per damaged vehicle in accident	41’690	/casualty
11	Cost per injured	276’568	/person
12	Cost per deaths	2’690’108	/person
13	Cost for CO2	2.40	/ton
14	PM	308’189	/ton
15	NOx	4’093	/ton
16	Cost for CO	3.10	/ton

[23] It should be noted that the unit costs are average values derived from several Dutch and European documents (e.g. HEATCO, 2002). The values are used for the purpose of illustration and can be adapted.

No.	Cost item	Unit cost (€)	Unit
17	VOS	1'139	/ton
18	Dust	30'675	/ton
19	Average noise cost	27.97	/dB
20	average vehicle price	20'000	/vehicle

[1] without taxes

7.6.4 Impacts of intervention strategy types during and between interventions

For the 12 ISTs the overall impact during intervention were estimated for each object and bundle of objects and are shown in Table 19.

Table 19 Impact of IST during intervention (unit = 1000 €)

Intervention bundle	Object	Traffic configuration			
		TC-1	TC-2	TC-3	TC-4
IB-1	1	466	465	334	319
	2	759	739	616	614
	3	489	484	355	352
	4	1'031	988	881,5	881
	5	579	581	447	445
	6	727	716	592	590
	7	784	762	640	639
	8	4'978	4'460	4'584	4'954
IB-2	1,2,3,4,5,6,7	3'345	3'955	3'206	2'889
	8	4'978	4'460	4'584	4'954
IB-3	1,2,3,4,5,6,7,8	8'074	7'725	7'679	7'743

IST-11 (IB-3 + TC-3) is the optimal intervention strategy, if only the costs incurred during intervention are considered. IST-11 is the strategy applied by the Dutch Highways Agency.

The estimated impacts already include the impacts incurred to owner, user, DAP and IAP. The distributions of impact incurred to different stakeholders per object for IST-1, 2, 3 and 4 are further illustrated in APPENDIX 16. These impacts show that:

- For overpass bridges, in all 4 strategies, impacts incurred to owner account for about 90% of the total impact. Impacts incurred to users rank as the second largest contribution to the total impact, with a proportion ranges around 4-6%. The impacts incurred to DAP are about 1-3 %.
- For the road sections, in all 4 strategies, impacts incurred to owner account for about 60-70% of the total impact. Impacts incurred to users rank as the second largest contribution to the total impact, with a proportion ranges around 20-30%. The impacts incurred to DAP are minor, with a range around 1%. This is significantly different from that of the overpass bridges. Reason is due

to the assumption that a fixed number of DAP is assumed for the analysis. Therefore, in this case, the impacts incurred to IAP are much higher than DAP, with a proportion of about 3-5%.

A brief illustration of model input values is shown in Table 20 for IST-9, 10, 11 and 12.

Table 20 Example of model input values

IST	TC	IB	Stakeholder group	During intervention (g)			In between intervention (f)		
				a	b	β	a	b	β
9	1	3	(1) Owner	5'221	0	0	3.9	2.3	0.06
			(2) User	2'431	0	0	38.5	21.2	0.06
			(3) DAP	73	0	0	4.5	3.1	0.06
			(4) IAP	178	0	0	8.3	5.5	0.06
10	2	3	(1) Owner	4'911	0	0	3.9	2.3	0.06
			(2) User	2'113	0	0	38.5	21.2	0.06
			(3) DAP	162	0	0	4.5	3.1	0.06
			(4) IAP	686	0	0	8.3	5.5	0.06
11	3	3	(1) Owner	5'992	0	0	3.9	2.3	0.06
			(2) User	2'051	0	0	38.5	21.2	0.06
			(3) DAP	73	0	0	4.5	3.1	0.06
			(4) IAP	332	0	0	8.3	5.5	0.06
12	4	3	(1) Owner	5'962	0	0	3.9	2.3	0.06
			(2) User	2'418	0	0	38.5	21.2	0.06
			(3) DAP	73	0	0	4.5	3.1	0.06
			(4) IAP	299	0	0	8.3	5.5	0.06

The evolutions of impacts after intervention are assumed to be the same for all strategies (values of a, b, and β in Table 20 are identical). The evolution of impacts to stakeholder after performing interventions is shown for each object in APPENDIX 17. The following impact evolutions are considered:

- The impact incurred to the owner is the routine maintenance cost that accounts for 10% of the impact incurred to the users.
- The increase in the impact incurred to users is calculated mainly based on vehicle cost; wear out of tires, repair and maintenance for trucks and cars, and safety.
- The increase in the impact on DAP is mainly due to safety issues, comfort, and emission of noise.[24]

[24] It should be noted that the assume numbers of DAP in this analysis is 1,500. The changes in the value of DAP will significantly affect the total impact incurred. Numbers of DAP should be re-examined in the area of study.

- The increase in the impact on IAP is mainly due to the emission of particles from vehicles. It is calculated based on the DTV, actual lengths of the investigated objects, and the standard amount of exhausted particles being discharged from the vehicles.

The evolutions of impact increase are similar due to the fact that the effectiveness of performing intervention is the same. For all overpass bridges the dominant impact after intervention is incurred to users which always take up to more than 60% of the total impact. However, the impact increase is different between bridges and road section. The impact increase for DAP is much lower than that for the owner and IAP. The reason is that the assumed number of 1’500 DAP is fixed for each individual object. Although the length of the road section is much longer than all 7 overpass bridges combined, the numbers of DAP does not change.

The annual cost of the intervention strategy types are shown in Table 21.

Table 21 Annual cost of IST

IST	TC	IB	Annual cost (€)	Difference in annual cost (€)
1	1	1	584’270.96	0.00
2	2	1	672’854.26	88’583.30
3	3	1	644’258.70	59’987.74
4	4	1	585’667.16	1’396.20
5	1	2	582’492.41	-1’778.55
6	2	2	671’119.56	86’848.60
7	3	2	616’546.25	32’275.29
8	4	2	584’993.28	722.32
9	1	3	527’920.51	-56’350.45
10	2	3	544’629.82	-39’641.14
11	3	3	547’211.77	-37’059.19
12	4	3	545’923.66	-38’347.30

When using IST-1 as reference strategy all other strategy types are compared with, it can be concluded that IST-9 is the optimal strategy, as it reduces the annual cost by €56,350 compared to IST-1. The intervention times and evolutions of impacts corresponding to IST-1 and IST-9 are presented in Figure 69 and Figure 70. This result is interesting because the strategy applied by the Dutch Highways Agency was IST-11.

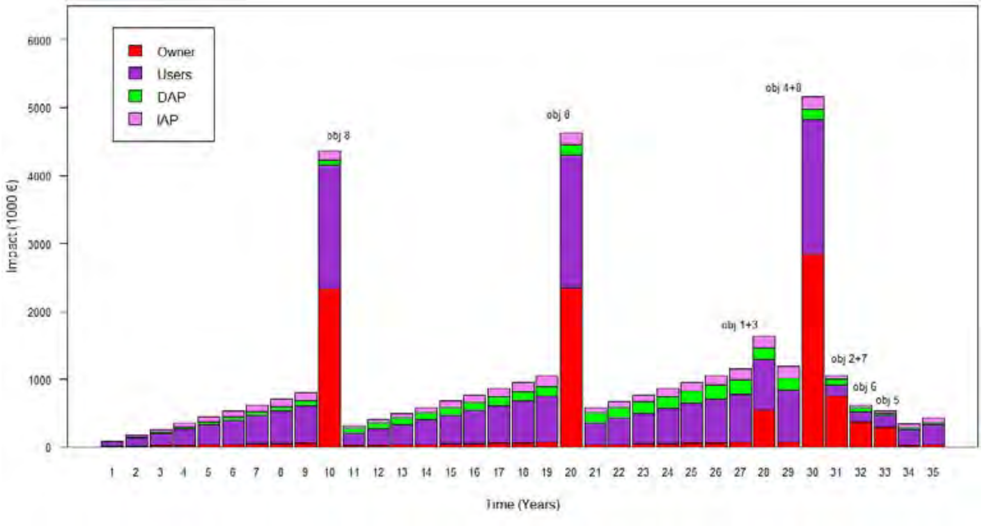


Figure 69 Intervention time and impact evolution of IST-1

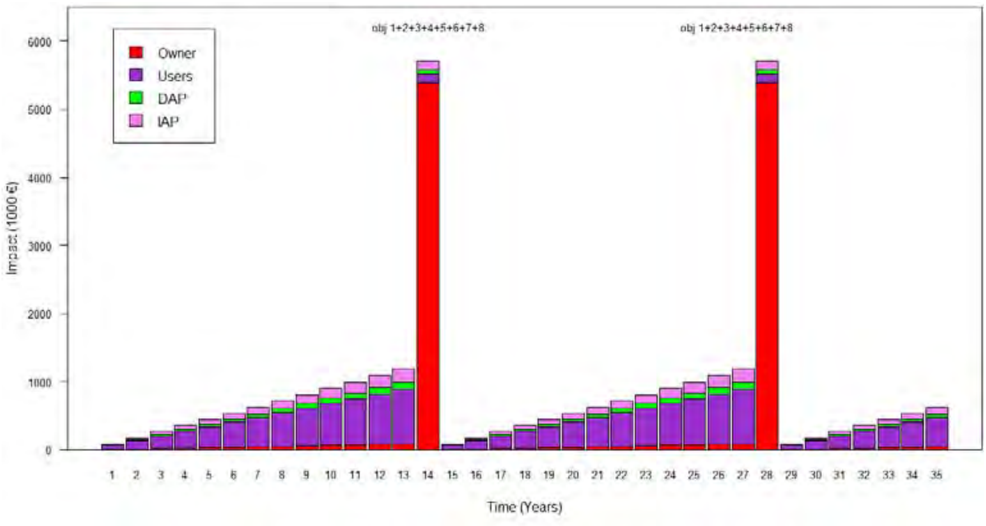


Figure 70 Intervention time and impact evolution of IST-9

The evolution of the intervention time and impact for the other strategies can be found in APPENDIX 18.

7.6.5 Sensitivity analysis

The analysis of the importance of road impacts to stakeholders revealed significant differences between stakeholders and a stakeholder oriented intervention strategy should consider these differences. In other words, the intervention strategy should reflect the stakeholder valuation of road impacts. For example, travel time is an important road impact for users and companies. There may be intervention strategies which particularly minimize the loss of travel time. In this section we will investigate the sensitivity of the investigated OIS to the valuation of road impacts by changing the average unit costs used in the previous section. According to the findings from the stakeholder analysis we conduct sensitivity analyses on:

- Travel time,
- Vehicle cost, and

- Emission.

In addition, we do sensitivity analyses for stakeholder groups to account for bundles of road impacts that are seen as important by these stakeholder groups (see APPENDIX 7). Although our stakeholder analysis of the A20 could not reveal bundles of road impacts which are significantly different between stakeholder groups, we investigate the sensitivity of the OIS to three bundles of road impacts or three stakeholder groups:

- Owner which includes intervention cost and traffic management cost,
- User which includes safety, travel time, and vehicle cost.

Since we made assumptions about other model parameters, we also investigate the sensitivity of the OIS to the following parameters:

- Discount factor,
- a, b, β (which relate to the change in the impact values after intervention).

For the sensitivity analysis a range between -50% and +50% of the mean impact value is chosen and applied on different impacts incurred. This range is seen to be sufficient to show the change, trend, or switch in OIS.

In order to take the different traffic configuration into account, IS-9, IS-10, IS-11, and IS-12 are selected for the sensitivity analysis. In addition, sensitivity analysis is carried out on IS-7.

In the following figures, the dotted lines show the optimal intervention times (OIT) and the solid lines show the annual impact. The value of OIT and impact are shown in the left vertical axis and right vertical axis, respectively. The horizontal axis shows the percentage of change in the value of impact under investigation. The value of impact corresponding to 0% in the horizontal axis represents the mean value (without variation in the value).

Sensitivity to travel time

The following figure shows the sensitivity of the OIS to the value of travel time in the range -50% to +50% of the mean value (see Table 18).

The variation of travel time value changes the optimal intervention time (OIT) and the annual impact for all strategies. If travel time becomes more important (higher value), the optimal intervention time will be later. If travel time is regarded less important (lower value), the intervention should be executed earlier. However, a change of the optimal intervention strategy can be only observed if the travel time value is about 30% to 40% lower than the mean value. In other words, if travel time is not much important other traffic configurations become optimal and consequently another intervention strategy. If travel time becomes more important IST-9 remains the optimal strategy.

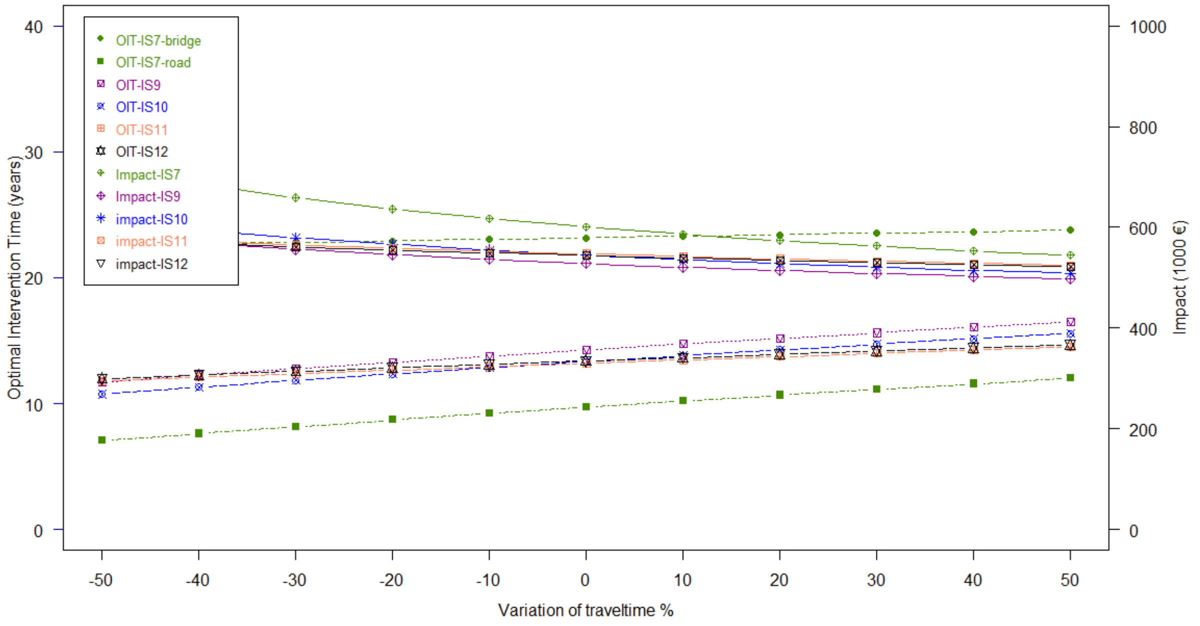


Figure 71 Sensitivity to travel time

Sensitivity to vehicle cost

The following figure shows the sensitivity of the OIS to the value of vehicle cost (VOC) in the range -50% to +50% of the mean value (see Table 18).

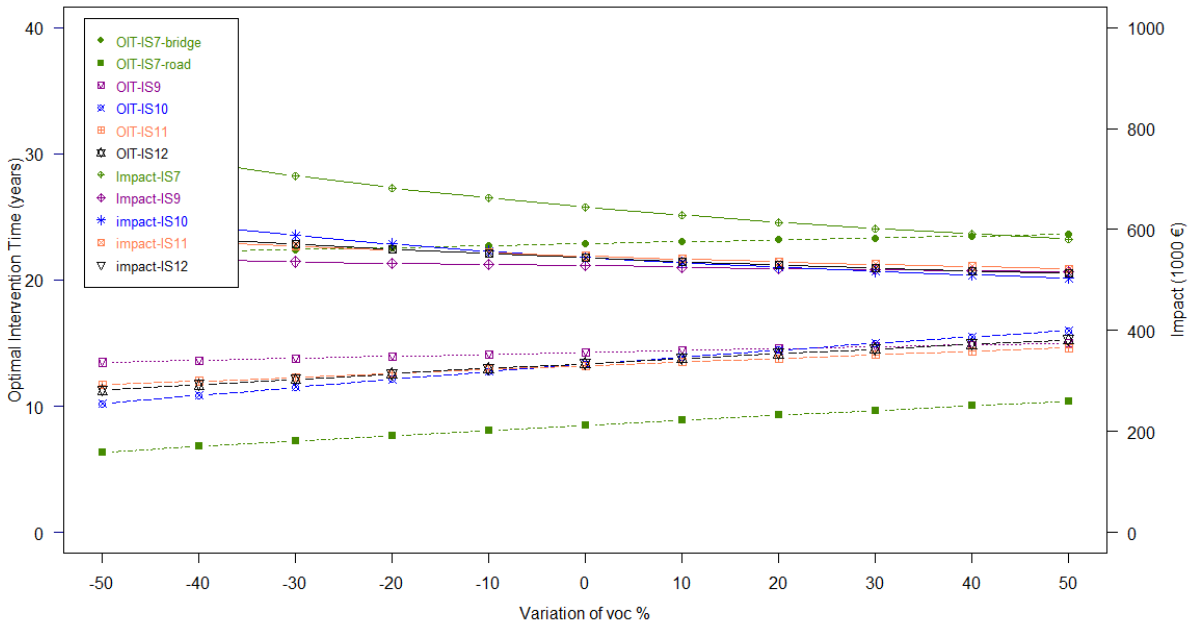


Figure 72 Sensitivity to vehicle cost

Again, the variation of the VOC value changes the optimal intervention time and the annual impact for all strategies. If VOC becomes more important (higher value), the OIT is later than for the mean value. If VOC is less important (lower value), the OIT is earlier than for the mean value. The graph also shows that if VOC increases about 20%, the OIS is changing from IST-9 to IST-10. Another traffic configuration (closed in the weekends) and thus another strategy becomes optimal. If VOC is less important IST-9 is still the optimal strategy.

Sensitivity to emission

The following figure shows the sensitivity of the OIS to the value of emission in the range -50% to +50% of the mean values (see Table 18).

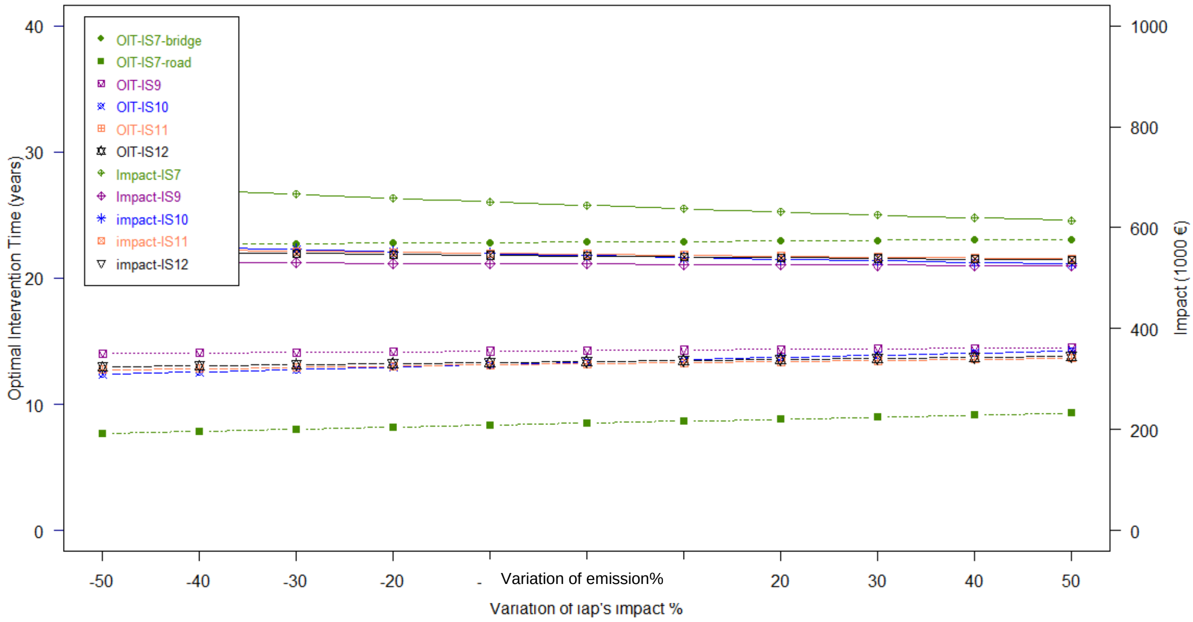


Figure 73 Sensitivity to emission

The impact of emission is calculated directly from the traffic volume. Figure 73 shows that the variation of emission does not have a big influence on the OIT and the annual costs. In addition, IST-9 remains the optimal intervention strategy for the varying values of emission.

Sensitivity to owner impact

In Figure 74 the sensitivity of the OIS to the variation of the owner impact values in in the range -50% to +50% is shown.

The sensitivity analysis shows that the variation of the impacts to the owner does not change the OIS. The OIS is still IST-9. However, it can be seen from the distance between solid lines that if the impact increases the gap between the solid lines becomes narrow. That suggests that the difference between strategies becomes insignificant. Additionally, the impact of IST-7 is much higher than impact of IST-9, IST-10, IST-11, and IST-12, which supports that the bundling of objects is preferable rather than executing interventions for each object separately. With respect to the OIT, if the impact incurred to the owner increases, the OIT of each strategy tends to become longer.

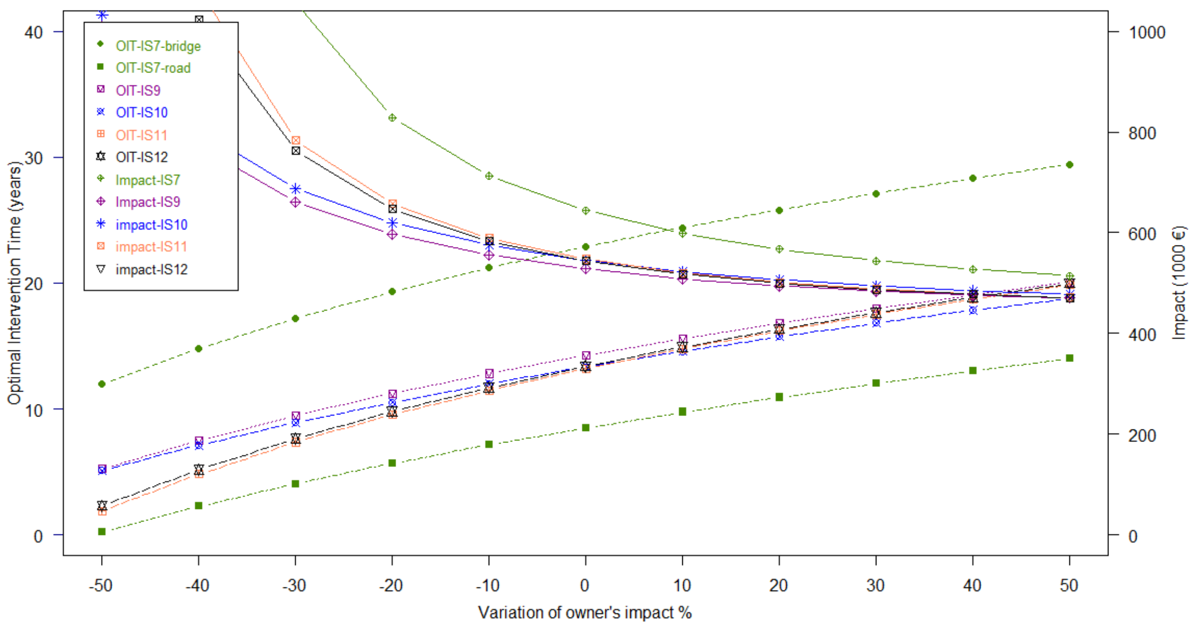


Figure 74 Sensitivity to owner impact

Sensitivity to user impact during intervention period

In Figure 75 the sensitivity of the OIS to the variation of the user impact values in in the range -50% to +50% is shown.

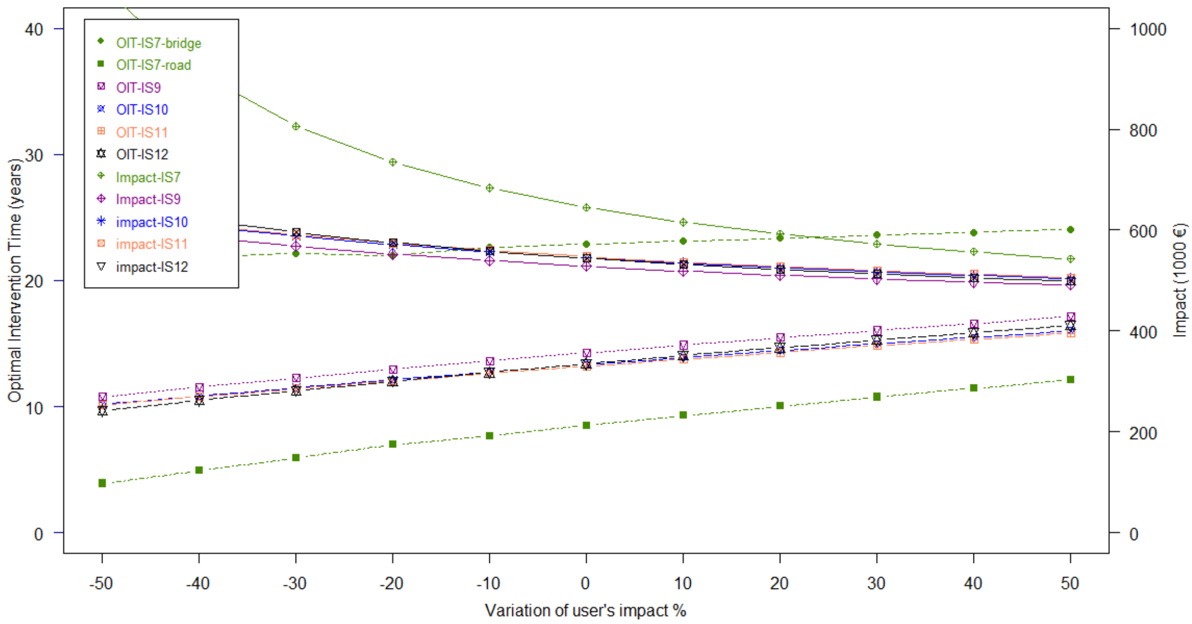


Figure 75 Sensitivity to user impact during intervention period

The sensitivity analysis shows that the variation of the impacts to the user during intervention does not change the OIS. The OIS is still IST-9. Compared to the impact to the owner the distance between solid lines is even smaller. The difference between strategies remains insignificant for the varying values. The only exception is IST-7, which again supports that the bundling of objects is preferable rather than executing interventions for each object separately. Also comparable with the owner impact, if the impact incurred to the user increases, the OIT of each strategy tends to become longer.

Sensitivity to discount factor

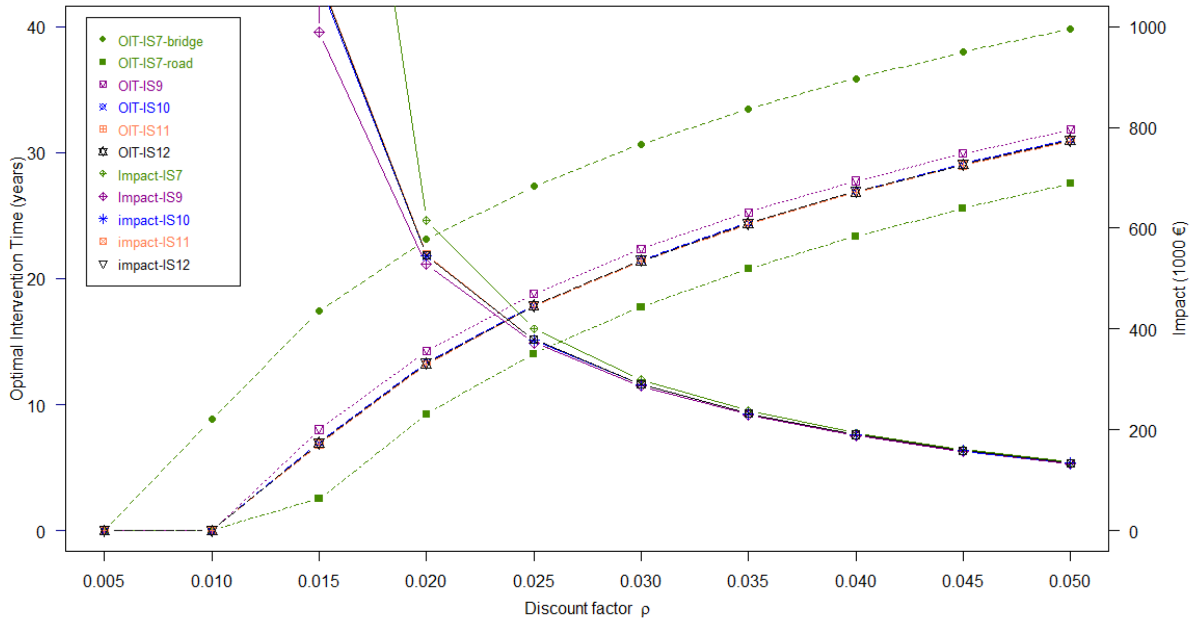


Figure 76 Sensitivity to discount rate

The increase in the value of discount factor results in later intervention times. Also, the annual impact decrease as the value of discount factor increase.

Sensitivity to cost parameters a, b

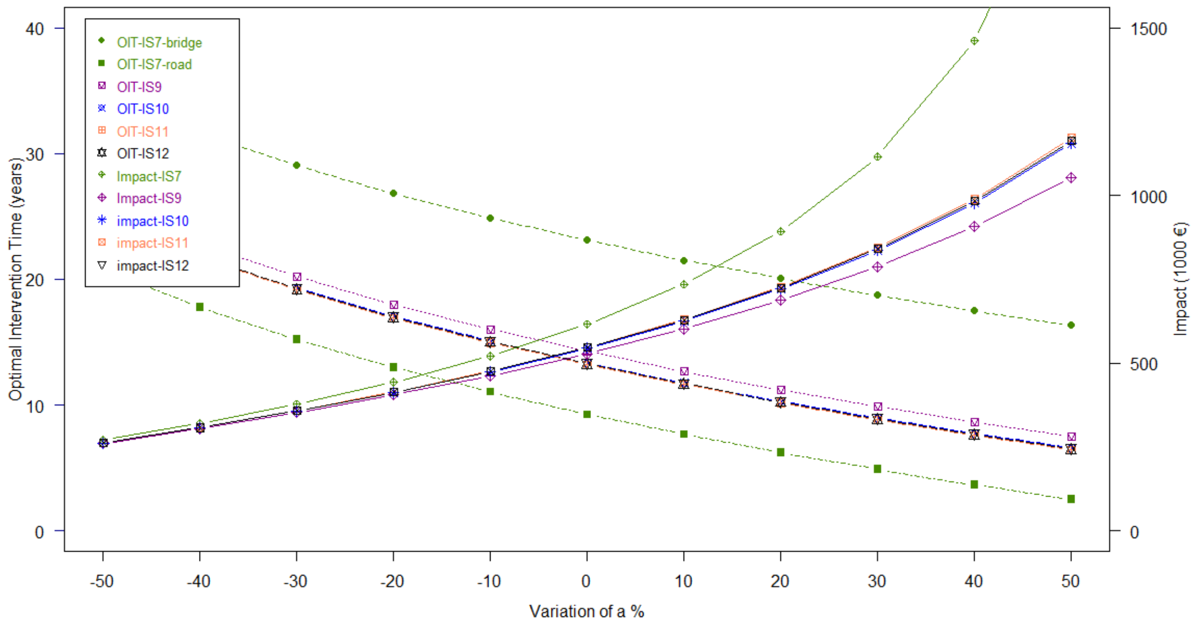


Figure 77 Sensitivity to cost parameter a

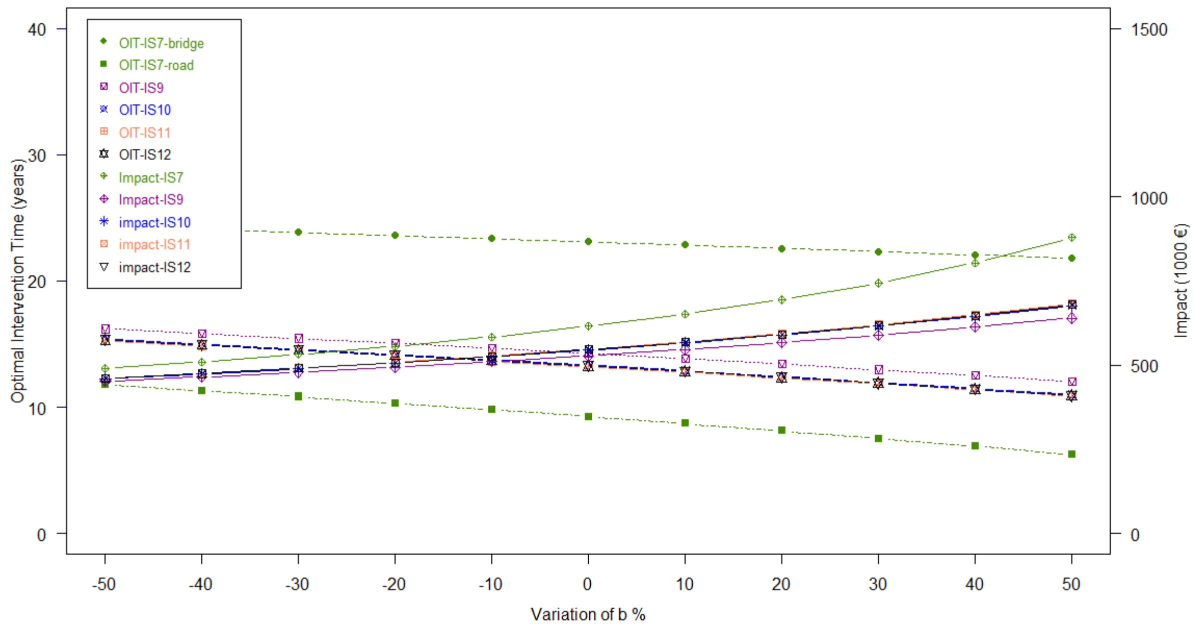


Figure 78 Sensitivity to cost parameter b

Both values a and b affect the change in the optimal intervention time in an equally manner. The OIS and the corresponding OIT and annual impact are very sensitive to the value of model parameters. This suggests a careful examination and verification of using empirical models to quantify the impact incurred.

Sensitivity to deterioration parameter β

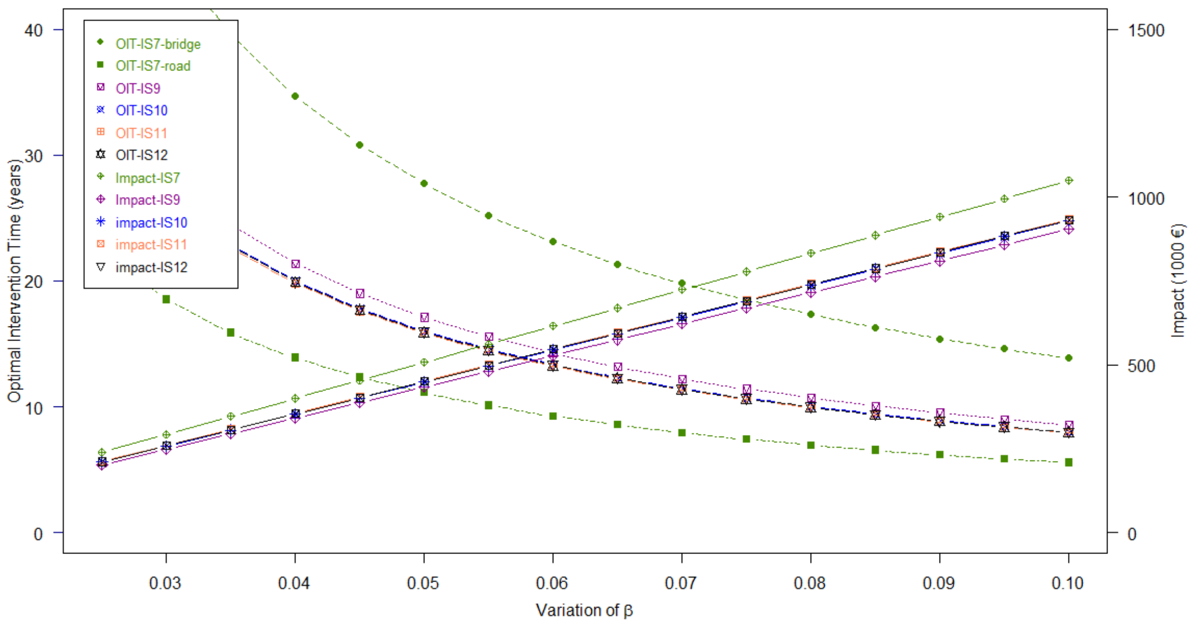


Figure 79 Sensitivity to deterioration parameter β

Intervention strategy and OIT are also sensitive to the deterioration parameter. If the deterioration parameter increases the OIT decreases and the annual cost increases. That also suggest a carefully consideration of the underlying deterioration assumption.

8 Belgian Case Study

8.1 Case description

8.1.1 Context and intervention

For the second case study we choose for about 20 km of the highway E17 between the cities of Ghent and Kortrijk in Belgium. In the period between March and August 2011 this part of the highway was under maintenance to completely replace the degraded pavement. A map of the highway section being maintained is shown in Figure 80. The area, especially on the north-west side is densely populated as the town of Zwijnaarde (around 6,000 inhabitants in total) has developed alongside of the two highways E40 and E17. The area contains a zone where part of the University of Ghent, spin-offs of the university and other companies are located, and two areas where logistics, food chain and other types of companies are located alongside of the river Schelde. The area was expected to be highly affected by the road works. The residents were expected to suffer from the noise and air pollution caused by the working zone and from reduced accessibility to their area because of the closure of the exit 'De Pinte' for a large part of the maintenance period. All traffic using that exit was deviated to the following exit, or to the one located on the E40 highway, with consequent increase of travelled distances and travel times. The reduction of accessibility also penalizes the companies located in this area, which on the other hand are expected to be less concerned about the environmental impacts.

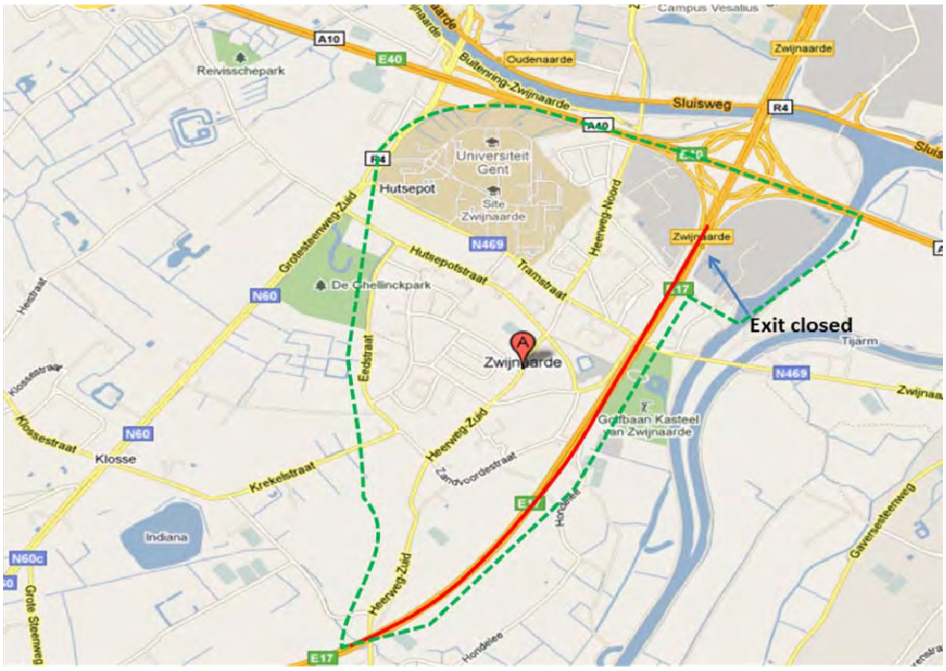


Figure 80 Case study area[25]

[25] In red the segment where the intervention is planned is indicated, while in dashed green is the area identified as 'neighborhood'. The arrow points at the exit that is being closed during part of the maintenance. From the map also the three main industrial areas (Technologypark, and Industriepark I and II) are indicated, respectively in brown and grey colors.

The intervention included 3 phases (Figure 81):

- Phase 1 (March 2011)
  Preparation of the maintenance during the night (signalization, removal of central reservations, building save havens and crossings);
- Phase 2 (until the 15th of July)
  Renewal of fundaments and top layers of E17 between Deinze and De Pinte in the direction of Antwerp.
- Phase 3 (July and August 2011)
  All traffic on one part of the highway between the complex De Pinte and the interchange in Zwijnaarde. Here are on a short distance four bridges crossing the highway, which makes the central reservation not suitable for traffic to pass. To limit the hindrance during phase 3 as much as possible, there is chosen to use the summer period for this complex intervention.

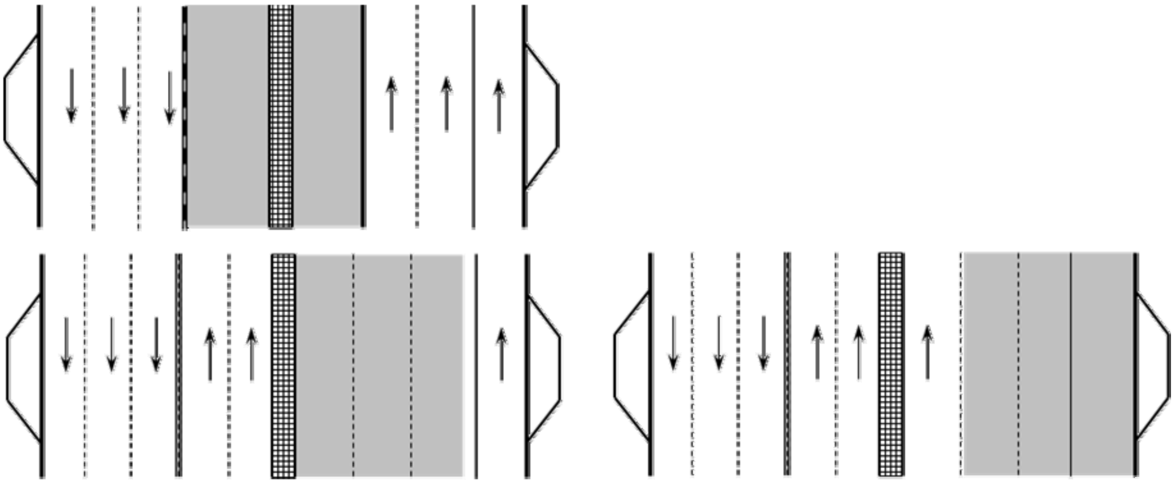


Figure 81 Traffic measures during the intervention

Figure 82 shows the traffic measures chosen for the exit 'De Pinte', which in phase three has three accesses closed out of four.

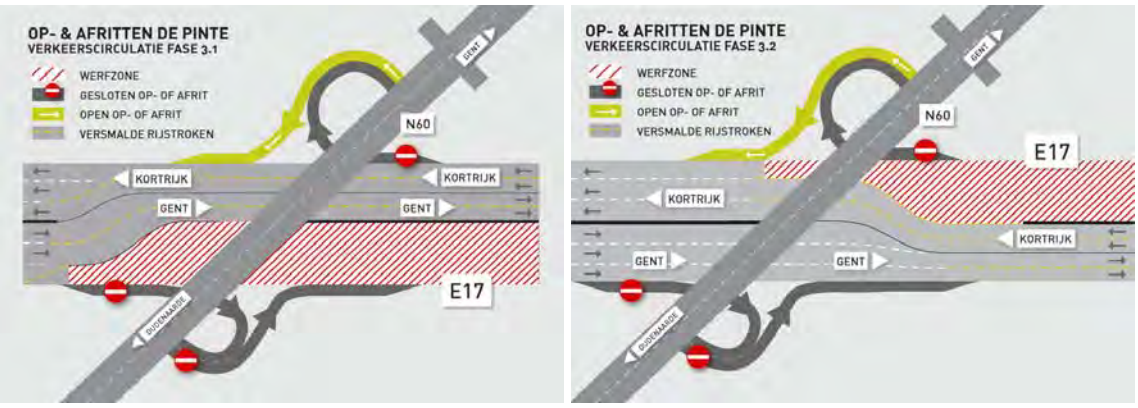


Figure 82 Traffic measures for the exit 'De Pinte'

Key elements of the intervention are:

- Working 24/24, 7/7;
- Removing of asphalt and renewal in concrete;

- Narrowed lanes during year, 2 lanes in summer;
- Limiting to 2 lanes and 1 peak lane would reduce project with 3-4 weeks => technologies for quick lane transfer not available (curved lanes);
- Implementing concrete on the emergency lane for possible future use;
- A part in asphalt (near the bridges at the Zwijnaarde complex);
- Coordination with other projects (TV3V complex Deinze/Nazareth beginning of August, asphalt works Destelbergen/Kruibeke).

The start of the intervention was originally planned for the 1st of April and had to be finished by the end of August 2011. Due to optimizing roadwork plans between AWV and the contractor and the early ending of night preparation of the works (in March) the works started ahead of schedule, i.e. around half of March. The interventions also ended two months earlier (in August and not in November as specified in the specifics). Phases 1 and 2 were already finished before the deadline in June.

Figure 83 Preparation work in March 2011

In APPENDIX 19 general information about the section (e.g. year of construction, length of objects), the traffic situation (e.g. daily traffic intensity), and the deterioration of the objects (e.g. condition states, survival rate) can be found.

8.1.2 Data collection

The collected data comprised:

- Description of the highway section,
- Description of the intervention work,
- Importance of road impacts to stakeholders,
- Expectations and experiences of stakeholders about the intervention project,
- Satisfaction of the stakeholders with the project.

The stakeholder perception data was collected at two points in time. By using a questionnaire survey importance of road impacts and expectations were measured prior to the maintenance of the E17 and stakeholder experiences and satisfaction were measured after the intervention project was finished.

The testing and preparation of the electronic and paper versions of the questionnaires have been lasting for nearly a month. To obtain a sufficient number of responses it was in fact important to have an extensive distribution of the questionnaires. We decided to follow this strategy:

- An electronic version was distributed to all stakeholders by e-mail. E-mails of road users and residents were identified and others were collected based on our direct contacts (friends, parents, colleagues, etc.). Company e-mails were obtained from the communication officer of the Flemish highway agency.
- For the collection of a paper version we chose the following strategy:
  - For the road users we decided to collect questionnaires directly on the road, more specifically at a gas station located in the area of Deinze. To obtain a sufficient amount of questionnaires we had to repeat this survey for three days;
  - For residents we could collect paper versions in two ways:
    - We approached the inhabitants of De Pinte, which is a town nearly at the end of the segment (near the exit Deinze), by standing outside of a supermarket or by approaching them at the main square of the town.
    - We distributed 800 letters directly by post to most of the postal addresses of the town of Zwijnaarde. These letters had a pre-paid return form so the return was not charged to the respondents.
  - For the companies we used the same strategy as for the residents, more specifically we visited all companies in the three main areas of Technologiepark and Industriepark I & II and we left a few letters per firm, with a total of 400 letters.

Unfortunately, the works already began when the first questionnaire was distributed, because the project started a few weeks before the expected starting date (1st of April). During this preparation phase a large part of the road was already closed. The three-lane carriageways were reduced to two short lanes and the speed limit was already reduced from 120 km/h to 70 km/h. Despite the unexpected changes in the timing, the data collection was however done on a very early stage of the intervention; so we assume that the expectations were not changed significantly during these weeks.

Each questionnaire was accompanied by a cover letter from the university and the Flemish highway agency. We asked respondents to report on the following road impacts (see also 4.2.1):

- Safety,
- Travel time,
- Comfort,
- Economy,
- Visual quality,
- Emission,
- Vehicle cost,
- Resource consumption.

For our analysis, the questionnaire was divided into four parts:

- In the first part respondents reported on certain characteristics (e.g. age, gender, user of the road), since different expectation may be assumed depending on these characteristics. The characteristics were collected to analyse group heterogeneity and eventually identify relevant sub-groups.[26]

- In the second part respondents were asked to give an indication of the importance of the above eight impacts independently from the intervention project.
- The third part focused on the stakeholders' expectations of how the road impacts will change because of the intervention project. More specifically:
  - How will the impacts change during maintenance (process).
  - How will the impacts improve after maintenance (result).
- The last part of the survey was dedicated to the expectation about type and quality of information received about the intervention project.

During the three days of the survey on the road and summing up the electronic questionnaires we collected 71 valid road users data records. The collection of road resident data was instead more effective as we could receive 86 returned envelops and 15 questionnaires were collected in De Pinte, with therefore a total of 101 records. The relative high share of returned letters (more than 10% of the delivered ones) points at an active participation of this group of stakeholders. On the contrary, the returned envelops from the companies was less than expected (34), arriving at a total of 38 with the electronic versions. On the other hand, although the total returned is slightly less than 10% of the delivered ones, the total number of companies in that neighbourhood is not too high (around 60 were visited during the delivery operation).The first questionnaire as it was prepared for road users can be found in APPENDIX 20.

The second questionnaire was sent out approximately one month after the project was completed. To obtain individual expectation (dis)confirmation it was important during the second measurement to get responses from the individuals who already participated in the first questionnaire. Therefore we asked respondents to fill in their e-mail address on the first questionnaire. The second questionnaire also consisted of four parts:

- In the first part we asked the respondents once more about the importance of the road impacts, in order to check the consistency in their evaluation.
- In the second part respondents were asked about their experiences of the intervention process related to the road impacts.
- In the third part the respondents reported about their experiences of the maintenance result related to the road impacts.
- The last part of the questionnaire asked about the experiences with the information provision and the satisfaction with the intervention project. We asked about the satisfaction with the process, the outcome, the information provision and the overall project.

[26] It should be noted that the same characteristics have been collected for both road users and residents. Note also that the characteristics asked to the respondents of a company are mainly on the characteristic of the company itself, not of the employee. Apart from questions about stakeholder characteristics the questionnaire did not differ significantly for each stakeholders group. This guaranteed that differences solely depend on the intrinsic stakeholders' characteristics and not on the specific survey design.

The second questionnaire as it was prepared for road users can be found in APPENDIX 21. The responses to the two questionnaires are summarized per stakeholder group in Table 22.

Table 22 Response to questionnaire 1 and 2

	Questionnaire 1	Questionnaire 2
Road Users	71 (10%)	16 (22%)
Residents	101 (12%)	35 (34%)
Companies	38 (10%)	8 (21%)
Total	**210 (11%)**	**59 (27%)**

8.2 Stakeholder identification

The Flemish highway agency did not explicitly identify stakeholders of the intervention project.

Although a wide number of stakeholders such as the municipality of Zwijnaarde, gas stations, and public transport could have been identified, the analysis of SABARIS focused on those stakeholders which were directly affected by the road section and the intervention project:

- Road users – directly affected by the reduced capacity and speed limit of the road, the eventual increase of traffic jams and denser flows, with consequently higher travel times, discomfort, etc.
- Residents – live alongside the highway and suffer of a reduced accessibility of their environment, longer distances travelled to access the highway, air and acoustic pollution, etc.
- Companies – facing higher costs for delays, more fuel consumed, eventual losses of costumers and contracts etc.

8.3 Stakeholder analysis before the intervention project

8.3.1 Respondent characteristics

210 respondents to questionnaire 1 were included in the analysis and can be characterized as follows:

- 34% are road users and 66% are road neighbours. The road neighbours can be further divided into residents (48%) and companies (18%).
- The majority of road users and residents were male (72%) and at an age between 26-65 years (78%). Only 12% were younger than 26 years and only 10% were older than 65 years.
- 56% of road users make use of the E17 1-7 days per week. 53% of the residents also use the A20 2-7 days per week, which indicates that residents switch stakeholder roles.
- 27% of the road users travel on the A20 for commuting purpose and 41% for business purpose. 68% of the residents travel for private purpose on the A20.

- 45% of the companies are of small and medium size (not more than 50 employees). 18% are bigger companies (more than 500 employees).
- For 86% of the companies the A20 plays an important role for doing business. 22% use the A20 for good transport and for 65% the main purpose of the A20 is the transportation of employees.

A graphical representation of the respondent characteristics can be found in APPENDIX 22.

8.3.2 Importance of road impacts

When asking all stakeholders about the importance of road impacts, the ranking of road impacts as depicted in Figure 84 could be obtained.[27] Safety is the most important impact to road stakeholders followed by travel time, comfort and economy. The importance of safety significantly differs from the other impacts.[28] Visual quality and resource consumption are the least important impacts. Their importance also significantly differs from the other impacts.[29]

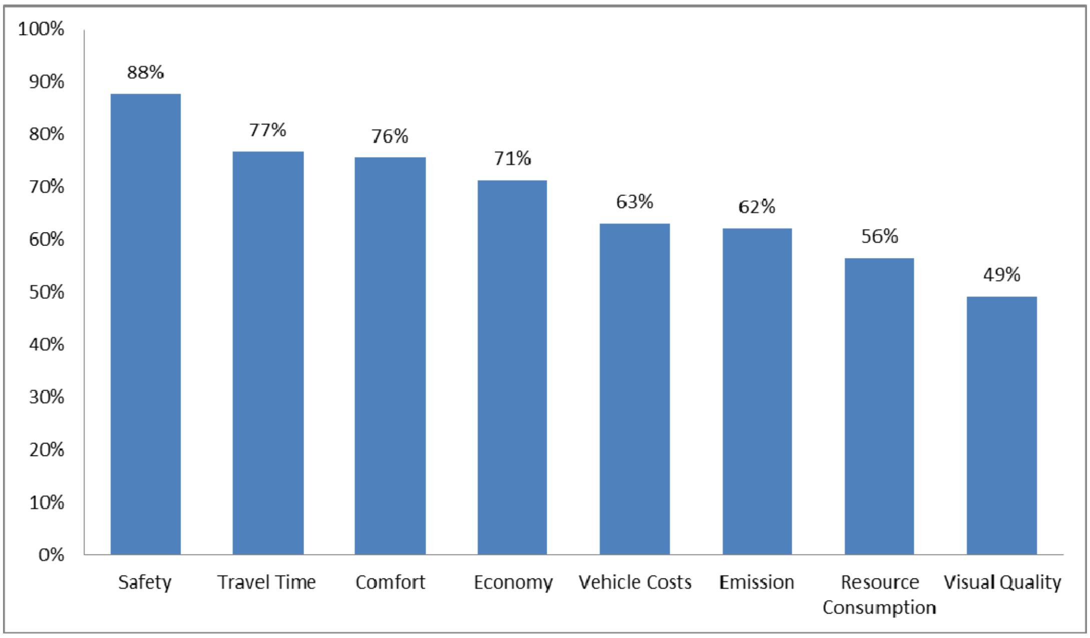
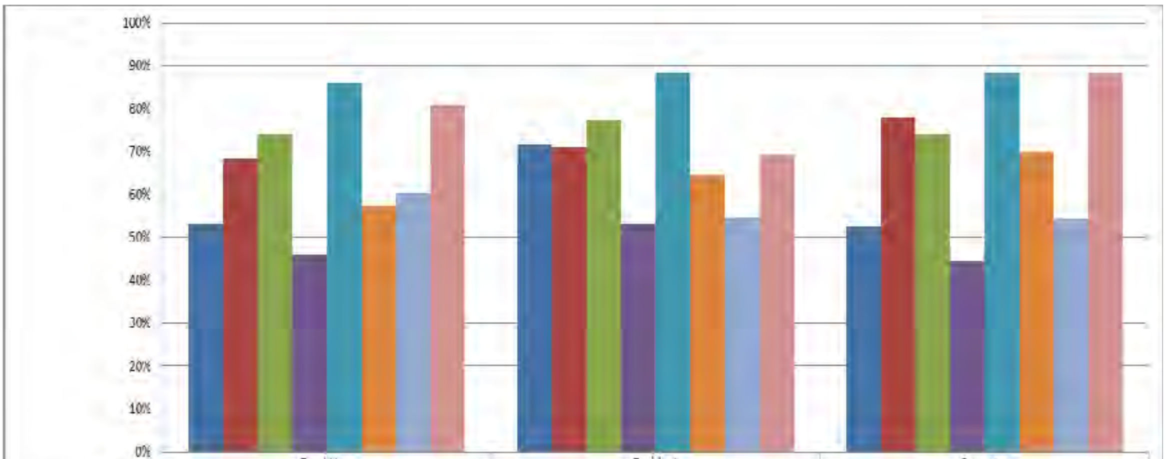


Figure 84 Overall importance of road impacts to stakeholders

The separate analysis of the importance of road impacts for the three stakeholder groups could reveal the following significant differences (Figure 85):

- Road users perceive travel time more important than residents.
- Residents perceive emission more important than road users and companies.
- Companies perceive travel time and vehicle cost more important than residents and economy more important than road users.

[27] The scale used ranges from 0% (very unimportant) to 100% (very important).
[28] The difference between the importance of travel time, comfort and economy is not significant.
[29] It should be noted that the difference between the importance of visual quality and the importance of resource consumption is also significant.



	Road User	Resident	Company
Emission	53%	72%	52%
Economy	68%	71%	78%
Comfort	74%	77%	74%
Visual Quality	46%	53%	44%
Safety	86%	88%	88%
Vehicle Costs	57%	64%	70%
Resource Consumption	60%	55%	54%
Travel Time	81%	69%	88%

Figure 85 Importance of road impacts per stakeholder group

Safety remains an important impact for all stakeholder groups.

We also analysed whether there are significant differences in the importance judgement depending on respondent characteristics. The analysis showed that:

- Males perceive economy more important than females.
- Stakeholders who are 66 and older perceive emissions more important than stakeholder who are 18-35 years old.
- Stakeholders who are 66 and older perceive comfort more important than stakeholder who 18-35 years old.

In order to limit the length of the questionnaire it was decided to not include questions about the satisfaction with the different road impacts. However, the importance of road impacts to stakeholders indicates that safety is an impact the Flemish highway agency should concentrate on when deciding on interventions. If it is assumed that safety already receive high attention, this attention should be kept. Travel time, comfort and economy are three other impacts which are particular important in the context of the E17 and should get attention as well.

8.3.3 Expectations about the intervention project

The respondents were asked to report about their expectation regarding the intervention project. This included expectations about the intervention process, intervention outcome, and the information provision. Only respondents who filled in questionnaire 1 and 2 were considered in the analysis, in order to allow comparison between expectation and experience.

8.3.3.1 Process expectation

Overall 61% of the stakeholders expected a strong or very strong influence of the intervention project on them (Figure 86). Only 8% expected a low influence. It is obvious that the road intervention project raised the expectation of stakeholders of being affected by the project.

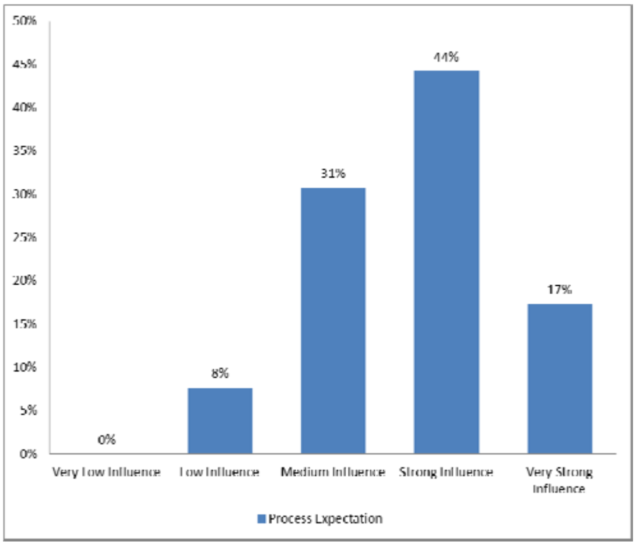


Figure 86 Overall expectation about the project influence on stakeholders

A closer look at the overall expectations of stakeholders about the influence of the intervention project on the road impacts show that first of all travel time was expected to be affected followed by safety, emission, economy and comfort (Figure 87).[30] The expected impact on travel time can be explained with the importance of the highway section for the entire road network. Reducing the capacity of a traffic intense highway is expected to have effects on the capacity of other parts of the network. An explanation for the expected impact on safety is the already existing high risk of accidents on the highway which might be seen to increase during the maintenance. The expected impact on economy can be explained by the importance of the highway section for the neighbouring companies and the effect a closed highway section might have on the accessibility of premises and the transportation of good and employees. The expected impact on emission can be explained in two ways. On the one hand, there might be the expectation that less traffic is on the highway which will lower the emissions. On the other hand, intervention work can also produce noise and dust. Traffic which takes other routes can increase emissions in other areas as well.

[30] The scale used ranges from 1 (very small influence) to 5 (very strong influence). Travel time is significantly different from all other impacts. Safety, emission, economy and comfort are also significantly different from the vehicle cost, resources and visual quality. The differences between safety, emission, economy and comfort are not significantly different.

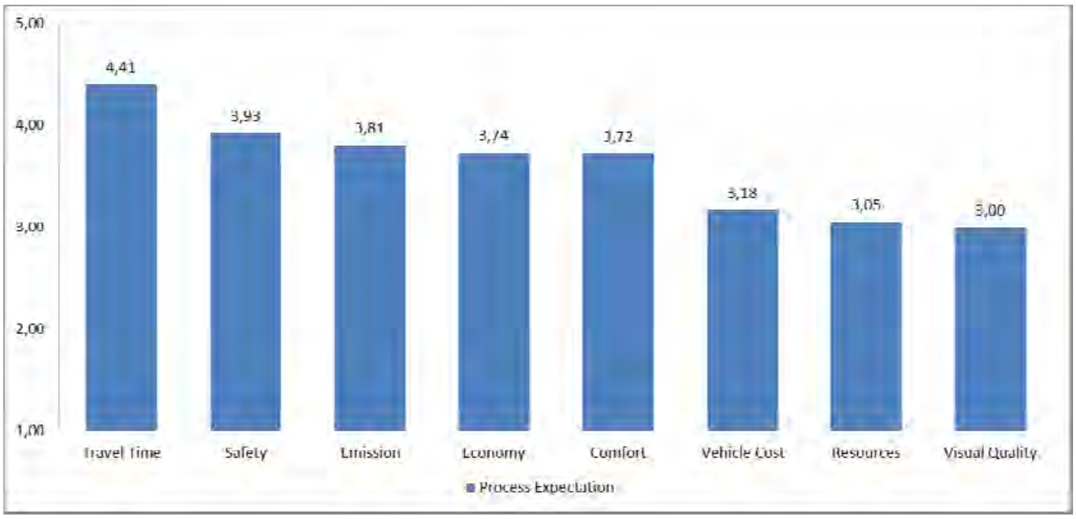


Figure 87 Overall expectations about the project influence on road impacts

A differentiation of process expectations per stakeholder group shows (Figure 88) that:

- Residents and companies expected a stronger influence on travel time, safety and emission than road users.
- Residents expected a stronger influence on economy than companies.

These differences are partly in line with the importance of road impacts to stakeholders. It is remarkable that residents expect a strong influence on economy which might be explained by the many spin-off firms in this area and the fact that many of the employees also live in this area. The expected impact on safety and emission by the companies might be related to the closeness of these firms to the highway.

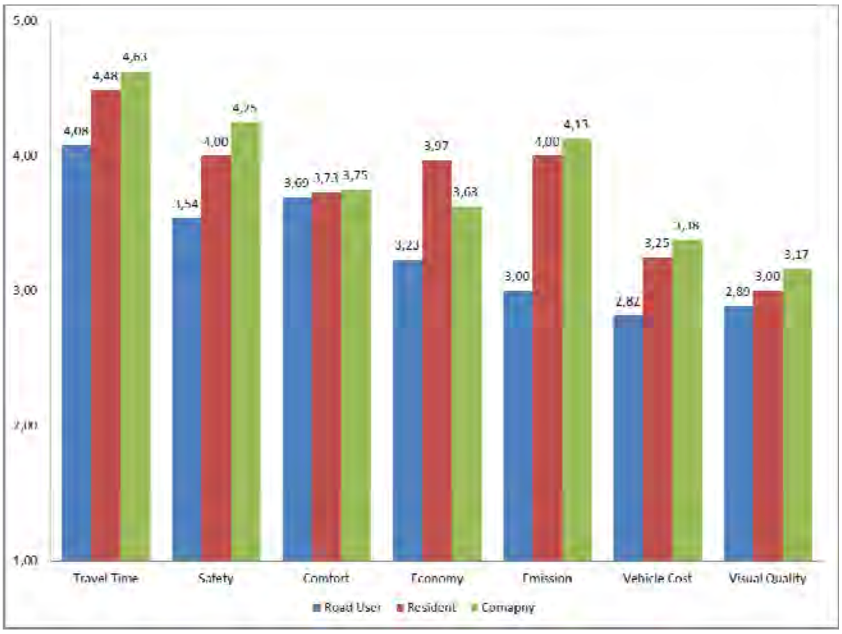


Figure 88 Expectations about the project influence on road impacts per stakeholder group

8.3.3.2 Outcome expectation

If it comes to the overall expectations about the outcomes of the intervention project, 70% of the stakeholders expected a strong to very strong improvement of the highway (Figure 89). That suggests that before the maintenance the stakeholder experienced a highway in a very bad condition.

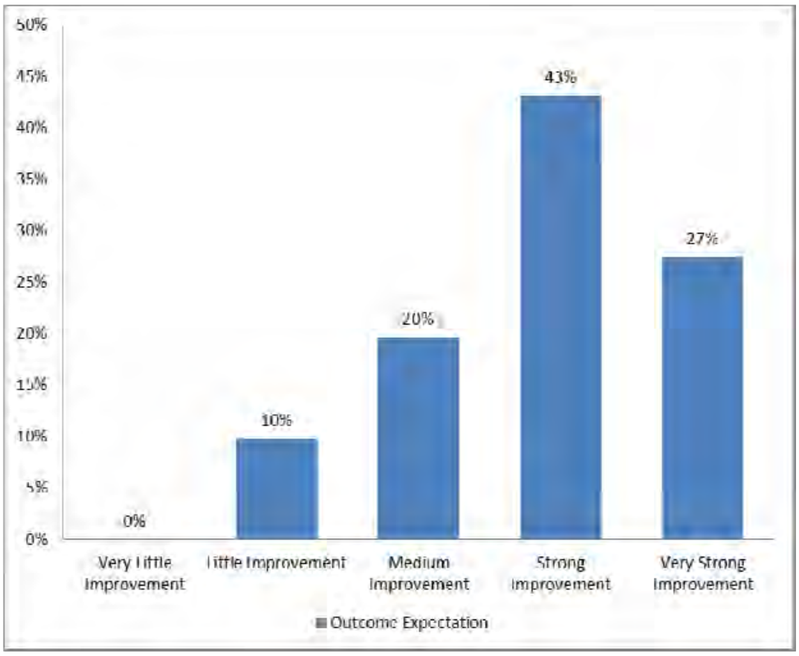


Figure 89 Overall expectations about the highway improvement after the project

The questions about the expectations about the improvement of road impacts after the intervention project revealed that stakeholders expected comfort to be improved after the maintenance (Figure 90). [31] That can be explained with the bad condition of asphalt which caused a bumpy ride on this section. Related to this are also the expectations about the improvement of safety and vehicle cost.

[31] The scale used ranges from 1 (very small improvement) to 5 (very strong improvement). Comfort is significantly different from all other impacts.

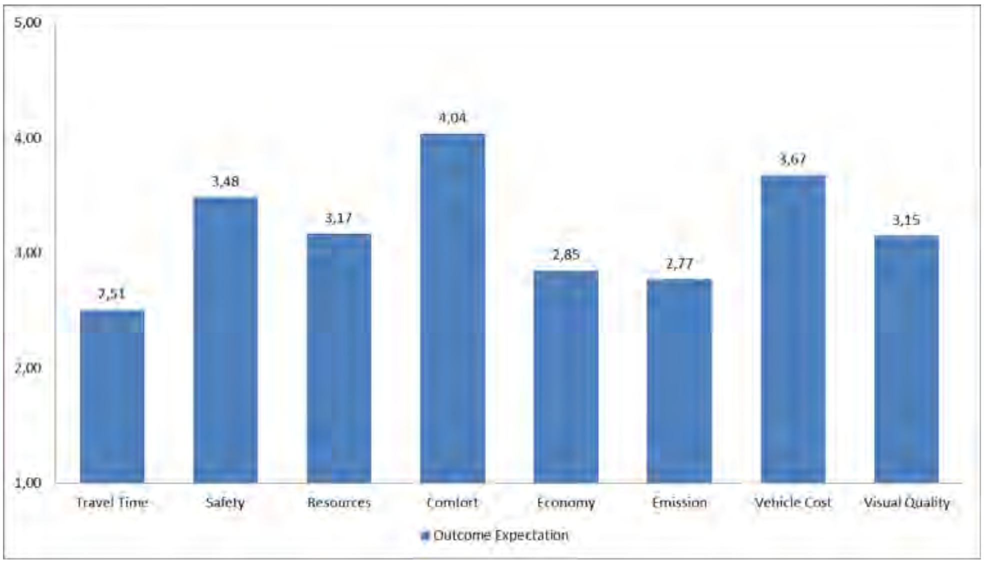


Figure 90 Overall expectations about the improvement of road impacts after the project

The three stakeholder groups expected a slightly different outcome from the project (Figure 91). Companies and residents expected a stronger improvement of comfort than road user. That indicates that the highway is also used by both groups and that they switch roles. That is supported by the expected improvement of safety and vehicle costs. Here, companies and residents again expect a stronger improvement than road users.

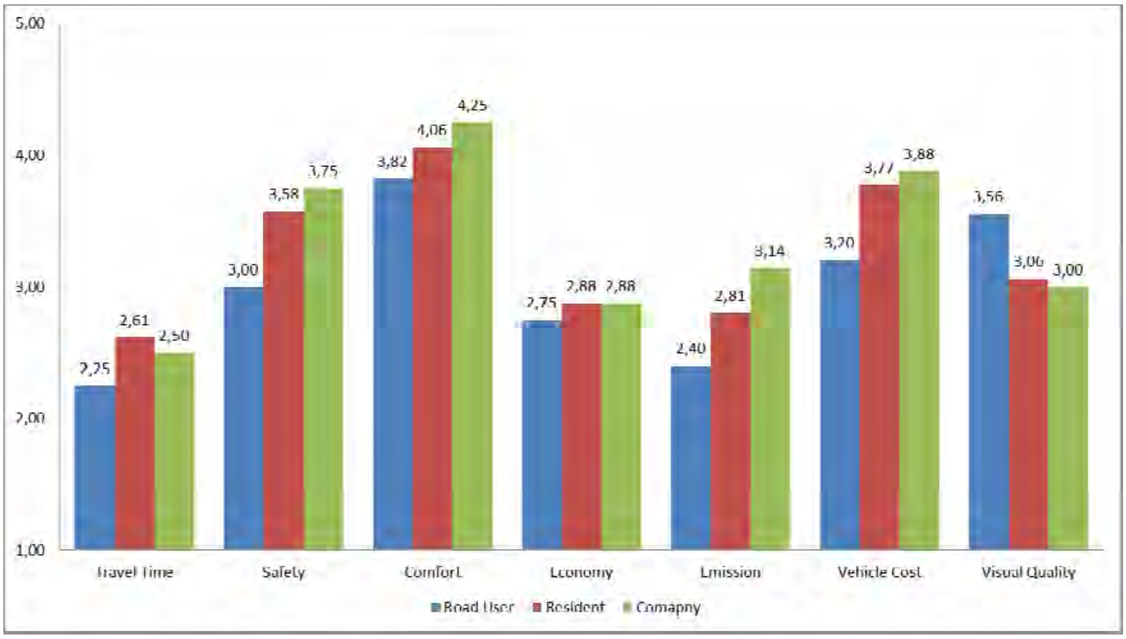


Figure 91 Expectations about the improvement of road impacts per stakeholder group

8.3.3.3 Information expectation

61 of the respondents expected to be informed about the road maintenance much or very much (Figure 46).[32] That suggests that stakeholders rely on such information to make decisions regarding their travel behaviour or the organisational processes.

[32] The scale used ranges from 1 (very little information) to 5 (very much information).

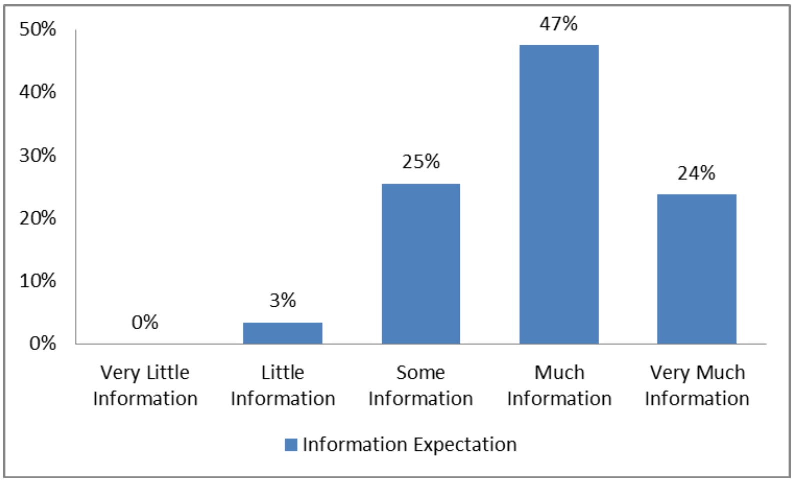


Figure 92 Overall expectations about the information provision

The expectations of the three stakeholder groups show some differences (Figure 93). Companies expect more information than residents and road users. That underlines the importance of this highway section to the companies located in the area and the expected effect of the maintenance on the companies processes.

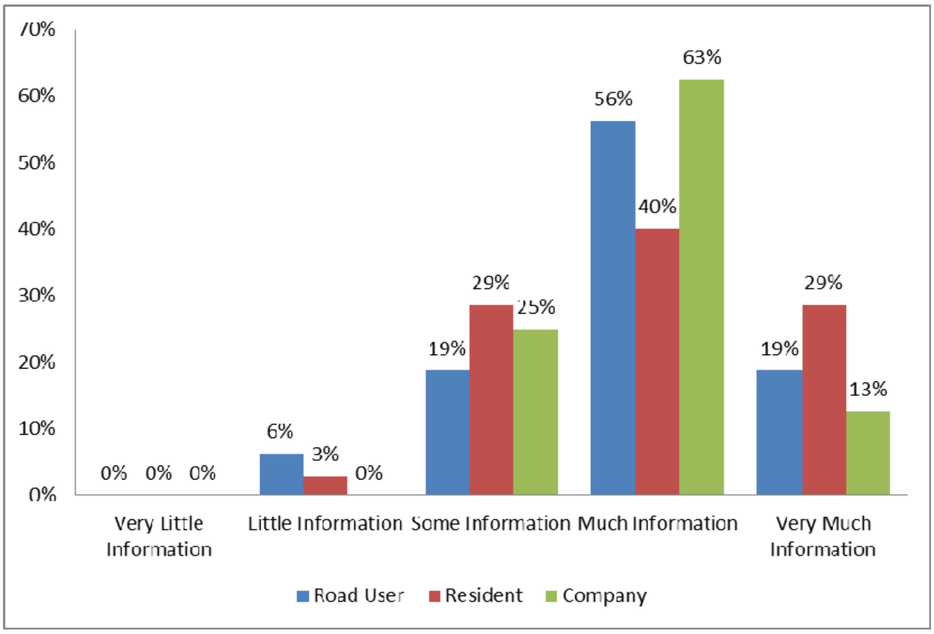


Figure 93 Expectations about the information provision per stakeholder group

8.4 Stakeholder management

Stakeholder management was focused on providing information in different ways:

- Meeting with some stakeholders directly, including:
  - Flemish traffic centre, which makes prognoses for spillback queues,
  - Local police,
  - Traffic police,
  - Local municipalities,
  - Cabinet of the minister of public works,

- Communication devices:
  - Website+communication campaign with phasing for all users,
  - Unizo/Voka/Febetrans: employers’ federations => local companies are informed and regularly updated.

No rerouting was advised except when the Zwijnaarde "De Pinte" complex was closed. To manage long distance travellers, the Flemish Traffic Centre agreed with foreign traffic centres long-distance detours. Moreover, a traffic management company was in charge of the incident management in the area and took following measures:

- Traffic warning signs were installed to avoid head tail collisions. They warn drivers in how many meter a traffic jam begins.
- Part of the transport from France was rerouted with heavy congestion (>50km traffic jam).

The rerouting measures are shown in the following figures.

Figure 94 Rerouting for the exit De Pinte (8) from Kortrijk (14 March - 31 August 2011)

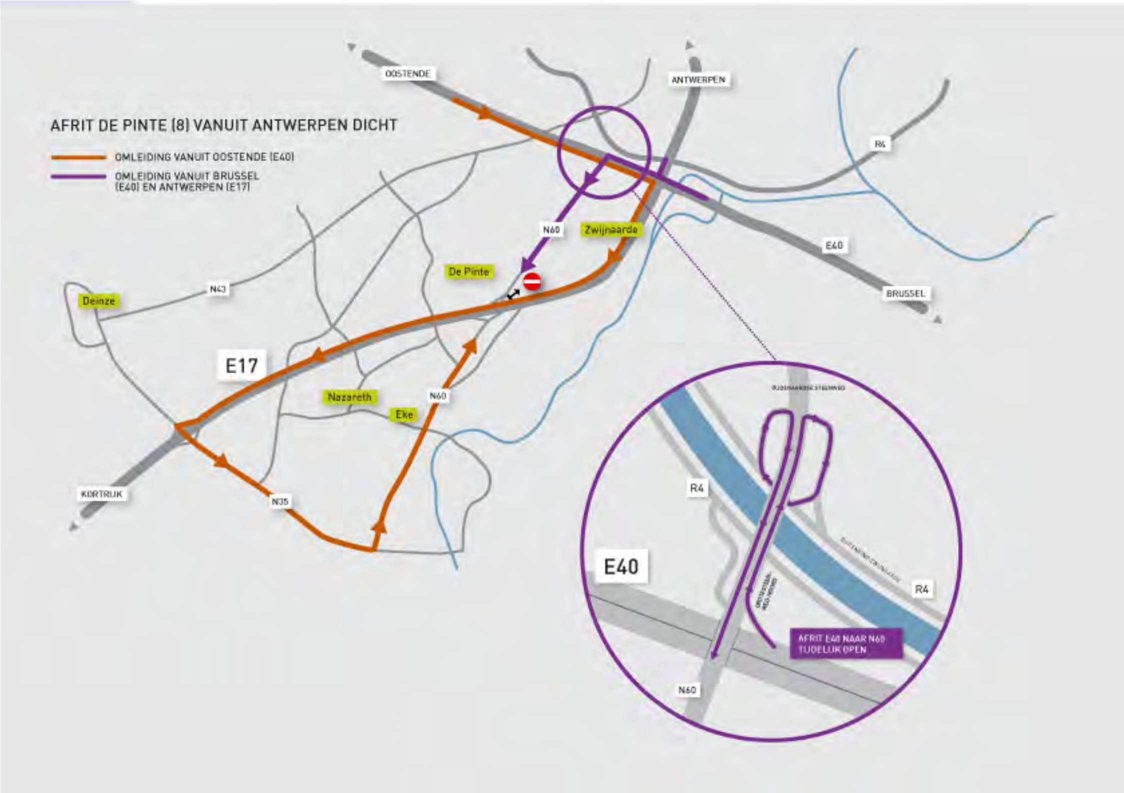


Figure 95 Rerouting for the exit De Pinte (8) from Antwerp (16 May - 31 August 2011)

Figure 96 Rerouting for drive-up E17 direction Kortrijk (14 March - 30 June 2011)

Figure 97 Deviation for drive-up E17 direction Antwerp (16 May - 31 August 2011)

Dust reduction

The intervention was expected to cause dust for the neighbours of the road works. To limit the impact of dust as much as possible, additional sprinklers were used in the concrete and crushing plants close to De Pinte. Also on site more spray-wagons were used. This was to ensure that the produced dust didn't get volatile.

Noise reduction

For the road works it was chosen to work 24/24 to minimize hindrance to the traffic. The counter side was that there was additional noise for local residents at night, especially during the destruction phase (second half of April and second half of May). The pavement (including foundation) of the E17 was completely broken down. Then the broken material was sent to the crushing stations to break them into smaller pieces so that it could be reprocessed into the new fundament. The sound was so intense and occurred only during the day. Concrete plants were running continuously, but make far less noise. The delivery of materials with trucks also gave extra noise, even at night. In the second half of May there was a second destruction phase between Kortrijk and De Pinte Deinze. There was approximately 1 km of pavement broken up per day, so the noise impact could be limited.

8.5 Stakeholder analysis after the intervention project

After the intervention project road users, residents and companies were asked about their experiences and satisfaction with the process, the outcome and the services provision of the project. The experiences are contrasted with the expectations, in order to reveal differences.

8.5.1.1 Process experiences

Only 26% of the respondents experienced a strong or very strong influence of the project (Figure 98).[33] That is in contrast with the 63% of stakeholders who expected a strong or very strong influence. That suggests that the project had a less strong effect on stakeholders. The difference between process expectation and experience is significant.

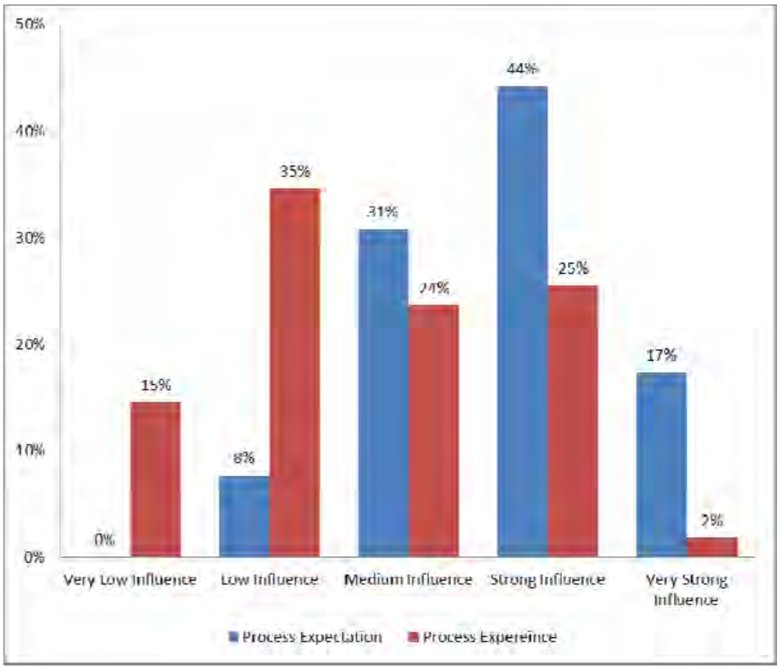


Figure 98 Overall experiences of the project influence on stakeholders

The picture of a lower influence than expected is confirmed when looking at the influences on the road impacts experienced by the stakeholders (Figure **99**). For all road impacts a lower influence is experienced than expected. The only exceptions are resource consumption and visual quality. Particularly the expected effects on travel time were much lower. But also the experienced effect on safety, comfort and economy was lower than expected.

[33] The scale used ranges from 1 (very low influence) to 5 (very strong influence). Apart from comfort and resource consumption experiences are significantly different from expectations.

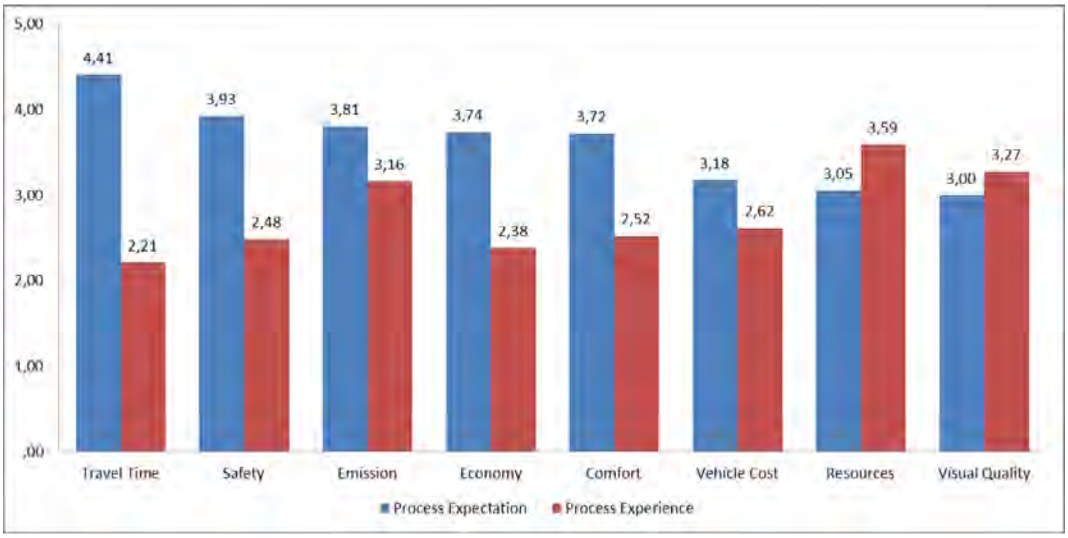


Figure 99 Overall experiences of the project influence on road impacts

The experienced influences of the maintenance on the road impacts only differed marginally between stakeholder groups (Figure 100). Most interesting, the experienced influence on vehicle cost and visual quality is for all stakeholder groups higher than expected. This reflects the detours related to the intervention project. That the experienced influence on travel time is low suggests that detours took not much more time.

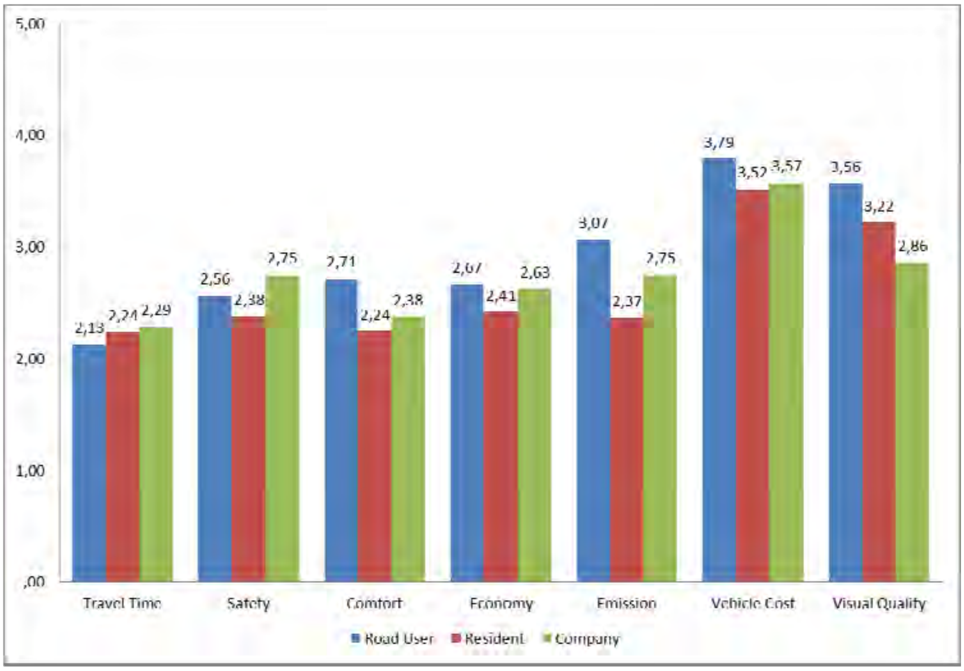


Figure 100 Experiences of the project influence on road impacts per stakeholder group

8.5.1.2 Outcome experiences

38% of all respondents experienced a strong or very strong improvement of the highway section after the maintenance (Figure 101)[34]. There is no significant difference between outcome expectation and experience.

[34] The scale used ranges from 1 (very low improvement) to 5 (very strong improvement).

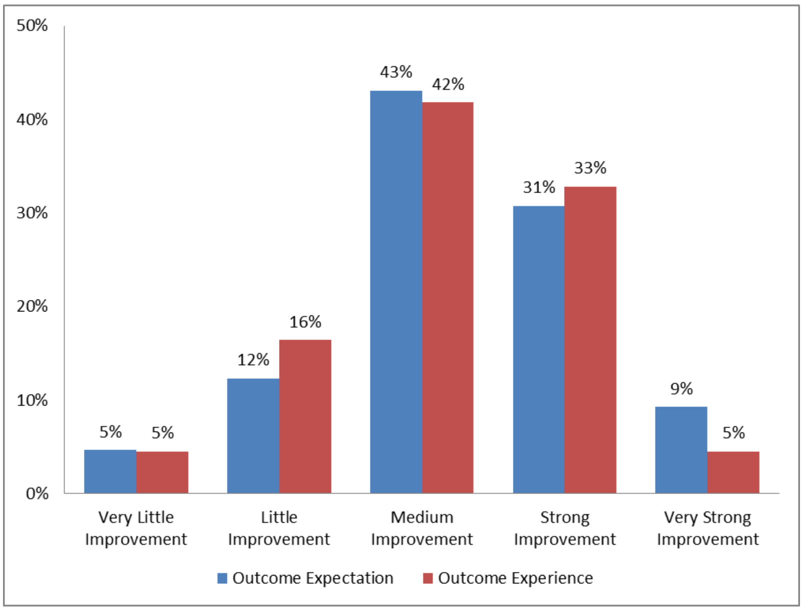


Figure 101 Overall experiences of the highway improvement after the project

Similar to process experiences, the outcome experiences related to the road impacts are lower than the expectations (Figure 102). The only exceptions are travel time and emission.[35] A possible explanation for the experienced improvement in travel time can be the increase in speed due to a better pavement. However, it seems that the riding comfort is not experienced as improvement. That might be related to the replacement of the asphalt with concrete.

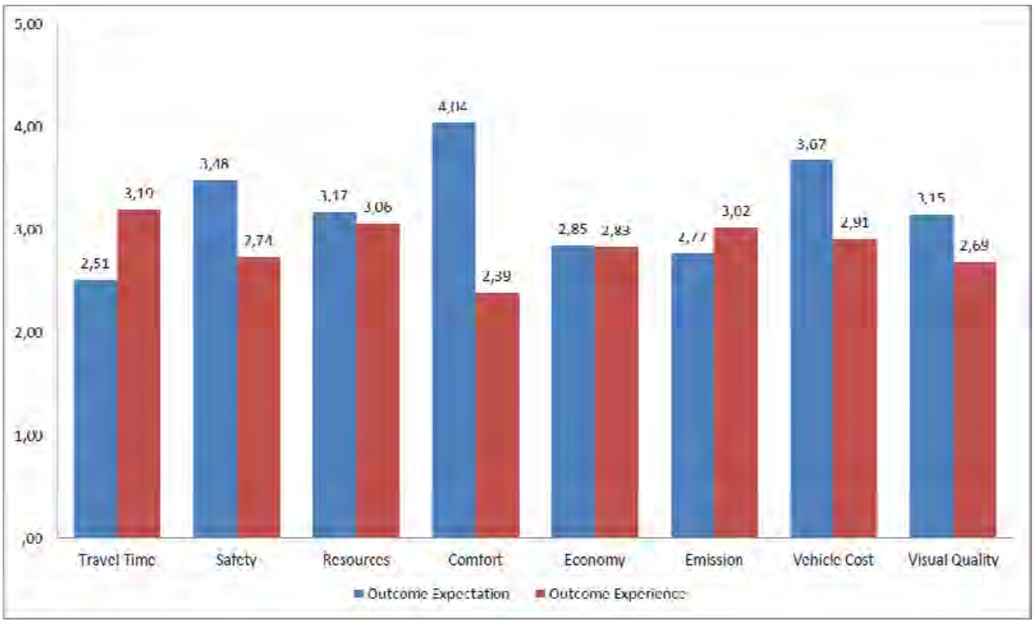


Figure 102 Overall experiences of the improvement of road impacts after the project

There is a difference between stakeholder groups in terms of the experienced improvements (Figure 103). While companies experienced an improvement of

[35] Apart from economy and emission the differences between expectation and experiences are significant.

comfort, road user and residents did not. On the other hand, road users and residents experienced a stronger improvement of travel time than companies.

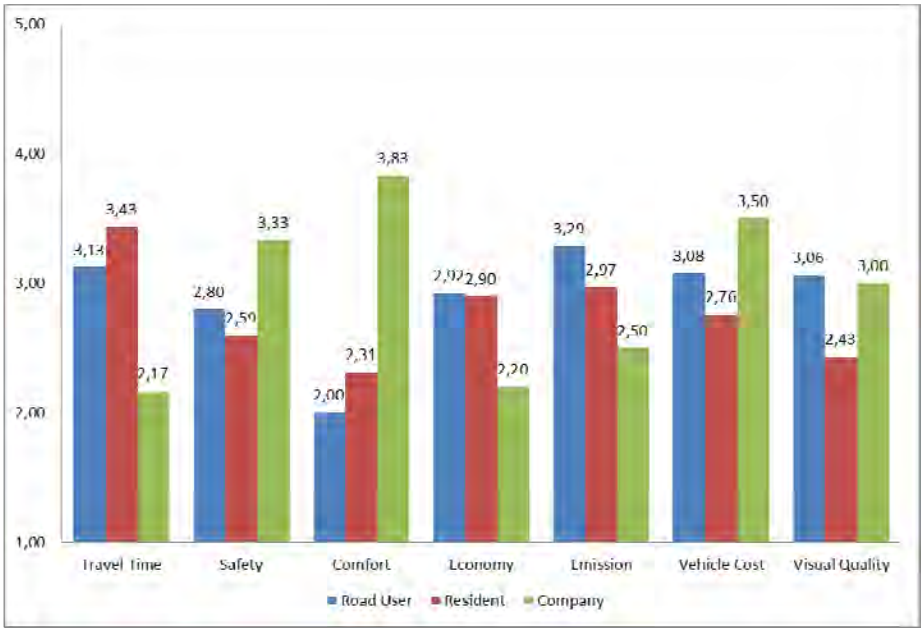


Figure 103 Experiences of the improvement of road impacts per stakeholder group

8.5.1.3 Information experiences

Only 9% of the respondents received much information about the maintenance (Figure 104).[36] That is in sharp contrast to the expectations. In other words, the stakeholders received less information than they expected.[37] That indicates that the Flemish highway agency did not inform enough about the maintenance or did not use the appropriate channels to distribute the information.

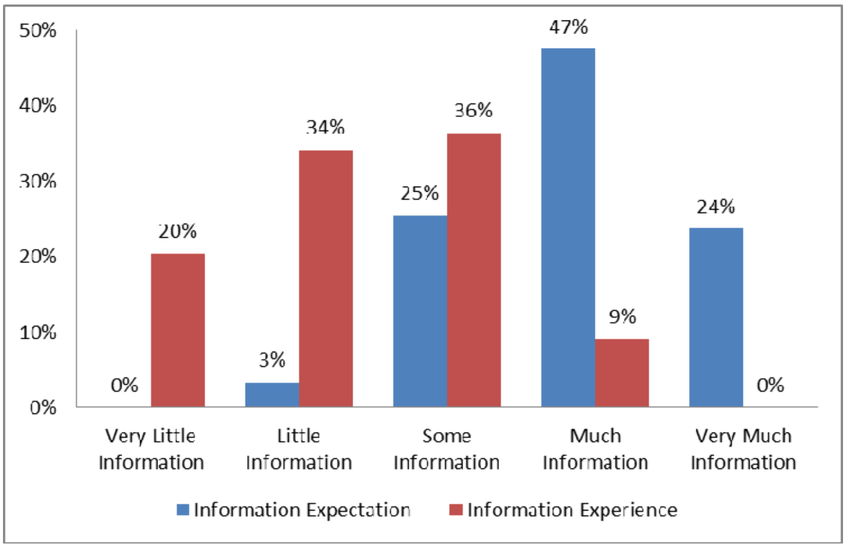


Figure 104 Overall expectations about the information provision

[36] The scale used ranges from 1 (very little information) to 5 (very much information).
[37] The difference between expectation and experience is significant.

Companies experienced some information provision whereas road users and residents received little information about the maintenance (Figure 105). That is in line with the stakeholder management strategy which not clearly addressed road users and neighbours.

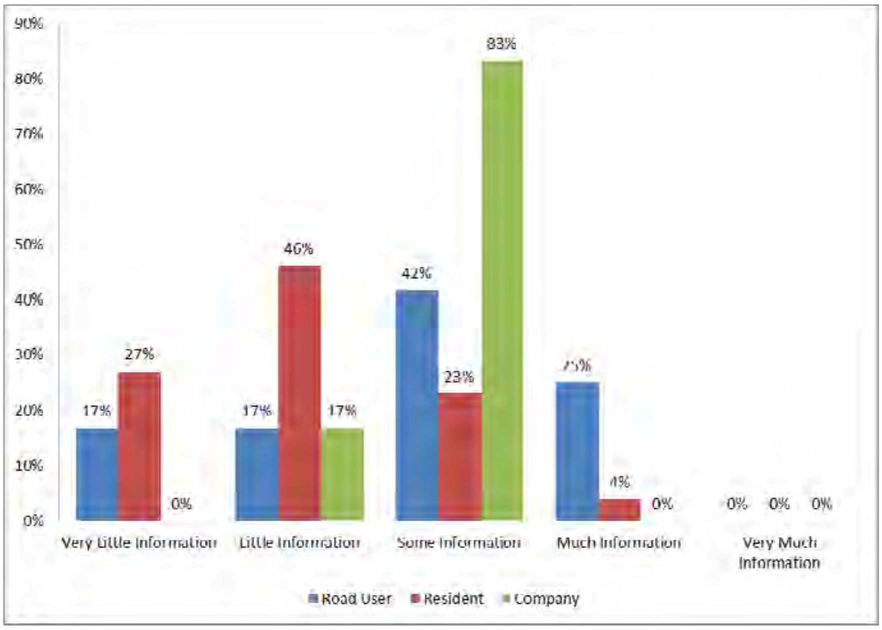


Figure 105 Experiences of the information provision per stakeholder group

8.5.2 Satisfaction with the intervention project

8.5.2.1 Process satisfaction

There is a sharp contrast in the satisfaction with intervention process (Figure 106).[38]. 51% of the respondents are satisfied of very satisfied and 46% are dissatisfied or very dissatisfied.

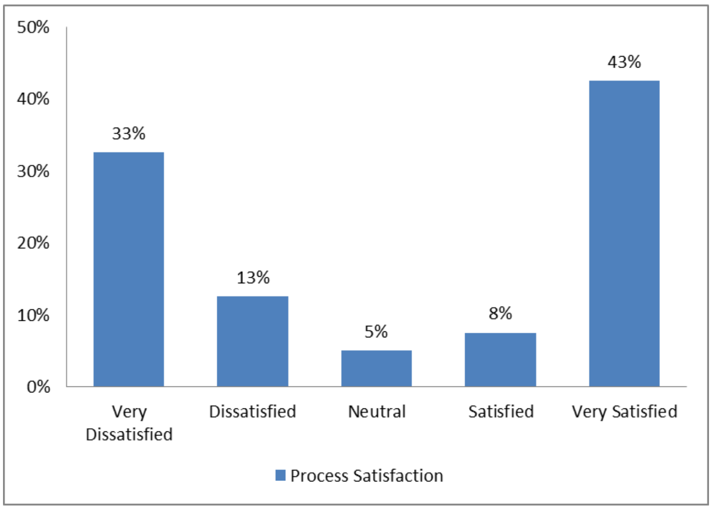


Figure 106 Satisfaction with the intervention process

[38] The scale used ranges from 1 (very dissatisfied) to 5 (very satisfied).

The most satisfied group are the residents whereas the road users are the least satisfied group (Figure 107). The satisfaction with the intervention process per stakeholder group reflects the influence that was experienced by the respondents. The road users experienced the greatest influence.

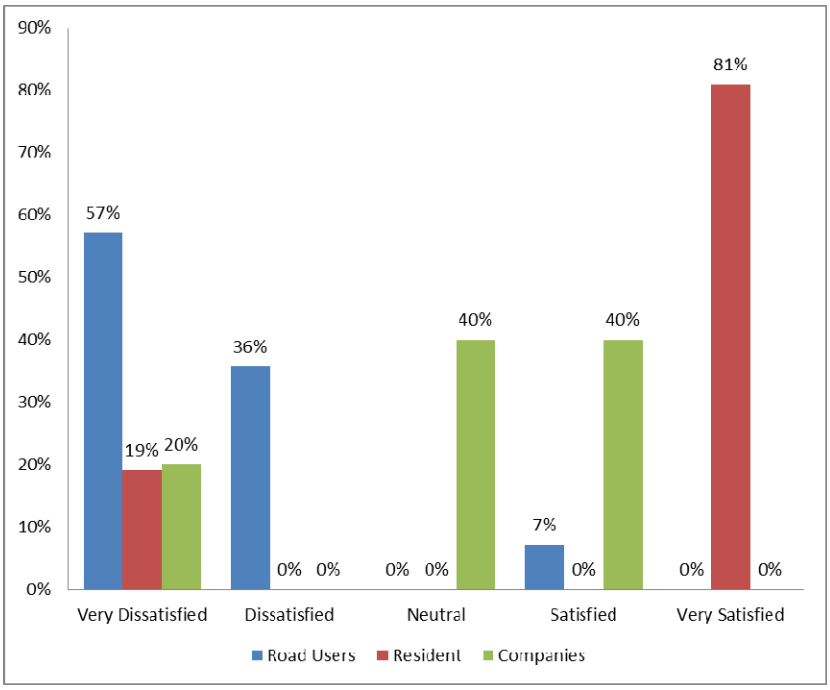


Figure 107 Satisfaction with the intervention process per stakeholder group

8.5.2.2 Outcome satisfaction

The majority of respondents (65%) was satisfied or very satisfied with the outcome of the maintenance (Figure 108). Since stakeholders experienced less improvement of all road impacts than expected except from travel time, the level of satisfaction appears to be achieved, first of all, through the travel time experience.

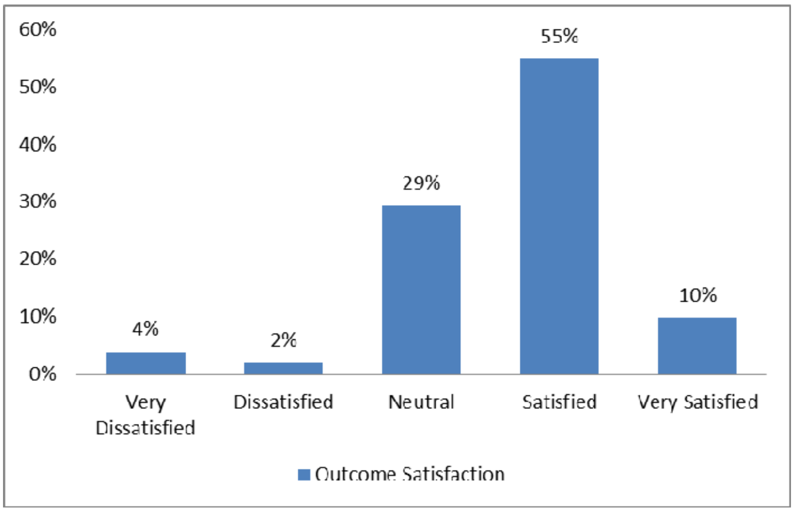


Figure 108 Satisfaction with the intervention outcome

The majority of respondents from all stakeholder groups are satisfied or very satisfied with the outcome of the maintenance (Figure 109). Only a group of road users (17%)

was very dissatisfied with the outcomes. A possible explanation is that their experiences did not match their expectations. Another explanation could be that they did not see the hindrance during the maintenance outweighed by the outcomes of the project.

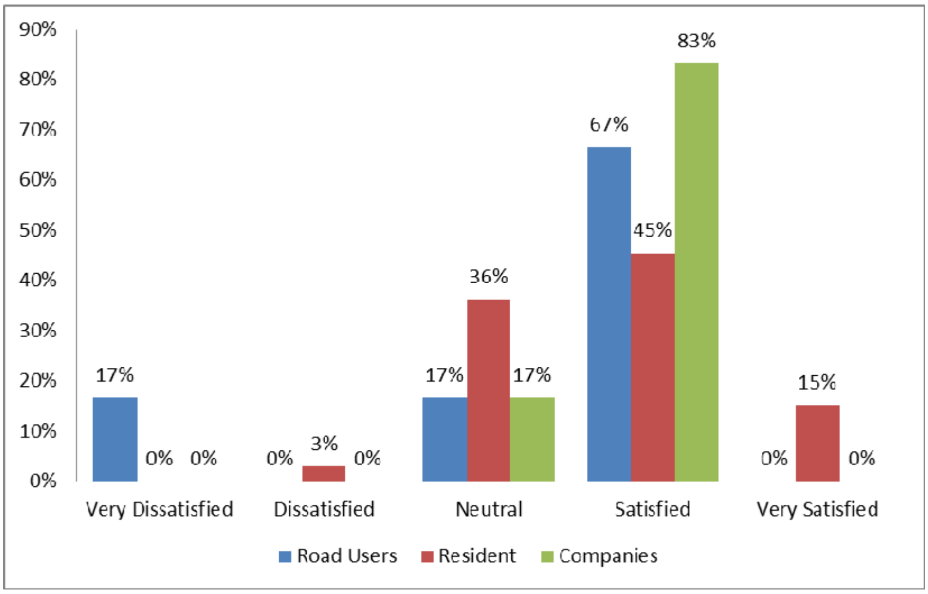


Figure 109 Satisfaction with the intervention outcome per stakeholder group

8.5.2.3 Information satisfaction

59% of the respondents were dissatisfied or very dissatisfied with the information provision (Figure 110). That indicates that they received not sufficient information to be informed about the intervention project and to make informed decisions regarding their travel behaviour etc. Only 18% were satisfied or very satisfied with information received.

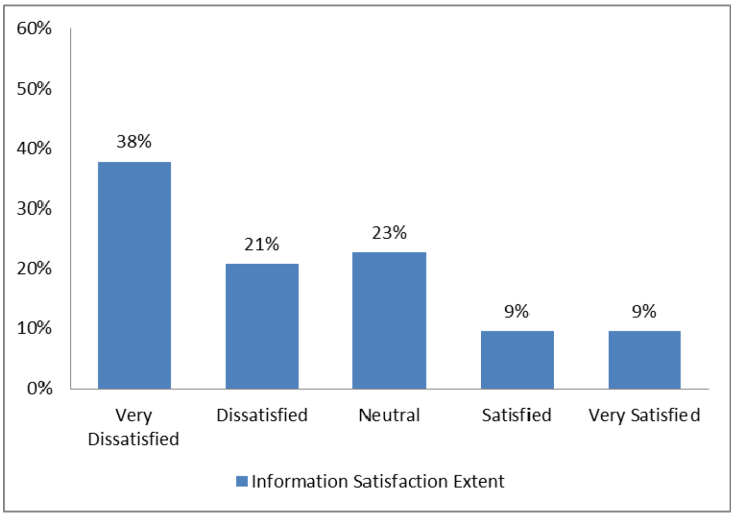


Figure 110 Satisfaction with the information provision

According to the amount of information received companies were most satisfied with the information provision and road users were least satisfied (Figure 111). This is another indication for the shortcomings of the stakeholder management strategy of the Flemish highway agency.

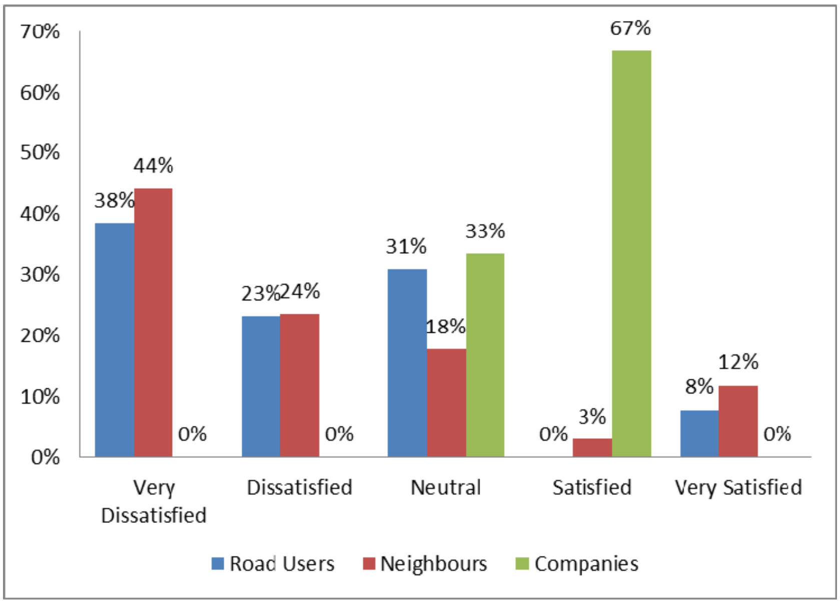


Figure 111 Satisfaction with the information provision per stakeholder group

8.5.2.4 Overall satisfaction

Besides the satisfaction with outcome, process and information provision, we also included a question about the overall satisfaction with the intervention project which was conceptualized as an aggregated assessment of the three maintenance aspects and as such is an indicator for the relative importance of intervention outcome, process and information provision for the formation of satisfaction. Despite the dissatisfaction with the information provision 79% of the respondents were overall satisfied or very satisfied with the intervention project (Figure 112).

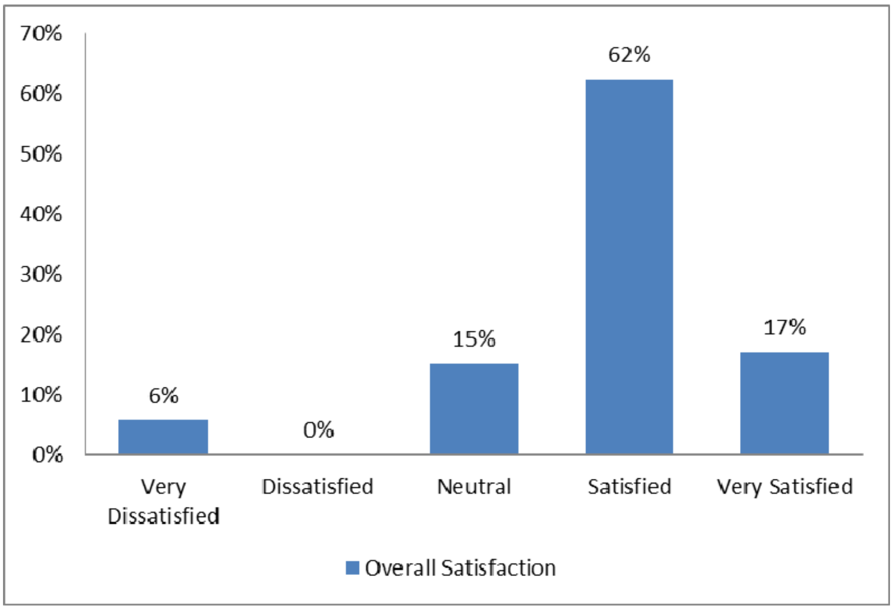


Figure 112 Overall satisfaction with the intervention project

The majority of respondents of all three stakeholder groups are satisfied or very satisfied with the intervention project (Figure 113). Only a few road users and residents are very dissatisfied. These stakeholders are also dissatisfied with intervention outcome and the intervention process.

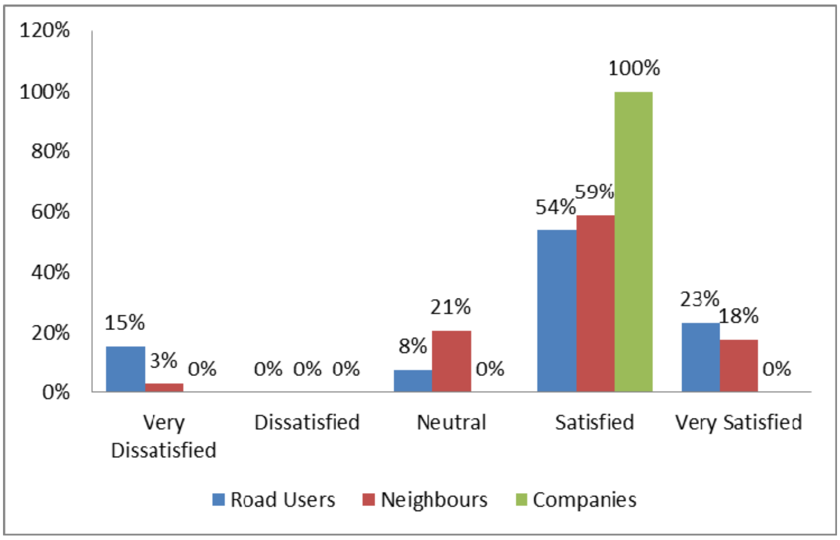


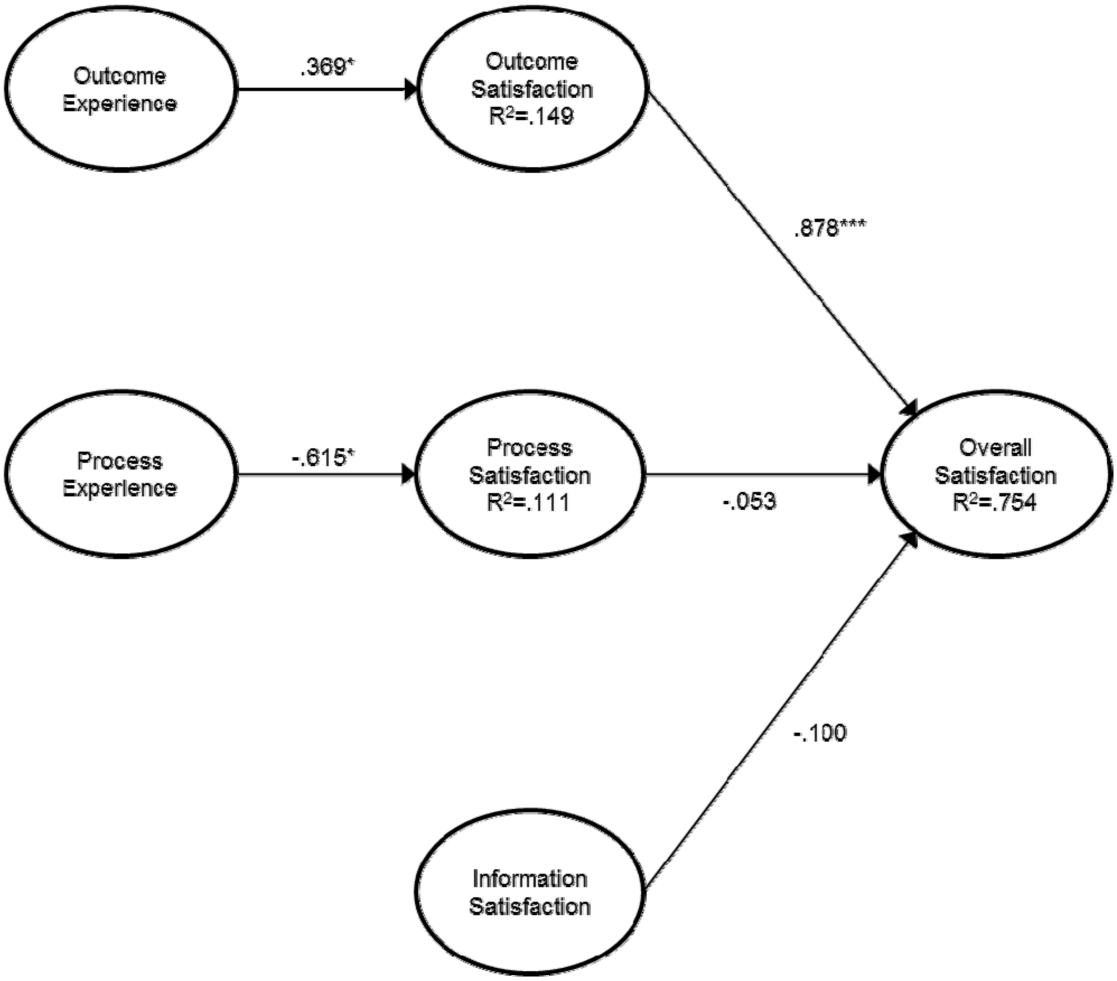
Figure 113 Overall satisfaction with the intervention project per stakeholder group

8.5.3 Expectancy (dis)confirmation analysis

We further analysed the relationship between expectation, experience and satisfaction to determine which interplay of expectation and experience explains stakeholder satisfaction. In addition, we analysed the contribution of process, outcome and information satisfaction to the overall satisfaction with the intervention project.[39] The results of the analysis are depicted in Figure 114.

The central criterion for the assessment of the relationship between the three aspects is the coefficient of determination R^2, which is used to characterize the ability of expectation and experience to explain and predict satisfaction and the ability of outcome, process and information satisfaction to explain and predict overall satisfaction. The R^2 values of outcome satisfaction (.149) and process satisfaction (.111) are low. With a R^2 value of .754 the explained variance of overall satisfaction is good. It was not possible to explain information satisfaction with information expectation and experience. In addition, overall satisfaction can be only explained with outcome satisfaction.

[39] The analysis was done with the programme SmartPLS 2.0 (Ringle et al., 2005)



***significant at .001 level, **significant at .05 level, * significant at .10 level

Figure 114 Relationship between expectation, experience and satisfaction

The analysis revealed a positive influence of outcome experience (.369) on outcome satisfaction whereas outcome expectation exhibits no influence. That suggests an experience-only mechanism in forming satisfaction with the intervention outcome. Stakeholders were most satisfied when they experienced a strong improvement of the highway impacts. They were least satisfied when they experienced a low impact improvement. In order to achieve a high level of satisfaction stakeholder need to be able to experience an improvement of the highway. According to our results it is not necessary to pay attention to stakeholder expectations. The relationship between outcome expectation, experience and satisfaction is graphically shown in Figure 115.

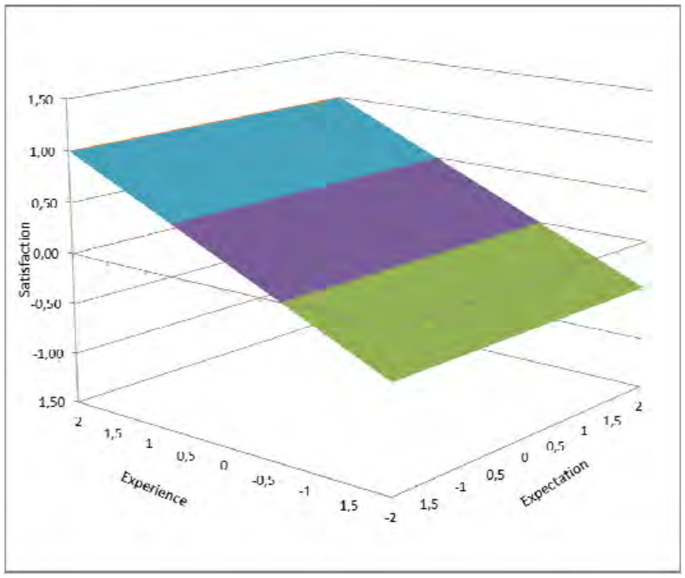


Figure 115 Outcome expectation, experience and satisfaction

There is a negative influence of process experience (-.615) on process satisfaction suggesting a reversed effect of both variables on process satisfaction. The higher the expected or experienced impact of the project on the stakeholders, the less satisfied the stakeholders were with the intervention process. Again, process expectations do not play a role in forming satisfaction with the intervention project. Stakeholders were most satisfied if they experienced an acceptable impact during the maintenance. Most interestingly, either information expectation nor information experience could explain the satisfaction with the information provision. In other words, although the Flemish highway agency was not able to provide sufficient information to all stakeholders, it does not influence the satisfaction of the stakeholders with the information provision. For the intervention process the relationship of expectation, experience and satisfaction is graphically shown in Figure 116.

Another result of the analysis is that the strongest influence on the overall satisfaction exerts outcome satisfaction. The influence of information satisfaction and process satisfaction is insignificant. A main implication is that the main emphasis should be on allowing stakeholders to experience the improvements of an intervention project. The peculiarities of the highway section (e.g. urban or rural area) will also determine whether the Flemish highway agency should raise expectations about certain road impacts by providing sufficient information about the intervention project or should concentrate on the actual outcome of the maintenance in order to gain satisfied stakeholders. In either case, intervention projects should lead to noticeably improved road infrastructure, since the value of a highway section will emerge at the moment of its usage. The duration of an intervention project will lead to a decrease of the initial importance of expectations over time and the importance of the immediate experience of the highway during and after the maintenance. We argue it is this time effect which finally accounts for the limited role of expectations in forming stakeholder satisfaction.

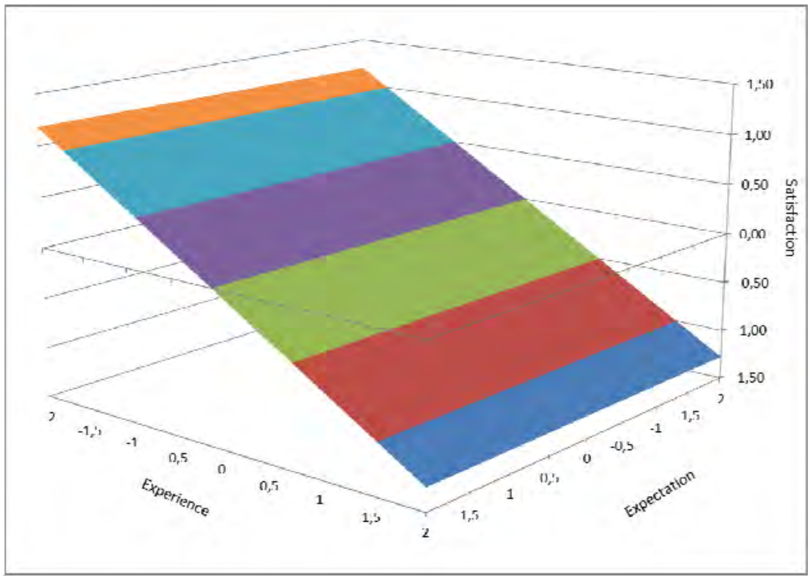


Figure 116 Process expectation, experience and satisfaction

8.6 Optimisation of intervention strategy

8.6.1 Strategic options

The case study included an analysis of the optimal intervention strategy for the maintained highway section of the E17. The investigated strategies differ in the way the interventions are executed for the 2 objects of the highway section (asphalt pavement and concrete pavement) and thus in the duration and timing of the intervention projects. The strategic decisions concern the bundling of objects and the traffic measures.

Interventions on the 2 objects can be bundled or done separately. We consider the following bundling options:

- **Intervention bundle 1 (IB-1)**
  Both objects are maintained separately.
- **Intervention bundle 2 (IB-2)**
  Both objects are combined. This option was applied by the Flemish Road Agency.

Another intervention strategy decision is the traffic measure applied during the intervention project. We distinguish the following options:

- **Closing lanes (TC-1)**
  Two out of six lanes are closed but the original width of the remaining lanes is kept. Speed limit is reduced to 90 km/h. This option was applied by the Flemish Road Agency.
- **Reducing lane width (TC-2)**
  The lane width is reduced and the speed limit is set to 80 km/h.

This results in 4 possible intervention strategies (Table 23).

Table 23 Investigated intervention strategy types (IST)

		Intervention Bundle	
		IB-1	**IB-2**
Traffic Configuration	**TC-1**	IST-1	IST-3
	TC-2	IST-2	IST-4

The kind of intervention remains the same for all strategies and comprises renewing the pavement. The intervention duration for object 1 is 154 days and 30 days for object 2. The differences between the strategies are the assumptions on the detour roads for traffic during intervention period. The traffic volume will change compared to the case of performing no intervention.

8.6.2 Simulation of traffic configurations

To reproduce the effects of the two different traffic configurations on the road network we used a simplified traffic model, shown on top of the geographical map of Gent in Figure 117. We argue that the extracted graph contains the most relevant changes in traffic patterns caused by the road works.

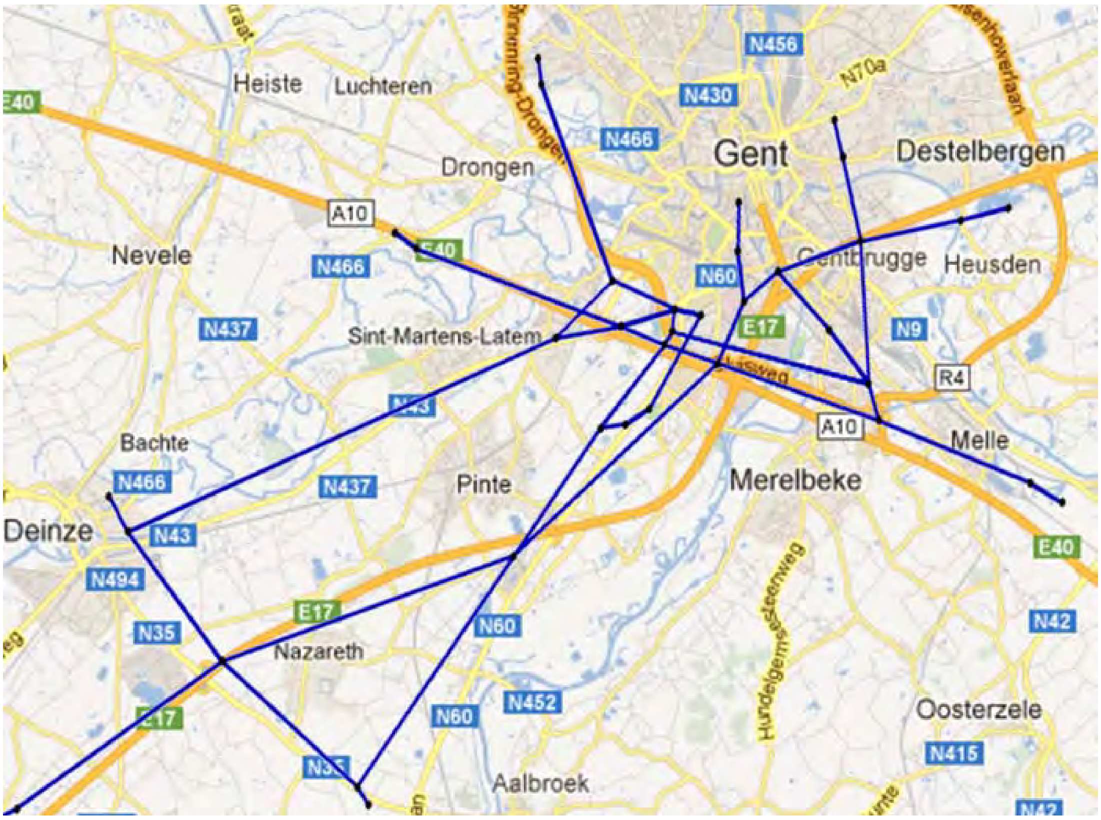


Figure 117 Graph representation of the Gent network around the working zone

Model description

The graph represented in Figure 117 represents an ordered sequence of road sections (links, or arcs in technical terms) and road junctions (nodes). Origins and destinations of the traffic demand are also represented by nodes in this network. Each link contains traffic flows and at each node these flows are redistributed according to the route choice of the road users, or extra demand is generated or disappears if this node is an origin or a destination.

In this study we used a static traffic assignment model, which means that the traffic propagation from one link to the other is not a function of time, but it is in steady-state conditions. This is common assumption in planning and design problems, or in cases where the precise emergence and distribution of congestion is not fundamental. In our study we are interested in the macroscopic changes of the flows and, more importantly, in the calculation of the extra delay in the whole network. Therefore this simplification is reasonable.

The cost function used for this study is the one suggested by the Bureau of Public Roads (BPR, 1964) in US, and also very common in planning analysis:

$$S_a(v_a) = t_a\left(1 + 0.15\left(\frac{v_a}{c_a}\right)^4\right) \tag{37}$$

Where:

t_a = free flow travel time on link a per unit of time

v_a = volume of traffic on link a per unit of time (somewhat more accurately: flow attempting to use link a).

c_a = capacity of link a per unit of time

$S_a(v_a)$ is the average travel time for a vehicle on link a

This function consists of two components. The first component takes care of the travel time in uncongested states (or free-flow travel time) while the second considers the non-linear increase of travel time due to queuing and reductions of the speeds. The advantage of this method in static assignment problems is that it allows for very large flows, which can occur when searching for the solution of the assignment process.

The assignment process on the other hand consists of the calculation of the flows in each link. These flows are a linear combination of the flows on each route using that link. These route flows are in turn determined using the demand generated by each origin and towards each destination, and assigned to each route alternative following some transport-economical function and assuming the users to make this choice in a rational and optimal way.

A popular principle governing the assignment process is the Wardrop's first principle (Wardrop, 1958), which translates in the transportation problem the concept of Nash equilibrium (Nash, 1951). This principle states that the users will distribute on the routes having the same total costs, which means that they will choose longer routes only when on the fastest routes they will experience a delay that is equal to the extra time needed on the alternative routes.

To account for the perception distortion and heterogeneity of the road users, the cost differences among the different route alternatives calculated by the BPR function are translated into stochastic choices, which mean that not all users will actually perceive in the same way the costs of each route. In practice, a part of the road users will be loaded on more costly routes. This stochastic choice is regulated in this study by the well-known Logit function (see e.g. Cascetta, 1998):

$$P^{w}(k)=\frac{\exp(U^{w}(k)/\theta_{d})}{\sum_{k'\in K}\exp(U^{w}(k')/\theta_{d})} \quad (38)$$

Where U^{w} represents the cost of a certain route, which is the sum of the deterministic cost calculated with the BPR function, and an error term component, while θ_d is a parameter regulating the impact of the error term on the deterministic component in the choice of the users, or equivalently it indicates the importance the users find for a certain cost difference between route alternatives. In practice, the bigger the θ_d, the less important is for the users that there is a (deterministic) cost difference between routes and the will distribute more evenly between routes.

Despite the simplicity of the Wardrop first principle and the functions determining travel times and route flows, the solution of the assignment process, i.e. the equilibrium link flows, are not easily found, since the costs on the links may depend on several routes and several origin-destination pairs that use the same links. An iterative process is therefore used to find consistent flows and costs. This is normally referred to as 'fixed-point' problem. These types of problems, under the simplified conditions used in this study, are solved by simply assigning the flows to the fastest routes at the first iteration; once the costs are calculated using the BPR function then new route alternatives become attractive for a certain origin-destination demand and the flows are distributed according to the Logit function. This process repeats over and over until no flow changes in the system, and obviously costs become also invariant. This will be the equilibrium solution.

Model calibration

A fundamental step to guarantee the validity of the model is the calibration of its main parameters.

A fundamental parameter in the model calibration is the choice of the θd, which controls the tendency of the users to choose different routes once conditions are changed with respect to the base case. To best calibrate this parameter, we need to use extra data than the demand. It was reported that during the maintenance period the traffic load on the sections being maintained was reduced of about 7%. We therefore used this information to calibrate the model: we simulated the scenario without road maintenance (base case) and the one with the intervention, and we found the θd that could reproduce a reduction of the flows on the links of 7%,

As one can see, and as expected, apart from the links and routes directly affected by the road intervention, the flows on the rest of the network did not change significantly. The extra delay caused by the rerouting of the travellers affected by the intervention is of 4.57 min and 6.30 min from the base case, respectively.

The graphical representation of the traffic flow generated in the Gent network around the E17 can be found in APPENDIX 23.

8.6.3 Unit costs and model input parameter values

In order to determine the optimal intervention strategy, the impacts incurred to each stakeholder during interventions and in between intervention from each object are calculated based on empirical models and following the unit costs shown in Table 24. According to APPENDIX 7 the stakeholders were grouped into:

- Owner,
- Road user,
- Directly affected public (DAP) which include residents and companies,
- Indirectly affected public (IAP) which includes the society in general.

Table 24 Unit costs[40]

	Cost item	Unit cost (€)	Unit
1	Operation cost per truck	1.91	/hour
2	Operation cost per car	3.1	/hour
3	Petrol price (gasoline)	0.53	/l
4	Hour wage (work)	15	/hour
5	Hour leisure	2	/hour
6	Cost per accident	45'100	/Casualty
7	Cost per injured	293'500	/Person
8	Cost per deaths	3'645'000	/Person
9	Cost for CO2	2.4	/ton
10	PM	308'189.2	/ton
11	NOx	4'093.3	/ton
12	Carbon Monoxide (CO)	3.1	/ton
13	VOS	1'139.9	/ton
14	Dust	30'675	/ton
15	Average noise cost	115	/Pers/dBA
16	Average vehicle price	25'000	vehicle

8.6.4 Impacts of intervention strategy types during and between interventions

For the 4 ISTs the overall impact during intervention were estimated for each object and bundle of objects and are shown in Table 25.

Table 25 Impact of IST during intervention (unit = 1000 €)

Intervention bundle	Object	Traffic configuration	
		TC-1	TC-2
IB-1	1	69'864	89'317
	2	9'185	9'753
IB-2	1,2	77'400	97'420

Table 25 shows the overall impact per object, which already includes the impacts incurred to owner, user, DAP and IAP. The distributions of impact incurred to different stakeholders are further illustrated in APPENDIX 24.

A brief illustration of model input values is shown in Table 26 for IST-3 and IST-4.

[40] It should be noted that the unit costs are average values derived from several Belgian and European documents (e.g. HEATCO, 2002). The values are used for the purpose of illustration and can be adapted.

Table 26 Example of model input values

IS	TC	IB	Stakeholder group	During intervention (g)			In between intervention (f)		
				a	b	β	a	b	β
3	1	2	(1) Owner	33’000	0	0	7.39	5.08	0.09
			(2) User	43’119	0	0	73.94	40.66	0.09
			(3) DAP	2’645	0	0	10.07	7.05	0.09
			(4) IAP	285	0	0	20.94	13.82	0.09
4	2	2	(1) Owner	33’000	0	0	7.39	5.08	0.09
			(2) User	63’129	0	0	73.94	40.66	0.09
			(3) DAP	2’648	0	0	10.07	7.05	0.09
			(4) IAP	292	0	0	20.94	13.82	0.09

The impact incurred to the road user is considerably high for both strategies. This is mainly due to three reasons:

- The expected accident rate during the intervention period is very high compared to normal Belgium record. It is recorded that the number of accidents during the intervention period has a mean of 30, while the standard number of accidents in Belgium is 11.
- The extra travel time is anticipated to be 4.57 and 6.30 minutes per day per user for strategy 1 and 2, respectively. This number multiplying with the total number of users and number of intervention days will give a significantly high expected impact.
- The assumed number of users is twice as the number of the daily traffic volume (vehicle). In another words, there is a minimum of two persons in each vehicles.

The differences of the two strategies are only due to the assumption of detour route and the reduction in the traffic volume. For TC-1, traffic volume reduces 7% and detour route is assumed to increase the length of travel to 5 km for both two objects. For TC-2, traffic volume reduces 8% and detour route is assumed to increase the length of travel also about 5 km for each. In addition, it is also assume that in the detour route the average car speed allowed is 120 km/hour.

The annual cost of the intervention strategy types are shown in Table 27.

Table 27 Annual cost of IST

IS	TC	IB	Annual cost (€)	Difference in annual cost (€)
1	1	1	2’067’052.55	0.00
2	2	1	2’198’202.01	131’149.45
3	1	2	2’051’685.10	-15’367.45
4	2	2	2’184’094.19	117’041.64

When using IST-1 as reference strategy all other strategy types are compared with, it can be concluded that IST-3 is the optimal strategy, as it reduces the annual cost by €15'367 compared to IST-1. The intervention times and evolutions of impacts corresponding to the 4 ISTs are presented in following figures.

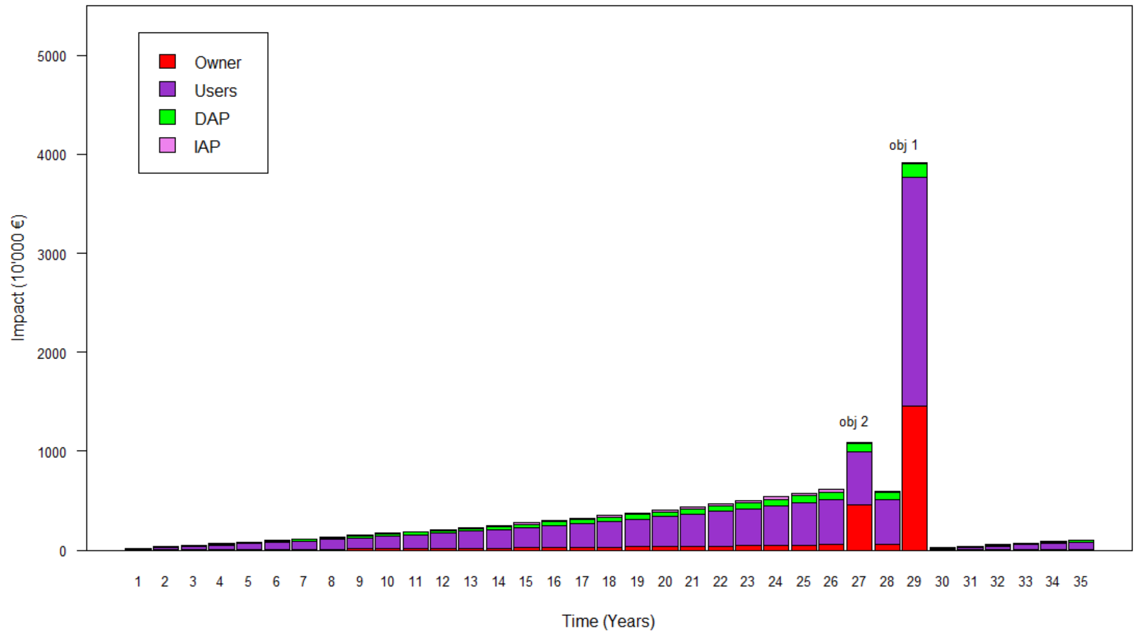


Figure 118 Intervention time and impact evolution (IS-1)

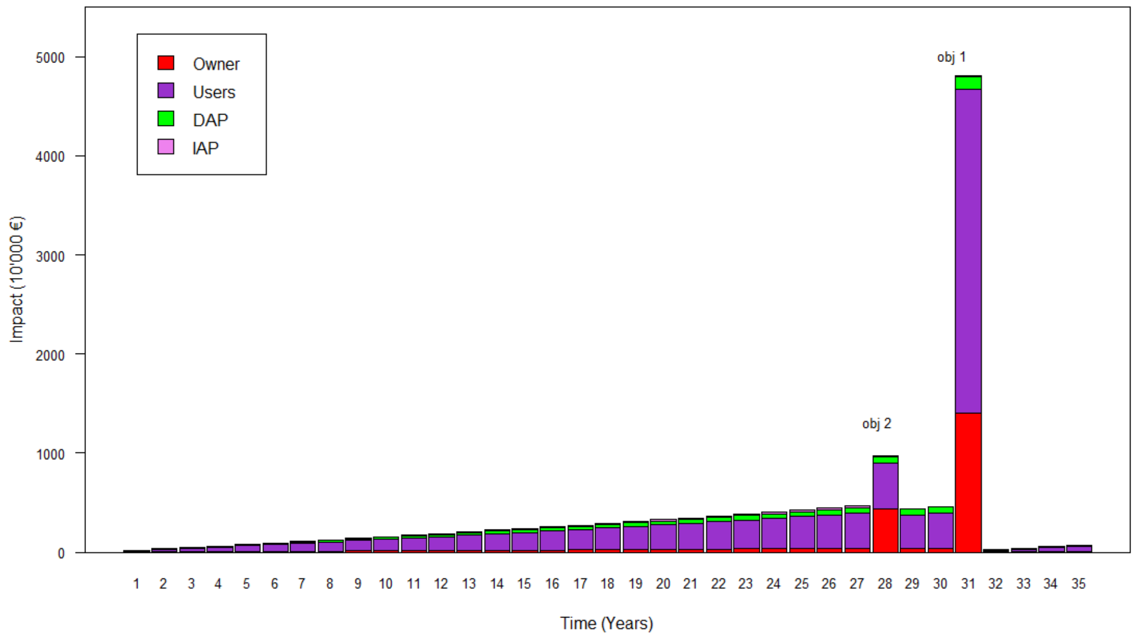


Figure 119 Intervention time and impact evolution (IS-2)

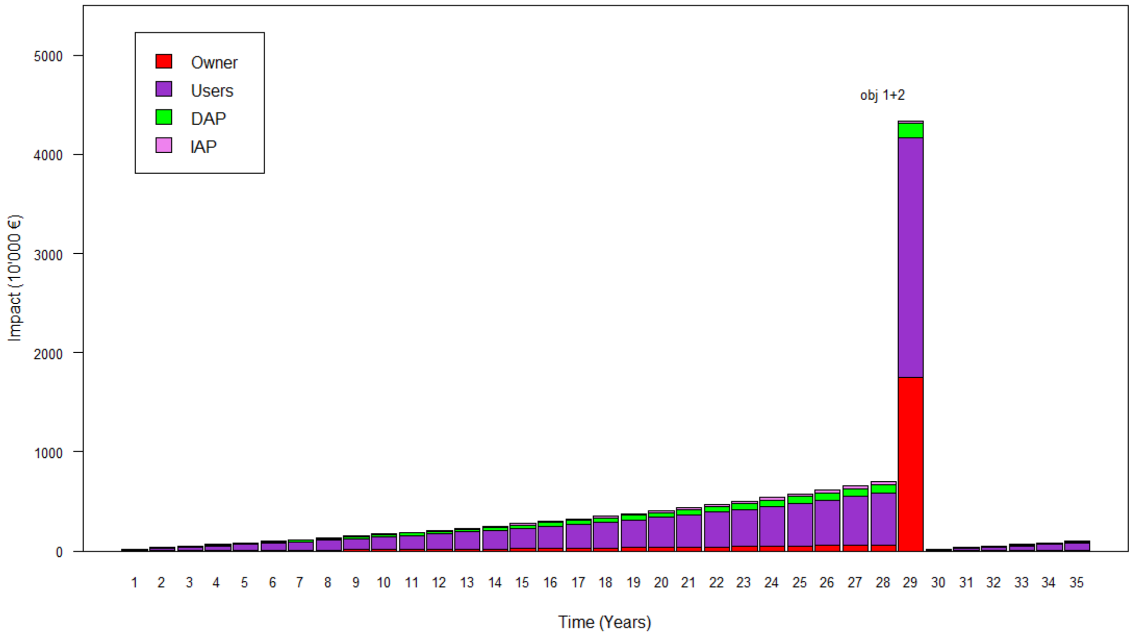


Figure 120 Intervention time and impact evolution (IS-3)

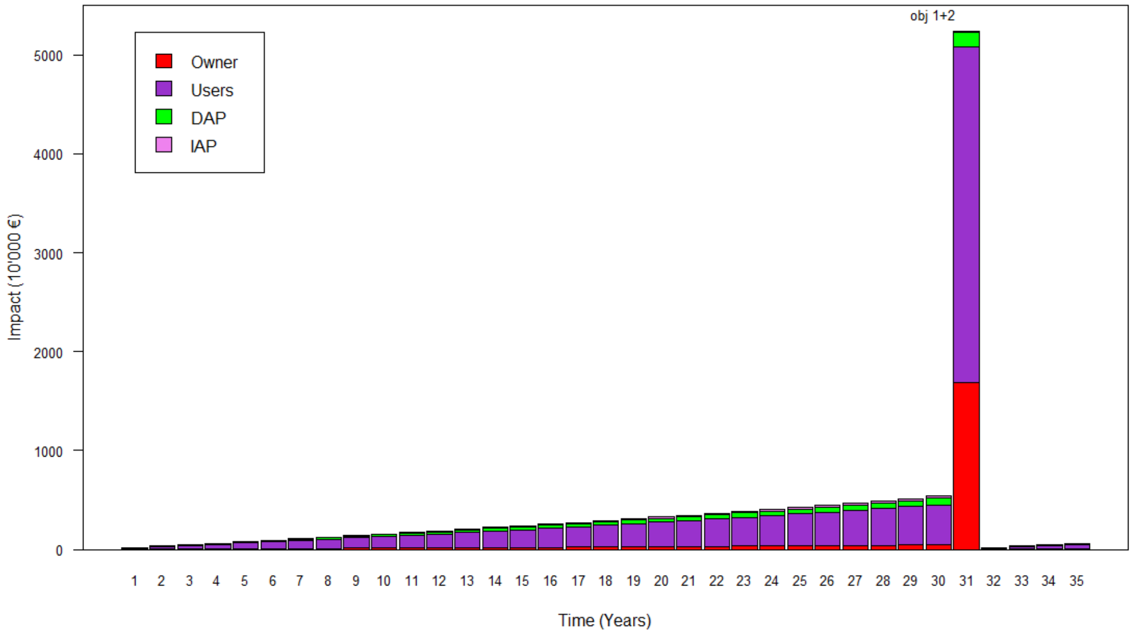


Figure 121 Intervention time and impact evolution (IS-4)

8.6.5 Sensitivity Analysis

The analysis of the importance of road impacts to stakeholders revealed significant differences between stakeholders and a stakeholder oriented intervention strategy should consider these differences. In other words, the intervention strategy should reflect the stakeholder valuation of road impacts. For example, travel time is an important road impact for users and companies. There may be intervention strategies which particularly minimize the loss of travel time. In this section we will investigate the sensitivity of the OIS to the valuation of road impacts by changing the average unit costs used in the previous section. According to the findings from the stakeholder analysis we conduct sensitivity analyses on:

- Travel time,
- Vehicle operation, and
- Emission.

In addition, we do sensitivity analyses for stakeholder groups to account for bundles of road impacts that are seen as important by these stakeholder groups. Although our stakeholder analysis of the E17 could not reveal bundles of road impacts which are significantly different between stakeholder groups, we investigate the sensitivity of the OIS to two bundles of road impacts associated with two stakeholder groups:

- Owner which include intervention cost and traffic management cost,
- User which include safety, travel time, and vehicle cost.

Since we made assumptions about other model parameters, we also investigate the sensitivity of the OIS to the following parameters:

- Discount factor,
- a, b, β (which relate to the change in the impact values after intervention).

For the sensitivity analysis a range between -50% and +50% of the mean impact value is chosen and applied on different impacts incurred. This range is seen to be sufficient to show the change, trend, or switch in OIS.

In order to take the different traffic configuration into account, IST-3 and IST-4 are selected for the sensitivity analysis.

In the following figures, the dotted lines show the optimal intervention times (OIT) and the solid lines show the annual impact. The value of OIT and impact are shown in the left vertical axis and right vertical axis, respectively. The horizontal axis shows the percentage of change in the value of impact under investigation. The value of impact corresponding to 0% in the horizontal axis represents the mean value (without variation in the value).

Sensitivity to travel time

The following figure shows the sensitivity of the OIS to the value of travel time in the range -50% to +50% of the mean value (see Table 24).

The change in the range of (-50% to +50%) of the mean value of extra time does not significantly change the optimal intervention time for both overpass bridges and road sections. IST-3 remains the optimal intervention strategy.

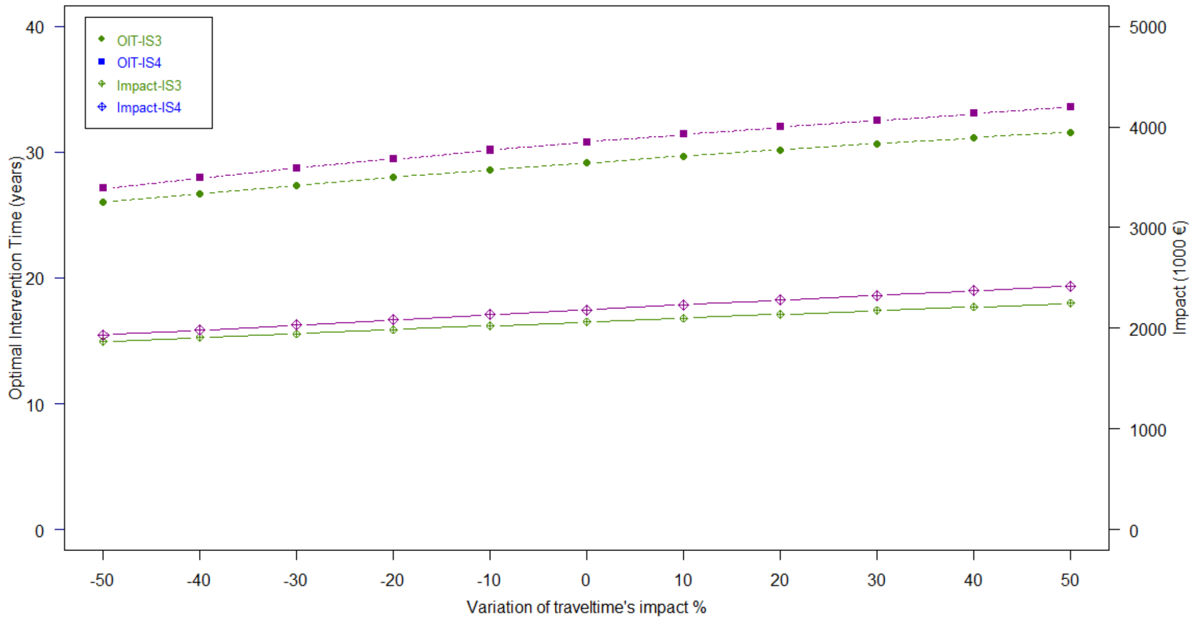


Figure 122 Sensitivity to travel time

Sensitivity to vehicle cost

The following figure shows the sensitivity of the OIS to the value of vehicle cost (VOC) in the range -50% to +50% of the mean value (see Table 24).

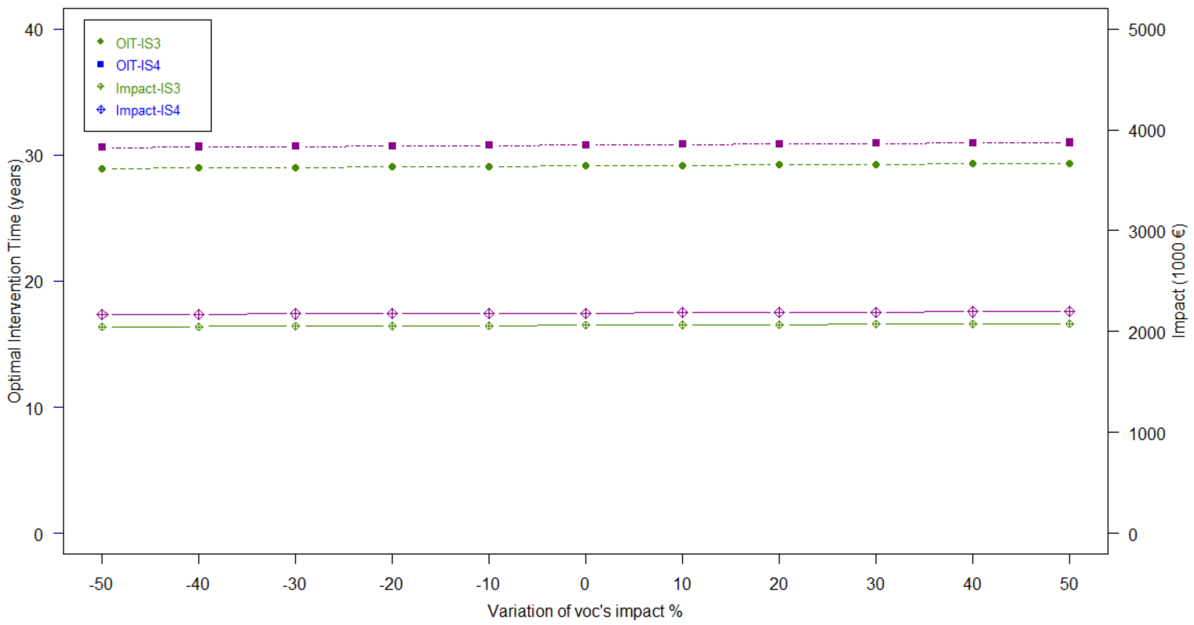


Figure 123 Sensitivity to vehicle cost

VOC does not have any significant impact on the optimality of the intervention strategy.

Sensitivity to emission

The following figure shows the sensitivity of the OIS to the value of emission in the range -50% to +50% of the mean value (see Table 24).

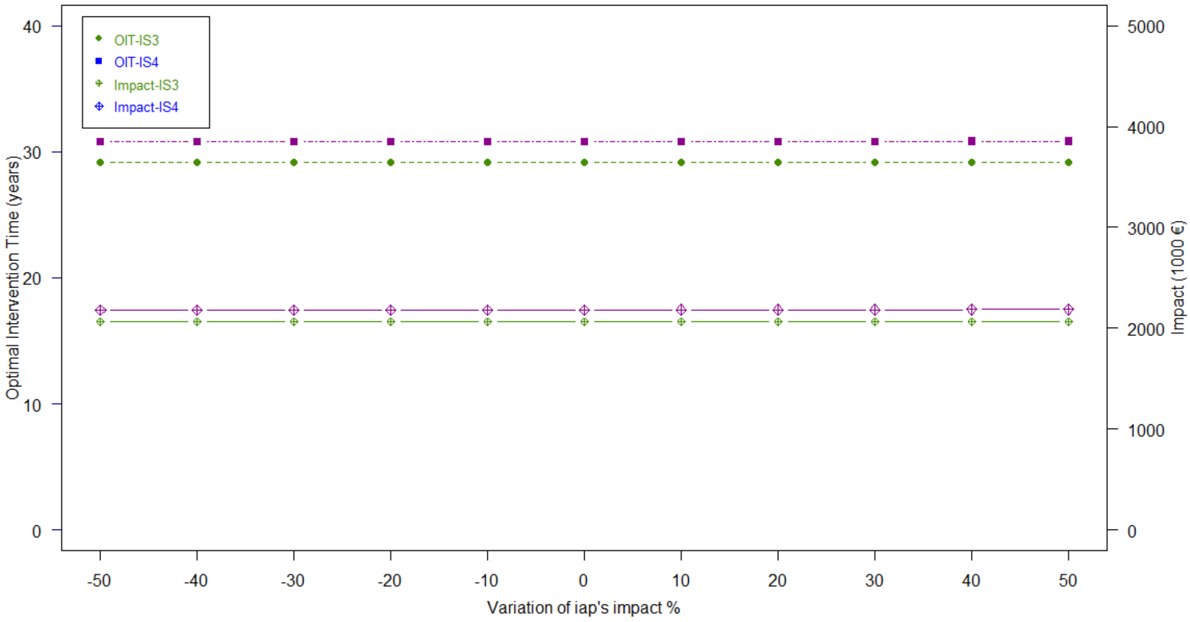


Figure 124 Sensitivity to emission

The impact of emission is calculated directly from the traffic volume. Figure 124 shows that the variation of emission does not have a big influence on the OIT and the annual costs. In addition, IST-3 remains the optimal intervention strategy for the varying values of emission.

Sensitivity to owner impact

In Figure 74 the sensitivity of the OIS to the variation of the owner impact values in in the range -50% to +50% is shown.

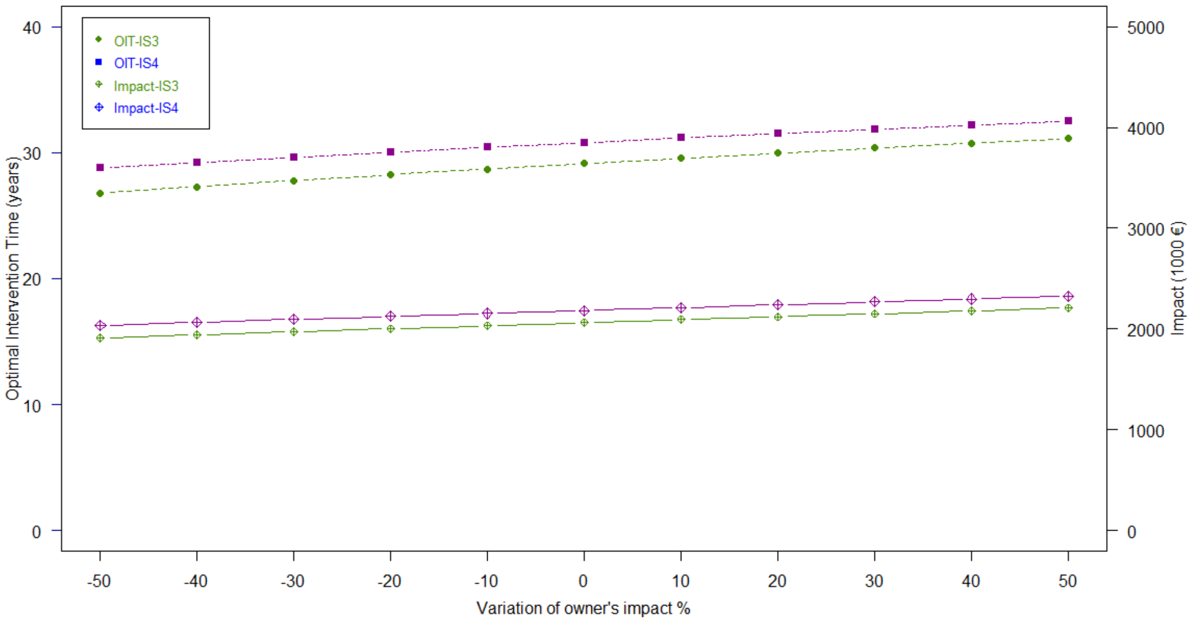


Figure 125 Sensitivity to owner impact

Figure 125 shows that the variation of owner impact does not have a big influence on the OIT and the annual costs. In addition, IST-3 remains the optimal intervention strategy for the varying values of emission.

Sensitivity to user impact during intervention period

In Figure 75 the sensitivity of the OIS to the variation of the user impact values in in the range -50% to +50% is shown.

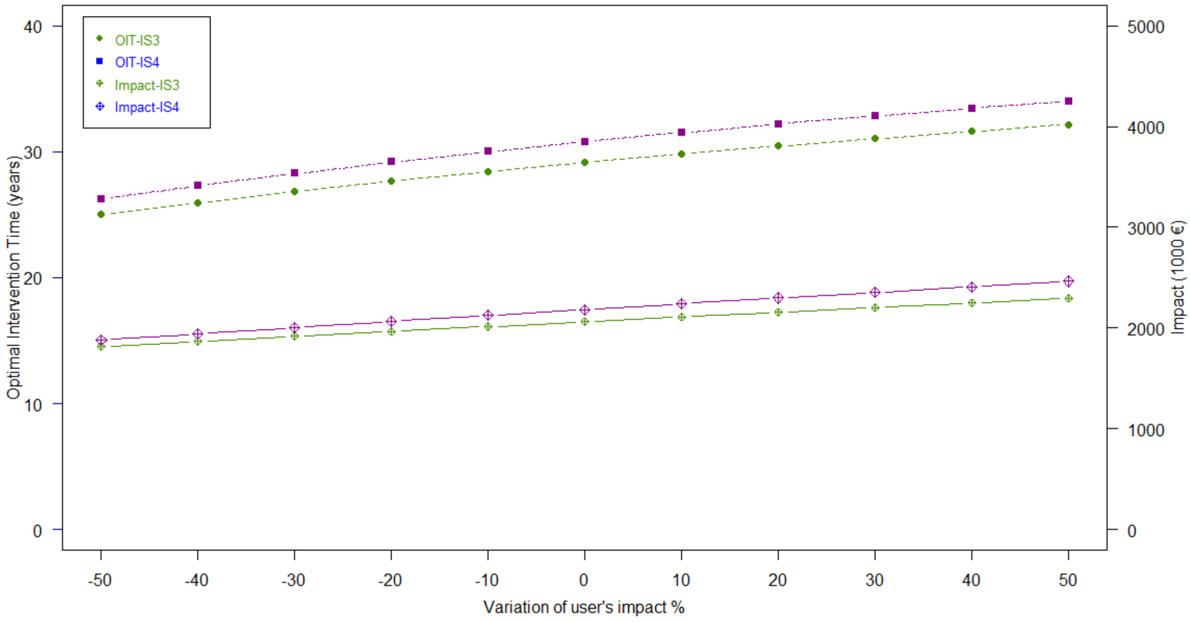


Figure 126 Sensitivity to user impact

Figure 126 shows that the variation of owner impact does not have a big influence on the OIT and the annual costs. In addition, IST-3 remains the optimal intervention strategy for the varying values of emission.

Sensitivity to discount factor

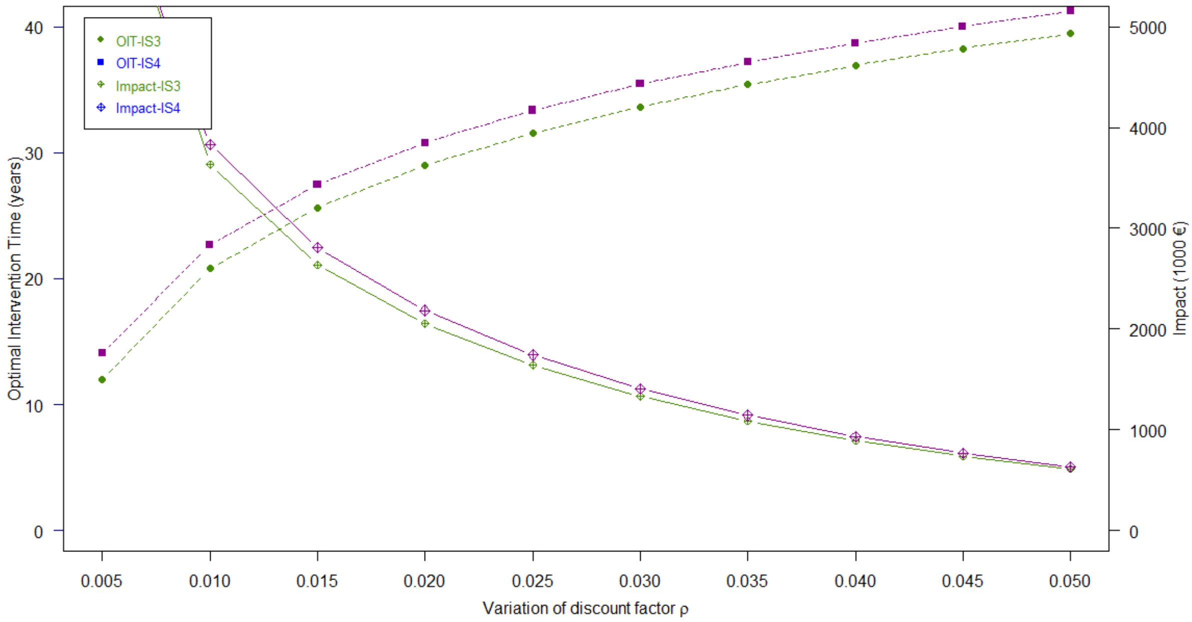


Figure 127 Sensitivity to discount rate

The increase in the value of discount factor results in later intervention times. Also, the annual impact decrease as the value of discount factor increase.

Sensitivity to cost parameters a, b

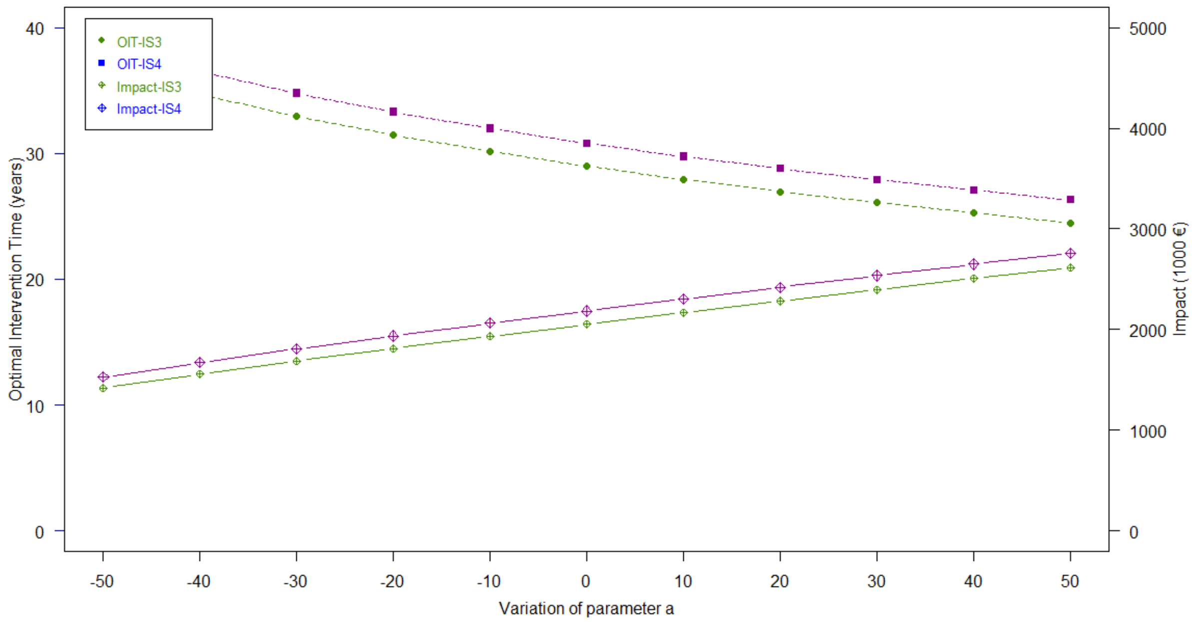


Figure 128 Sensitivity to cost parameter a

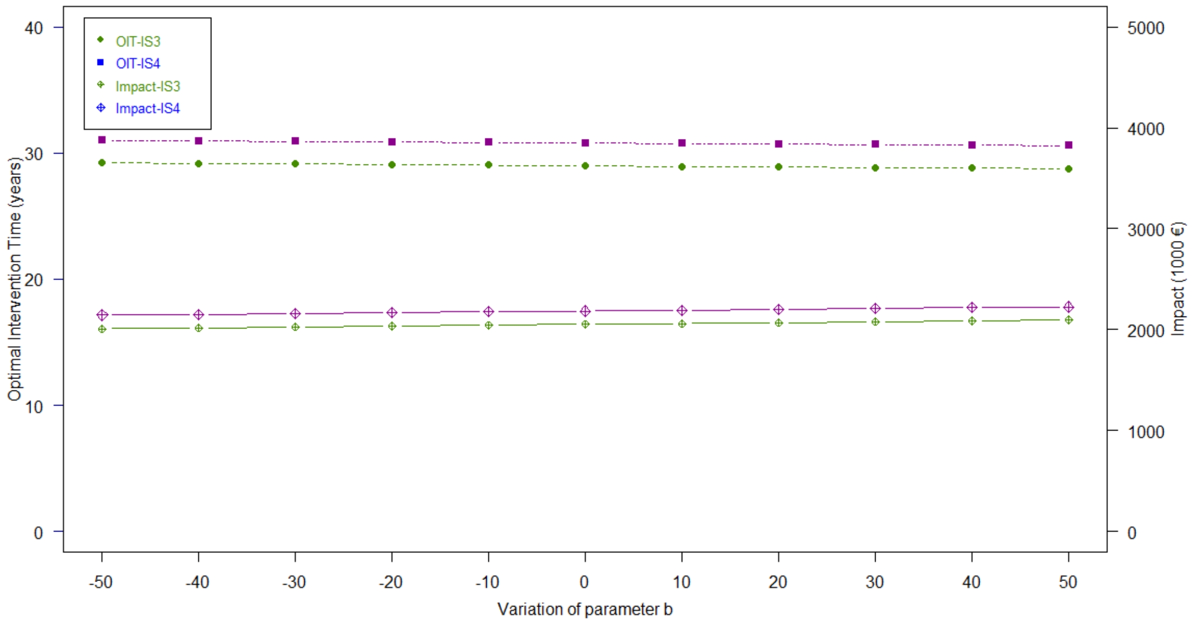


Figure 129 Sensitivity to cost parameter b

The value of the model parameter a affects the change in the optimal intervention time. The OIS and the corresponding OIT and annual impact are sensitive to the model parameter a. This suggests a careful examination and verification of using empirical models to quantify the impact incurred.

Sensitivity to deterioration parameter β

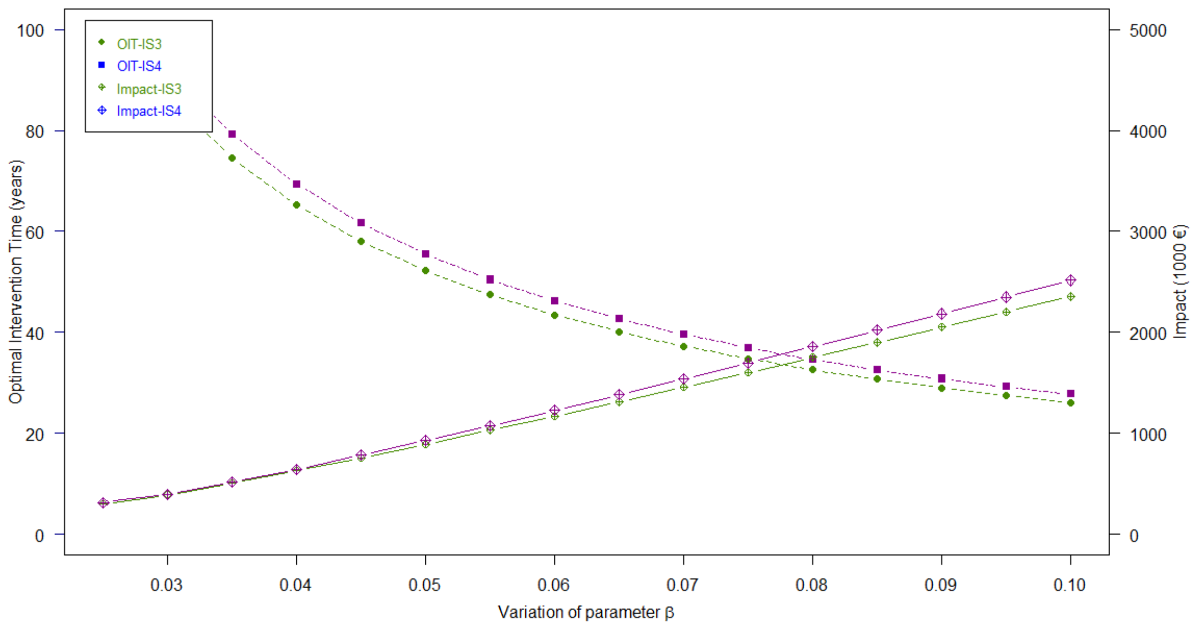


Figure 130 Sensitivity to deterioration parameter β

Intervention strategy and OIT are also sensitive to the deterioration parameter. If the deterioration parameter increases the OIT decreases and the annual cost increases.

That also suggest a carefully consideration of the underlying deterioration assumption.

The sensitivity analysis on the Belgium case revealed that the optimal intervention strategy is always IST-3. The variation in value tends to lengthen the optimal intervention time and decreases the total impact. However, the annual impact decreases slightly. Reason is that the increase or decrease in the impact incurred to each stakeholder group does not significantly increase or decrease the optimal intervention time, and therefore, with the increase of total cost the annual cost also slightly increases.

9 Case Comparison

Both case studies show some similarities and differences which are presented in Table 28.

Table 28 Case comparison

	Dutch Case A20	Belgian Case E17
Location of intervention project	Urban area (Rotterdam)	Urban area (Gent)
Duration of intervention project	1 month	6 months
Length of intervention section	7 km	20 km
Intervention objects	Pavement Overpass bridges	Pavement
Kind of intervention	Renewing asphalt layer Repairing bridge joints Replacing road furniture	Replacing asphalt with concrete Renewing asphalt layer
Intervention strategy type (applied)	Weekends: 1 direction closed – 1 direction open Weekdays: 1 direction closed – 1 direction open Bundling of all objects	Two out of six lanes are closed Bundling of all objects
Stakeholder groups	Road users Residents Companies	Road users Residents Companies
Important road impacts (all stakeholders)	Safety Travel time Economy	Safety Travel time Comfort
Important road impacts (per stakeholder group)	Road users: Travel time, vehicle cost Residents: Emission Companies: Economy, travel time	Road users: Travel time Residents: Emission Companies: Economy, travel time
Stakeholder expectations about the intervention project	Strong influence during the project Strong improvement after the project	Strong influence during the project Medium improvement after the project
Stakeholder management	Information and communication with stakeholder groups before and during the intervention project	Information of stakeholder groups before and during the intervention project

Table 28 Case comparison contd.

	Dutch Case A20	Belgian Case E17
Stakeholder experiences of the intervention project	Low influence during the project Strong improvement after the project	Low influence during the project Medium improvement after the project
Stakeholder satisfaction with the intervention project	High satisfaction with process, outcome and information provision of the project Satisfaction with outcomes determines overall satisfaction	High satisfaction with project outcome Medium satisfaction with project process Low satisfaction with information provision Satisfaction with outcomes determines overall satisfaction
Optimal intervention strategy type (estimated)	Weekends: both directions closed Weekdays: both directions open – 4 narrow lanes Bundling of all objects	Two out of six lanes are closed Bundling of all objects
Sensitivity of intervention strategy	Sensitive to travel time and vehicle cost Sensitive to model parameters	Not sensitive for impact values Sensitive to model parameters

Main insights generated by the case studies and their comparison are:

- **Road impacts can be important to all stakeholders**
  Both cases suggest that all road stakeholders judge a number of road impacts as being important. These impacts include safety, travel time, economy, and comfort. The importance of these impacts is related to the groups that were involved in the case studies: road users, residents and companies. This result shows that individuals and organisations adopt different stakeholder roles. Particularly residents and companies are also road users of the investigated highway links which makes safety, travel time and comfort important impacts for all stakeholders. Depending on the satisfaction with the four impacts intervention strategies and projects should focus on keeping these impacts on a certain level or improving them.

- **The importance of road impacts between stakeholder groups can differ**
  Although some impacts are important to all stakeholders, the ranking of impacts can differ between stakeholder groups. Travel time and vehicle cost are very important impacts for road users and companies. Emission is an important impact for residents and economy is an important impact for companies. These differences can lead to different intervention strategies depending on the satisfaction of the stakeholder group with the impact and the position of the group in the context of the particular road link. The only

exception is safety which is the most important impact for all stakeholder groups.

- **Stakeholder experiences are more important for the satisfaction with an intervention project than expectations**
  Both cases point out that experiences are more important for the satisfaction of stakeholders with an intervention project than expectations. That includes experience with the process, the outcome and the information provision of the project. An implication for road agencies is to put more emphasis on a noticeable positive experience of process, outcome and information provision of an intervention project. That also means that the engagement with stakeholders is not only crucial before but also during the project. At a basic level stakeholders should receive enough information about the project to be able to make decisions, for example, about their travel behaviour.

- **Satisfaction with the outcomes of an intervention project determines the overall satisfaction with the project**
  The outcome of an intervention project is decisive for the overall satisfaction with the project. In both cases the overall satisfaction of stakeholders was mainly influenced by the satisfaction with the intervention outcome. It seems essential to improve road infrastructure in a way that the improvement can be clearly experienced by stakeholders and any inconvenience faced during the intervention project is outweighed. That may also include keeping stakeholders up to date about the intervention process and the intended improvements on the road during the project.

- **The stakeholder management strategy has an effect on the satisfaction of road stakeholders with an intervention project**
  The results of both cases suggest that engagement with stakeholders will have an influence on the satisfaction with an intervention project. In the Dutch case the road agency took a lot of effort to inform stakeholders but also to communicate with the stakeholders about the project. The stakeholders were much satisfied about process and information provision of the project. In the Belgian case the information was restricted to a few selected groups which resulted in unsatisfied stakeholders that were not involved. An interesting questions emerging from this finding and related to the costs associated with engagement strategies is: what is the appropriate level of engagement to ensure satisfied stakeholders?

- **An optimal intervention strategy does not guarantee satisfied stakeholders**
  A conclusion related to the previous one is that an optimal intervention strategy is not sufficient for having satisfied stakeholders. In both cases the intervention strategy applied corresponded with the optimal strategy estimated for the period during intervention. However, in the Dutch case stakeholders appeared to be more satisfied than in the Belgian case with the intervention project. In other words, although the maximum net positive impact for stakeholders was achieved, stakeholders were not necessarily satisfied in the Belgian case. Intervention strategy and stakeholder management are two

sides of the same coin ensuring stakeholder satisfaction with road intervention projects.

- **An intervention strategy that is optimal during intervention is not necessarily the optimal intervention strategy over the whole life cycle**
  As mentioned before, in both cases the intervention strategy applied was in line with the optimal strategy estimated for the period during intervention. In this sense, both agencies succeeded in selecting the strategy with the lowest overall costs during intervention. However, when taking the costs between interventions into account the optimality was changing for the Dutch case. Another strategy than the one applied became optimal. The reason for the change lies in the deterioration and impact development between interventions which suggests different intervention times. The implication is that the planning of an intervention project should be always based on the underlying optimal intervention strategy.

- **The optimal intervention strategy depends on impact values and model parameters**
  Which intervention strategy becomes optimal depends on the impact values and model parameters that are used to estimate the costs. The sensitivity analysis showed that changes of impact value and model parameter can lead to another optimal strategy. Clearly, the optimal intervention strategy was not sensitive to all impacts and for some impacts the optimality only changed for larger values. However, impact values and parameters should be carefully selected and critically reviewed. A sensitivity analysis is always recommended to investigate the stability of the optimal strategy.

10 Conclusions and Recommendations

The project "Stakeholder Benefit and Road intervention Strategies" (SABARIS) aimed at supporting the decisions-making at road agencies on the determination of an optimal intervention strategy for a road link considering the varying and sometimes conflicting values of road impacts for road stakeholders. Based on literature and case study research SABARIS developed and tested a guideline and a number of tools to provide this support. Although the tools can be used alone, it is particularly their combination of stakeholder management, traffic management and intervention optimization which can advance the management of road infrastructure.

The SABARIS project has shown that the satisfaction of road stakeholders is not a matter of either managing stakeholders during intervention projects or selecting an intervention strategy with the lowest life cycle costs. Rather, the satisfaction of road stakeholders depends on an intervention strategy that maximizes the net positive impacts (or benefits) of road infrastructure and the perception of stakeholders that during the execution of this strategy the benefits are achieved. That guideline and tools can provide road agencies this combined value in decision-making has been shown through the two case studies, one in the Netherlands and one in Belgium. The case comparison revealed that an optimal intervention strategy is not sufficient to satisfy stakeholders and that an optimal approach during intervention, leading to satisfied stakeholders, is not necessarily the optimal approach over the whole life cycle of road infrastructure.

The added value of the SABARIS results for road agencies was also indicated by practitioners from Rijkswaterstaat (RWS) in the workshop held at the end of the project. Responses of RWS employees to the presented results include:

> *"Guideline and tools give RWS the opportunity to initiate the discussion about the essential parts of projects (stakeholders, traffic flows, costs, benefits, strategy, duration)"*

> *"The added value of guideline and tools is that the values of stakeholders (benefits) are taken into account in planning the maintenance projects."*

> *"The added value of guideline and tools is that it has different dimensions; technique, stakeholders and traffic management. The three are the most important aspects in planning an intervention."*

The workshop also pointed to possible adjustments and extensions of guideline and tools to consider peculiarities of the decision-making process at road agencies. For example, at RWS infrastructure management decisions are based on agreements about the availability of road networks. These availability agreements represent condition for the optimal intervention strategy and the question for the RWS manager is: What would be the optimal intervention strategy for a road link, if this road link needs to be available for traffic 95% of the time? RWS employees additionally stated:

> *"It is not realistic that every maintenance project holds a questionnaire to gain insight in expectations. So, the question is what can be done instead. It would be of great value to know what neighbours and road users expect in general from these kinds of projects."*

> *"Risk based maintenance is probabilistic, while this model uses a deterministic approach. RWS is currently implementing risk based maintenance in many projects, how can this be combined with the model."*

> *"There is currently a project at RWS which is called 'Getting the area alright'. The goal of this project is to get all the data about every object (road links, bridges, tunnels, etc.) up to date. It*

would be very useful to add data about the residents and companies to every road link, to give the data an extra dimension."

They even saw applications for project results in areas which the SABARIS project team had not in mind at the beginning of the project:

"The model can help RWS in the decision-making process, for example in deciding about the length of a DBFM [Design Build Finance Maintenance] contract, but also to have the right discussion about the costs and benefits related to these decisions."

In other words, guideline and tools possess enough flexibility to be adapted to the specific questions and needs of road agencies. However, to fully utilise the potential of the results in the future we recommend to:

Allow road agencies to experience the possibilities of guideline and tools
Past experiences show that the adoption of new developments can be difficult and organizations often hesitate to change to other methods, processes and tools. One of the main adoption barriers is that the advantage of the new development compared to the existing way of working is not immediately observable from reports or presentations. People need to experience the new development in a safe environment to become persuaded and see the possibilities of the new development for the daily work. We would like to propose the development of a simulation based on the SABARIS results. Such a simulation would allow infrastructure managers at road agencies to experience the effects of their decision-making on the life cycle costs of road assets and stakeholder satisfaction.

Refine the questionnaire for revealing the satisfaction with road impacts
Although the questionnaire used in the case studies already includes a question about the importance of road impacts to stakeholders, it does not include a question about the satisfaction of stakeholders with these impacts. In order to determine those impacts of a particular road link an intervention strategy should pay attention to, the stakeholder survey needs to reveal the importance of road impacts and the satisfaction of stakeholders with these impacts.

Collect more data on the expectation, experience and satisfaction of road stakeholders
We collected data on the expectation, experience and satisfaction around two specific intervention projects, which restricts the generalizability of the results. Further data should be collected to investigate how expectation, experience and satisfaction interrelate in other project settings. That would also include a comparison of different types of roads and different stakeholder groups. Road agencies could benefit from such insights when formulating intervention strategies and defining stakeholder management approaches for particular projects. In other words, it may help them in increasing the effectiveness of their service provision under remaining budget constraints, if stakeholder satisfaction is an important success criterion.

Determine the effectiveness of stakeholder engagement strategies
Road agencies can use different stakeholder engagement strategies to influence expectation, experience and eventually satisfaction of stakeholders. Our case studies could show that such strategies will have an effect on stakeholder satisfaction. What our cases could not show is the effectiveness of different strategies. However, knowing the effectiveness is important, since each strategy and each measure is related to different costs. Road agencies should be able to select the most cost-effective strategy for a particular intervention project.

Improve the reliability of the input parameter for the intervention optimisation

The intervention optimisation for the two case studies was based on a number of assumptions related to the input parameter such as deterioration, impact indicators and cost figures. For some of the parameters it was difficult to obtain the correct data and for other parameter the data were not available. In order to increase the accuracy of the optimisation, the reliability of the input data should be improved.

Develop a sophisticated user interface for the optimisation tool

The optimisation tool developed is a prototype with a simple interface based on Excel spread sheets. For a next version of the tool the interface should be improved to allow for an easy data entry. That should be done based on the specific needs of the agencies.

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APPENDIX 1: Examples of Deterministic Deterioration Models

Tsunokawa and Schofer, 1994

(Tsunokawa & Schofer, 1994) modelled the deterioration of a road section as a continuous deterministic process, using the following equation.

$$s(t) = s(t_0) \cdot \exp[\gamma(t - t_0)] \tag{39}$$

Where:

$s(t)$ is an indicator of the roughness of the pavement of a road section at time t

t is time and

γ is the deterioration rate.

Ouyang and Madanat, 2004 and 2006

(Ouyang & Madanat, 2004) and (Ouyang & Madanat, 2006) modelled the evolution of pavement roughness with the following the following equations:

$$s(t) = \left[s(t_0) + f(t - t_0)\right] \cdot \exp\left[\gamma(t - t_0)\right], \quad t \geq t_0 \tag{40}$$

$$s(t+1) = \left[s(t) + \overline{f}^*\right] \cdot \exp\left[\gamma\right], \tag{41}$$

Where

$s(t_0)$: is the value of roughness when the road section is like new, i.e. no deterioration has occurred,

$f(t - t_0)$: is a function of the type of pavement section and the traffic volume accumulated from the last intervention,

$\overline{f}^*$: is a function of the type of pavement section and the traffic volume accumulated from the last intervention,

$\overline{f}^*$: is a representation of $f(t - t_0)$,

γ: is deterioration dependent parameter.

HDM-4

The World Bank in its HDM-4 modelled the condition of a road section using the so-called Present Serviceability Index (PSI), an aggregate indicator that reflects the condition of the road section (Eq. (42)), using the following equation:

$$PSI_t = 5 \cdot e^{-0.0002598 \cdot IRI_t} - 0.002139 \cdot R_t^2 - 0.03 \cdot (C_t + S_t + P_t)^{0.5} \tag{42}$$

It is based on the value of the international roughness index ($IRI(mm/km)$), the amount of cracking $C_t\,(m^2/100m^2)$, the amount of surface disintegration $S_t\,(m^2/100m^2)$, and the extent of rutting R_t (mm) . These values were modelled using the following equations:

$$IRI_t = 980.0 \times e^{m \cdot Y_t} \cdot \left(\frac{IRI_0}{1000} + 135 \cdot SNCK_t^{-5} \cdot N_{80_t}^{\dim} \right) + 143.0 \cdot R_t + 6.8 \cdot C_t + 56.0 \cdot P_t \quad (43)$$

$$SNCK_t = 1.0 + SNC_t - 0.00004 \cdot HB_t \cdot C_t \quad (44)$$

$$SNC_t = \sum_{n=1}^{N} H_n \cdot C_n^e \cdot C_n^d + 3.51 \cdot \log CBR - 0.85 \cdot (\log CBR)^2 - 1.43 \quad (45)$$

$$C_t = 617.14 \times N_{80_t}^{Dim} \times SN_t^{-SN_t} \quad (46)$$

$$S_t = 2.29 \times (e^{2.2677 \times N_{80_t}^{\dim}} - 1) \quad (47)$$

$$R_t = 4.98 \times SN_t^{-0.5} \times Y_t^{0.166} \times (N_{80^t}^{\dim})^{0.13} \quad (48)$$

$$N_{80_t}^{\dim} = 365 \times TMDA_p \times \frac{(1+tc)^{Y_t} - 1}{tc} \times \alpha \quad (49)$$

$$SN_t = \sum_{n=1}^{N} H_n \times C_n^e \times C_n^d \quad (50)$$

Where

$SNCK_t$: is the modified structural number for the pavement, reduced for the effect of cracking in the asphalt layers,

P_t : is the total area with patching in year $t(m^2/100m^2)$,

SNC_t : is the modified structural number for the pavement that takes into account the sub-grade strength,

HB_t : is the thickness of the bound layers in year t (mm)

CBR : stands for the California Bearing Ratio of sub-grade,

CBR : stands for the California Bearing Ratio of sub-grade,

SN: is a structural number given by Eq. (50),

Y_t : is the thickness of the bound layers in year t (mm)

$TDMA_p$: is the annual average daily traffic volume (of the heavy vehicle) in the year of construction or the year of last rehabilitation.

tc : is the annual growth average tax of heavy traffic,

α : is the average damage factor of heavy traffic,

C_n^e : is the structural coefficient of layer n,

C_n^d : is the drainage coefficient of layer n, and

H_n : is the thickness of layer n (mm).

APPENDIX 2: Markov Deterioration Model

Using the Markovian model, road condition is defined in discrete states *i(i=1,…,I)*, where *I* denotes the absorbing state. The deterioration of a road section is modelled as transitions among the condition states, from a lower (better) condition state to higher (worse) condition state after a period of time (refer to Figure 131). The transition probability p_{ij} can be stated as: at time $t(\text{or } \tau_A)$, the condition state of road section is $h(\tau_A = i)$, and at time $t+\Delta t$ $(\text{or } \tau_B)$, it reaches to $h(\tau_B) = j(i \le j \le I)$ (Tsuda et al., 2006).

$$p_{ij} = \Pr ob\left[h(\tau_B) = j \mid h(\tau_A) = i\right] \tag{51}$$

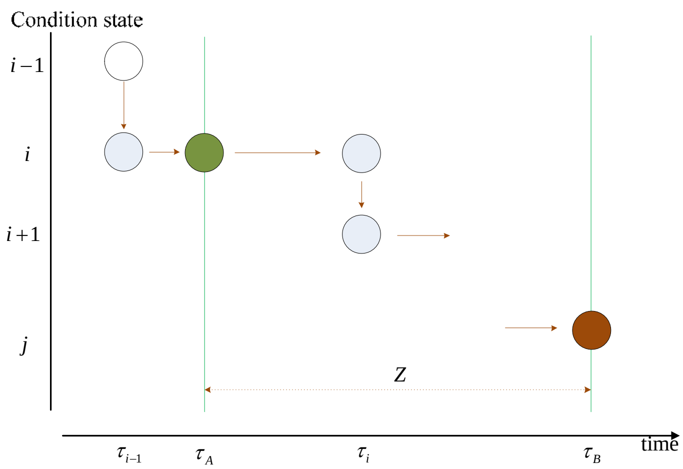


Figure 131 Transition of condition states over time without intervention

As indicated in Eq. (51) the transition probabilities are the conditional probabilities of having the condition state of the road section at time τ_B $h(\tau_B) = j(i \le j \le I)$, given that the condition state of the road section at time τ_A is $h(\tau_A = i)$. In cardinal form, Eq. (51) can be written as:

$$P = \begin{pmatrix} p_{11} & \cdots & p_{1I} \\ \vdots & \ddots & \vdots \\ 0 & \cdots & p_{II} \end{pmatrix} \tag{52}$$

Subject to the following conditions:

$$\left.\begin{array}{l} p_{ij} \ge 0 \\ p_{ij} = 0 \ \ (\text{when } i > j) \\ \sum_{j=1}^{I} p_{ij} = 1 \end{array}\right\} \tag{53}$$

With regard to the condition state of a road section at time τ_i, it is assumed that it changes from i to $i+1$ and that the total duration of condition state (or life expectancy) i can be represented as a stochastic variable $\zeta_i = \tau_i - \tau_{i-1}$. When this duration is represented as a stochastic variable, it is possible to investigate its probability density function $f_i(\zeta_i)$ and distribution function $F_i(\zeta_i)$. In the domain $\zeta_i = [0, \infty]$, the distribution function is defined as:

$$F_i(y_i) = \int_0^{y_i} f_i(\zeta_i) d\zeta_i \tag{54}$$

The survival probability $\tilde{F}_i(\zeta_i)$ as the likelihood of a transition in condition state i during the time interval in the domain $y_i = [0, \infty]$ is defined as:

$$\Pr ob\{\zeta_i \geq y_i\} = \tilde{F}_i(y_i) = 1 - F_i(y_i) \tag{55}$$

The conditional probability that a road section at time y_i passes from condition state i to $i+1$ during the interval is then given by:

$$\lambda_i(y_i)\Delta y_i = \frac{f_i(y_i)\Delta y_i}{\tilde{F}_i(y_i)} \tag{56}$$

In Eq. (56), the term $\lambda_i(y_i)$ is often referred as the hazard function (Lancaster, 1990). The form of hazard function can be assumed to follow various types of probability distributions, such as the Poison, Weibull, and Exponential distributions. When the exponential distribution is used, the hazard function with regard to a condition state is referred to as constant, and thus the functional form can omit the time variable to become $\lambda_i(y_i) = \theta_i$, which is commonly referred to as the hazard rate or the deterioration rate from condition state i.

With this definition, the survival function $\tilde{F}_i(\zeta_i)$ can be further expressed as:

$$F_i(y_i) = \exp\left[-\int_0^{y_i} \lambda_i(u) du\right] = \exp(-\theta_i y_i) \tag{57}$$

And the survival function and probability density function can be expressed as:

$$\tilde{F}_i(\zeta_i) = \exp(-\theta_i \zeta_i) \tag{58}$$

$$f_i(\zeta_i) = \theta_i \exp(-\theta_i \zeta_i) \tag{59}$$

In using Markovian model, the transition probabilities p_{ij} are normally estimated based on past inspection data. (Tsuda et al., 2006) have proposed doing this as follows.
By defining the subsequent conditional probability of passing from condition state j to i, within the time interval z of inspection (instead of variable ζ_i), a general mathematical formula for estimating the Markov transition probability can be defined:

$$\pi^{ij}(z) = Prob[g(t+1) = j \mid g(t) = i] = \sum_{k=i}^{j} \prod_{m=i,\neq k}^{k-1} \frac{\theta_m}{\theta_m - \theta_k} \exp(-\theta_k z), \quad (60)$$

Where:

$$\prod_{m=i,\neq k}^{k-1} \frac{\theta_m}{\theta_m - \theta_k} \exp(-\theta_k z) = \prod_{m=i}^{k-1} \frac{\theta_m}{\theta_m - \theta_k} \prod_{m=k}^{j-1} \frac{\theta_m}{\theta_{m+1} - \theta_k} \exp(-\theta_k z),$$

$$\begin{cases} \prod_{m=i}^{k-1} \frac{\theta_m}{\theta_m - \theta_k} = 1 & (k = i) \\ \prod_{m=k}^{j-1} \frac{\theta_m}{\theta_{m+1} - \theta_k} = 1 & (k = j) \end{cases} \quad (i = 1, \cdots, I-1;\ j = i+1, \cdots, I).$$

The transition probability from condition state i to absorbing condition state I can then be defined in the following equation:

$$\pi^{iI}(z) = 1 - \sum_{j=i}^{I-1} \pi^{ij}(z)\ (i = 1, \cdots, I-1). \quad (61)$$

The likelihood function of hazard rate θ_i can be expressed in multiplicative form with characteristic variable x and unknown parameter β'_i. The characteristic variables are actually the information concerning the data obtained from inspections such as daily traffic volume, ambient temperature, and pavement thickness.

$$\theta_i = \theta_i(x) = x\beta'_i. \quad (62)$$

The length of time that the object spends in condition state i, $RMD_i(x)$ is then given by the survival probability of condition state i over continuous time.

$$RMD_i(x) = \int_0^\infty \tilde{F}_i(y_i \mid \theta_i(x)) dy_i = \int_0^\infty \exp\{-\theta_i(x) y_i\} dy_i = \frac{1}{\theta_i}. \quad (63)$$

The average time of the object remaining in condition state $j\,(>1)$ is then defined by the summation of the times over the range of condition states counted from $i = 1$:

$$ET_j(x) = \sum_{i=1}^{j} \frac{1}{\theta_i}, \tag{64}$$

where ET_j stands for average time of the object being in condition state j.

When inspection data is available, it is possible to obtain the model parameter (or unknown parameter β), by using regression analysis and the maximum likelihood estimation approach (Tsuda et al., 2006).

APPENDIX 3: Deterministic Strategy Evaluation Models

Ferreira et al., 2002b

A typical deterministic optimal control model can be found in (Ferreira et al., 2002b) (Equation (65). This model is a good representation of models currently used in PMS in many nations in the world, such as HDM-4 and Rosy PMS.

$$Min\ TC(N,T)=\sum_{k=1}^{K}\sum_{n=1}^{N}\sum_{t=1}^{T}\frac{1}{(1+r)^{t}}(Ca_{knt}+Cu_{knt})-\sum_{n=1}^{N}\frac{1}{(1+r)^{T+1}}V_{n,T+1} \quad (65)$$

Where:

Ca, Cu: are respectively the owner cost (intervention cost) and user cost (composed of vehicle costs, travel time costs, accident costs).

k, n, t: are indexes respectively representing intervention type, name of segment, and time in years.

r: is the discount factor

V: is the residual value of the road section, i.e. at the end of the investigated time period.

Although not mentioned in the cited paper, it is expected that the functional forms of owner cost and user cost can be understood as functions of pavement condition indicators as mentioned in Eqs. (44)-(42) and intervention type.

The constraints considered are the yearly budget constraint, and constraints imposed to affect the number of interventions that can be simultaneously executed. For example, there is a constraint that if intervention type *r* is selected in year *t* for segment *s*, intervention of other intervention types cannot be selected.

This type of modelling, as indicated by the author of the cited paper, is an extremely difficult to solve nonlinear programming problem. Due the difficulty that commercial software optimisation solvers had at the time of the research, the author developed a heuristic approach named GENETIPAV-D, which gives a near optimal solution to the problem.

Ouyang & Madanat, 2004

(Ouyang & Madanat, 2004) also set up a minimization control problem to simultaneously manage a network consisting of multiple objects, as the objective function is given by:

$$Min\ TC(N,T)=\sum_{t=0}^{T-1}\sum_{n=1}^{N}\left\{\int_{t}^{t+1}C_n(s_n(u))e^{-ru}du+\delta_{tn}\cdot M_{tn}(w_{tn})e^{-rt}\right\} \quad (66)$$

Where:

$C_n(s_n(u))$: is referred as user cost associated with facility n. The user cost is a function of pavement condition indicator $s_n(u)$, which decreases over time unless an intervention is executed. The functional form of the evolution of the pavement condition indicator is described in Eq. (39).

$M_{tn}(w_{tn})$: is intervention cost, which depends on the intervention effectiveness w_{tn}:, i.e. the intervention cost depends on pre-determined type of intervention.
r: is discount factor
δ_{tn}: is binary variable (control variable)

Whenever, an intervention is selected for year t, the value of user cost $C_n(s_n(u))$ changes.

A heuristic approach based on the concept of MINLP was proposed to solve the dynamic problem.

Yoo & Garcia-Diaz, 2008
(Yoo & Garcia-Diaz, 2008), proposed a linear dynamic program for determining cost-effective pavement maintenance and rehabilitation strategies. The objective function is.

$$Max \sum_{t=1}^{T} \sum_{n=1}^{N} \sum_{k=1}^{K} E_{nkt} \delta_{nkt} \tag{67}$$

Where:
E_{nkt}: Effectiveness of intervention of the k, on pavement section n, at year t.
δ_{tn}: is binary variable, which is regarded as control variable.

The effectiveness of intervention E_{nkt} is determined by means of evaluating the pavement quality index curve. The quality index curve infers only the improvement on the quality of the pavement.

APPENDIX 4: Possible Additional Constraints

Maximum number of interventions of an intervention type
Maximum number of interventions of the same intervention type on a road section. For example, crack sealing interventions are normally not executed over and over again on the same road section. This is because; crack sealing does not fundamentally improve the condition of the road surface or stop the deterioration process. It is usually only executed one or two times while planning the execution of a more substantial intervention. Another example is interventions that involve resurfacing with an asphalt layer. As a road section deteriorates over time, the top asphalt layer often deteriorates the fastest, or first. As the surface is deteriorating, however, so is the base, albeit often more slowly. This results in the situation where it often makes sense that the first intervention executed is one where the road section is resurfacing with an asphalt and the base is not touched, as it is only lightly deteriorated, whereas the second intervention will require an intervention where the base and the pavement is replaced. Generally, this type of constraint can be formulated as:

$$\sum_{t=1}^{T}\sum_{k_{n_l}=1}^{K_{n_l}}\delta_{n_l}^{k_{n_l}}(t)\le N_{n_l}^{k_{n_l}} \qquad (68)$$

where, $N_n^{k_n}$: is maximum number of interventions of an intervention type on road section n_l.

Maximum number of interventions
Or similarly, the constraint can be imposed that strictly focuses on total number of interventions of a specific intervention type.

$$\sum_{t=1}^{T}\delta_{n_l}^{k_{n_l}}(t)\le N_{n_l}^{k_{n_l}} \qquad (69)$$

Quantity discounts
As many of the costs incurred during the execution of an intervention are related to the interruption of traffic flow on the road link, the costs of executing two interventions simultaneously on the road link are not simply the summation of the costs if the two interventions were executed separately. The value of function $g_{n_l}^{k_{n_l}}(t,x)$ can vary depending on the nature of the combination of interventions of various intervention types. For example, within a road link, if two road sections n_l and n_l+1 are selected, the value of function $g_{n_l}^{k_{n_l}}(t,x)$ is quite different from the value if the intervention of road section n was combined with the intervention on road section n_l+i_l $(i_l\neq n_l, n_l+1)$. In spite of the fact that such quantity discounts constraints have been long discussed in literature of operation research (e.g. (Gertsbakh, 1977)), they have not yet been extensively addressed in the field of infrastructure management and are not included in the state-of-the-art models used in pavement management systems to determine OISs.

APPENDIX 5: General Deterministic Model

The general deterministic model, of which the investigated deterministic model can be used to investigated a subset of OIS, is also a MINLP model is based on the deterministic models of proposed by (FWA et al., 2000); (PPC, 1998); and (Ouyang & Madanat, 2004). Although initially considered for use in the SABARIS project, it was ruled out due to programming complexity. It remains a viable model for future investigations.

Objective function
This model assumes that the absolute benefits related to the road are identical under all intervention strategies, making it possible to formulate the objective function as the minmization of the total discounted costs over the investigated time period.

$$Min\ \mathrm{TC}(T, L, N_L, K_{N_L}) = \sum_{t=0}^{T-1}\sum_{l=1}^{L}\sum_{n_l=1}^{N_l}\sum_{k_{n_l}=1}^{K_{n_l}}\left\{\int_t^{t+1}\sum_{x=1}^{X}\left[\sum_{j_{n_l}=1}^{K_{n_l}}\vartheta_{n_l}^{j_{n_l}}(t)\cdot f_{n_l}^{k_{n_l}}(u,x)\cdot e^{-ru}du\right]+\delta_{n_l}^{k_{n_l}}(t)\cdot e^{-rt}\cdot\sum_{x=1}^{X}g_{n_l}^{k_{n_l}}(d_{n_l}^{k_{n_l}},x)\right\} \quad (70)$$

Where:

$t=(0,...,T)$: an index of year
$l=(1,...,L)$: an index of road links with total number of links, L.
$n_l=(1,...,N_l)$: an index of road section in link *l*, where N_l is the number of segments in link *l*.
$k_{n_l}=(1,...,K_{n_l})$: an index of intervention types associated with road section n of link l.
r: discount factor
x: impact indicators
$d_{n_l}^{k_{n_l}}$: duration of intervention k on the object n of the link l.
$f_{n_l}^{k_{n_l}}(u,x)$: the impact on a stakeholder between interventions, associated with impact indicator x, when an intervention of intervention type k is executed on road section n of link l, at time t. This function will take its value from time t to time t+1.
$g_{n_l}^{k_{n_l}}(d,x)$: the impact on a stakeholder during the execution of an intervention, associated with impact indicator x, when an intervention of intervention type k is executed on road section n of link l, at time t. The value of this function is obtained through integration from time t to time t+1.
$\delta_{n_l}^{k_{n_l}}(t)$: binary variable (control variable), which has a value of 1 at time t when an intervention of intervention type k is executed on road section n of link l, otherwise, if no intervention is selected, has a value of 0.
$\vartheta_{n_l}^{j_{n_l}}(t)$: binary variable (control variable), whose value is dependent on the value of binary variable , and ensures through the appropriate constraints that the appropriate impact values between interventions are taken during the year in which an intervention is executed.

Constraints

Integrality constraint

The integrality constraint imposes that only one intervention regardless of intervention type k can be selected at time t on road section n of link l. i.e. if one intervention of intervention type k is selected, than no other intervention of any intervention type for the same road section n of link l, can be selected.

$$\sum_{k_{n_l}=1}^{K_{n_l}} \delta_{n_l}^{k_{n_l}}(t) \leq 1 \tag{71}$$

Impact constraints

The impact constraints, $B^t(x)$, ensure that the value of the impacts of impact type x does not exceed prescribed limits (72). A typical example of this type of constraint is budget constraint. Each year, there is only a limited amount of financial resources available to be allocated for interventions. In this case x is a vector of impact indicators associated with the owner. Other examples of constraints are the amount of emissions emitted or noise emitted.

$$\sum_{n_l=1}^{N_l} \sum_{k_{n_l}=1}^{K_{n_l}} \delta_{n_l}^{k_{n_l}}(t) \cdot g_{n_l}^{k_{n_l}}(d,x) \leq B^t(x) \tag{72}$$

Constraint on the dependent binary variable

The binary variable $\vartheta_{n_l}^{j_{n_l}}(t)$ has been added to the objective function to eliminate the double counting of the impacts between interventions $f_{n_l}^{k_{n_l}}(u,x)$ for the full year when an intervention is executed within the year.

$$\begin{cases} \vartheta_{n_l}^{j_{n_l}} = 1 & \text{when } j = k \\ \vartheta_{n_l}^{j_{n_l}} = 0 & \text{otherwise } (j \neq k) \end{cases} \tag{73}$$

i.e. when j = k then count the impacts between interventions in the year of intervention for the additional time within the year in which the intervention is not being executed, otherwise do not.

It is assumed that an intervention $d_{n_l}^{k_{n_l}}$ is executed entirely within one year. The value is thus in the domain (0,1]. If $\delta_{n_l}^{k_{n_l}}(t)$= 1 then the cost function $f_{n_l}^{k_{n_l}}(u,x)$ takes its value only in duration (1- d), where d is the start of the intervention. If $\delta_{n_l}^{k_{n_l}}(t)$= 0 then the cost function $f_{n_l}^{k_{n_l}}(u,x)$ takes its value over the entire year.

Additional constraints

In actual practice, there are many other possible constraints, which are may eliminate feasible intervention strategies. Some examples are given in Appendix E.

Budget constraint
In the use of either deterministic model 1 it is necessary to determine on which objects interventions should be executed, if there is not enough funding to execute all interventions to be executed, if the optimal intervention strategies are followed. In order to do this, the following priority rule is used:

If the summation of all specific incurred impacts with respect to the objects on which interventions are to be executed in a specified time interval

- is less than or equal to summation of the specific impacts associated with the impact constraint (here refer as allowed impact), then all possible interventions are executed. The remaining impacts, when applicable (e.g. budget) are transferred to the following year, thus, the restricted impacts in the following year will be equal to the remaining impact of last year plus the new allowed impact (e.g. new allocated budget);
- is greater than the allowed impact, the infrastructure object having highest reduction in negative impacts within the selected year is selected for intervention,
  - if the impact of the intervention is still greater than allowed impact, the intervention will be rejected and the candidate intervention with the next highest reduction in total negative impact in the investigated year will be selected. All the non-selected infrastructure objects for intervention will be deferred to the immediate following year.
  - a similar procedure is repeated at each year to determine the potential infrastructure objects for intervention.

The overarching MINLP model is a candidate to be used to determine the OIS for an investigated time period. Its principal disadvantage for use in an optimisation tool is dimensionality, i.e. the number of strategies to investigate grows exponentially with the number of objects in the link and the number of years in the investigated time period. There has, however, recently been some promising research in the use of a heuristic method to solve such a problem (Bonami et al., 2008). The judged attributed of the overarching MINLP model are shown in . It was chosen not to pursue this model further in the SABARIS project due to the programming difficulty.

Table 29 Judged attributes of overarching MINLP model

Type of intervention strategies considered	Programmability	Ease of determination of model parameters	Consideration of uncertainties	use of historical data for deterioration prediction	Number of condition states considered	Memory	Dimensionality
All	very difficult	difficult	No	Yes	Infinite - continuous	Yes	No

APPENDIX 6: Markov Decision Process

The Markov Decision Process (MDP) is a potential model to be used. To use this model it is assumed that the condition of an object can be classified into K discrete states, where i is referred to as condition state $i(i=1,...,K)$, and t is time $t=(0,1,.....)$. An intervention is considered to be composed of multiple activities $d \in D$, and the vector η^d refers to the activities within the intervention to be executed on the object in each condition state $i(i=1,...,K)$

$$\eta^d = \left(\eta^d(1),\cdots,\eta^d(K)\right) \quad (74)$$

$\eta^d(i) \in \Theta(i)$ represents the set of activities included in the intervention that if executed results in a change of the condition state from i to j, i.e. $\eta^d(i)=j$. $\Theta(i)$ is the set of interventions that can be executed when the object is in condition state i. If no intervention is selected $\eta^d(i)=i$.

As the infrastructure reaches the highest (or worst) condition state $i=K$, an intervention is executed out and the object is returned to condition state 1, represented as $\eta^d(K)=1$.

The impacts on stakeholders are represented by $c^d=(c_1^d,...,c_K^d)$ and are related to each intervention η^d. c_i^d is therefore the impact on all stakeholders of intervention $\eta^d(i)$ of the object being in condition state i. It is important to note here that $(1 \le j \le i)$ and c_{ij} is the impact of changing the condition state of the object from i to j. It can be inferred that $\eta^d(i)=j$ then $c_j^d=c_{ij}$, and $\eta^d(i)=i$ then $c_i^d=c_{ii}=c$ (in this case c is considered to be the impacts that would occur due to routine maintenance interventions, e.g. cleaning).

In general:

$$c_{kk} \le \cdots \le c_{jk} \le \cdots \le c_{Kk} \quad (75)$$
$$(k \le j \le K; k=1,\cdots,K)$$

The information associated with $d \in D$ is described by class $(i,\eta_i^d,c_i^d)(i=1,...,K)$ of the impact c_i^d for intervention η_i^d.

The condition state belongs to state space $S=\{1,2,...,K\}$ with $K(\ge 2)$. The deterioration process on state space S is described as $\{h_t\}$. From time t to $(t+1)$, the condition state changes from $h_t=i$ to $h_{t+1}=j$.

The probability that the object will make a transition between condition states i and j is given as:

$$Prob[j \mid i]=p_{ij} \quad (76)$$

Clearly the values in the transition matrices are different depending on whether or not an intervention was executed. In order to form the new transition matrix, from the deterioration transition matrix, a dummy variable q was defined. The values of q are given by:

$$q_{ij}^{d} = \begin{cases} 1 & \eta^{d}(i) = j \\ 0 & \text{otherwise} \end{cases} \quad (i = 1, \cdots, K; j = 1, \cdots, i) \tag{77}$$

As the dummy variable q represents the interventions executed in each condition state when a specific intervention strategy is followed, they can collectively described in canonical form as:

$$Q^{d} = \begin{pmatrix} q_{11}^{d} & \cdots & q_{1K}^{d} \\ \vdots & \cdots & \vdots \\ q_{K1}^{d} & \cdots & q_{KK}^{d} \end{pmatrix} \tag{78}$$

When the object deteriorates to condition state K, it is considered that an intervention is executed immediately. Therefore, the value of $q_{KK}^{d} = 0$.

The new transition matrix when each intervention strategy is followed is then given by

$$P^{d} = Q^{d} P \tag{79}$$

$$p_{iK}^{d} = 0 \; (i = 1, \cdots, K-1) \tag{80}$$

which is represented in canonical form as:

$$\tilde{P}^{d} = \begin{pmatrix} p_{11}^{d} & \cdots & \cdots & p_{1K-1}^{d} \\ \vdots & \ddots & & \vdots \\ \vdots & & \ddots & \vdots \\ p_{K-11}^{d} & \cdots & \cdots & p_{K-1K-1}^{d} \end{pmatrix} \tag{81}$$

The new transition probability matrix p^{d} is a $(K-1, K-1)$ matrix.

Knowing the transition probabilities when a specific intervention strategy is followed allows the estimation of the steady state probabilities $\pi_{ij}^{d}(n)$ at time $t = n$, at which the condition state advances to j from i by $\tilde{P}^{d}$.

$$\pi_{ij}^{d}(n) = \sum_{k=1}^{K-1} \pi_{ik}^{d}(n-1) p_{kj}^{d} \tag{82}$$

When time n goes to infinity $(n \mapsto \infty)$, the stationary probabilities will determined: $\{\pi_{ij}^{d}(n) \mapsto \pi_{ij}^{d}\}$.

$$\pi_{ij}^d = \lim_{n\to\infty} \pi_{ij}^d(n) \qquad j\,(j=1,\cdots,K-1) \tag{83}$$

$$\pi_{1j}^d = \pi_{2j}^d = \cdots = \pi_{K-1j}^d \tag{84}$$

Objective function

The objective function is expressed as:

$$\psi_t(i) = \min_{k\in K}\left\{ e_i^k + r\sum_{j=1}^{I} p_{ij}^k \psi_{t+1}(j) \right\} \tag{85}$$

$$\forall t \in \{0,1,2,...,T-1\}, i, j \in I$$

where:

$i, j = (1,...,I)$: indices of a road section (or network) condition state

$k = (1,...,K)$: an index of intervention types

$t = (0,...,T-1)$: an index of year

c_i^k: the (single-year) impact of being in condition state i and applying intervention I

p_{ij}^k: the probability of being in condition state j one year after being in condition state I with intervention k applied.

r: discount factor

$\psi_t(i)$: the expected discounted future costs when in condition state i in year t.

$\psi(i)\,(i=1,\cdots,K-1)$ represents the minimum expected impacts after time $(t+1)$ when the optimal intervention d^* is executed. For example, if it is assumed that intervention *d* is executed at time t and the OIS is followed after time t, then the total expected impacts $\psi^d(i)$ incurred at time t and those incurred due to the future condition states j will be calculated from following equation.

$$\psi^d(i) = e_i^d + rE_i^d[\psi(j)] \tag{86}$$

Where:

e_i^d: shows the expected impact due to the execution of intervention d just before time (t+1), when the object is in condition state i at time t

$$e_i^d = \sum_{j=i+1}^{K} p_{ij} c_j^d \; (i=1,\cdots,K-1) \tag{87}$$

r: discount factor and

$E_i^d[\psi(j)]$: is the impact of the expected costs that occur when executing intervention d and following the OIS after time (t+1) (evaluated by period concerning the value at time (t+1) in time t when deteriorated condition state is i. It is given by:

$$E_i^d[\psi(j)] = \sum_{j=1}^{K-1} p_{ij}^d \psi(j)$$

The minimum value of the expected impacts, evaluated at time t yields the OIS. It is from the above equation that the OIS can be determined η^{d*}.

Constraints
No constraints were introduced in the Markov model.

Impact models
There is significant difference between the input of deterministic model and the MDP model , with respect to the assumption of impacts on stakeholders. The impact on stakeholders in the deterministic model can be estimated precisely at any time using the functions $f_{n_l}^{k_{n_l}}(t,x)$ and $g_{n_l}^{k_{n_l}}(d,x)$ that are described in Eq. **(3)**. The impact on stakeholders when the MDP model at a point in time must be considered as an expected value , estimated based on the probability that the object happens to be in certain discrete condition state at certain time interval.

With the MDP model, after one year, the condition of object will be represented as a probability of being in any of the five defined condition states. The impacts on stakeholders in each of the discrete condition states are different. Although there is some variation in actual physical condition of the object when it is classified in a discrete condition state, it is assumed that the impacts on the stakeholders are the same.

To estimate the impacts for probabilistic model 1, were assumed to be valid for the middle value of what is expected in a discrete condition state were taken. For VC for example, it was assumed that as long as object 1 is in condition state 1 that 2,578 CHF/year VC would be incurred by the user. The VC associated with condition state 2, 3, 4, and 5 were similarly estimated as 2,700 CHF, 2,900 CHF, 3,000 CHF, and 3,200 CHF per day. ,

With the given the state probability vector of (0.6703, 0.30621, 0.02206, 0.0013, 0.0001), the expected VC incurred to users in year 1 due to object 1 is estimated as: (2,578*0.6703+2,700*0.30621+2,900*0.02206+3,000*0.0013+3,200*0.0001) ≈ 2,623 CHF.

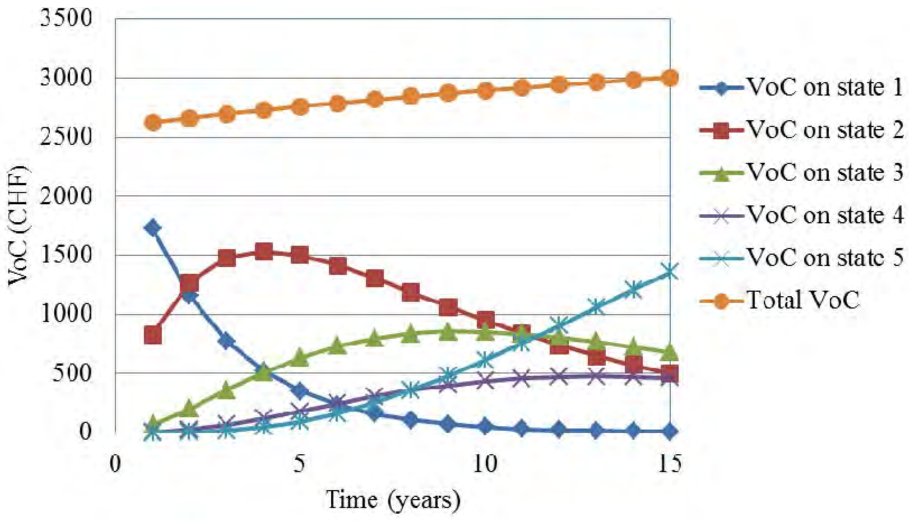


Figure 132 Evolution of VCs over time in Markov chain model

In Markov chain model, the evolution of VoC related to object 1 is shown in Figure 132. As can be seen from the figure, the total of VoC over time increases similar with the one that we assume in the deterministic model.

This model is developed based on the theory of Markov decision process. It is convenient to apply for a network of homogenous infrastructure objects, whose condition state of multiple objects are in the same discrete scale. A limitation of the model is that it is less applicable for a heterogeneous system, where the heterogeneity factors associated with the infrastructure objects vary greatly. The judged attributed of the Markov model are shown in Table 30. The Markov decision process model was not pursued in this project due its inherent problem with dimensionality.

Table 30 Judged attributes of the Markov decision process model

Type of intervention strategies considered	Programmability	Ease of determination of model parameters	Consideration of uncertainties	use of historical data for deterioration prediction	Number of condition states considered	Memory	Dimensionality
Only single stage	moderate	Moderate	Yes	Yes	Multiple discrete condition states	No	Yes

APPENDIX 7: Impact Hierarchy

The hierarchy has been developed to help reduce confusion at the onset of the determination of optimal intervention strategies, with respect to the stakeholders to be considered and the evaluation of how they are affected. It is developed using a multiple stakeholder approach, where it is considered that all people at a specific point in time can be classified into one of the four principle stakeholder groups: the owner, the users, the directly affected stakeholders, and the indirectly affected stakeholders. To help to ensure orthogonality in the impact hierarchy, each impact type, on the lowest defined level, is explained and classified as contributing to one of the pillars of sustainability (economic, societal, environmental).

Stakeholder groups

A stakeholder is herein considered as an individual, group, or organization, which is affected by changes to public roads. Being a stakeholder is time dependent, i.e. when a person is driving a vehicle on a road he is a user at that point in time. When he is off of the road and in his house far from the road he is part of the indirectly affected public. It is considered that all stakeholders can be grouped as either first level or second level stakeholders. The first level stakeholders are those whose net positive impacts should be maximized. The second level stakeholders are those whose impacts are the outcome of the maximization of the net impacts of the first level stakeholders, and should be monitored.

The four first level stakeholder groups are the owner, the user, the DAP, and the IAP. It is assumed that all impacts to be maximized can be attributed to one of these four principle stakeholder groups. The impacts are attributed to the stakeholder who is most directly affected. The definitions of each stakeholder group are given in Table 31.

Second level stakeholder groups, such as contractors, financial institutions, and operators are not considered further than they are considered when considered as one of the above listed stakeholders. The impacts on these stakeholder groups are only the outcome of our efforts to maximize the positive net impact of the four first level stakeholders in the first level.

Table 31 Stakeholder groups

Stakeholder group	Definition	Examples
Owner	the persons who are responsible for decisions with respect to physically modifying the infrastructure	a federal road authority
Users	the persons who are using the roads	a driver and passengers of a vehicle on a road.
Directly affected public	the persons who are in the vicinity of the road but are not using it	persons in a house next to the road that hear vehicles driving on the road.
Indirectly affected public	the persons who are not in the vicinity of the road but are affected by its use	persons in a house far away from the road that do not hear vehicles driving on the road, but are affected by a changing climate due to the emissions produced by vehicles driving on the road.

Impact Types

The impacts on each stakeholder are grouped as impact types. The impact types are subdivided at increasingly fine levels until the impact of each type can be reasonably and objectively quantified and modelled. To help to ensure orthogonality in the impact hierarchy, each impact type, on the lowest defined level, is explained and classified as contributing to one of the pillars of sustainability (economic, societal, environmental). An example is given for each to help clarify its meaning. Impact indicators, which are considered to be representative of each impact type are given for each impact type. By estimating the values of these indicators over time, and attributing monetary values to each unit change in the indicators, it is possible to evaluate the impact of the stakeholders. The impact hierarchy is given in the following subsections. Examples of models to be used to estimate how their values change over time per impact type are given in APPENDIX 8.

Owner

The impacts attributed to the owner are grouped as LOS (intervention)[41] costs (Table 32), i.e. the impact on the owner of maintaining the expected LOS or in other words the executing of interventions. The impact indicators are the amount of labor, equipment, and material to be used to execute interventions, e.g. intervention w required x man-hours, y generator-hours and z kilograms of material.

The monetary value placed on the:

- labour used represents the economic impact of persons performing tasks, i.e. i.e. the value from society's perspective of the person doing the intervention;
- material used represents the economic impact of people ensuring that materials are available for use, i.e. i.e. the value from society's perspective of persons preparing the materials for use;
- equipment used represents the economic impact of people ensuring that equipment is available for use, i.e. i.e. the value from society's perspective of persons preparing the equipment for use. The estimation of the value of an intervention is often done using one of two approaches:
  - a disaggregate approach where expenditures for each item or activity are estimated and summed. When this approach is used the work break down structure of the intervention project it is often used.
  - an aggregate approach where sum of all expenditures is estimated directly. An aggregate approach often includes regression analysis and historical information.

Table 32 Owner impact types

Level 1		Level 2	
Label	Description	Label	Description
Level of service (Intervention)	the impact of executing interventions	Labour*	the economic impact of people performing tasks
		Material*	the economic impact of people ensuring that materials are available for use
		Equipment*	the economic impact of people ensuring that equipment is available for use

* These could be further subdivided based on the type of activity performed, e.g. administration, planning, etc.

User

During the interventions, users experience inconveniences such as traffic jams, bumping condition of temporarily roads (detour roads). The unfavorable conditions of travelling via the road sections and links subjected to intervention will eventually lead to increased negative impacts. These could include the higher possibility of accidents, various types of physical exhaustion and illness as comfort levels decrease, loss of travel time, and increases in fuel consumption and frequency of the maintenance of vehicles.

[41] The main label denotes an expectation of the stakeholder, e.g. it is expected from the owner that he will need to intervene to maintain an adequate level-of-service. The in brackets denoted label is an alternate label meant to help clarify what is being quantified, e.g. for the owner "intervention" is used.

In between interventions, deterioration processes result in a worsening condition of any infrastructure object. The increasingly poor condition of infrastructure also results in a change in how stakeholders are affected e.g. increases in the number of accidents, travel time, the costs of operating and maintaining vehicles.
The impacts attributed to the user are grouped as: safety, operation efficiency, operation quality, and environment preservation (Table 33).

Table 33 User impact types

Level 1		Level 2	
Label	Description	Label	Description
Safety (Accident)	the impact on the user due to the user being involved in an accident	property damage	the economic impact of repairing the vehicle
		injury	the societal impact due to the injury
		death	the societal impact due to death
Operation efficiency (Travel time and vehicle operation)	the impact of travel condition in terms of time lost	work	the economic impact of wasting work time travelling
		leisure	the economic impact of wasting leisure time travelling
	the impact of travel condition on the vehicle cost	operation	the economic impact of people ensuring that fuel and oil is available for use
		maintenance	the economic impact of people repairing vehicles and ensuring that materials, e.g. tires and brake pads, are available for use
Operation quality (Comfort)	the impact of travelling on the user	physical	the societal impact of obtaining for example, bruises from an extremely bumpy ride
		psycho-logical	the societal impact of having for example, anxiety due to a perceived increase in the probability of being involved in an accident, or of seeing things while travelling.
Environment preservation (Noise)	the societal impact due to the user coming in contract with sound emissions		

Safety

Accidents result in damage to the property of involved parties. The owners will often repair the damaged objects so as to provide adequate service to users after accidents (this would be attributed to the owner). The users, however, will be required to repair their vehicles, and will also be affected by any injury and of course, death, that may befall them. The safety impact type attributed to the user is subdivided into property damage, injury and death impact types.

- Property damage: The property damage impact type represents the economic impact of repairing the vehicle, i.e. of providing the user with a functioning mode of transport similar to the one being used before the accident, e.g. the costs of the labor, materials and equipment required to replace the bumper on a vehicle that has been in an accident. The impact indicators for property damage are the amount of labor and materials used to repair vehicles damaged in an accident, expressed as the property damage costs. The value of this impact type can be approximated using the receipts from past repairs.
- Injury and death: The injury impact type and the death impact type attributed to the user represent the social impact due to injuries and deaths, respectively. They represent the change in interactions between persons that will occur because the user is injured or dead. It is not to be confused with the injury impact type and the death impact type attributed to the DAP (section 0) or to the IAP (section 0). The impact indicators are the number of injuries and deaths incurred in a specified time interval. The value of these impact types can be estimated by using the user’s willingness to pay to avoid injury or death.

Operation efficiency (Travel time and vehicle operation)

The operation efficiency impact type represents the impact on the travelling of users and on the maintenance and operation of the vehicles.

- Travel time: The amount of time travelling on the road is determined by speed driven which in turn is affected by various factors. These factors include road condition (drivers feel comfortable on a smooth road, and therefore drives faster than on a bumpy road), and the DTV (the daily traffic volume, especially in relation to the road capacity), and road geometry. Furthermore, in case of an intervention, a detour might be needed. The economic impact of wasting work and leisure time travelling may be thought of as the loss of productivity of the users due to time spent travelling. The impact indicators are the amounts of work and leisure time wasted while travelling. The value of travel time can be determined using willingness to pay surveys.
- Vehicle operation and maintenance: The vehicle operation and maintenance impact types represent the economic impact of people ensuring that fuel and oil is available for use, and the economic impact of people repairing vehicles and ensuring that materials, e.g. tires and brake pads, are available for use, respectively. The value of the vehicle operation and maintenance impact types can be approximated using the receipts from fuel and vehicle service receipts.

Operation quality (Comfort)
The operation quality impact type is subdivided into the physical and psychological impact types. The physical impact type represents the social impact of obtaining for example, bruises from an extremely bumpy ride. It represents the change in interactions between people that will occur because the physical change in the user due to the bumpy ride. The psychological impact type represents the impact of having for example, anxiety due to a perceived increase in the probability of being involved in an accident, or of seeing things while travelling, e.g. aesthetics. It is believed that any economic impacts relevant to society due to the physical and psychological impacts of travelling, such as the loss of productivity, are negligible, in developed countries. The impact indicators are the amounts of physical and psychological impacts of travelling. The value of degrees of bumpiness could be determined through willingness to pay investigations.

Environment preservation (Noise)
The environment preservation impact type represents the social impact due to the user coming in contact with sound emissions. It is meant to capture the changes that occur in the interactions between people due to sound emissions, e.g. the inability to communicate between driver and passenger while driving. The impact indicator is the amount of sound emissions to which the users is exposed. The value of an amount of sound emissions can be determined through willingness to pay investigations.

Directly affected public (DAP)

The impacts attributed to the DAP are grouped as: safety, operation quality, and environment preservation (Table 34), similar to the impact types of the user. The reason they are handled seperately is that the DAP is affected in fundamentally different ways than the user.

Table 34 Directly affected public impact types

Level 1		Level 2	
Label	Description	Label	Description
Safety (Accidents)	the impact on the directly affected public due being involved in an accident	property damage	the economic impact of repairing property damaged due to a vehicle coming off of the road
		injury	the societal impact due to the injury
		death	the societal impact due to death
Operation quality (Comfort)	the impact of travelling on the directly affected public	physical	the societal impact of physical changes due to people travelling on the road, e.g. due to vibrations
		psychological	the societal impact of having for example, anxiety due to a perceived increase in the probability of being involved in an accident, due to others travelling.
Environment preservation (Noise)	the societal impact due to the directly affected public coming in contract with sound emissions		
Environment preservation (Particle emissions)	the impact on people due to the environment being impacted by particle emissions	CO2	the societal impact due to emissions (human health)
		PM10	same as for CO2
		nitrogen	
		carbon monoxide	
		aldehydes	
		nitrogen dioxide	
		sulphur dioxide	
		polycyclic aromatic hydro-carbons	
		dust	

Safety (Accidents)

The safety impact type is subdivided into property damage, injury and death impact types.

- Property damage: The property damage impact type represents the economic impact of repairing damaged property, to the condition it was prior to the occurrence of the accident, e.g. the costs of the labour, and materials required to repair a retaining wall that has been damaged in an accident. The impact indicator is the property damage cost. The value of this impact type can be approximated using the receipts from past repairs.
- Injury and death: The injury impact type and the death impact type attributed to the DAP represent the societal impact due to injuries and deaths, respectively. They represent the change in interactions between persons that will occur because someone other than the user is injured or dead. It is not to be confused with the injury impact type and the death impact type attributed to the IAP. The impact indicators are the number of injuries and deaths incurred in a specified time interval. The value of these impact types can be estimated by using willingness to pay of the DAP to avoid injury or death.

Operation quality (Comfort)

The operation quality impact type is subdivided into the physical and psychological impact types. The physical impact type represents the societal impact of obtaining for example, discomfort through vibrations that occur due to road use. It represents the change in interactions between persons that will occur because the physical change in the directly affected public. The psychological impact type represents the social impact of having for example, anxiety due to a perceived increase in the probability of being involved in an accident, or of seeing the infrastructure, e.g. aesthetics. It is believed that any economic impacts to be attributed to the directly affected public due to the physical and psychological impacts of others travelling, such as the loss of productivity, are negligible. The impact indicators are the amounts of physical and psychological impacts of travelling. The value of degrees of bumpiness can be determined through willingness to pay investigations.

Environment preservation (Noise and particle emissions)
The environment preservation impact type represents the social impact due to the DAP coming in contact with sound and particle emissions. The sound emission impact type is meant to capture the changes that occur in the interactions between people due to sound emissions, e.g. the necessity to change where people meet due to excess noise. The impact indicator is the amount of sound emissions to which the DAP is exposed. The value of an amount of sound emissions can be determined through willingness to pay investigations.
The particle emission impact type represents the societal impact due emissions emitted during the production and transport of materials and persons and that directly affect persons. It is meant to capture the changes that occur in the interactions between people due the changes in the people, e.g. due to sickness. It is subdivided by particle emitted, e.g. CO_2, PM10, NO, CO, aldehydes, NO_2, SO_2, polycyclic aromatic hydrocarbons and dust. The impact indicators are the amounts of each that are emitted. The value of each amount can be determined by analyzing historical records or by conducting empirical studies using emission measurement tools and instruments.

Indirectly affected public (IAP)

The IAP are those that are affected by roads through other mediums, e.g. a person who is affected by an increase in the temperature of the earth due to the CO_2 emitted during the execution of an intervention on a road. The impacts attributed to the IAP are grouped as: safety, socio-economic activity, environment preservation, and environment consumption. It is noted that several impact types, such as gas and particle emission also directly affect the users and the DAP. However, it is assumed that these impacts are minimal.

Safety (Accidents)
The injury impact type and the death impact type attributed to the IAP represents the economic impact due to injuries and deaths, respectively. They represent the loss in productivity due to injuries and deaths, respectively. It includes changes to human activity, such as a doctor’s time in an emergency room and the time required to ensure that an insurance company conducts the required financial transactions. The impact indicator is the amount of work time lost, when compared to the reference case where the the accident had not occurred. The value of each amount can be determined by estimating the loss of productivity of the person involved in the accident.

Socio-economic activity
The socio-economic activity impact type represents the contribution of the road to socio-economic development. It is composed of persons, goods and employment impact types.

- Persons: The person impact type is further divided into a productiveness impact type and a health impact type.
  - *The productiveness impact type* represents the economic impact due to not being able to travel, e.g. a farmer cannot harvest his entire crop because he needs to spend a significantly larger portion of his time getting his goods to market. The impact indicator is the amount of lost work, and expressed in units of time. The value of each amount can be determined by conducting through simulations of the performance of the region.
  - *The health impact type* represents the societal impact due to injuries and deaths that occur due to not being able to obtain standard medical care, due to a shortage of available persons. The impact indicators are the number of injuries and deaths incurred in a specified time interval. The value of each amount can be determined by conducting through simulations of the region.
- Goods: The goods impact type is also further divided into a productiveness impact type and a health impact type.
  - *Productiveness:* The productiveness impact type represents the economic impact due to not being able to deliver goods, e.g. a farmer cannot plant his crop on time since fertilizer could not be delivered as planned. The impact indicator is the amount of lost work, and expressed in units of time.
  - *Health:* The health impact type represents the societal impact due to injuries and deaths due to goods such as food or medical supplies not being delivered as planned. This includes, for example, the change in society that occurs due to the death of someone in a hospital that would not have died if medical supplies had been delivered as planned. The impact indicators are the number of injuries and deaths incurred in a specified time interval.
- *Employment:* The employment impact type represents the societal impact of executing interventions in terms of employing people that is not captured by the impact type attributed to the owner due to the execution of interventions or the user due to the maintenance of vehicles used for travelling. It includes economic development. The impact indicator is the amount of work provided. The value can be estimated as using economic impact assessment models, using predictions of business output, value added, employment level, wages and salaries, and wealth are made (CUBRC, 2001), (Davis, 2001), (Kumares & Samuel, 2007).

Environment preservation (Emissions)

The environment preservation (Emissions) impact type of the IAP represents the environmental and societal impact due emissions emitted during the production and transport of materials and persons. It is subdivided by particle emitted, e.g. CO2, PM10, NO, CO, aldehydes, NO2, SO2, polycyclic aromatic hydrocarbons and dust. The impact indicators are the amounts of each that are emitted. Each of these are further subdivided into

- the production impact type, which represents the environmental impact of emissions emitted during the production of materials
- the material transport impact type, which represents the environmental impact of emissions emitted during the transport of materials to and from the construction site
- the person transport impact type, which represents the environmental impact of emissions emitted during travel
- the health transport impact type, which societal impact due to emissions (human health). It is meant to capture the changes that occur in the interactions between people due the changes in the people, e.g. due to sickness.

The value of each amount can be determined by analysing historical records or by conducting empirical studies using emission measurement tools and instruments.

Table 35 IAP impact types

Level 1		Level 2		Level 3	
Label	Description	Label	Description	Label	Description
Safety (Accidents)	The impact on the indirectly affected public of accidents occurring on roads	injuries	the economic impact due to an injury	Productivenes s	
		deaths	the economic impact due to a death	Productivenes s	
Socio-economic activity	The contribution of the road operation to socio-economic development	Persons	the impact of not on persons of not being able to transport people	Productivenes s	the economic impact due to not being able to travel, e.g. not being able to work
				Health	the societal impact due to injuries and deaths of not being able to get proper medical care
		Goods	the impact of not being able to move goods	Productivenes s	the economic impact due to not being able to deliver goods, e.g. because of not being able to work as planned
				Health	the societal impact due to not being able to deliver goods, e.g. due to deaths because of lack of food or medical supplies
		Employ ment	the impact of interventions in terms of employing people		

Environment consumption

The environment consumption impact type represents the depletion of finite amounts of non-renewable resources. It is subdivided into the energy impact type, the material impact type, the land impact type and the culture impact type.

- Energy: The energy impact type represents the environmental impact due to the consumption of energy not related to emissions, e.g. depletion of finite amounts of non-renewable energy sources. The impact indicator is a measure of the significance of a unit depletion of a finite resource.
- Material: The material impact type represents the environmental impact of consuming materials, not related to emissions, e.g. the consumption of wood has an impact on woodland areas. The impact indicator is the amount of consumed material, e.g. kg of wood cut.
- Land: The land impact type represents the environmental impact due to the consumption of land not related to emissions, e.g. increased environmental damages due to floods. The impact indicator is the m^2 of land converted from a natural state to a built state.
- Culture: The culture impact type represents the societal impact of changing things important to our identity (of which heritage is part). The impact indicator is a measure of the significance of an object to our identity. The value can be estimated through willingness to pay investigations.

Table 36 IAP impact types (Cont'd).

Level 1		Level 2		Level 3	
Label	Description	Label	Description	Label	Description
Environ-ment preservation (Particle emissions)	the impact on people due to the environment being impacted by particle emissions	CO_2	the impact due to the emissions	Production	the environmental impact of emissions emitted during the production of materials
				Material transport	the environmental impact of emissions emitted during the transport of materials
				Person transport	the environmental impact of emissions emitted during travel
				Health	the societal impact due to emissions (human health)
		PM10	same as for CO_2		"
		nitrogen			"
		carbon monoxide			"
		aldehydes			"
		nitrogen dioxide			"
		sulphur dioxide			"
		polycyclic aromatic hydrocarbons			"
		dust			"
Environment consumption	depletion of finite amounts of non-renewable resources	Energy	the environmental impact due to the consumption of energy not related to emissions, e.g. depletion of finite amounts of non-renewable energy sources		
		Materials	the environmental impact of consuming materials, not related to emissions		
		Land	the environmental impact due to the consumption of land not related to emissions		
		Culture	the societal impact of changing things important to our identity (of which heritage is part)		

Discussion

In reading such an impact hierarchy some people will imagine things that may seemingly not be in the list of impacts. This section explains how some of these "other" impacts can be read out of the given impact hierarchy.

Access

The improvement of access is often stated as an impact (Kumares & Samuel, 2007). Improved access, however, is a proxy for the many things that actually happen when access is improved. For example, if access to a highway is improved a user travelling from point A, to point B, who normally would not take the highway, would perhaps have a shorter travel time, reduced vehicle costs, and reduced accident costs. It is proposed that if it is desired to approximate the value of improved access that the changes in the relevant impact types for each stakeholder are calculated.

For example, if there are two interventions being considered for a highway (option A with a medium level of access and option B with a high level of access, it is possible that the option B in comparison with option A, since the users will need to travel a shorter distance to arrive at their destination, results for the user (Table 36) in a reduction in:

- accident costs of 2 units,
- comfort costs of 5 units,
- travel time costs of 4 units, and
- vehicle costs of 2 units.

Table 36 Example 1

Option	Accident	Comfort	Travel Time	Vehicle
A	10	15	14	8
B	8	10	10	6

This means that option B is 13 units better than option A, or in other words, the improvement in access has a value of 13 units.

Natural hazard risks

The reduction of natural hazard risks is often stated as an impact (Ellingwood & Wen, 2005). The reduction of natural hazard risk is, however, a proxy for the many things that may actually happen when the risk of natural hazards is reduced. It is proposed that if it is desired to approximate the value of reduced natural hazard risk that the changes in the relevant impact types (probability of occurrence and values) for each stakeholder be estimated.

For example, if there are two interventions being considered for a highway (option A with a medium level of natural hazard risk and option B with a high level of natural hazard risk), it is possible that the option B in comparison with option A, if a natural hazard occurs and severs the highway, results for the user in the need to travel a longer distance to arrive at their destination. This increased risk to the user could be (Table 37) an increase in:

- accident costs of 1.5 units (0.1 x 15 units),
- comfort costs of 2.4 units (0.1 x 24 units),
- travel time costs of 11.3 units (0.1 x 113 units), and
- vehicle costs of 5.7 units (0.1 x 57 units).

Table 37 Example 2

Option	Accident	Comfort	Travel Time	Vehicle
A	10	15	14	8
B	11.5	17.4	25.3	13.7

This means that option A is 20.9 units better than option B, or in other words, the reduced natural hazard risk has a value of 20.9 units.

APPENDIX 8: Impact Models

In this section, examples of models are given to be used to quantify the functions $f_{n_l}^{k_{nl}}(t,x)$ and $g_{n_l}^{k_{nl}}(d,x)$ or each impact indicator (BI) given in the impact hierarchy. It is assumed that the values of the two functions $f_{n_l}^{k_{nl}}(t,x)$ and $g_{n_l}^{k_{nl}}(d,x)$ are transformed into monetary values.

An example of the cost function is given in following equation (Ouyang & Madanat, 2004)

$$\int_{t_1}^{t_2} C(s(t)) \cdot e^{-rt} dt = c_1 \cdot \int_{t_1}^{t_2} s(t) \cdot e^{-rt} dt \qquad (88)$$

Eq. (88) represents the discounted total user and public cost incurred during the period [t_1,t_2], c_1 is constant parameter, and r is discount factor. This equation can be used to link any impact on any stakeholder that varies as a function of condition to the condition of the object. This enables, for instance, impacts related to noise and particle emissions from vehicles to be modelled as a function of the pavement condition state. As the condition state is modelled as a function of time than so can the impacts on the stakeholders.

An example of the evolution of vehicle cost (Eq. (6)) along with the evolution of roughness estimated by using Eq. (40) for 1 m length of road section is shown in Figure 133 and Figure 134. In the figure, Eq. (3) has parameter values *a*=500, *b*=800, and $\beta = 0.095$, which are approximated from the values of $s(t_0) = 20$, $\bar{f}^* = 2$, $\gamma = 0.0153$, and $c_1 = 2.1$ (Ouyang & Madanat 2006) within a period of 30 years. The cost curve represents the cumulative increase of vehicle cost over time. The discount rate used to compute the curve is 2%.

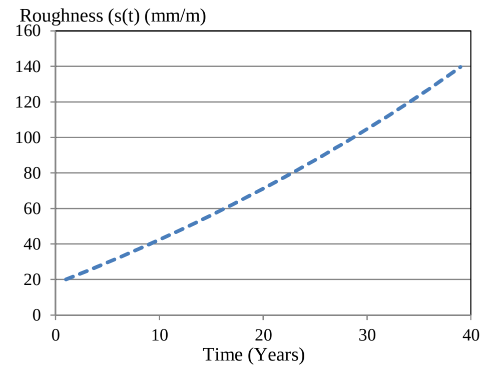


Figure 133 Evolution of roughness

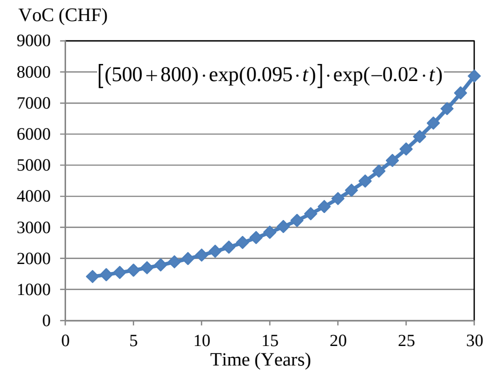


Figure 134 Evolution of vehicle cost

Being generic Eqs. (3) and (4) can be used to model the evolution of any impact that varies as a function of the condition of an object, and allows the heterogeneity of each object, e.g. the different deterioration rates, to be taken into consideration. For example, if it is desired to model the relationship between impacts on the user and the condition of a road section the values of a, b, and β (e.g. for user) could be selected as non-negative values, ensuring that the function f will result in the values of the impact on the users that increase exponentially with time, which is similar to that of the user cost estimated using Eq. (88).

Although the form of functions *f* and *g* are flexible, in this report, the exponential form in Eqs. (3) and (4) is used. This is realistic enough to represent the evolution of impacts incurred to stakeholders, for the purposes of demonstrating the proposed approach to determine the optimal preservation strategies for a road section composed of multiple objects. The following section describes the proposed MINLP.

Owner

The following general functions can be used to approximate the values of impacts on the owners:

$$f_{n_l}^{k_{n_l}}(t, x_i^o) = \sum_{i=1}^{3} BI_{in_l}^o(t) \cdot c_{in_l}^o(t) \tag{89}$$

$$g_{n_l}^{k_{n_l}}(\overline{t}, x_i^o) = \sum_{j=1}^{3} BI_{ik_{n_l}}^o(\overline{t}) \cdot c_{ik_{n_l}}^o(\overline{t}) \tag{90}$$

Where:

i: is the index to indicate labour, equipment, and materials.

BI_i^o: is the impact indicator for the index i.

$c_i^o(t), c_i^o(\overline{t})$: are unit cost, which vary as a functions of time t and $\overline{t}$

The impact indicator BI_i^o for each index i in this case is the number of work-man hour, number of equipment, and quantity of materials used for intervention.

Safety

Property damage, injury, and death

The expected value of function concerning the accidents can be expressed in following equations.

$$f_{n_l}^{k_{n_l}}(t, x_i^u) = \sum_{i=1}^{3} BI_{ik_{n_l}}^u(t) \cdot c_{ik_{n_l}}^u(t) \tag{91}$$

$$g_{n_l}^{k_{n_l}}(\overline{t}, x_i^u) = \sum_{i=1}^{3} BI_{ik_{n_l}}^u(\overline{t}) \cdot c_{ik_{n_l}}^u(\overline{t}) \tag{92}$$

Where:

i: is the indication for property damage, injury, and death respectively.

BI_i^u: is the impact indicator for the index i.

$c_i^u(t), c_i^u(\overline{t})$: are unit cost (or cost rate), which are considered as functions of time t and $\overline{t}$

The values of impact indicators ($BI_{ik_{n_l}}^u(t)$ and $BI_{ik_{n_l}}^u(\overline{t})$) are generally estimated through regression analysis using empirical models. In empirical models, values of impact indicators associated with accidents can be estimated by using the "accident rate" multiplied by the cost of the accidents if they occur. Both depend on multiple factors such as the condition of the road, daily traffic volume, the physical condition of the driver of the vehicle and environmental factors such as, the occurrence of poor weather that can impact accident rate (Miaou, 1994) (Hauer, 2004).

For example, a popular way to estimate the value of impact indicators is by use of following equation (Lindenmann, 2008).

$$BI^{u}_{property,k_{n_l}} = t * DTV * s.\theta * \omega * \upsilon \tag{93}$$

Where

t: is number of days,

DTV: is daily traffic volume,

s: is length of civil infrastructure,

θ: is coefficient depending on the deterioration level of the civil infrastructure,

ω: is correction factor for accident rate,

υ: is approximate numbers of vehicles involved in an accident.

Three ways commonly used to estimate the accident rate (Tarko et al., 2000) are

1) crash rate method, which recommends a rate of crash for a specific type of road, in specific location, and with specified level of traffic volume;
2) crash equation method, which relies on a functional form of traffic volume and engineering factors;
3) crash reduction factor method, which is an extension method of crash equation method, where the crash reduction factor is given by:

$$f(X) = kYQ^{\gamma}e^{\beta x}, \tag{94}$$

Where:

$f(X)$: is crash reduction function,

k: is a constant,

Y, Q: are exposure variables representing the temporal span of data and indicate the section length and traffic volume, respectively, and

β: is an unknown parameter associated with the variable X.

X: is variable vector of engineering factors, including the performance condition of the road.

After obtaining accident rate related to the execution of an intervention for each intervention type on an each infrastructure object (i.e. between and during interventions), the value of impact indicators $BI^{u}_{ik_{n_l}}(t)$ and $BI^{u}_{ik_{n_l}}(\overline{t})$ can be calculated.

For example, after the execution of an intervention, an asphalt road section of 20 km is renewed to be in condition state 1. The daily traffic volume is 600 vehicles/day. The accident rates during and after intervention are estimated to be 0.03% and 0.005% out of the total traffic volume in a day. The duration of the intervention is 30 days. It is assumed that the average number of vehicles involved in an accident are two..

The expected total numbers of vehicles involved in accidents in a year after intervention will be:

$$BI^{u}_{property,k_{n_l}}(t = 365 \text{ days}) = 365 * 600 * 0.005\% * 2 \approx 22 \text{ vehicles}$$

The expected total numbers of vehicles involved in accidents during intervention will be:

$$BI^{u}_{property,k_{n_l}}(\bar{t} = 30 \text{ days}) = 30 * 600 * 0.03\% * 2 \approx 11 \text{ vehicles}$$

The average unit cost $c^{u}_{\text{property},k_{n_l}}(t)$ per vehicle can be approximated from historical data (Lindberg, 1999).

Travel time

The expected value of lost travel time of users in the period between interventions and during intervention can be summed up in following equations.

$$f^{k_{n_l}}_{n_l}(t, x^{u}_{travel-time}) = BI^{u}_{travel-time,k_{n_l}}(t) \cdot c^{u}_{travel-time,k_{n_l}}(t) \qquad (95)$$

$$g^{k_{n_l}}_{n_l}(\bar{t}, x^{u}_{travel-time}) = BI^{u}_{travel-time,k_{n_l}}(\bar{t}) \cdot c^{u}_{travel-time,k_{n_l}}(\bar{t}) \qquad (96)$$

Where:

$BI^{u}_{travel-time}$: is the impact indicator for the travel time.

$c^{u}_{travel-time}(t), c^{u}_{travel-time}(\bar{t})$: are unit cost (or cost rate), which are considered as functions of time t and $\bar{t}$

The values of impact indicators $BI^{u}_{travel-time,k_{n_l}}(t), BI^{u}_{travel-time,k_{n_l}}(\bar{t})$ can be approximated as a function of following variables.

$$BI^{u}_{travel-time,k_{n_l}}(t) = f(\text{speed, deterioration, DTV, road-types,...}) \qquad (97)$$

$$BI^{u}_{travel-time,k_{n_l}}(\bar{t}) = f(\text{speed, deterioration, DTV, road-types,...}) \qquad (98)$$

The selection of functional form for Eqs. (97) and (98) is a case specific matter.

Vehicle operation and maintenance

The expected value concerning the loss in operating and maintaining vehicles of users in the period between interventions and during intervention are BI^{u}_{v-main} and BI^{u}_{v-oper}, which can be estimated in following equations.

$$f^{k_{n_l}}_{n_l}(t, x^{u}_{i}) = BI^{u}_{i,k_{n_l}}(t) = \sum_{i=1}^{2}\sum_{j=1}^{J} C^{u}_{ij}(t) \cdot VH_{j}(t) \qquad (99)$$

$$g^{k_{n_l}}_{n_l}(\bar{t}, x^{u}_{i}) = BI^{u}_{i,k_{n_l}}(\bar{t}) = \sum_{i=1}^{2}\sum_{j=1}^{J} C^{u}_{ij}(\bar{t}) \cdot VH_{j}(\bar{t}) \qquad (100)$$

Where:

BI^{u}_{i}: is the impact indicator for the index i .

i: is the index for vehicle maintenance cost and vehicle cost.

VH: is total number of vehicle type j. (type j means type of vehicles such as car, truck, bus, etc). The value of VH can be obtained from examining historical record on traffic volume and annual growth of traffic volume.

The value of $C_{ij}^{u}(t)$ can be estimated by empirical study or regression analysis based on recorded numbers of bill paid for operation and maintenance respectively. To date, several models have been developed to relate such cost to deterioration or performance of the road. For example, (OCL, 1999) studied the relationship between vehicle cost and international roughness index.

Comfort

The expected values concerning comfort of users in the period between interventions and during intervention can be summed up in following equations.

$$f_{n_l}^{k_{nl}}(t, x_i^u) = \sum_{i=1}^{2} BI_{ik_{nl}}^{u}(t) \cdot c_{ik_{nl}}^{u}(t) \quad (101)$$

$$g_{n_l}^{k_{nl}}(\bar{t}, x_i^u) = \sum_{i=1}^{2} BI_{ik_{nl}}^{u}(\bar{t}) \cdot c_{ik_{nl}}^{u}(\bar{t}) \quad (102)$$

Where:

BI_i^u : is the impact indicator for the index i .

BI_i^u : is the index for physical and psychological respectively.

$c_i^u(t), c_i^u(\bar{t})$: are unit cost (or cost rate), which are considered as functions of time t and $\bar{t}$

Impact indicators associated with $BI_{\text{physical},k_{nl}}^{u}$ and $BI_{\text{psychological},k_{nl}}^{u}$ can be measured by using qualitative scale (e.g, scale from 1 to 5, with 1 is the best and 5 is the worst) or by carrying out an empirical study on the loss in effective working time if users travel on a target road link. The values of the differences between these states in these scales can be determined through willing to pay investigations.

Following proposed function can be used for estimating the values of impact indicators $BI_{\text{physical},k_{nl}}^{u}$ and $BI_{\text{psychological},k_{nl}}^{u}$.

$$BI_{i,k_{nl}}^{u} = t \cdot U \cdot \mu_i \quad (103)$$

Where:

t: is number of days.

U: is expected number of users per day, which can be approximated by means of daily traffic volume (DTV)

μ_i : is mean values of amount of impact on physical and psychological aspects. The mean value μ_i can be obtained by carrying out surveys on a population sample of the users.

For example, a survey using qualitative method on 300 users, who travel on a certain road link of 20 km, reveals a mean value $\mu_{physical} = 3.4$ (from a scale of 5) per 1 km. The daily users have a factor of 2.5 times the daily traffic volume, which is 600 vehicles/day. Thus, in 30 days, the values of $BI_{physical,k_{nl}}^{u}$ will be determined as:

$$BI_{physical,k_{nl}}^{u} = 30 * (600 * 2.5) * 3.4 = 153{,}000 \text{ units}$$

If each unit of physical impact is relatively cost 0.05 CHF, then in total 30 days, the cost incurred to users due to physical impact will be 0.05(CHF)*153,000 (units)=7,650 (CHF).

Emission

Noise

The expected values concerning noise reduction for the users in the period between interventions and during intervention can be summed up in following equations.

$$f_{n_l}^{k_{n_l}}(t, x_{noise}^u) = BI_{noise,k_{n_l}}^u(t) \cdot c_{noise}^u \tag{104}$$

$$g_{n_l}^{k_{n_l}}(\bar{t}, x_{noise}^u) = BI_{noise,k_{n_l}}^u(\bar{t}) \cdot c_{noise}^u \tag{105}$$

Where:

BI_{noise}^u : is the impact indicator concerning noise

c_{noise}^u : is unit cost (or cost rate), which are often measured in Person/dBA/day.

Impact indicators associated with $BI_{noise,k_{n_l}}^u$ can be approximated by use of following equations.

$$BI_{noise,k_{n_l}}^u = t \cdot \overline{dBA} \cdot U \quad \text{(units)} \tag{106}$$

Where

t : are number of day in between interventions and during intervention

$\overline{dBA}$: is the expected increase unit of noise (in dBA) compare to a baseline. Baseline can be a sort of value, at which, no additional compensation cost for noise is required.

U : is the expected number of users within a specific period.

For example, an intervention is scheduled in 30 days. The expected numbers of users are 300 persons. It is estimated that during intervention, the noise due to construction activities increase 2 dBA compared to the normal day without intervention. It is assumed that 1 additional level of noise has a compensation cost of 100 CHF. Using Eq. (106), the values of impact indicator will be

$$BI_{noise,k_{n_l}}^u = 30 \cdot 2 \cdot 300 = 18.000 \text{ (units)}$$

and thus, the values of function $g_{n_l}^{k_{n_l}}(\bar{t}, x_{noise}^u)$ will be

$$g_{n_l}^{k_{n_l}}(\bar{t}, x_{noise}^u) = 18000 \cdot 100 = 1.800.000 \text{ (CHF)}$$

Directly affected public

Safety

Property damage, injury, and death

The expected value of function concerning the safety can be expressed in following equations.

$$f_{n_l}^{k_{n_l}}(t, x_i^{dap}) = \sum_{i=1}^{3} BI_{ik_{n_l}}^{dap}(t) \cdot c_{ik_{n_l}}^{dap}(t) \qquad (107)$$

$$g_{n_l}^{k_{n_l}}(\bar{t}, x_i^{dap}) = \sum_{i=1}^{3} BI_{ik_{n_l}}^{dap}(\bar{t}) \cdot c_{ik_{n_l}}^{dap}(\bar{t}) \qquad (108)$$

Where:

BI_i^{dap}: is the impact indicator for index i.

i: is the indication for property damage, injury, and death respectively.

$c_i^{dap}(t), c_i^{dap}(\bar{t})$: are unit cost (or cost rate), which are considered as functions of time t and $\bar{t}$. it is noted that there cost can be estimated by using the directly affected public's willingness to pay in order to avoid property damage, injury, or death.

The values of impact indicators ($BI_{ik_{n_l}}^{dap}(t)$ and $BI_{ik_{n_l}}^{dap}(\bar{t})$) are the same with $BI_{ik_{n_l}}^{u}(t)$ and $BI_{ik_{n_l}}^{u}(\bar{t})$ of section 0 for the case of injury and death. With respect to property damage, the values of $BI_{property,k_{n_l}}^{dap}(t)$ can be estimated in a similar way of estimating the value of $BI_{property,k_{n_l}}^{u}(t)$. In this respect, Eq. (93) can be used to estimate the value of $BI_{property,k_{n_l}}^{dap}(t)$.

Operational Quality

Physical and psychological conditions

The expected values concerning the physical and psychological condition of directly affected public in the period between interventions and during intervention can be summed up in following equations.

$$f_{n_l}^{k_{n_l}}(t, x_i^{dap}) = \sum_{i=1}^{2} BI_{ik_{n_l}}^{dap}(t) \cdot c_{ik_{n_l}}^{dap}(t) \qquad (109)$$

$$g_{n_l}^{k_{n_l}}(\bar{t}, x_i^{dap}) = \sum_{i=1}^{2} BI_{ik_{n_l}}^{dap}(\bar{t}) \cdot c_{ik_{n_l}}^{dap}(\bar{t}) \qquad (110)$$

Where:

BI_i^{dap}: is the impact indicator for index i.

i: is the indication for physical and psychological respectively.

$c_i^{dap}(t), c_i^{dap}(\bar{t})$: are unit cost (or cost rate), which are estimated in daily basis (CHF/day).

Impact indicators associated with $BI^{dap}_{\text{physical},k_{n_l}}$ and $BI^{dap}_{\text{psychological},k_{n_l}}$ can be measured by using qualitative scale (e.g., scale from 1 to 5, with 1 is the best and 5 is the worst) or by carrying out an empirical study on the loss in effective working time of directly affected public due to intervention activities or bad condition of the road. The values of the differences between these states in these scales can be determined through willing to pay investigations.

Following proposed function can be used for estimating the values of impact indicators $BI^{dap}_{\text{physical},k_{n_l}}$ and $BI^{dap}_{\text{psychological},k_{n_l}}$.

$$BI^{dap}_{i,k_{n_l}} = t \cdot U \cdot \gamma_i \tag{111}$$

Where:

t : is number of days.

U : is total number of directly affected public, which can be obtained from up to date census. It is noted that the value of U in Eq. (111) is different from that of Eq. (103).

γ_i : is mean values of amount of impact on physical and psychological aspects. The mean value γ_i can be obtained by carrying surveys on a population sample of the directly affected public.

For example, a survey using qualitative method on 1000 users, who live nearby a certain road link of 20 km during the intervention period, reveals a mean value $\gamma_{physical} = 2.5$ (from a scale of 5). Thus, in 30 days, the values of $BI^{dap}_{physical,k_{n_l}}$ will be determined as:

$$BI^{dap}_{physical,k_{n_l}} = 30 * 1000 * 2.5 = 75{,}000 \text{ units}$$

If each unit of physical impact is relatively cost 2 CHF/day, then in total 30 days, the cost incurred to directly affected public due to physical impact will be 2(CHF)*75,000 (units)=150,000 (CHF).

Environment preservation (Noise)

The expected values concerning noise reduction for the directly affected public in the period between interventions and during intervention can be summed up in following equations.

$$f^{k_{n_l}}_{n_l}(t, x^{dap}_{noise}) = BI^{dap}_{noise,k_{n_l}}(t) \cdot c^{dap}_{noise} \tag{112}$$

$$g^{k_{n_l}}_{n_l}(\overline{t}, x^{dap}_{noise}) = BI^{dap}_{noise,k_{n_l}}(\overline{t}) \cdot c^{dap}_{noise} \tag{113}$$

Where:

BI^{dap}_{noise} : is the impact indicator concerning noise impact to directly affected public.

c^{dap}_{noise} : is unit cost (or cost rate), which are are often measured in Person/dBA/day.

Impact indicators associated with $BI^{dap}_{noise,k_{n_l}}$ can be approximated by using a similar function form in Eq. (106), with U is the total number of people in directly affected public.

Indirectly affected public

Safety

The expected values concerning safety for the indirectly affected public in the period between interventions and during intervention can be summed up in following equations.

$$f_{n_l}^{k_{n_l}}(t, x_i^{iap}) = \sum_{i=1}^{2} BI_{i,k_{n_l}}^{iap}(t) \cdot c^{iap} \tag{114}$$

$$g_{n_l}^{k_{n_l}}(\overline{t}, x_i^{iap}) = \sum_{i=1}^{2} BI_{i,k_{n_l}}^{iap}(\overline{t}) \cdot c^{iap} \tag{115}$$

Where

BI_i^{iap} : is the impact indicator for index i that concerning to indirectly affected public.

i : is index for injury and death

c_i^{iap} : is unit cost, which is equivalent to the wage per time unit (for example, 100 CHF/hour of working)

The values of impact indicator $BI_{i,k_{n_l}}^{iap}(t)$ can be approximated in following equation

$$BI_{i,k_{n_l}}^{iap}(t) = t \cdot \varphi \cdot a \cdot U \tag{116}$$

Where:

φ : is expected number of injury or death per time unit (day or year), which can be approximately estimated by using models for predicting accident rate (refer to section 0 and Eq. (94).

a : is expected percentage of population, who is indirectly affected by encountering the news or number of injuries or deaths. For example, one injury can affect 1% of population in a town.

U : is total number of population belong to indirectly affected public.

Socio-economic activities

Persons

Productiveness

The expected values concerning productiveness for the indirectly affected public in the period between interventions and during intervention can be summed up in following equations.

$$f_{n_l}^{k_{n_l}}(t, x_{trans-p-wt}^{iap}) = BI_{trans-p-wt,k_{n_l}}^{iap}(t) \cdot c_{trans-p-wt}^{iap} \tag{117}$$

$$f_{n_l}^{k_{n_l}}(\overline{t}, x_{trans-p-wt}^{iap}) = BI_{trans-p-wt,k_{n_l}}^{iap}(\overline{t}) \cdot c_{trans-p-wt}^{iap} \tag{118}$$

Where:

$BI^{iap}_{trans-p-wt,k_{n_l}}$: is impact indicator, which is measured in units of time. It represents the amount of lost work due to intervention within an approximate time schedule. In order to approximate the value of this impact indicator within a period of time, economic models are often used (CUBRC, 2001), (Davis, 2001), (Kumares & Samuel, 2007)

$c^{iap}_{trans-p-wt}$: is unit cost (e.g. average wage)

Health

The expected values concerning health for the indirectly affected public in the period between interventions and during intervention can be summed up in following equations.

$$f_{n_l}^{k_{n_l}}(t, x_i^{iap}) = \sum_{i=1}^{2} BI^{iap}_{i,k_{n_l}}(t) \cdot c_i^{iap} \quad (119)$$

$$f_{n_l}^{k_{n_l}}(\overline{t}, x_i^{iap}) = \sum_{i=1}^{2} BI^{iap}_{i,k_{n_l}}(\overline{t}) \cdot c_i^{iap} \quad (120)$$

Where:

$BI^{iap}_{i,k_{n_l}}(BI^{iap}_{trans-g-injury}, BI^{iap}_{trans-g-death})$: is vector of impact indicators, which is measured as numbers of injuries and death incurred in a specific time interval. Empirical models and simulations are recommended to approximate the values of these impact indicators.

i : is index for injury and death

c_i^{iap} : is unit cost for injury or death

For example, a main road to a town of 10,000 inhabitants is scheduled for renewal. The intervention time is expected to last about 60 days. Based on recent survey, in one year, there are about 9 people die out of 1000 population. Due to the intervention, it is probabilistically approximate that the number of deaths will increase with a probability of 0.05. Reasons for the increase could be due to various factors such as: the delay of medical supply or late arrival of doctor to emergency room because of traffic jam. The cost involved in a fatality case is about 2 million CHF.

Give this simple example; we can approximate the expected number of deaths due to intervention as

$$\text{Number of deaths} = 10{,}000*(9/1000)*(60/365)*0.05 = 0.74 \approx 1$$

Therefore, the increase cost (or the loss) equivalents to 1(death)*2(million) = 2 million CHF.

Goods

Productiveness
Similar to the productiveness of person, the value concerning the productiveness in terms of goods can be measured in following equations.

$$f_{n_l}^{k_{n_l}}(t, x_{trans-g-wt}^{iap}) = BI_{trans-g-wt,k_{n_l}}^{iap}(t) \cdot c_{trans-g-wt}^{iap} \quad (121)$$

$$f_{n_l}^{k_{n_l}}(\overline{t}, x_{trans-g-wt}^{iap}) = BI_{trans-g-wt,k_{n_l}}^{iap}(\overline{t}) \cdot c_{trans-g-wt}^{iap} \quad (122)$$

Where:

$BI_{trans-g-wt,k_{n_l}}^{iap}$: is impact indicator, which is measured in units of time. It represents the amount of lost work that can create added values on goods and products due to intervention within an approximate time schedule. In order to approximate the value of this impact indicator within a period of time, economic models are often used (CUBRC, 2001), (Davis, 2001), (Kumares & Samuel, 2007). It is noted here that these impact indicators can be the same with the impact indicators $BI_{trans-p-wt,k_{n_l}}^{iap}$ in section 0 as they are measured in unit of time. However, they can be significantly different depending on whether they are labour intensities or not. For example, many electronic products nowadays are manufactured in automate and robot systems.

$c_{trans-g-wt}^{iap}$: is average unit cost of the goods that can be produced or processed in a unit of time

Health
The expected values concerning the impact on health for the indirectly affected public in the period when goods cannot be delivered between interventions and during intervention can be summed up in following equations.

$$f_{n_l}^{k_{n_l}}(t, x_i^{iap}) = \sum_{i=1}^{2} BI_{i,k_{n_l}}^{iap}(t) \cdot c_i^{iap} \quad (123)$$

$$f_{n_l}^{k_{n_l}}(\overline{t}, x_i^{iap}) = \sum_{i=1}^{2} BI_{i,k_{n_l}}^{iap}(\overline{t}) \cdot c_i^{iap} \quad (124)$$

Where:

$BI_{i,k_{n_l}}^{iap}(BI_{trans-g-injury}^{iap}, BI_{trans-g-death)}^{iap}$: is vector of impact indicators, which is measured as numbers of injuries and death incurred in a specific time interval. Empirical models and simulations are recommended to approximate the values of these impact indicators.

i : is index for injury and death

c_i^{iap} : is unit cost for injury or death

For example, a main road to a town of 10,000 inhabitants is scheduled for renewal. The intervention time is expected to last about 60 days. Based on recent survey, in one year, there are about 9 people die out of 1000 population due to the lack of available goods. Due to the intervention, it is probabilistically approximate that the number of deaths will increase with a probability of 0.05. Reasons for the increase could be due to various factors such as: the delay of medical supply or late arrival of doctor to emergency room because of traffic jam. The cost involved in a fatality case is about 2 million CHF.

Give this simple example; we can approximate the expected number of deaths due to intervention as

$$\text{Number of deaths} = 10{,}000 * (9/1000) * (60/365) * 0.05 = 0.74 \approx 1$$

Therefore, the increase cost (or the loss) equivalents to 1(death)*2(million) = 2 million CHF.

Employment

The expected values concerning employment for the indirectly affected public in the period between interventions and during intervention can be summed up in following equations.

$$f_{n_l}^{k_{n_l}}(t, x_{work}^{iap}) = BI_{work,k_{n_l}}^{iap}(t) \cdot c_{work}^{iap} \tag{125}$$

$$f_{n_l}^{k_{n_l}}(\overline{t}, x_{work}^{iap}) = BI_{work,k_{n_l}}^{iap}(\overline{t}) \cdot c_{work}^{iap} \tag{126}$$

Where:

$BI_{work,k_{n_l}}^{iap}$: is impact indicator, which is measured as amount of work. In this case, it is the number of people that can be employed due to intervention. A way to approximate the number of work provided (increase or decrease) for a region is often done by means of economic models (CUBRC, 2001) (Davis, 2001) (Kumares & Samuel, 2007).

c_{work}^{iap} : is unit cost (eg. average wage)

Environment (Particle emissions)

The expected values concerning reduction of particle emissions for the indirectly affected public in the period between interventions and during intervention can be summed up in following equations.

$$f_{n_l}^{k_{n_l}}(t, x_i^{iap}) = \sum_{i=1}^{I} BI_{i,k_{n_l}}^{iap}(t) \cdot c_i^{iap} \tag{127}$$

$$f_{n_l}^{k_{n_l}}(\overline{t}, x_i^{iap}) = \sum_{i=1}^{I} BI_{i,k_{n_l}}^{iap}(\overline{t}) \cdot c_i^{iap} \tag{128}$$

$BI_{i,k_{n_l}}^{iap}$: is vector of impact indicators ($BI_{CO_2}^{iap}$., $BI_{PM_{10}}^{iap}$, BI_{NO}^{iap}, BI_{CO}^{iap}, $BI_{aldehydes}^{iap}$, $BI_{NO_2}^{iap}$, $BI_{SO_2}^{iap}$, BI_{pah}^{iap}, BI_{dust}^{iap} .), which can be measured by analysing historical records or by conducting empirical studies using emission measurement tools and instruments (HEATCO, 2002), (Kumares & Samuel, 2007).

i : is index for the name of particle emitted (CO2, PM10, NO, CO, aldehydes, NO_2, SO_2, polycyclic aromatic hydrocarbons and dust) due to interventions. The number of particle emitted can be decreased or increased if required.

c_i^{iap} : is unit cost for a unit of particle emitted to the environment. The cost per unit of particle can be approximated by empirical study. To date, several research works have attempted to establish a benchmark values (HEATCO, 2002).

An example of evaluating the environmental impact of particle emission is with mobile source emission factor model (Pollack et al., 2004). This model is mainly developed in relation with change of speed of vehicle. The emission factor (EF) is defined as follows:

$$EF_{ijk} = \sum_{m=1}^{n} [FVMT_{im}(E_{ijkm}C_{ijkm})], \quad (129)$$

Where:

EF_{ijk} : is the fleet-average emission factor for calendar year i, pollutant type j, and emission-prodang process k;

$FVMT_{im}$: is the fractional vehicle-mile travel attributed to model year m for calendar year i; E_{ijkm} and

C_{ijkm} : are the basic emission rate and correction factor for year i, pollutant j, process k, and model year m respectively.

From this equation, it is possible that the correction factor can be attributed to deterioration of infrastructure object. As the result, the marginal effect of deterioration on emission factor can be derived. The emission factor EF is then used for calculating the economic loss for respective intervention strategy.

Environment consumption

Energy

The expected values concerning energy consumption for the indirectly affected public in the period between interventions and during intervention can be summed up in following equations.

$$f_{n_l}^{k_{n_l}}(t, x_{energy}^{iap}) = \sum_{i=1}^{I} BI_{i,k_{n_l}}^{iap}(t) \cdot c_i^{iap} \quad (130)$$

$$f_{n_l}^{k_{n_l}}(\bar{t}, x_{energy}^{iap}) = \sum_{i=1}^{I} BI_{i,k_{n_l}}^{iap}(\bar{t}) \cdot c_i^{iap} \quad (131)$$

$BI_{i,k_{n_l}}^{iap}$: is vector of impact indicators concerning each type of energy source. The value of impact indicators concerning energy can be measured by the significant of unit depletion of a finite resource.

i : is index for the name of energy source.

c_i^{iap} : is unit cost for consuming an certain amount of energy source . For instance, 1 KWh of electricity generated by hydro power and geothermal energy cost in a range of 0.2 CHF and 0.25 CHF respectively.

Material

The expected values concerning energy consumption for the indirectly affected public in the period between interventions and during intervention can be summed up in following equations.

$$f_{n_l}^{k_{n_l}}(t, x_{material}^{iap}) = \sum_{i=1}^{I} BI_{i,k_{n_l}}^{iap}(t) \cdot c_i^{iap} \tag{132}$$

$$f_{n_l}^{k_{n_l}}(\bar{t}, x_{material}^{iap}) = \sum_{i=1}^{I} BI_{i,k_{n_l}}^{iap}(\bar{t}) \cdot c_i^{iap} \tag{133}$$

$BI_{i,k_{n_l}}^{iap}$: is vector of impact indicators concerning each type of materials and its value can be measured by the amount of consumed materials.

i : is index for the name of material.

c_i^{iap} : is unit cost for consuming an certain amount of material .

Land

The expected values concerning land consumption for the indirectly affected public in the period between interventions and during intervention can be summed up in following equations.

$$f_{n_l}^{k_{n_l}}(t, x_{land}^{iap}) = BI_{land,k_{n_l}}^{iap}(t) \cdot c_{land}^{iap} \tag{134}$$

$$f_{n_l}^{k_{n_l}}(\bar{t}, x_{land}^{iap}) = BI_{land,k_{n_l}}^{iap}(\bar{t}) \cdot c_{land}^{iap} \tag{135}$$

$BI_{land,k_{n_l}}^{iap}$: is area (m^2) of land that has been converted from natural state to a built state due to intervention.

c_{land}^{iap} : is unit cost for converting 1 m^2 of land from natural state to a built state.

Culture

The expected values concerning culture aspects for the indirectly affected public in the period between interventions and during intervention can be summed up in following equations.

$$f_{n_l}^{k_{n_l}}(t, x_{culture}^{iap}) = BI_{culture,k_{n_l}}^{iap}(t) \cdot c_{culture}^{iap} \tag{136}$$

$$f_{n_l}^{k_{n_l}}(\bar{t}, x_{culture}^{iap}) = BI_{culture,k_{n_l}}^{iap}(\bar{t}) \cdot c_{culture}^{iap} \tag{137}$$

$BI_{culture,k_{n_l}}^{iap}$: is a scale of impact or level of significance of intervention on the culture value or identity. The impact indicator can be measured by carrying our social survey based on the definition of quantifiable scale of impact (eg. from 1 to 10, with 1 is the least impact and 10 is heavily impact).

$c_{culture}^{iap}$: is an amount of money that the citizen is willing to pay to preserve the culture value or identity, which could be potentially ruined by a certain scale of impact due to intervention.

APPENDIX 9: Optimisation Tool – Data Sheets

Project name:	**Improvement work: Renewal and rehabilitation of engineering structure**
Project manager:	Bryan T. Adey
Country:	Switzerland
Location:	Wallis
Project description:	Intervention of a road link

This project is to implement intervention on 3 infrastructure objects of the Furkastrasse road link in the Canton of Wallis.

Project information:

1. Type of infrastructure		road links	
2. Total number of infrastructure objects		3	objects 1760 km
in which	Pavement	2	
	Overpass bridge	1	
	Underpass bridge	0	
	Ram	0	
	Tunnel	0	
	Pipeline	0	
	Other (pls specify)	0	
3. Planning horizon		30	years
4. Number of stakeholders		4	
5. Current year		2011	

Responsibile researcher for inputting the data

Name	Nam Lethanh
Titlte	Postdoc fellow, ETH
Email	lethanh@ibi.baug.ethz.ch

Figure 135 Front page of database

For the consistency of information accross fields, please spend few minutes to read following note before entering your data

information, then you can understand in next step (in sheet named intervention) the type of intervention it would be (for example, technical or non-technical interventions, intervention based on routine or renewal strategies, etc)

II- Daily Traffic information: Daily Traffic Volume (DTV) for each infrastructure objects should be entered. This information can be derived from annual traffic volume, which is often recorded by road administrators.

III - Deterioration: The deterioration of each infrastructure object will be illustrated by discrete condition state. The scale of condition state is from 1 to 5, with 1 representing the best performance of infrastructure objects (For instance, just after the construction or renewal time), condition state 5 is worse or absorbing condition state. In order to use discrete condition state. It is important to link each condition state to a range of performance indicator (for example, in pavement system, cracking is often used as performance indicator. It is measured in percentage. Condition state 1 can be a representation of cracking from 1 to 20%, and condition state 5 is with percentage of crack more than 80%). Similar approach to convert other

Defaul numbers of objects are 10, if having more than 10 objects, please copy one entire object column and paste it as new column one after the others

In remark column, you can write additional information to make things clearer.

HISTORICAL PERFORMANCE

Line No	Description	Unit	Remark	Infrastructure Objects: object 1	object 2	object 3
I	**General information**					
1	Name of infrastructure object			Road section 1	Overpass RC bridge	Road section 2
2	Structural type	type		Asphalt concrete	RC bridge	Asphalt concrete
3	Number of lanes	lane		2	2	2
4	Year of construction	year		1980	1980	
5	Design length	m		290.00	25.00	160.00
6	Design width	m		5.70	6.50	5.70
7	Design thickness of surface layer	cm		NA	NA	NA
8	Other (if applicable)			NA	NA	NA
9	Other (if applicable)			NA	NA	NA
II	**Daily traffic information (All lanes included)**					
1	Recorded year	year		2010	2010	2010
2	Total Daily Traffic Volume (DTV)	vehicles		600.00	600.00	600.00
3	Truck/Freight	vehicles		100.00	100.00	100.00
4	Light-weight car	vehicles		400.00	400.00	400.00
5	Medium-weight car	vehicles		40.00	40.00	40.00
6	Heavy-weight car	vehicles		50.00	50.00	50.00
7	Bus	vehicles		10.00	10.00	10.00
8	Shared of diesel power vehicles in total	%		33.00%	33.00%	33.00%
9	Annual growth rate of traffic volume	%		0.50%	0.50%	0.50%
III	**Deterioration**					
1	Number of discrete condition states	5	for all objects	5	5	5
2	Threhold condition state for intervention (if applicable)			4	4	4
3	Before condition state (select from drop list)	states		4	3	4
4	Before roughness index (enter actual value)	mm/km		115	100	115
5	Other performance indicator (if applicable)	%	cracking	60	40	60
6	Other performance indicator (if applicable)	%	cracking	NA	20	
7	Average survival duration	years				
8	Accident rate	No./year		5	1	1
9	Fatality rate	No./year		0	0	0
10	Injuries rate	No./year		20	3	3

Important note

If you can obtain the information related to historical of infrastructure objects in detail, please send it as separated sheet to us.

For example, data recorded from two recent inspection times on infrastructure objects. This information will help us to define exact deterioration curve and life expectanc

Figure 136 Historical information

For the consistency of information accross fields, please spend few minutes to read following note before entering your data

INTERVENTION INFORMATION

Line No	Description	Unit	Remark	Infrastructure object – object 1: Before intervention	During intervention	After intervention
I	**Basic information**					
1	Name				Road section 1	
2	Structural type				Asphalt concrete	
II	***Strategy 1 (individual intervention)***					
1	***General information***					
1.1	Name			NA	Resurfacing asphalt layer with 7 cm thickness	
1.2	Category	type		NA	Technical intervention	
1.3	Strategy	type		NA	Long-term	
1.4	Intervention type	type		NA	Major maintenance	
1.5	Intervention year	year		NA	2011	
1.6	Condition state			4		Condition 1
1.7	Performance indicator	mm/km	roughness	115	NA	30
1.8	Other performance indicator (if applicable)	%	crack	NA	NA	NA
1.9	Length	m		290	NA	290
1.10	Width	m		5.70	NA	5.70
1.11	Thickness	cm		NA	NA	7
1.12	Average survival duration	years				
2	***Cost incurred to the Owners***				66,946.50	
2.1	*Total intervention cost*	CHF		NA	66,946.50	NA
2.1.1	Labor	CHF		NA	9,918.00	NA
2.1.2	Material	CHF		NA	49,590.00	NA
2.1.3	Equipment	CHF		NA	4,959.00	NA
2.1.4	Overhead (admin)	CHF		NA	2,479.50	NA
2.2	*Intervention schedule*					
2.2.1	Early start date	dd/mm/yy		NA	1/2/2011	NA
2.2.2	Early finish date	dd/mm/yy		NA	2/1/2011	NA
2.2.3	Intervention duration	days		NA	30	NA
2.2.4	Operation cost/year	CHF				
3	***Users (DAS)***			2,655.46	5,270.70	1,753.36
3.1	Number of affected users	people/day		1200	1200	1206
3.2	Total Daily Traffic Volume (DTV)	vehicles		600.00	600.00	603.00
3.3	Truck/Freight	vehicles	truck is not permitted, therefore we have only 0% of truck in total DTV	100.00	100.00	100.50
3.4	Light-weight car	vehicles		400.00	400.00	402.00
3.5	Medium weight car	vehicles		40.00	40.00	40.20
3.6	Heavy-weight car	vehicles	heavy-weight car is not permitted	50.00	50.00	50.25
3.7	Bus	vehicles		10.00	10.00	10.05
3.8	*Safety*	CHF	per day	2,535.89	4,267.67	927.67
3.9	*Accident*	number/year	expected number of accident	1	2	1
3.9.1	Property damage	CHF	per case	0	0	0
3.9.2	Injuries	No./year		3	5	1
3.9.3	Deaths	No./year		0	0	0
3.10	*Riding comfort/Operational quality*	CHF	€/user/day	6	15	4
3.10.1	Physical	CHF	€/user/day	4	10	3
3.10.2	Phychological and aesthetics	CHF	€/user/day	2	5	1
3.11	*Travel time*	Minutes	per user/day	9	13	8
3.11.1	Work	Minutes	per user/day	7	10	6
3.11.2	Leisure	Minutes	per user/day	2	3	2
3.12	Vehicle	CHF/vehicle/day		7	11	5
3.12.1	Operation	CHF	per vehicle/day	5	8	4
3.12.2	Maintenance	CHF	per vehicle/day	2	3	1
4	***Cost attributed to neighbours (DAS)***					
4.1	Number of affected neighbours	people		500	500	500
4.2	*Safety*	CHF				
4.2.1	*Accident*					
4.2.1.1	Property damage	CHF	per case	0	0	
4.2.1.2	Injuries	CHF	per case	500	500	
4.2.1.3	Deaths	CHF	per case	2000	2000	
4.3	*Comfort*			5	8	
4.3.1	Physical	CHF	per day	4	6	
4.3.2	Phychological and aesthetics	CHF	per day	1	2	

Figure 137 Intervention information

Cost items	(Price of 2011)		
Items	unit price	currency	
Operation cost per light-weight vehicle	1.91	CHF	/hour
Operation cost per medium-weight vehicle	3.1	CHF	/hour
Operation cost per heavy-weight vehicle	6.16	CHF	/hour
Operation cost per bus	6.16	CHF	/hour
Petrol price (gasoline)	0.53	CHF	/l
Diesel price	0.58	CHF	/l
Hour wage (work)	15	CHF	/hour
Hour leisure	2	CHF	/hour
Cost per accident	45,100	CHF	/Casualty
Cost per injured	293,500	CHF	/Person
Cost per deaths	3,645,000	CHF	/Person
Cost for CO2	0.05	CHF	/kg
PM10 cost for a passager	0.0231	CHF	/hour/km
PM10 cost for a freight	0.1474	CHF	/hour/km
PM10 cost for construction	28675	CHF	/t
Nitrogen		CHF	/ppb
Carbon Monoxide (CO)		CHF	/ppm
Aldehyde		CHF	/ppb
Nitrogen dioxide		CHF	/ppb
Sulphur dioxide		CHF	/ppm
Polycyclic aromatic hydrocarbons		CHF	ng/m3
Dust	30675	CHF	/t
Average noise cost	115	CHF	/Pers/dBA

Figure 138 Cost information

APPENDIX 10: Dutch Case - General Information on A20 Highway Section

Table 38 Section parameters

Line No	Description	Unit	Infrastructure Objects							
			object 1	object 2	object 3	object 4	object 5	object 6	object 7	object 8
I	**General information**									
1	Name of infrastructure object		Overpass bridge 1	Overpass bridge 2	Overpass bridge 3	Overpass bridge 4	Overpass bridge 5	Overpass bridge 6	Overpass bridge 7	Pavement
2	Structural type	type	RC	RC	RC	RC	RC	RC	RC	asphalt concrete
3	Number of lanes	lane	8	8	8	8	8	8	8	8
4	Year of construction	year	1970	1970	1970	1970	1970	1970	1970	1970
5	Design length	m	210.00	330.00	240.00	550.00	190.00	310.00	350.00	5,720.00
6	Design width	m	15.00	30.00	15.00	30.00	30.00	30.00	30.00	30.00
7	Design thickness of surface layer	cm	5.00	5.00	5.00	5.00	5.00	5.00	5.00	6
8	Design thickness of asphalt foundation	cm	6.00	6.00	6.00	6.00	6.00	6.00	6.00	30
9	KM post		29,07-29,28	29,80-30,13	31,08-31,32	31,68-32,23	32,48-32,67	32,83-33,14	35,38-35,73	28,5-36,4
II	**Daily traffic information (All lanes included)**									
1	Recorded year	year	2009	2009	2009	2009	2009	2009	2009	2009
2	Total Daily Traffic Volume (DTV)	vehicles	159,212.00	159,212.00	159,212.00	159,212.00	159,212.00	159,212.00	159,212.00	159,212.00
3	Truck/Freight	vehicles	0.00							
4	Light-weight car (Car)	vehicles	0.00							
5	Medium-weight car (Truck)	vehicles	141,699.00	141,699.00	141,699.00	141,699.00	141,699.00	141,699.00	141,699.00	141,699.00
6	Heavy-weight car	vehicles	17,513.00	17,513.00	17,513.00	17,513.00	17,513.00	17,513.00	17,513.00	17,513.00
7	Bus	vehicles	0.00							
8	Shared of diesel power vehicles in total	%								
9	Annual growth rate of traffic volume	%	3.50%	3.50%	3.50%	3.50%	3.50%	3.50%	3.50%	3.50%
III	**Deterioration**									
1	Number of discrete condition states	5	5	5	5	5	5	5	5	3
2	Threhold condition state for intervention (if applicable)		4	4	4	4	4	4	4	2
3	Before condition state (select from drop list)	states	4	4	4	4	4	4	4	2
4	Before roughness index (enter actual value)	mm/km								
5	Other performance indicator (if applicable)	%								
6	Other performance indicator (if applicable)	%								
7	Average survival duration	years	20	20	20	20	20	20	20	7
8	average fatalities rate in Netherland	per billion vehicle-km	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7
9	average injuries rate in Netherland	per billion vehicle-km	53.9	53.9	53.9	53.9	53.9	53.9	53.9	53.9
10	Average accident rate in Netherland	per billion vehicle-km	6.16	6.16	6.16	6.16	6.16	6.16	6.16	6.16

Note: Value of average fatalities rate is taken from http://en.wikipedia.org/wiki/List_of_countries_by_traffic-related_death_rate

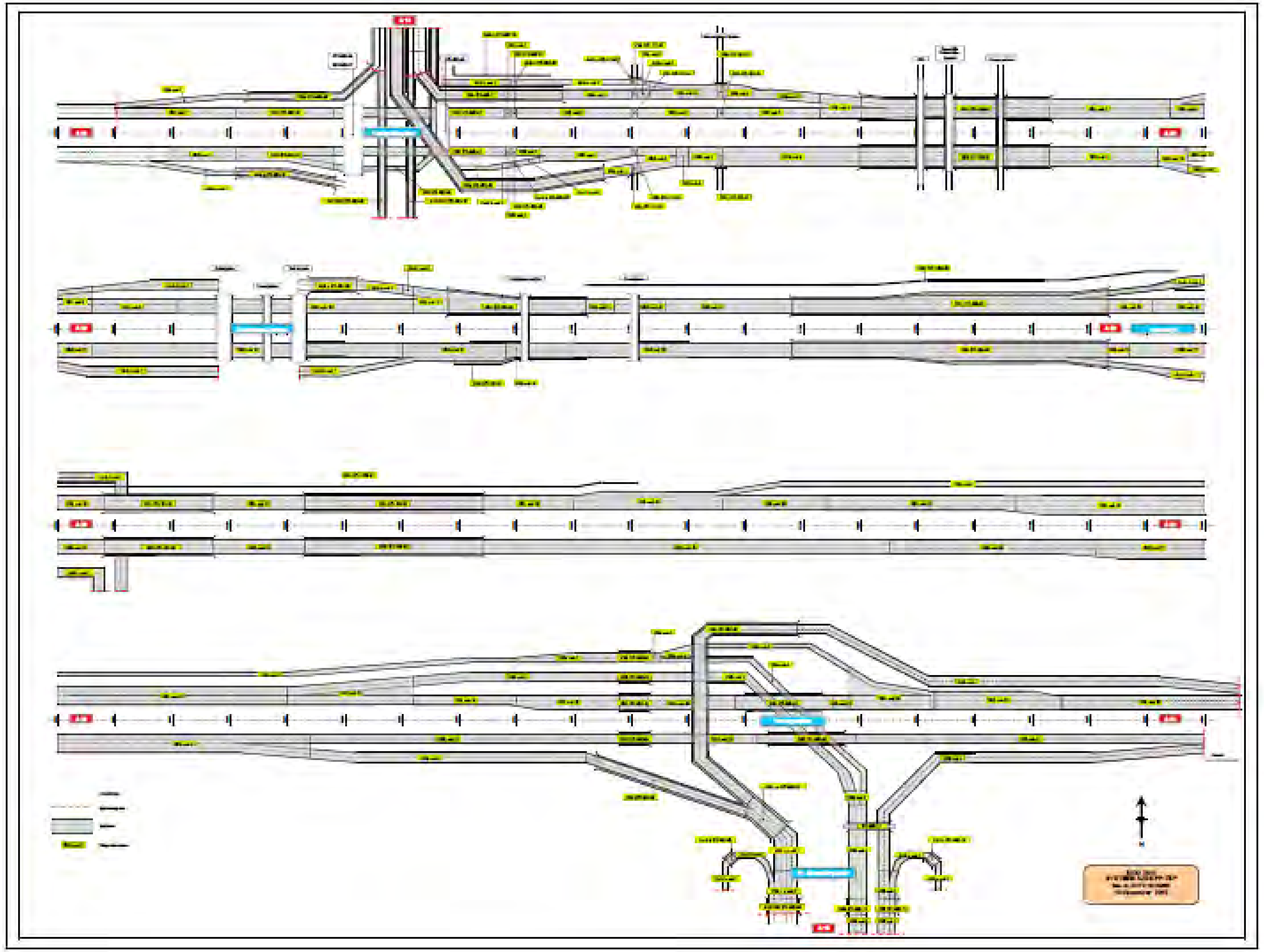


Figure 139 Section drawing

APPENDIX 11: Dutch Case – Questionnaire 1

Dutch Version

Geachte heer/mevrouw,

Rijkswaterstaat is druk bezig met het aanleggen en onderhouden van wegen in Nederland. Verschillende grote wegwerkzaamheden zijn reeds uitgevoerd, maar er staan ook nog een groot aantal projecten in de planning, waaronder de A20 tussen knooppunt Terbregseplein en Kleinpolderplein.

Het onderhoud aan de A20 tussen Terbregseplein en Kleinpolderplein bestaat uit het vernieuwen van een groot aantal voegovergangen, het vervangen van het asfalt en het vervangen of repareren van wegmeubilair. De werkzaamheden op de A20 richting Hoek van Holland zullen van zaterdagavond 30 juli tot en met zondag 7 augustus plaatsvinden. De werkzaamheden richting Gouda zullen van zondag 7 augustus tot en met maandagochtend 15 augustus plaatsvinden.

Rijkswaterstaat wil bij wegwerkzaamheden zo min mogelijk hinder veroorzaken voor weggebruikers en de omgeving. Een belangrijk onderdeel van het creëren van minder hinder tijdens wegwerkzaamheden is het luisteren naar de gebruiker en de omgeving. Daarom willen we u, vanuit de Universiteit Twente en Rijkswaterstaat, vragen deze enquête in te vullen. De enquête richt zich specifiek op de A20 waar groot onderhoud uitgevoerd gaat worden. We willen weten wat voor u belangrijk is tijdens het uitvoeren van het onderhoud en wat u verwacht van het eindresultaat van dit onderhoud.

De enquête bestaat uit vier onderdelen met in totaal 11 (hoofd)vragen en neemt 10 minuten tijd in beslag. Onder de respondenten, die na afronding van de onderhoudswerkzaamheden ook onze tweede enquête willen invullen (per e-mail), wordt ter beloning ……. verloot.

De vragen hebben betrekking op beide rijrichtingen van de A20 tussen knooppunt Terbregseplein en Kleinpolderplein, te zien in onderstaand figuur:

Al uw informatie behandelen wij vertrouwelijk. Wij rapporteren niet per individu of onderneming over de resultaten: er wordt geen beeld geschetst van de afzonderlijke bedrijven of personen.

U kunt de enquête versturen met de bijgevoegde enveloppe. Voor vragen kunt u contact opnemen met m.hietbrink@utwente.nl.

Bij voorbaat dank voor het invullen van de enquête. We zien uit naar uw reactie!

Onderdeel 1 - Algemene Vragen

1.1 Wat is uw geslacht?

Vrouw	☐	Man	☐

1.2 Wat is uw leeftijd?

18 t/m 25	☐	Tussen de 46 en 55	☐
Tussen de 26 en 35	☐	Tussen de 56 en 65	☐
Tussen de 36 en 45	☐	66 of ouder	☐

1.3 Hoe vaak rijdt u op de A20 tussen Terbregseplein en Kleinpolderplein (zie figuur in brief):

Dagelijks (5, 6 of 7 dagen per week)	☐
Enkele keren per week (2, 3 of 4 dagen per week)	☐
Eens per week (1 dag)	☐
Enkele keren per maand	☐
Minder dan eens per maand	☐
Nooit (ga door naar onderdeel 2)	☐
Weet ik niet	☐

De kilometers die u aflegt kunnen worden verdeeld naar verschillende doelen. Wij onderscheiden drie 'hoofddoelen': woon-werk (reizen van en naar uw werk), zakelijk (bijvoorbeeld reizen in het kader van uw werk) en privé. Hoe zijn de kilometers, die u over dit stuk A20 rijdt, verdeeld over de verschillende doelen? **Verdeelt u alstublieft percentages over de drie doelen, zodat deze samen optellen tot 100 %.**

Woon-Werk	_________ %
Zakelijk (anders dan woon-werk)	_________ %
Privé	_________ %
	100 %

Onderdeel 2 - Kenmerken van de A20

Bij het rijden over de A20 zijn er verschillende kenmerken van de weg die voor u als weggebruiker belangrijk kunnen zijn. We willen graag weten welke kenmerken van de A20 belangrijk voor u zijn, zodat hiermee rekening gehouden kan worden bij het plannen van onderhoud.

2.1 Hoe belangrijk vindt u de volgende kenmerken bij gebruik van de A20?

Geeft u a.u.b. met 1 t/m 8 de rangorde van de kenmerken aan. Voor het meest belangrijke kenmerk geeft u een "1" en voor het minst belangrijke kenmerk een "8". U mag ieder getal eenmaal gebruiken.

	Kenmerken A20	Rang 1-8
1	Uitstoot (emissies) veroorzaakt door de A20 (bv. geluid, uitlaatgassen)	
2	Bijdrage van de A20 aan de economie (bv. bereikbaarheid bedrijven, werkgelegenheid)	
3	Comfort bij het gebruik van de A20 (bv. kwaliteit wegdek, soepelheid van rijden)	
4	Visuele kwaliteit van de A20 (bv. schoonheid/fraaiheid omgeving)	
5	Veiligheid van de A20 (bv. risico op ongevallen en schades door ongevallen)	
6	Kosten aan voertuig veroorzaakt door de A20 (bv. schade door asfalt, benzine)	
7	Verbruik van middelen voor uitvoeren onderhoud A20 (bv. onderhoudsmateriaal, energie)	
8	Reistijd bij gebruik van de A20	

2.2 Hoe belangrijk vindt u elk kenmerk van de A20 op basis van uw gemaakte rangorde (vraag 2.1)?

Geeft u a.u.b. de belangrijkheid van elk kenmerk op een schaal van 0% (zeer onbelangrijk) tot 100% (zeer belangrijk) aan! U mag per kenmerk één vakje aankruisen.

	Kenmerken A20	Zeer onbelangrijk 0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	Zeer belangrijk 100 %	Geen mening
1	**Uitstoot** (emissies) veroorzaakt door de A20 (bv. geluid, uitlaatgassen)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
2	Bijdrage van de A20 aan de **economie** (bv. bereikbaarheid bedrijven, werkgelegenheid)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
3	**Comfort** bij het gebruik van de A20 (bv. kwaliteit wegdek, soepelheid van rijden)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
4	**Visuele kwaliteit** van de A20 (bv. schoonheid/fraaiheid omgeving)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
5	**Veiligheid** van de A20 (bv. risico op ongevallen en schades door ongevallen)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
6	**Kosten aan voertuig** veroorzaakt door de A20 (bv. schade door asfalt, benzine)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
7	**Verbruik van middelen** voor uitvoeren onderhoud A20 (bv. onderhoudsmateriaal, energie)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
8	**Reistijd** bij gebruik van de A20	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Onderdeel 3 - Verwachtingen over het onderhoud aan de A20

In dit onderdeel vragen we naar uw verwachtingen van de A20 tijdens het onderhoud en naar uw verwachtingen van de uiteindelijke verbetering aan de A20 na het onderhoud. Naast uw verwachtingen stellen we ook vragen over uw wensen met betrekking tot de verbetering van de A20.

3.1 Hoeveel denkt u, als weggebruiker, dat de onderhoudswerkzaamheden u zullen beïnvloeden?

	Zeer weinig beïnvloedt	Weinig beïnvloedt	Gemiddeld beïnvloedt	Veel beïnvloedt	Zeer veel beïnvloedt	Ik heb geen verwachting
Ik denk dat het onderhoud mij als weggebruiker:	☐	☐	☐	☐	☐	☐

→ Indien u geen verwachtingen heeft, kunt u doorgaan met vraag 3.3.

3.2 Hoeveel denkt u dat de kenmerken van de A20 tijdens de onderhoudswerkzaamheden zullen worden beïnvloed? U mag per kenmerk één vakje aankruisen.

		Zeer weinig beïnvloed wordt	Weinig beïnvloed wordt	Gemiddeld beïnvloed wordt	Veel beïnvloed wordt	Zeer veel beïnvloed wordt	Ik heb geen verwachting
	Als weggebruiker denk ik dat tijdens het onderhoud aan de A20:						
1	de **reistijd**	☐	☐	☐	☐	☐	☐
2	de **veiligheid** (bv. risico op ongevallen)	☐	☐	☐	☐	☐	☐
3	het verbruik van **middelen voor onderhoud** A20 (bv. onderhoudsmateriaal)	☐	☐	☐	☐	☐	☐
4	het **comfort** (bv. kwaliteit wegdek)	☐	☐	☐	☐	☐	☐
5	de bijdrage aan **economie** (bv. werkgelegenheid, bereikbaarheid)	☐	☐	☐	☐	☐	☐
6	de **uitstoot** (emissies) (bv. geluid, uitlaatgassen)	☐	☐	☐	☐	☐	☐
7	**kosten aan voertuig** (bv. schade door asfalt, benzine)	☐	☐	☐	☐	☐	☐
8	de **visuele kwaliteit** (bv. schoonheid/fraaiheid omgeving)	☐	☐	☐	☐	☐	☐
9	anders, namelijk ____________________	☐	☐	☐	☐	☐	☐

3.3 Hoeveel denkt u, als weggebruiker, dat de A20 verbeterd zal zijn na het onderhoud?

	Zeer weinig verbetert	Weinig verbetert	Gemiddeld verbetert	Veel verbetert	Zeer veel verbetert	Ik heb geen verwachting
Als weggebruiker denk ik dat het onderhoud de A20:	☐	☐	☐	☐	☐	☐

→ Indien u geen verwachtingen heeft, kunt u doorgaan naar vraag 3.5.

3.4 Hoeveel denkt u dat de kenmerken van de A20 verbeterd zullen zijn na het onderhoud? U mag per kenmerk één vakje aankruisen.

		Zeer weinig verbetert	Weinig verbetert	Gemiddeld verbetert	Veel verbetert	Zeer veel verbetert	Ik heb geen verwachting
	Als weggebruiker denk ik dat door het onderhoud aan de A20:						
1	de **reistijd**	☐	☐	☐	☐	☐	☐
2	de **veiligheid** (bv. risico op ongevallen)	☐	☐	☐	☐	☐	☐
3	het verbruik van **middelen voor onderhoud** A20 (bv. onderhoudsmateriaal)	☐	☐	☐	☐	☐	☐
4	het **comfort** (bv. kwaliteit wegdek)	☐	☐	☐	☐	☐	☐
5	de bijdrage aan **economie** (bv. werkgelegenheid, bereikbaarheid)	☐	☐	☐	☐	☐	☐
6	de **uitstoot** (emissies) (bv. geluid, uitlaatgassen)	☐	☐	☐	☐	☐	☐
7	**kosten aan voertuig** (bv. schade door asfalt, benzine)	☐	☐	☐	☐	☐	☐
8	de **visuele kwaliteit** (bv. schoonheid/fraaiheid omgeving)	☐	☐	☐	☐	☐	☐
9	anders, namelijk ____________________	☐	☐	☐	☐	☐	☐

3.5 Hoeveel zou u, als weggebruiker, willen dat de A20 ten opzichte van de huidige situatie verbetert na het onderhoud?

	Zeer weinig verbetert	Weinig verbetert	Gemiddeld verbetert	Veel verbetert	Zeer veel verbetert	Ik heb geen wensen
Als weggebruiker wil ik dat het onderhoud de A20:	☐	☐	☐	☐	☐	☐

→ Indien u geen wensen heeft, kunt u doorgaan naar vraag 4.1.

3.6 Hoeveel zou u, als weggebruiker, willen dat het onderhoud de kenmerken van de A20 ten opzichte van de huidige situatie verbetert? U mag per kenmerk één vakje aankruisen**.**

		Zeer weinig verbetert	Weinig verbetert	Gemiddeld verbetert	Veel verbetert	Zeer veel verbetert	Ik heb geen wensen
	Als weggebruiker wil ik dat door het onderhoud aan de A20:						
1	de **reistijd**	☐	☐	☐	☐	☐	☐
2	de **veiligheid** (bv. risico op ongevallen)	☐	☐	☐	☐	☐	☐
3	het verbruik van **middelen voor onderhoud** A20 (bv. onderhoudsmateriaal)	☐	☐	☐	☐	☐	☐
4	het **comfort** (bv. kwaliteit wegdek)	☐	☐	☐	☐	☐	☐
5	de bijdrage aan **economie** (bv. werkgelegenheid, bereikbaarheid)	☐	☐	☐	☐	☐	☐
6	de **uitstoot** (emissies) (bv. geluid, uitlaatgassen)	☐	☐	☐	☐	☐	☐
7	**kosten aan voertuig** (bv. schade door asfalt, benzine)	☐	☐	☐	☐	☐	☐
8	de **visuele kwaliteit** (bv. schoonheid/fraaiheid omgeving)	☐	☐	☐	☐	☐	☐
9	anders, namelijk ___________________	☐	☐	☐	☐	☐	☐

Onderdeel 4 - Betrokkenheid bij het onderhoud aan de A20

Dit laatste onderdeel focust op uw gewenste betrokkenheid bij het onderhoudsproject.

4.1 Hoeveel zou u, als weggebruiker, betrokken willen worden bij de planning van de werkzaamheden voor het onderhoudsproject aan de A20?

		Zeer weinig betrokken worden	Weinig betrokken worden	Gemiddeld betrokken worden	Veel betrokken worden	Zeer veel betrokken worden	Ik heb geen wens
1	Als weggebruiker wil ik bij het plannen van het onderhoud:	☐	☐	☐	☐	☐	☐

4.2 Hoeveel zou u, als weggebruiker, geïnformeerd willen worden voor aanvang van de werkzaamheden?

		Zeer weinig geïnformeerd worden	Weinig geïnformeerd worden	Gemiddeld geïnformeerd worden	Veel geïnformeerd worden	Zeer veel geïnformeerd worden	Ik heb geen wens
1	Als weggebruiker wil ik voor het onderhoud:	☐	☐	☐	☐	☐	☐

4.3 Hoe zou u, als weggebruiker, voor aanvang van de werkzaamheden geïnformeerd willen worden?

		Ja	Nee			Ja	Nee
	Als weggebruiker wil ik geïnformeerd worden door:						
1	informatiebrieven	☐	☐	6	informatiebijeenkomst	☐	☐
2	informatie in kranten	☐	☐	7	twitter/hyves/facebook	☐	☐
3	informatie op websites	☐	☐	8	sms (vrijwillig)	☐	☐
4	informatielijn met vraag en antwoord	☐	☐	9	persoonlijk gesprek	☐	☐
5	anders, namelijk ___________________	☐	☐	10	anders, namelijk ___________________	☐	☐

Hartelijk dank voor het invullen van de enquête. Het doel van het onderzoek is om na het onderhoud te onderzoeken of de verwachtingen over het onderhoud overeenkomen met de beleving van het onderhoud. Daarom zouden we graag nog eenmaal een tweede enquête willen toesturen na het onderhoud. Zou u daarom uw e-mail adres hieronder willen invullen?

Uw e-mail adres: ______________________________________

Uw e-mail adres wordt enkel gebruikt voor het versturen van de tweede vragenlijst en eventueel een bericht over de prijs die we verloten onder de respondenten die beide enquêtes invullen.
U kunt de enquête versturen met de bijgevoegde enveloppe. Een postzegel is niet nodig. Hartelijk bedankt!
Einde van de enquête.

English Version

Part 1 - General Questions

1.1 **What is your gender?**

Female	☐	Male	☐

1.2 **What is your age?**

18 - 25 years	☐	46 - 55 years	☐
26 - 35 years	☐	56 - 65 years	☐
36 - 45 years	☐	66 or older	☐

1.3 **How often do you use the.....** ?

Daily (5, 6 or 7 days per week)	☐
Several times per week (2, 3 or 4 days per week)	☐
Once in the week (1 day)	☐
Several times per month	☐
Fewer than once per month	☐
Never (continue with part 2)	☐
I do not know	☐

1.4 We distinguish three purposes of using the A20: work commuting, business travelling and private journey. To which extent do you use the A20 for the three purposes? Please allocate percentages to each purpose. The sum should be 100%.

Work Commuting	_ _ _ _ _ _ _ _ _ %
Busieness Travelling	_ _ _ _ _ _ _ _ _ %
Private Journey	_ _ _ _ _ _ _ _ _ %
	100 %

Part 2 - Characteristics of the A20

The A20 possesses several characteristics which could be important for you as a road user. We would like to know which characteristics are important to you, so that these characteristics can be considered for the planning of road maintenance.

2.1 How important are the following characteristics of the A20 to you as a road user?

Please rank the characteristics from 1 (most important) to 8 (least important). You may use each number once.

	Characteristics	Rank 1-8
1	Emissions caused by the A20 (i.e. noise, exhaust gases)	
2	Contribution of the A20 to the economy (i.e. accessibility of companies, employment opportunities)	
3	Comfort during the use of the A20 (i.e. quality of the road surface, convenience of travelling)	
4	Visual quality of the A20 (i.e. cleanliness)	
5	Safety of the A20 (i.e. risk of accidents and damages caused by accidents)	
6	Vehicle costs caused by the A20 (i.e. damages, fuel)	
7	Consumption of resources through maintenance of the A20 (i.e. material, energy)	
8	Travel time when using the A20	

2.2 **Based on your ranking (question 2.1) what is the importance of each characteristic of the A20?**

Please indicate the importance of each characteristic on a scale from 0% (very unimportant) to 100% (very important)! You may tick one box per characteristic.

Characteristics	Very unimportant 0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	Very important 100 %	No opinion
1 **Emissions** caused by the A20 (i.e. noise, exhaust gases)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
2 Contribution of the A20 to the **economy** (i.e. accessibility of companies, employment opportunities)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
3 **Comfort** during the use of the A20 (i.e. quality of the road surface, convenience of travelling)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
4 **Visual quality** of the A20 (i.e. cleanliness)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
5 **Safety** of the A20 (i.e. risk of accidents and damages caused by accidents)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
6 **Vehicle costs** caused by the A20 (i.e. damages, fuel)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
7 **Consumption of resources** through maintenance of the A20 (i.e. material, energy)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
8 **Travel time** when using the A20	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Part 3 - Expectations about the maintenance of the A20.

3.1 How much, do you think, will the maintenance work affect you as a road user?

	Very little	Little	More than a bit	Much	Very much	I do not have expectations
As a road user I think the maintenance will affect me:	☐	☐	☐	☐	☐	☐

→ If you have no expectations, please continue with question 3.3.

3.2 How much, do you think, are the characteristics of the A20 affected during the maintenance work? You may tick one box per characteristic.

		Is very little	Is little	Is more than a bit	Is great	Is very great	I do not have expectations
	As a road user I think that during the maintenance of the A20 the effect on:						
1	**Travel time**	☐	☐	☐	☐	☐	☐
2	**Safety** (i.e. risk of accidents and damages caused by accidents)	☐	☐	☐	☐	☐	☐
3	**Consumption of resources** through maintenance (i.e. material, energy)	☐	☐	☐	☐	☐	☐
4	**Comfort** (i.e. quality of the road surface, convenience of travelling)	☐	☐	☐	☐	☐	☐
5	Contribution to the **economy** (i.e. accessibility of companies, employment opportunities)	☐	☐	☐	☐	☐	☐
6	**Emissions** (i.e. noise, exhaust gases)	☐	☐	☐	☐	☐	☐
7	**Vehicle costs** (i.e. damages, fuel)	☐	☐	☐	☐	☐	☐
8	**Visual quality** (i.e. cleanliness)	☐	☐	☐	☐	☐	☐
9	Other ____________________	☐	☐	☐	☐	☐	☐

3.3 **How much, do you think as a road user, will the A20 be improved after the maintenance?**

	Very little	Little	More than a bit	Much	Very much	I do not have expectations
As a road user I think that the maintenance will improve the .A20:	☐	☐	☐	☐	☐	☐

→ If you have no expectations, please continue with question 3.5.

3.4 **How much, do you think, will the characteristics of the A20 be improved after the maintenance?** You may tick one box per characteristic.

		Very little	Little	More than a bit	Much	Very much	I do not have expectations
	As a road user I think that the maintenance of the A20 .improves:						
1	**Travel time**	☐	☐	☐	☐	☐	☐
2	**Safety** (i.e. risk of accidents and damages caused by accidents)	☐	☐	☐	☐	☐	☐
3	**Consumption of resources** through maintenance (i.e. material, energy)	☐	☐	☐	☐	☐	☐
4	**Comfort** (i.e. quality of the road surface, convenience of travelling)	☐	☐	☐	☐	☐	☐
5	Contribution to the **economy** (i.e. accessibility of companies, employment opportunities)	☐	☐	☐	☐	☐	☐
6	**Emissions** (i.e. noise, exhaust gases)	☐	☐	☐	☐	☐	☐
7	**Vehicle costs** (i.e. damages, fuel)	☐	☐	☐	☐	☐	☐
8	**Visual quality** (i.e. cleanliness)	☐	☐	☐	☐	☐	☐
9	Other ________________	☐	☐	☐	☐	☐	☐

Part 4 - Involvement in the maintenance of the A20.

The last part of the questionnaire focuses on your desired involvement in the maintenance project..

4.1 How much would you as a road user like to be involved in the planning of the maintenance work for the A20?

		Very little	Little	More than a bit	Much	Very much	I do not have expectations
1	As road user I would like to be involved in the maintenance project:	☐	☐	☐	☐	☐	☐

4.2 How much would you as road user like to be informed before the start of the maintenance work?

		Very little	Little	More than a bit	Much	Very much	I do not have expectations
1	As a road user I would like to be informed:	☐	☐	☐	☐	☐	☐

4.3 How would you as a road user like to be informed before the start of the maintenance work?

		Yes	No			Yes	No
	As a road user I would like to be informed via:						
1	Information letters	☐	☐	6	Twitter/hyves/facebook	☐	☐
2	Newspapers	☐	☐	7	Sms (voluntary)	☐	☐
3	Websites	☐	☐	8	Personal talk	☐	☐
4	Hotline	☐	☐	9	other	☐	☐
5	Information meetings	☐	☐	10	other ____________________	☐	☐

Thank you very much for answering the questions. The aim of the research is to investigate whether your expectations of the maintenance match your experience of the maintenance. Therefore, we would like to send you a second questionnaire after the maintenance. Could you please provide us with your e-mail address:

Your e-mail address: ____

Your e-mail address will be only used for sending the questionnaire and possibly informing you about the price we draw among all respondents.
You may send the questionnaire with attached envelope. A stamp is not required. Thank you very much!
End of the questionnaire.

APPENDIX 12: Dutch Case – Questionnaire 2

Dutch Version

Geachte heer/mevrouw,

Onlangs hebben we u gevraagd om een enquête in te vullen waarin we naar uw verwachtingen ten aanzien van het onderhoud aan de A20 vroegen. We hebben veel respons ontvangen op deze enquête, hartelijk dank hiervoor! Inmiddels hebben de onderhoudswerkzaamheden tussen knooppunt Terbregseplein en Kleinpolderplein plaatsgevonden (30 juli t/m 15 augustus). Zoals we in de eerste enquête al aankondigden, zouden we u graag nog eenmaal naar uw ervaringen met betrekking tot het onderhoud aan de A20 willen vragen. Met de resultaten kan RWS het onderhoud in het vervolg beter op uw wensen aansluiten.

De enquête bestaat uit drie onderdelen en neemt 10 minuten tijd in beslag. De vragen hebben betrekking op het onderhoud dat is uitgevoerd aan beide rijrichtingen van de A20 tussen knooppunt Terbregseplein en Kleinpolderplein, te zien in onderstaand figuur:

Al uw informatie behandelen wij vertrouwelijk. Wij rapporteren niet per individu of onderneming over de resultaten: er wordt geen beeld geschetst van de afzonderlijke bedrijven of personen.

Bij voorbaat dank voor het invullen van de enquête.

Onderdeel 1 – Kenmerken van de A20

1.1 Hoe belangrijk vindt u de volgende kenmerken als weggebruiker van de A20?

We willen u vragen om de volgende kenmerken van de A20 nog eenmaal te ranken, omdat u de kenmerken nu kunt bekijken vanuit uw ervaringen tijdens en na de werkzaamheden aan de A20.

Geeft u daarom a.u.b. met 1 t/m 8 de rangorde van de kenmerken aan. Voor het meest belangrijke kenmerk geeft u een "1" en voor het minst belangrijke kenmerk een "8". U mag ieder getal eenmaal gebruiken.

	Kenmerken A20	Rang 1-8
1	Uitstoot (emissies) veroorzaakt door de A20 (bv. geluid, uitlaatgassen)	
2	Bijdrage van de A20 aan de economie (bv. bereikbaarheid bedrijven, werkgelegenheid)	
3	Comfort bij het gebruik van de A20 (bv. kwaliteit wegdek, soepelheid van rijden)	
4	Visuele kwaliteit van de A20 (bv. schoonheid/fraaiheid omgeving)	
5	Veiligheid van de A20 (bv. risico op ongevallen en schades door ongevallen)	
6	Kosten aan voertuig veroorzaakt door de A20 (bv. schade door asfalt, benzine)	
7	Verbruik van middelen voor uitvoeren onderhoud A20 (bv. onderhoudsmateriaal, energie)	
8	Reistijd bij gebruik van de A20	

Onderdeel 2 – Evaluatie onderhoudswerkzaamheden

2.1 Hoeveel hebben de onderhoudswerkzaamheden u als weggebruiker beïnvloed?

	Zeer weinig beïnvloed	Weinig beïnvloed	Gemiddeld beïnvloed	Veel beïnvloed	Zeer veel beïnvloed	Weet ik niet
Het onderhoud heeft mij als weggebruiker:	☐	☐	☐	☐	☐	☐

2.2 Hoeveel zijn de kenmerken van de A20 volgens u als weggebruiker tijdens de onderhoudswerkzaamheden beïnvloed? U mag per kenmerk één vakje aankruisen.

	Zeer weinig beïnvloed is	Weinig beïnvloed is	Gemiddeld beïnvloed is	Veel beïnvloed is	Zeer veel beïnvloed is	Weet ik niet
Als weggebruiker heb ik tijdens het onderhoud aan de A20 waargenomen dat:						
de **reistijd**	☐	☐	☐	☐	☐	☐
de **veiligheid** (bv. risico op ongevallen)	☐	☐	☐	☐	☐	☐
het verbruik van **middelen voor onderhoud** A20 (bv. onderhoudsmateriaal)	☐	☐	☐	☐	☐	☐
het **comfort** (bv. kwaliteit wegdek)	☐	☐	☐	☐	☐	☐
de bijdrage aan **economie** (bv. werkgelegenheid, bereikbaarheid)	☐	☐	☐	☐	☐	☐
de **uitstoot** (emissies) (bv. geluid, uitlaatgassen)	☐	☐	☐	☐	☐	☐
kosten aan voertuig (bv. schade door asfalt, benzine)	☐	☐	☐	☐	☐	☐
de **visuele kwaliteit** (bv. schoonheid/fraaiheid omgeving)	☐	☐	☐	☐	☐	☐
anders, namelijk ____________________	☐	☐	☐	☐	☐	☐

2.3 Heeft u door deze onderhoudswerkzaamheden uw reisgedrag aangepast? U kunt meerdere antwoorden geven.

☐	ja, ik ben eerder of later gaan reizen
☐	ja, ik heb een of meerdere geplande reizen niet gemaakt (bijv. door thuis te werken)
☐	ja, ik heb een andere bestemming/locatie bezocht voor mijn bezigheden
☐	ja, ik heb een ander vervoermiddel gebruikt, namelijk ………………………………………………………………………………..
☐	ja, ik heb een andere route genomen
☐	nee, want …….

Onderdeel 3 – Evaluatie onderhoudsresultaat

3.1 Hoeveel vindt u, als weggebruiker, dat de A20 verbeterd is na het onderhoud?

	Zeer weinig verbeterd is	Weinig verbeterd is	Gemiddeld verbeterd is	Veel verbeterd is	Zeer veel verbeterd is	Weet ik niet
Als weggebruiker vind ik dat de A20:	☐	☐	☐	☐	☐	☐

3.2 Hoeveel zijn volgens u als weggebruiker de volgende kenmerken verbeterd na het onderhoud? U mag per kenmerk één vakje aankruisen**.**

		Zeer weinig verbeterd is	Weinig verbeterd is	Gemiddeld verbeterd is	Veel verbeterd is	Zeer veel verbeterd is	Weet ik niet
	Als weggebruiker heb ik na het onderhoud waargenomen dat:						
1	de **reistijd**	☐	☐	☐	☐	☐	☐
2	de **veiligheid** (bv. risico op ongevallen)	☐	☐	☐	☐	☐	☐
3	het verbruik van **middelen voor onderhoud** A20 (bv. onderhoudsmateriaal)	☐	☐	☐	☐	☐	☐
4	het **comfort** (bv. kwaliteit wegdek)	☐	☐	☐	☐	☐	☐
5	de bijdrage aan **economie** (bv. werkgelegenheid, bereikbaarheid)	☐	☐	☐	☐	☐	☐
6	de **uitstoot** (emissies) (bv. geluid, uitlaatgassen)	☐	☐	☐	☐	☐	☐
7	de **kosten aan mijn voertuig** (bv. schade door asfalt, benzine)	☐	☐	☐	☐	☐	☐
8	de **visuele kwaliteit** (bv. schoonheid/fraaiheid omgeving)	☐	☐	☐	☐	☐	☐
9	anders, namelijk ___________________	☐	☐	☐	☐	☐	☐

Onderdeel 4 – Evaluatie informatievoorziening en algemene tevredenheid

4.1 Hoeveel bent u geïnformeerd voor aanvang van de onderhoudswerkzaamheden aan de A20?

		Zeer weinig geïnformeerd	Weinig geïnformeerd	Gemiddeld geïnformeerd	Veel geïnformeerd	Zeer veel geïnformeerd	Weet ik niet
1	Als weggebruiker ben ik voor het onderhoud:	☐	☐	☐	☐	☐	☐

4.2 Op welke manier bent u geïnformeerd over de onderhoudswerkzaamheden? U mag meerdere vakjes aankruisen

☐	Informatiebrief	☐	Informatielijn met vraag en antwoord
☐	Informatie in krant	☐	Twitter/hyves/facebook
☐	Informatie op website	☐	Borden langs de weg
☐	Anders, namelijk	☐	Anders, namelijk

4.3 Kunt u aangeven per onderstaande vraag hoe tevreden u bent…..

		Zeer ontevreden	Ontevreden	Noch tevreden noch ontevreden	Tevreden	Zeer tevreden	Weet ik niet
1	met de invloed van de onderhoudswerkzaamheden op u als weggebruiker?	☐	☐	☐	☐	☐	☐
2	over de mate van verbetering van de A20 na het onderhoud?	☐	☐	☐	☐	☐	☐
3	over de mate waarin u geïnformeerd bent over de onderhoudswerkzaam- heden	☐	☐	☐	☐	☐	☐
4	over de manier waarop u geïnformeerd bent over de onderhoudswerkzaamheden?	☐	☐	☐	☐	☐	☐
5	over de gehele onderhoudswerkzaamheden aan de A20 in zijn totaliteit?	☐	☐	☐	☐	☐	☐

Hartelijk dank voor het invullen van de enquête.

U kunt de enquête versturen met de bijgevoegde enveloppe. Een postzegel is niet nodig. Hartelijk dank voor uw moeite!

English Version

Part 1 – Characteristics of the A20

1.1 How important are the following characteristics of the A20 to you as a road user?

We would like to ask you once more to rank order the characteristics of the A20.

Please rank the characteristics from 1 (most important) to 8 (least important). You may use each number once.

	Characteristics	Rank 1-8
1	Emissions caused by the A20 (i.e. noise, exhaust gases)	
2	Contribution of the A20 to the economy (i.e. accessibility of companies, employment opportunities)	
3	Comfort during the use of the A20 (i.e. quality of the road surface, convenience of travelling)	
4	Visual quality of the A20 (i.e. cleanliness)	
5	Safety of the A20 (i.e. risk of accidents and damages caused by accidents)	
6	Vehicle costs caused by the A20 (i.e. damages, fuel)	
7	Consumption of resources through maintenance of the A20 (i.e. material, energy)	
8	Travel time when using the A20	

Part 2 – Evaluation of process during maintenance work

In this part we would like to know more about your experiences during the maintenance and after the maintenance. Besides your expectations we also ask you about your wishes regarding the improvement of the .....

2.1 How much did the maintenance work affect you as a road user?

	Very little	Little	More than a bit	Much	Very much	I do not have expeciences
As a road user the maintenance will affected me:	☐	☐	☐	☐	☐	☐

→ If you have no experiences, please continue with question 3.

2.2 How much were the characteristics of the A20 affected during the maintenance work? You may tick one box per characteristic.

		Was very little	Was little	Was more than a bit	Was great	Was very great	I do not have experiences
	As a road user I think that during the maintenance of the A20 the effect on:						
1	**Travel time**	☐	☐	☐	☐	☐	☐
2	**Safety** (i.e. risk of accidents and damages caused by accidents)	☐	☐	☐	☐	☐	☐
3	**Consumption of resources** through maintenance (i.e. material, energy)	☐	☐	☐	☐	☐	☐
4	**Comfort** (i.e. quality of the road surface, convenience of travelling)	☐	☐	☐	☐	☐	☐
5	Contribution to the **economy** (i.e. accessibility of companies, employment opportunities)	☐	☐	☐	☐	☐	☐
6	**Emissions** (i.e. noise, exhaust gases)	☐	☐	☐	☐	☐	☐
7	**Vehicle costs** (i.e. damages, fuel)	☐	☐	☐	☐	☐	☐
8	**Visual quality** (i.e. cleanliness)	☐	☐	☐	☐	☐	☐
9	Other ________________	☐	☐	☐	☐	☐	☐

Part 3 – Evaluation of results of maintenance work

3.3 How much, do you think as a road user, is the A20 improved after the maintenance?

	Very little	Little	More than a bit	Much	Very much	I do not have experiences
As a road user I think that the maintenance improved the A20:	☐	☐	☐	☐	☐	☐

→ If you have no experiences, please continue with question 4.

3.5 How much, do you think, are the characteristics of the A20 improved after the maintenance? You may tick one box per characteristic.

		Very little	Little	More than a bit	Much	Very much	I do not have experiences
	As a road user I think that the maintenance of the A20 improved:						
1	**Travel time**	☐	☐	☐	☐	☐	☐
2	**Safety** (i.e. risk of accidents and damages caused by accidents)	☐	☐	☐	☐	☐	☐
3	**Consumption of resources** through maintenance (i.e. material, energy)	☐	☐	☐	☐	☐	☐
4	**Comfort** (i.e. quality of the road surface, convenience of travelling)	☐	☐	☐	☐	☐	☐
5	Contribution to the **economy** (i.e. accessibility of companies)	☐	☐	☐	☐	☐	☐
6	**Emissions** (i.e. noise, exhaust gases)	☐	☐	☐	☐	☐	☐
7	**Vehicle costs** (i.e. damages, fuel)	☐	☐	☐	☐	☐	☐
8	**Visual quality** (i.e. cleanliness)	☐	☐	☐	☐	☐	☐
9	Other ____________________	☐	☐	☐	☐	☐	☐

Part 4 – Evaluation of information provision and satisfaction

4.1 How much were you informed before the maintenance of the A20?

		Very little informed	Little informed	More than a bit informed	Much informed	Very much informed	I do not know
1	As road user I was:	☐	☐	☐	☐	☐	☐

4.2 How were you informed about the maintenance of the A20? You may tick more than one box.

☐	Information letter	☐	Hotline
☐	Newspaper	☐	Twitter/hyves/facebook
☐	Websites	☐	Information sign on the highway
☐	Other……………………………………………	☐	Other ………………………………………..

4.3 How satisfied are you with…..

		Very dissatisfied	Dissatisfied	Neither satisfied nor dissatisfied	Satisfied	Very satisfied	I do not knwo
1	the influence of the maintenance work on you as a road user?	☐	☐	☐	☐	☐	☐
2	the extent of improvement of the A20?	☐	☐	☐	☐	☐	☐
3	the extent of information received about the maintenance on the A20?	☐	☐	☐	☐	☐	☐
4	the way of receiving information about the maintenance work on the A20?	☐	☐	☐	☐	☐	☐
5	the maintenance work overall?	☐	☐	☐	☐	☐	☐

Thank you very much for your assistance and filling in the questionnaire.

APPENDIX 13: Dutch Case – Respondent Characteristics (Questionnaire 1)

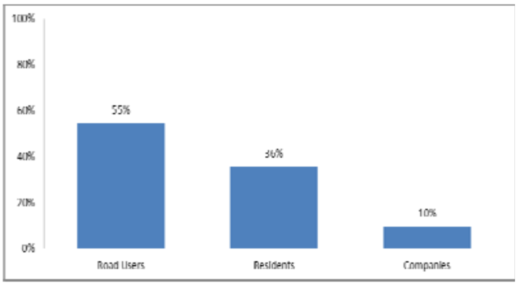


Figure 140 Stakeholder group

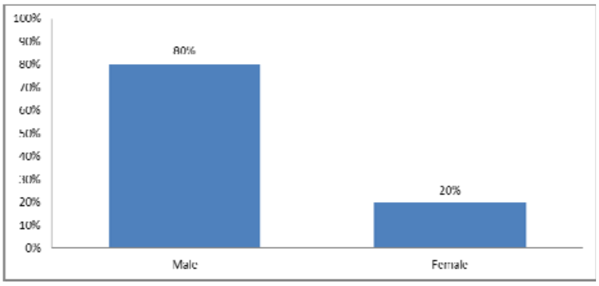


Figure 141 Gender (road user and resident)

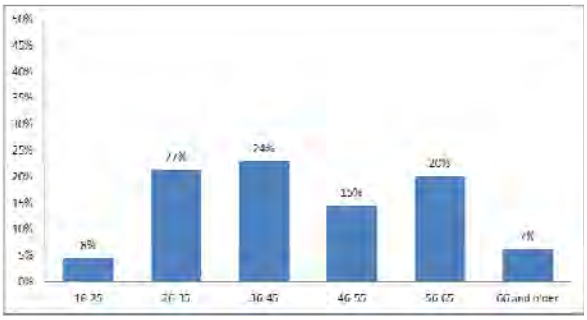


Figure 142 Age (road user and resident)

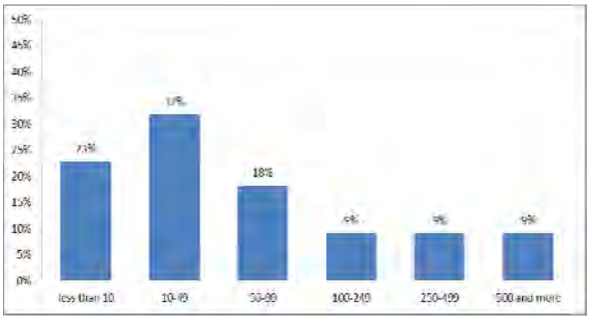


Figure 143 Size (company)

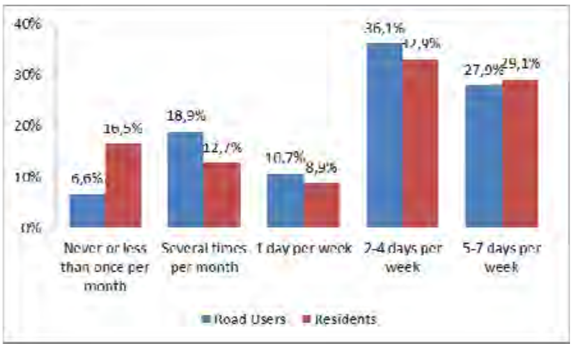


Figure 144 Frequency of road use (road user and resident)

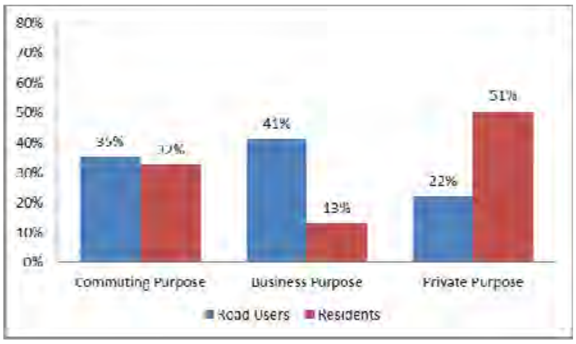


Figure 145 Travel purpose (road user and resident)

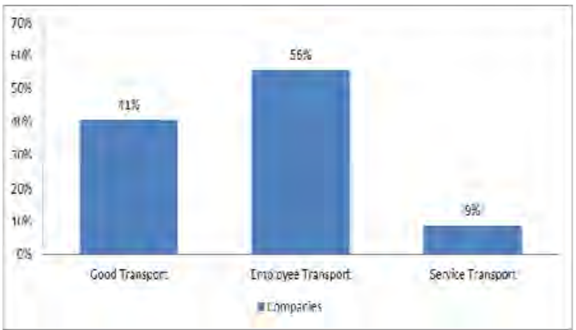


Figure 146 Transportation purpose (company)

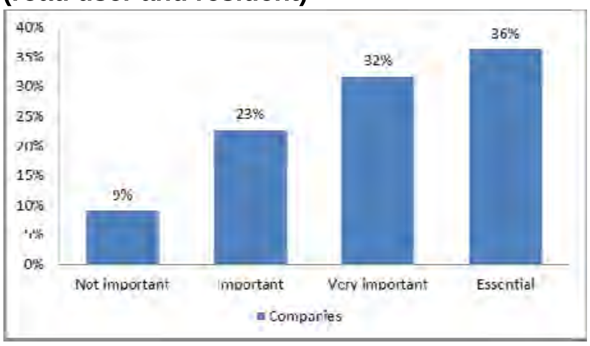


Figure 147 Road importance (company)

APPENDIX 14: Dutch Case – Traffic flows generated

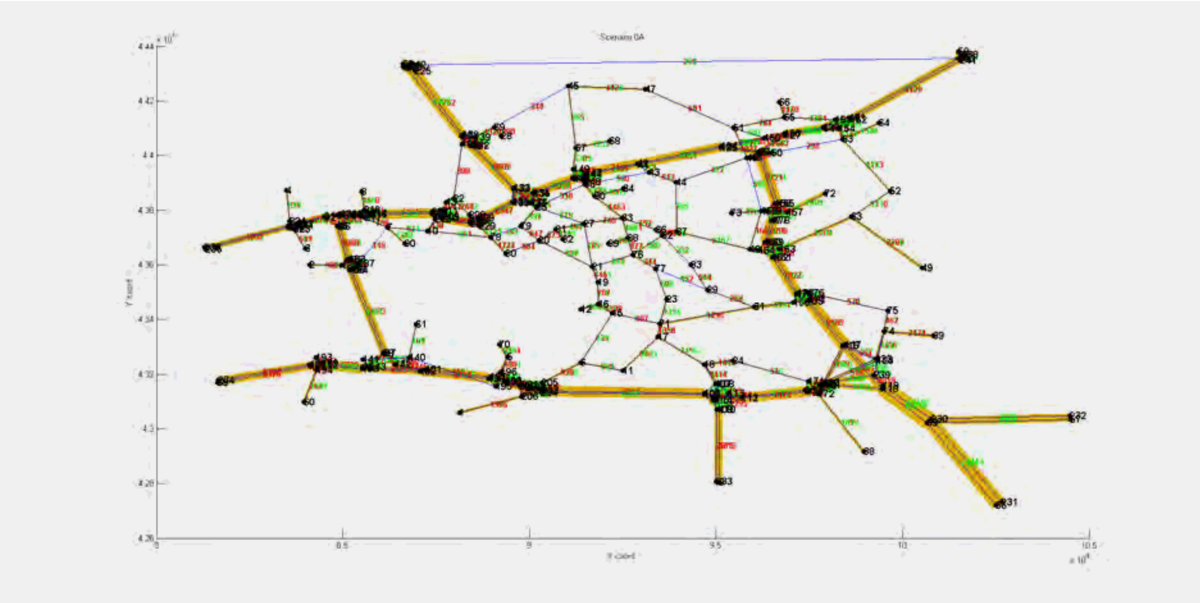


Figure 148 Base scenario at weekdays– no intervention strategy

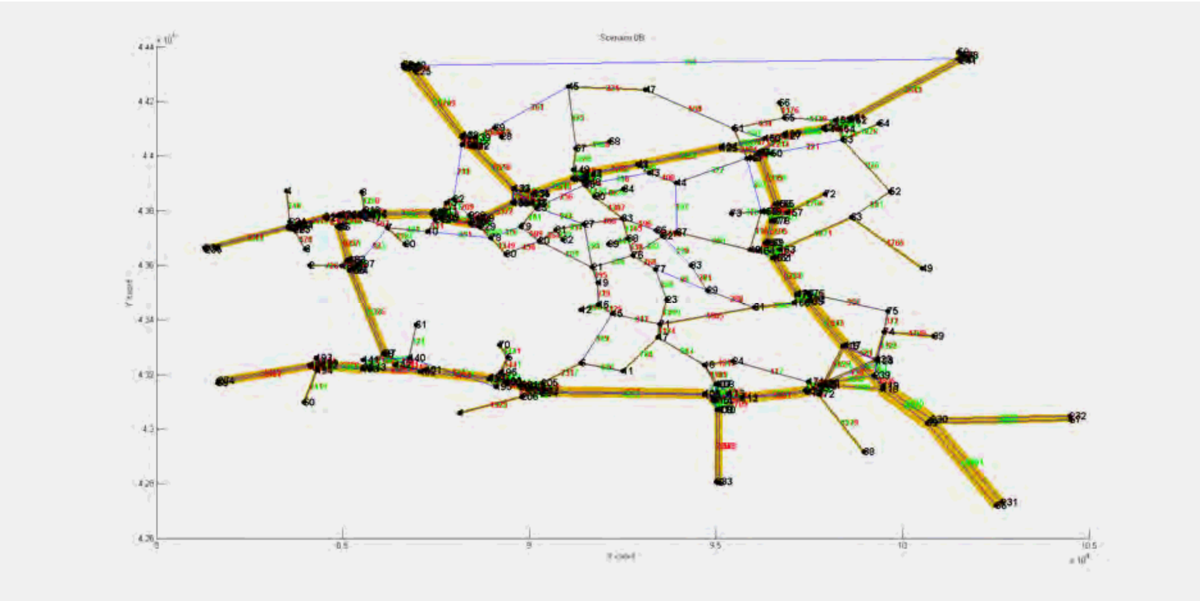


Figure 149 Base scenario at the weekend– no intervention strategy

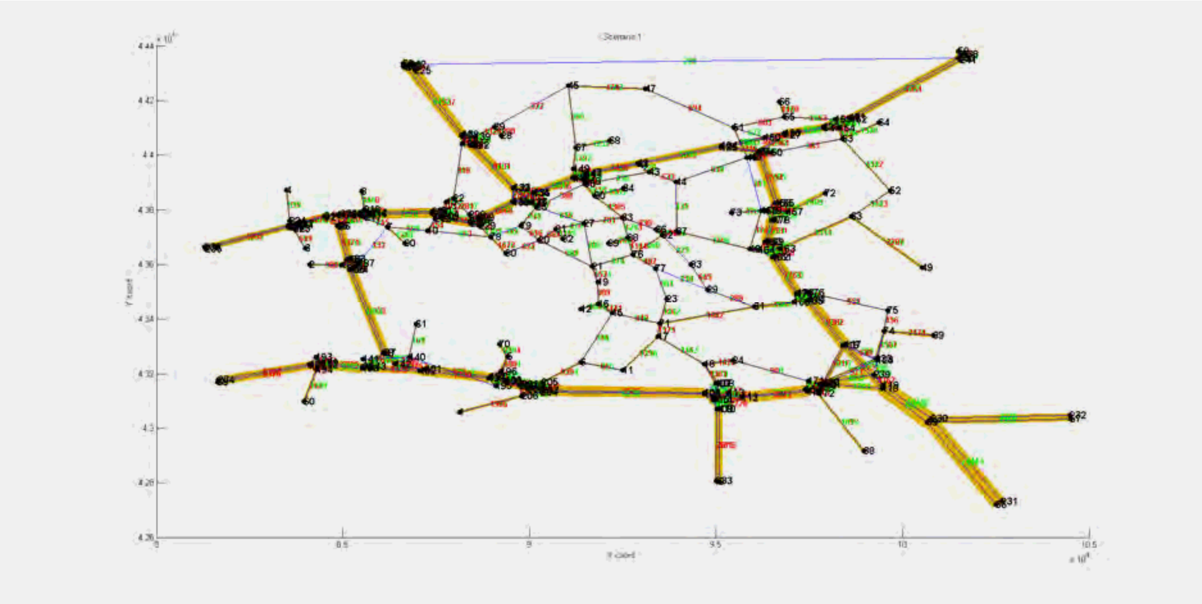


Figure 150 TC-1 - 4-0 scenario

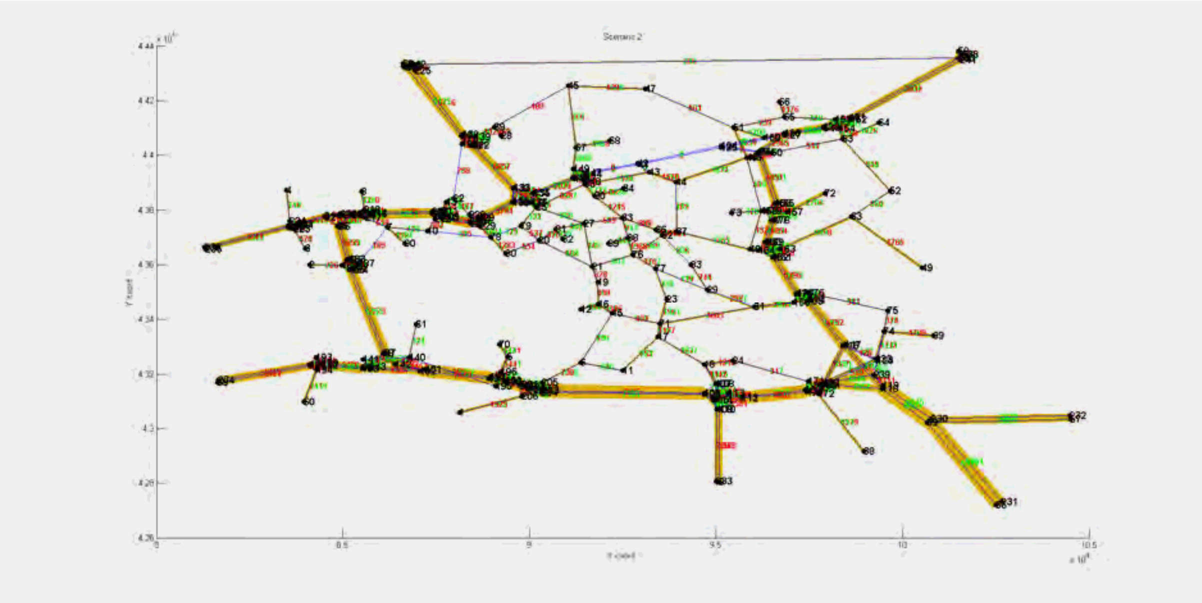


Figure 151 TC-2 - Closed in weekends

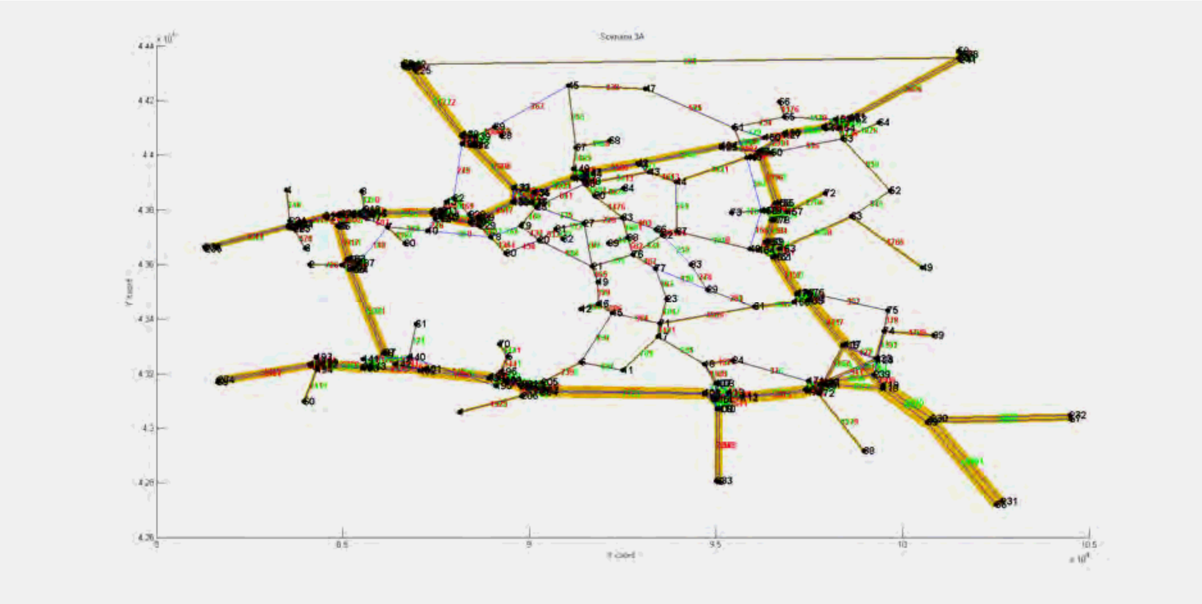


Figure 152 TC-3 - West/East closed at weekends

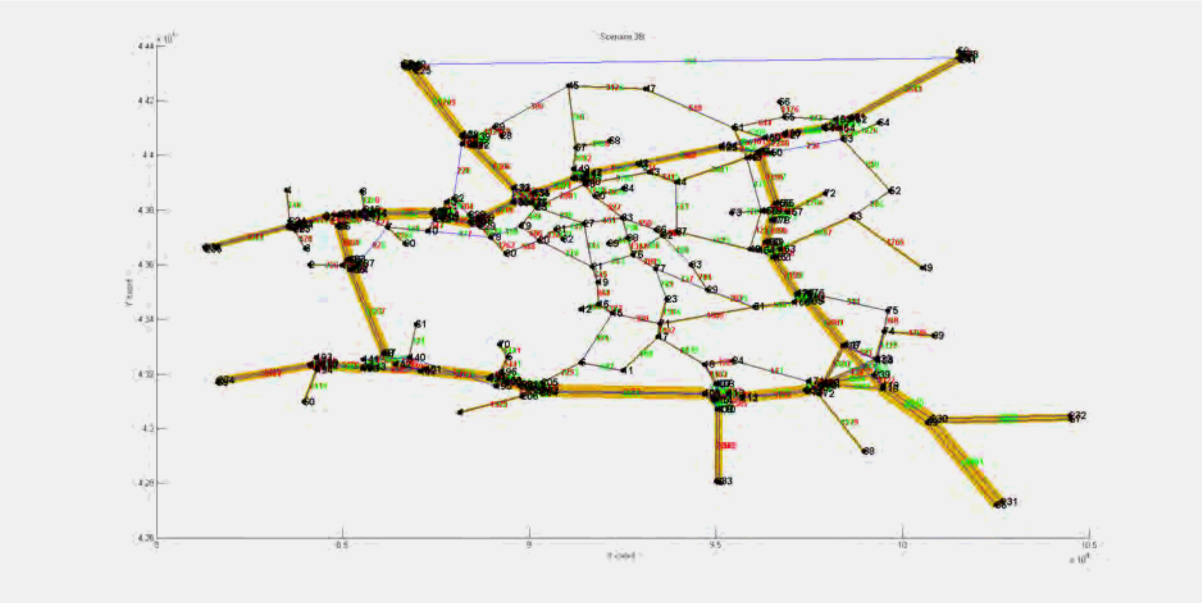


Figure 153 TC-3 - East/West closed at weekend

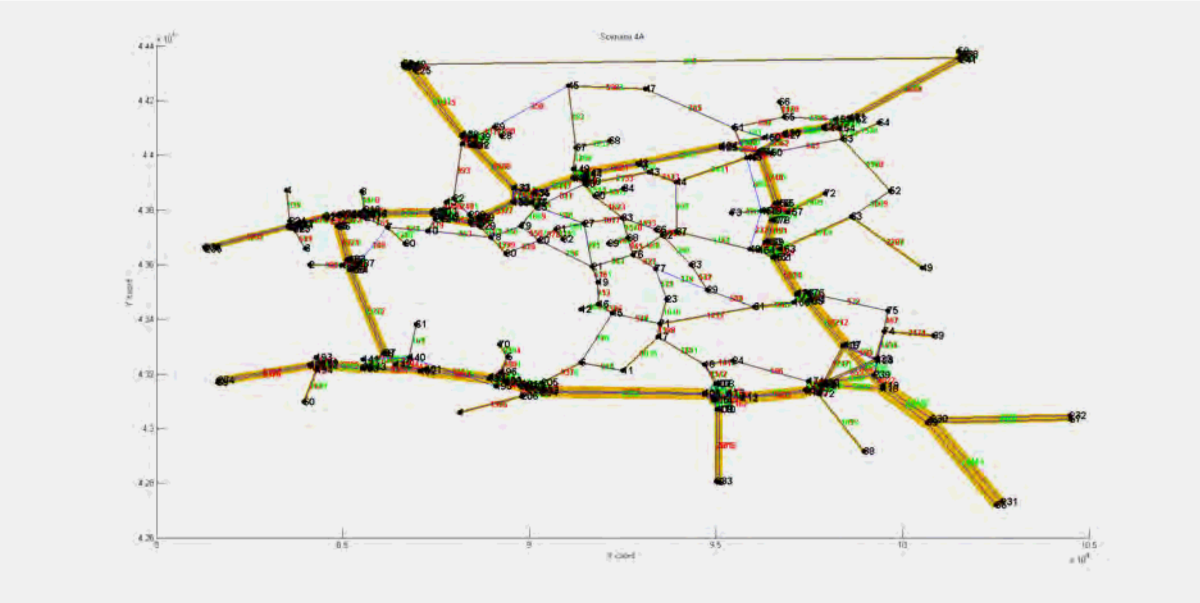


Figure 154 TC-4 - West/East closed at weekdays

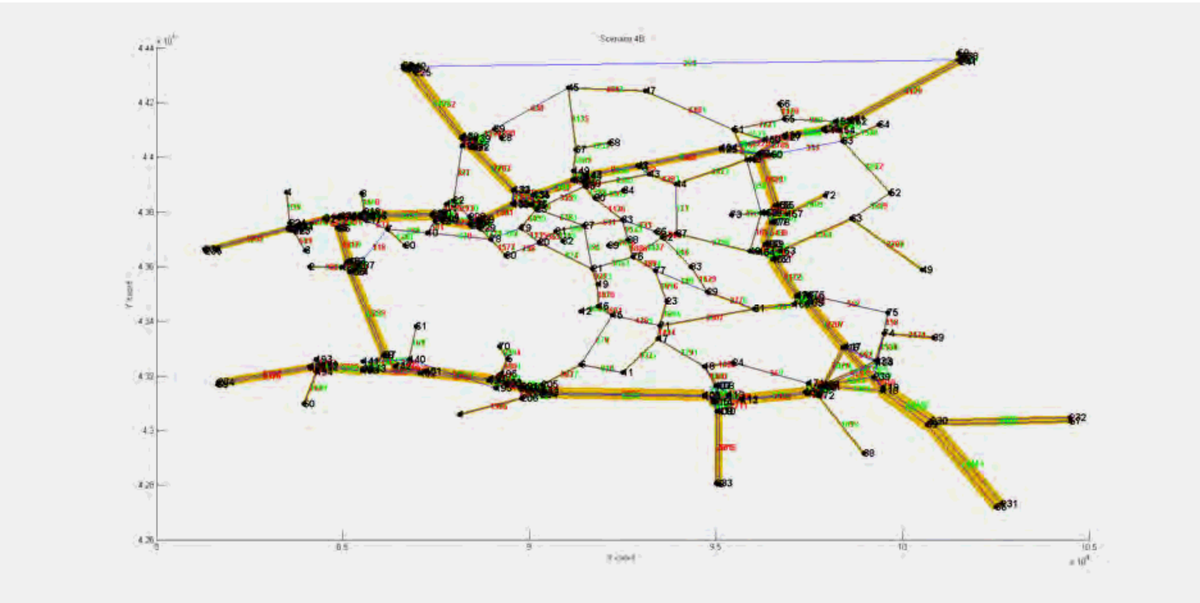


Figure 155 TC-4 – East/West closed at weekdays

APPENDIX 15: Dutch Case – Values of model parameters

Table 39 Costs incurred to stakeholder (IST-1)

Highway objects	Stakeholder groups	During interventions (g)			In between interventions (f)		
		a	*b*	*β*	*a*	*b*	*β*
object 1	(1) Owner	406’201.60	0.00	0.00	76.25	53.37	0.06
	(2) User	47’157.76	0.00	0.00	762.49	419.37	0.06
	(3) DAP	8’120.11	0.00	0.00	525.65	367.95	0.06
	(4) IAP	4’778.87	0.00	0.00	163.97	108.22	0.06
object 2	(1) Owner	676’396.00	0.00	0.00	119.82	71.89	0.06
	(2) User	67’971.65	0.00	0.00	1’198.20	659.01	0.06
	(3) DAP	8’120.03	0.00	0.00	525.68	367.97	0.06
	(4) IAP	6’190.74	0.00	0.00	257.67	170.06	0.06
object 3	(1) Owner	424’144.00	0.00	0.00	87.14	52.28	0.06
	(2) User	52’361.23	0.00	0.00	871.41	479.28	0.06
	(3) DAP	8’120.09	0.00	0.00	525.66	367.96	0.06
	(4) IAP	5’131.84	0.00	0.00	187.39	123.68	0.06
object 4	(1) Owner	918’853.60	0.00	0.00	199.70	119.82	0.06
	(2) User	95’431.31	0.00	0.00	1’996.99	1’098.35	0.06
	(3) DAP	8’119.88	0.00	0.00	525.73	368.01	0.06
	(4) IAP	8’779.18	0.00	0.00	429.45	283.43	0.06
object 5	(1) Owner	522’104.80	0.00	0.00	68.99	41.39	0.06
	(2) User	43’688.78	0.00	0.00	689.87	379.43	0.06
	(3) DAP	8’120.13	0.00	0.00	525.64	367.95	0.06
	(4) IAP	4’543.56	0.00	0.00	148.35	97.91	0.06
object 6	(1) Owner	654’354.40	0.00	0.00	112.44	67.46	0.06
	(2) User	58’472.25	0.00	0.00	1’124.40	618.42	0.06
	(3) DAP	8’120.04	0.00	0.00	525.67	367.97	0.06
	(4) IAP	5’955.43	0.00	0.00	242.05	159.75	0.06
object 7	(1) Owner	698’437.60	0.00	0.00	127.08	76.25	0.06
	(2) User	71’440.63	0.00	0.00	1’270.81	698.95	0.06
	(3) DAP	8’120.01	0.00	0.00	525.68	367.98	0.06
	(4) IAP	6’426.06	0.00	0.00	273.28	180.37	0.06
object 8	(1) Owner	2’829’334.00	0.00	0.00	3’054.22	1’832.53	0.06
	(2) User	1’994’990.31	0.00	0.00	30’542.23	16’798.23	0.06
	(3) DAP	16’231.84	0.00	0.00	774.93	542.45	0.06
	(4) IAP	136’906.76	0.00	0.00	6’567.98	4’334.87	0.06

Note: a, b, and β are cost parameters of function g and f in the deterministic model

Table 40 Costs incurred to stakeholder (IST-2)

Highway objects	Stakeholder groups	During interventions (g)			In between interventions (f)		
		a	*b*	*β*	*a*	*b*	*β*
object 1	(1) Owner	287’701.60	0.00	0.00	76.25	53.37	0.06
	(2) User	59’284.59	0.00	0.00	762.49	419.37	0.06
	(3) DAP	8’119.56	0.00	0.00	525.65	367.95	0.06
	(4) IAP	2’470.78	0.00	0.00	163.97	108.22	0.06
object 2	(1) Owner	557’896.00	0.00	0.00	119.82	71.89	0.06
	(2) User	93’161.50	0.00	0.00	1’198.20	659.01	0.06
	(3) DAP	8’119.56	0.00	0.00	525.68	367.97	0.06
	(4) IAP	3’882.65	0.00	0.00	257.67	170.06	0.06
object 3	(1) Owner	305’644.00	0.00	0.00	87.14	52.28	0.06
	(2) User	67’753.82	0.00	0.00	871.41	479.28	0.06
	(3) DAP	8’119.56	0.00	0.00	525.66	367.96	0.06
	(4) IAP	2’823.75	0.00	0.00	187.39	123.68	0.06
object 4	(1) Owner	800’353.60	0.00	0.00	199.70	119.82	0.06
	(2) User	155’269.17	0.00	0.00	1’996.99	1’098.35	0.06
	(3) DAP	8’119.56	0.00	0.00	525.73	368.01	0.06
	(4) IAP	6’471.09	0.00	0.00	429.45	283.43	0.06
object 5	(1) Owner	403’604.80	0.00	0.00	68.99	41.39	0.06
	(2) User	53’638.44	0.00	0.00	689.87	379.43	0.06
	(3) DAP	8’119.56	0.00	0.00	525.64	367.95	0.06
	(4) IAP	2’235.47	0.00	0.00	148.35	97.91	0.06
object 6	(1) Owner	535’854.40	0.00	0.00	112.44	67.46	0.06
	(2) User	87’515.35	0.00	0.00	1’124.40	618.42	0.06
	(3) DAP	8’119.56	0.00	0.00	525.67	367.97	0.06
	(4) IAP	3’647.34	0.00	0.00	242.05	159.75	0.06
object 7	(1) Owner	579’937.60	0.00	0.00	127.08	76.25	0.06
	(2) User	98’807.65	0.00	0.00	1’270.81	698.95	0.06
	(3) DAP	8’119.56	0.00	0.00	525.68	367.98	0.06
	(4) IAP	4’117.97	0.00	0.00	273.28	180.37	0.06
object 8	(1) Owner	2’760’834.00	0.00	0.00	3’054.22	1’832.53	0.06
	(2) User	3’229’598.78	0.00	0.00	30’542.23	16’798.23	0.06
	(3) DAP	16’239.12	0.00	0.00	774.93	542.45	0.06
	(4) IAP	134’598.67	0.00	0.00	6’567.98	4’334.87	0.06

Note: a, b, and *β*are cost parameters of function g and f in the deterministic model

Table 41 Costs incurred to stakeholder (IST-3)

Highway objects	Stakeholder groups	During interventions (g)			In between interventions (f)		
		a	*b*	*β*	*a*	*b*	*β*
object 1	(1) Owner	267'701.60	0.00	0.00	76.25	53.37	0.06
	(2) User	48'868.64	0.00	0.00	762.49	419.37	0.06
	(3) DAP	8'121.08	0.00	0.00	525.65	367.95	0.06
	(4) IAP	8'825.10	0.00	0.00	163.97	108.22	0.06
object 2	(1) Owner	537'896.00	0.00	0.00	119.82	71.89	0.06
	(2) User	59'932.86	0.00	0.00	1'198.20	659.01	0.06
	(3) DAP	8'120.85	0.00	0.00	525.68	367.97	0.06
	(4) IAP	10'236.97	0.00	0.00	257.67	170.06	0.06
object 3	(1) Owner	285'644.00	0.00	0.00	87.14	52.28	0.06
	(2) User	51'646.33	0.00	0.00	871.41	479.28	0.06
	(3) DAP	8'121.02	0.00	0.00	525.66	367.96	0.06
	(4) IAP	9'178.07	0.00	0.00	187.39	123.68	0.06
object 4	(1) Owner	780'353.60	0.00	0.00	199.70	119.82	0.06
	(2) User	80'148.22	0.00	0.00	1'996.99	1'098.35	0.06
	(3) DAP	8'120.43	0.00	0.00	525.73	368.01	0.06
	(4) IAP	12'825.41	0.00	0.00	429.45	283.43	0.06
object 5	(1) Owner	383'604.80	0.00	0.00	68.99	41.39	0.06
	(2) User	47'028.67	0.00	0.00	689.87	379.43	0.06
	(3) DAP	8'121.12	0.00	0.00	525.64	367.95	0.06
	(4) IAP	8'589.79	0.00	0.00	148.35	97.91	0.06
object 6	(1) Owner	515'854.40	0.00	0.00	112.44	67.46	0.06
	(2) User	58'068.52	0.00	0.00	1'124.40	618.42	0.06
	(3) DAP	8'120.89	0.00	0.00	525.67	367.97	0.06
	(4) IAP	10'001.66	0.00	0.00	242.05	159.75	0.06
object 7	(1) Owner	559'937.60	0.00	0.00	127.08	76.25	0.06
	(2) User	61'748.47	0.00	0.00	1'270.81	698.95	0.06
	(3) DAP	8'120.81	0.00	0.00	525.68	367.98	0.06
	(4) IAP	10'472.29	0.00	0.00	273.28	180.37	0.06
object 8	(1) Owner	2'660'834.00	0.00	0.00	3'054.22	1'832.53	0.06
	(2) User	1'643'443.85	0.00	0.00	30'542.23	16'798.23	0.06
	(3) DAP	16'255.56	0.00	0.00	774.93	542.45	0.06
	(4) IAP	261'685.06	0.00	0.00	6'567.98	4'334.87	0.06

Note: a, b, and *β* are cost parameters of function g and f in the deterministic model

Table 42 Costs incurred to stakeholder (IST-4)

Highway objects	Stakeholder groups	During interventions (g)			In between interventions (f)		
		a	*b*	*β*	*a*	*b*	*β*
object 1	(1) Owner	257'701.60	0.00	0.00	76.25	53.37	0.06
	(2) User	45'130.71	0.00	0.00	762.49	419.37	0.06
	(3) DAP	8'120.83	0.00	0.00	525.65	367.95	0.06
	(4) IAP	7'788.35	0.00	0.00	163.97	108.22	0.06
object 2	(1) Owner	527'896.00	0.00	0.00	119.82	71.89	0.06
	(2) User	69'122.07	0.00	0.00	1'198.20	659.01	0.06
	(3) DAP	8'120.64	0.00	0.00	525.68	367.97	0.06
	(4) IAP	9'200.22	0.00	0.00	257.67	170.06	0.06
object 3	(1) Owner	275'644.00	0.00	0.00	87.14	52.28	0.06
	(2) User	60'378.00	0.00	0.00	871.41	479.28	0.06
	(3) DAP	8'120.78	0.00	0.00	525.66	367.96	0.06
	(4) IAP	8'141.32	0.00	0.00	187.39	123.68	0.06
object 4	(1) Owner	770'353.60	0.00	0.00	199.70	119.82	0.06
	(2) User	90'496.44	0.00	0.00	1'996.99	1'098.35	0.06
	(3) DAP	8'120.28	0.00	0.00	525.73	368.01	0.06
	(4) IAP	11'788.66	0.00	0.00	429.45	283.43	0.06
object 5	(1) Owner	373'604.80	0.00	0.00	68.99	41.39	0.06
	(2) User	55'520.19	0.00	0.00	689.87	379.43	0.06
	(3) DAP	8'120.86	0.00	0.00	525.64	367.95	0.06
	(4) IAP	7'553.04	0.00	0.00	148.35	97.91	0.06
object 6	(1) Owner	505'854.40	0.00	0.00	112.44	67.46	0.06
	(2) User	67'178.94	0.00	0.00	1'124.40	618.42	0.06
	(3) DAP	8'120.67	0.00	0.00	525.67	367.97	0.06
	(4) IAP	8'964.91	0.00	0.00	242.05	159.75	0.06
object 7	(1) Owner	549'937.60	0.00	0.00	127.08	76.25	0.06
	(2) User	34'004.69	0.00	0.00	1'270.81	698.95	0.06
	(3) DAP	8'119.00	0.00	0.00	525.68	367.98	0.06
	(4) IAP	4'117.97	0.00	0.00	273.28	180.37	0.06
object 8	(1) Owner	2'700'834.00	0.00	0.00	3'054.22	1'832.53	0.06
	(2) User	1'995'736.80	0.00	0.00	30'542.23	16'798.23	0.06
	(3) DAP	16'252.88	0.00	0.00	774.93	542.45	0.06
	(4) IAP	240'950.04	0.00	0.00	6'567.98	4'334.87	0.06

Note: a, b, and *β* are cost parameters of function g and f in the deterministic mode

APPENDIX 16: Dutch Case – Impacts During Interventions

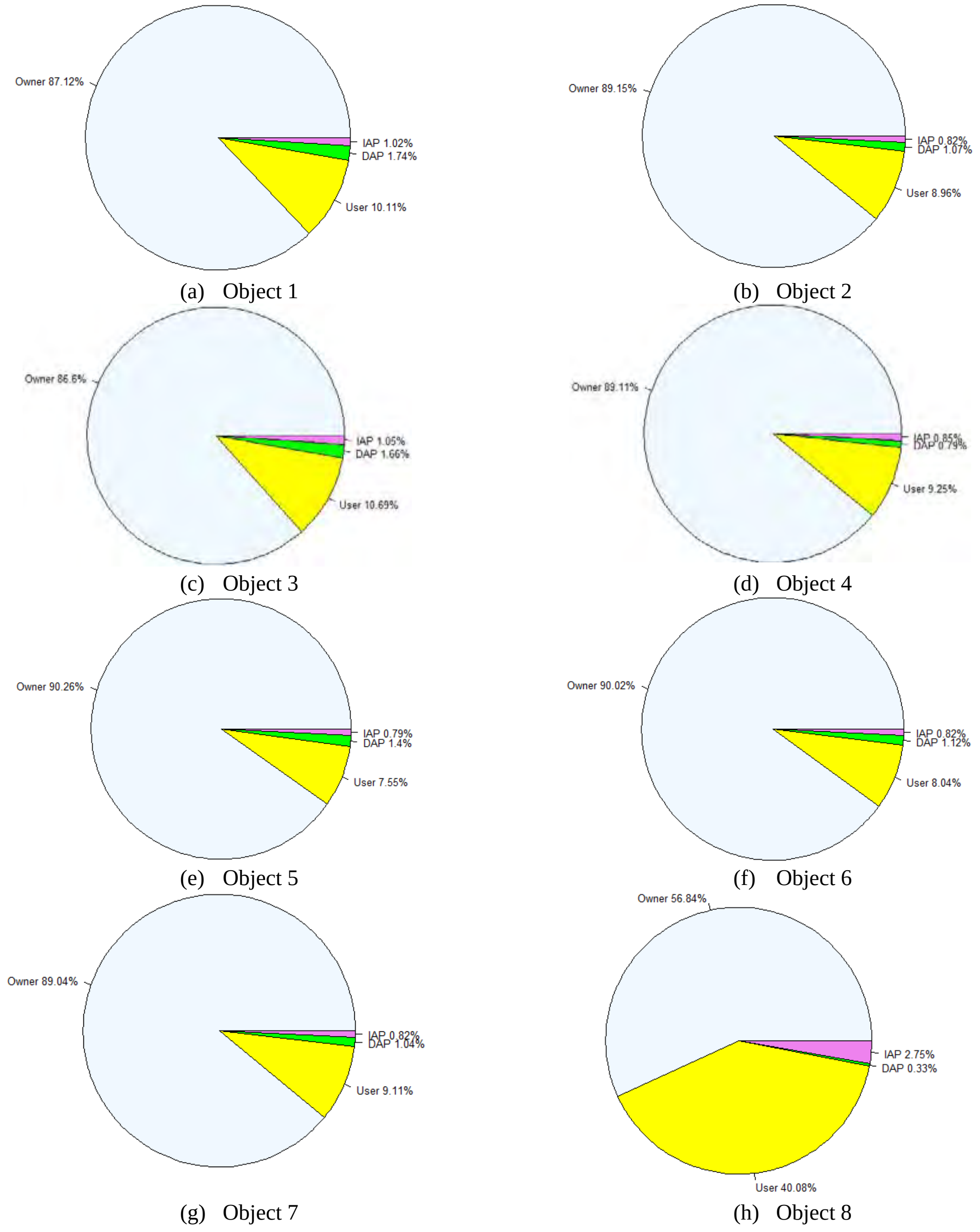


Figure 156 Impacts during intervention period (IST-1)

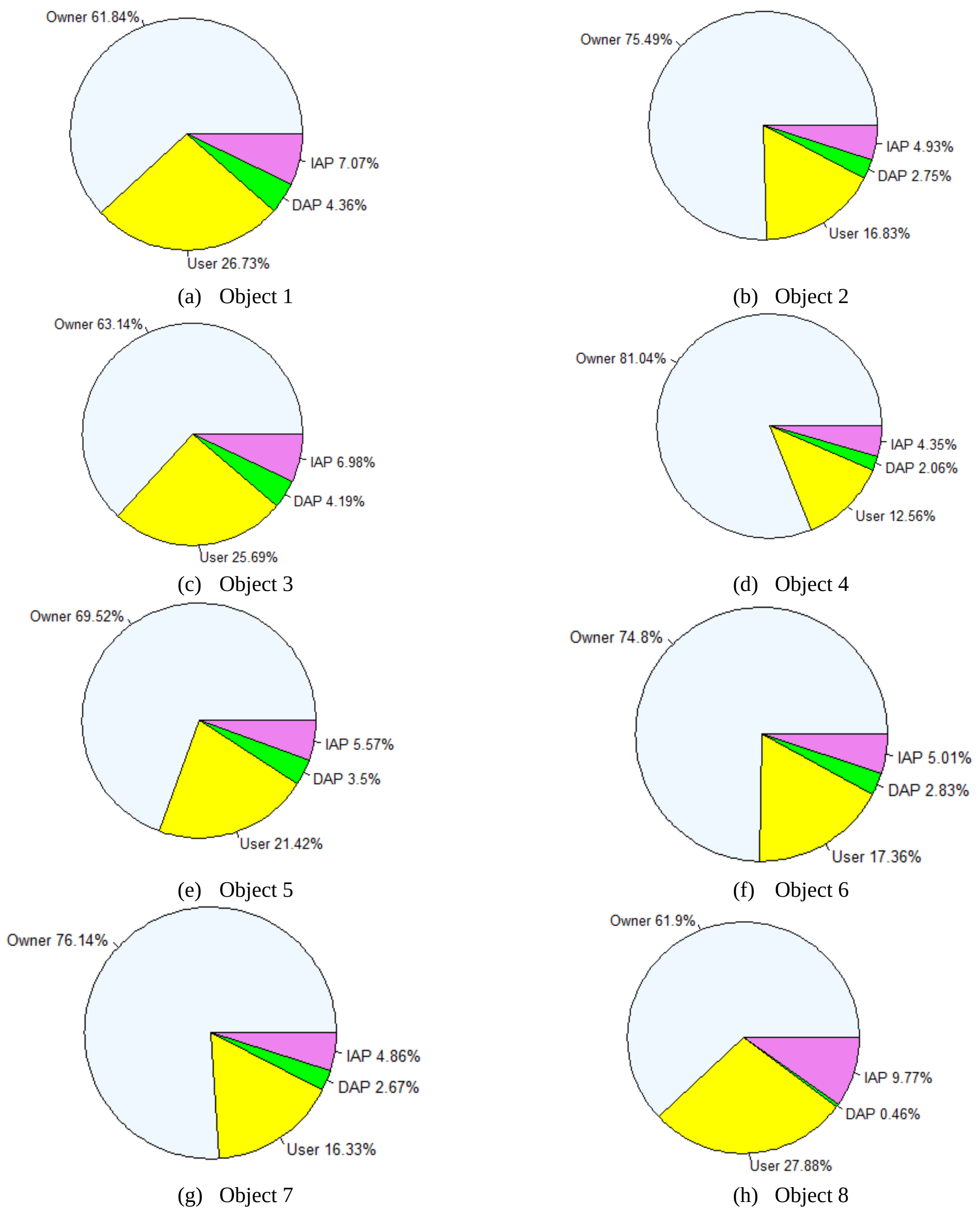


Figure 157 Impacts during intervention period (IST-2)

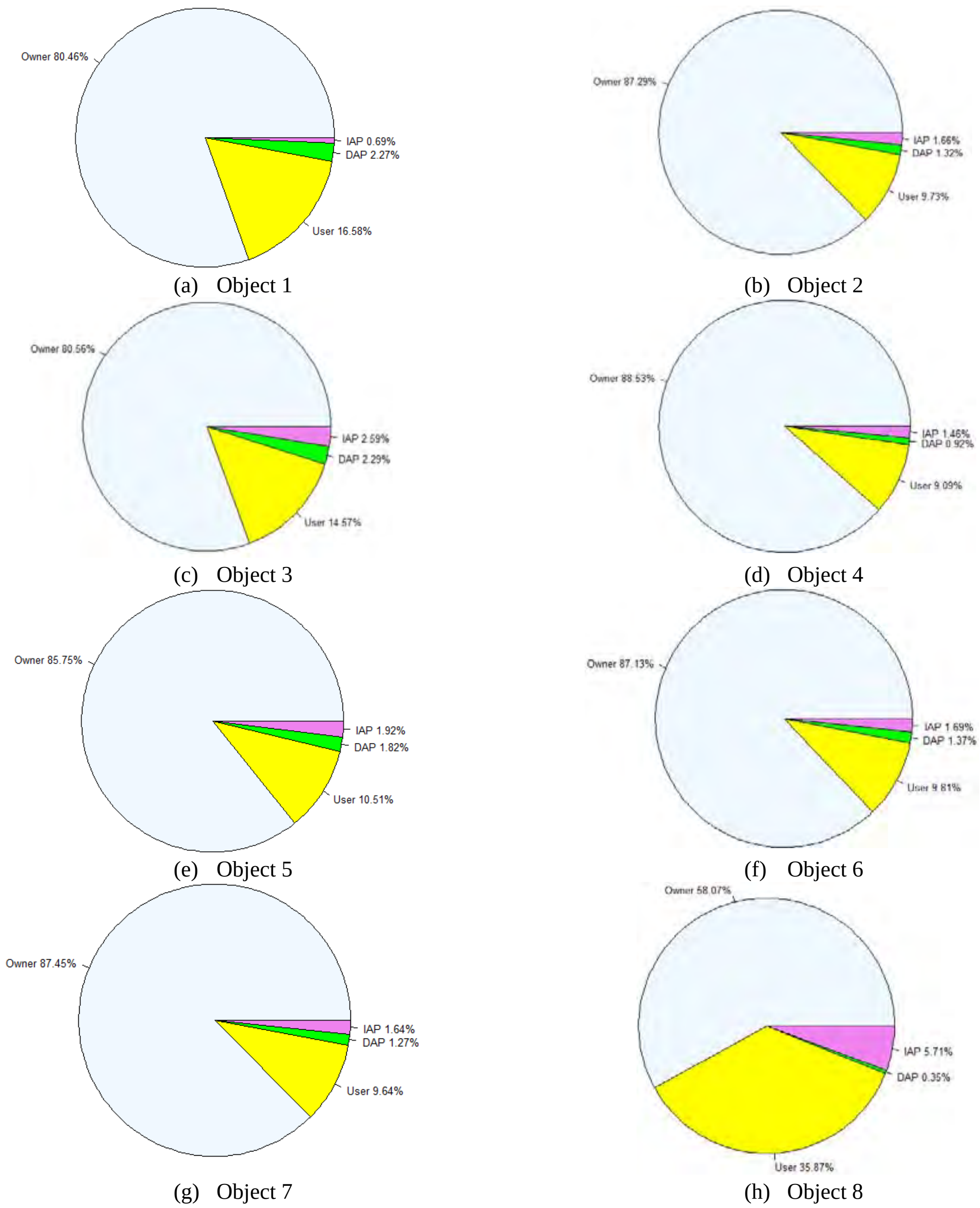
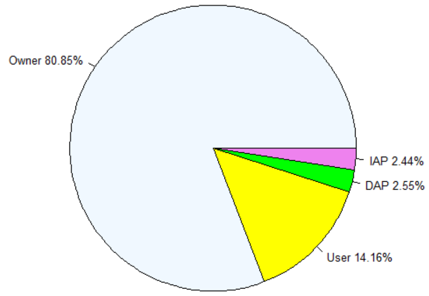
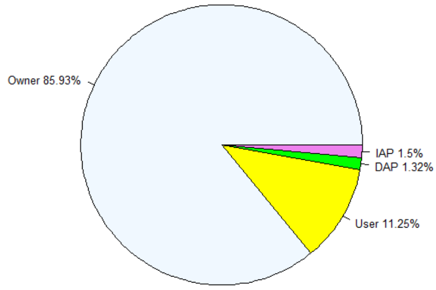


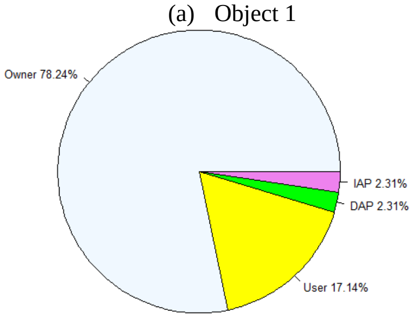
Figure 158 Impacts during intervention period (IST-3)



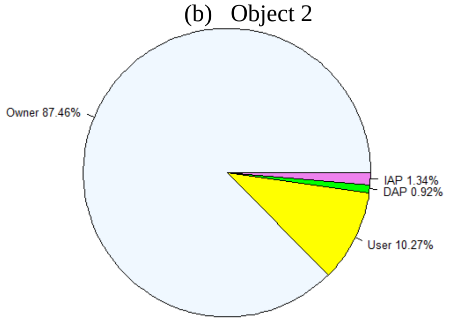
(a) Object 1



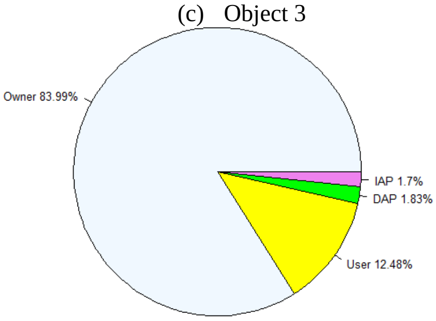
(b) Object 2



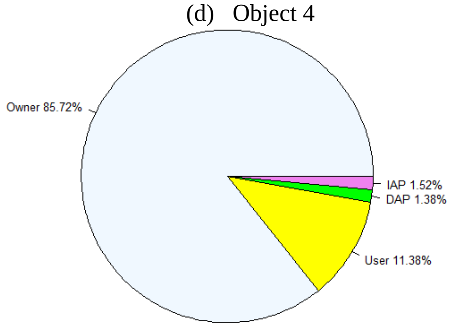
(c) Object 3



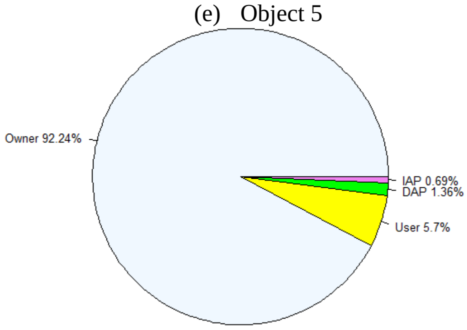
(d) Object 4



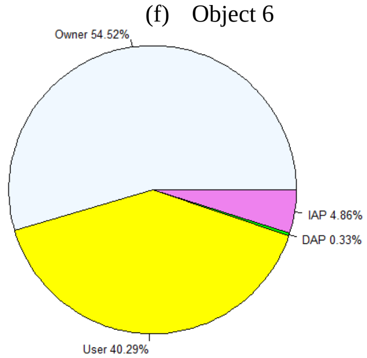
(e) Object 5



(f) Object 6



(g) Object 7



(h) Object 8

Figure 159 Impacts during intervention period (IST-4)

APPENDIX 17: Dutch Case –Impact Development Between Interventions

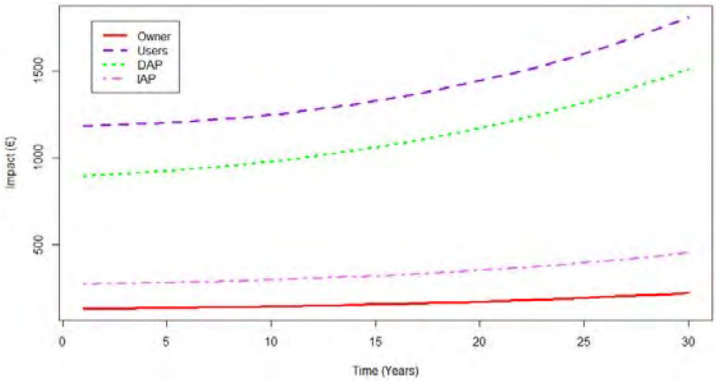


Figure 160 Impacts in between intervention (object 1)

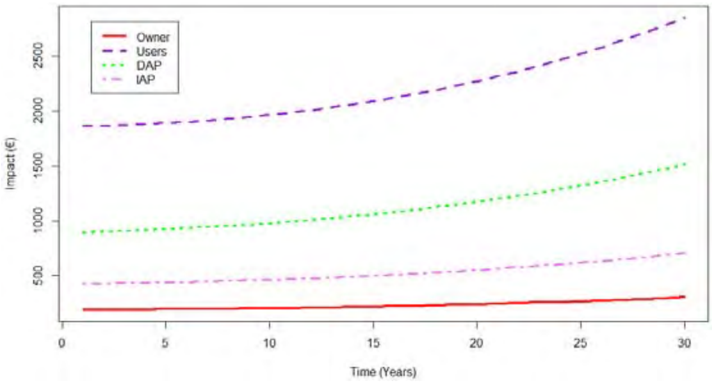


Figure 161 Impacts in between intervention (object 2)

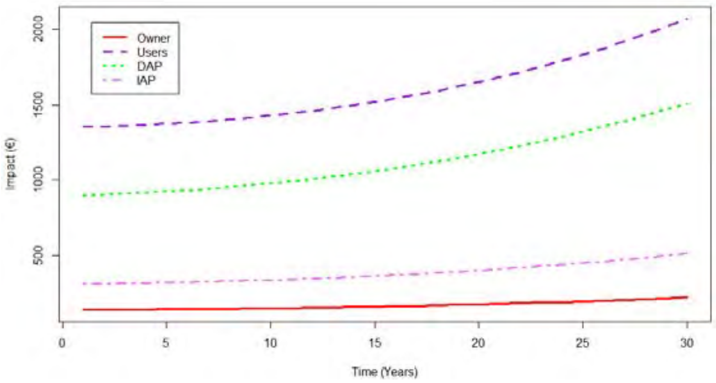


Figure 162 Impacts in between intervention (object 3)

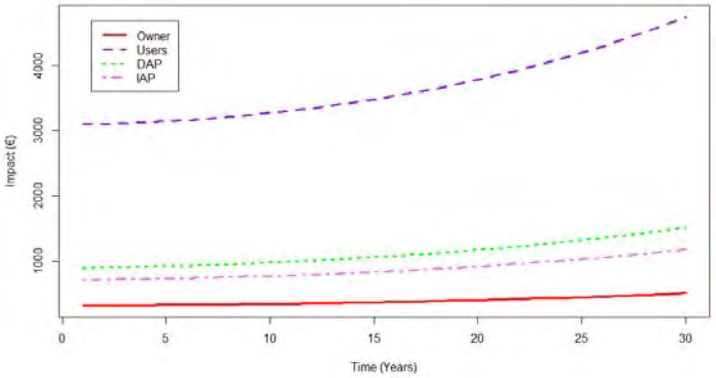


Figure 163 Impacts in between intervention (object 4)

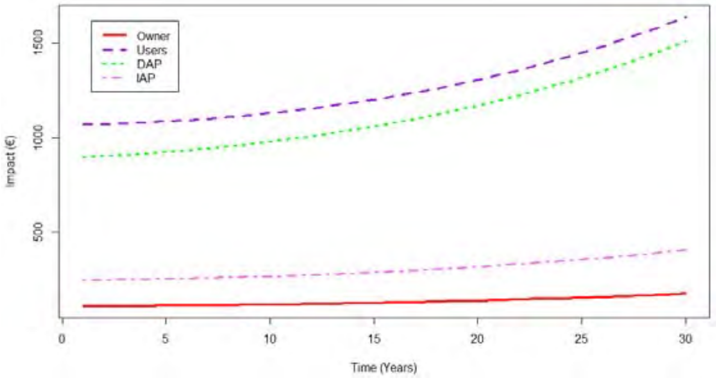


Figure 164 Impacts in between intervention (object 5)

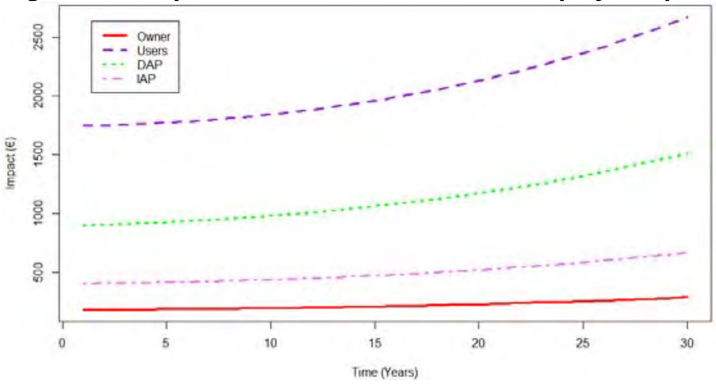


Figure 165 Impacts in between intervention (object 6)

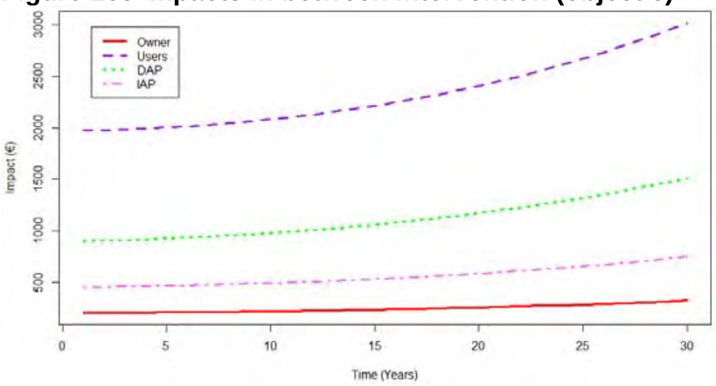


Figure 166 Impacts in between intervention (object 7)

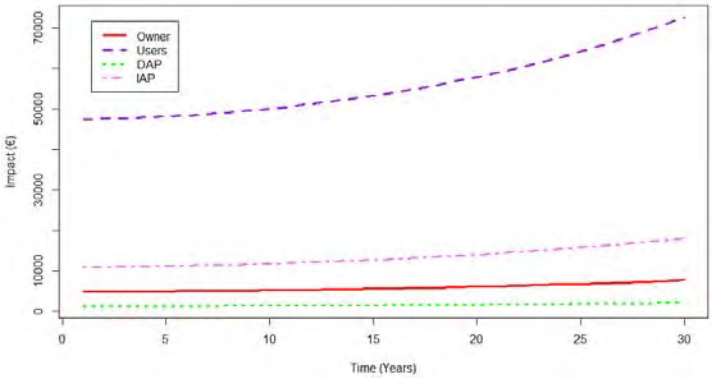


Figure 167 Impacts in between intervention (object 8)

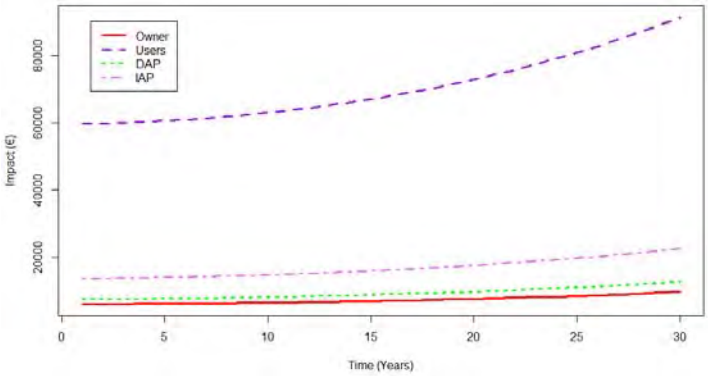


Figure 168 Impacts in between intervention (total)

APPENDIX 18: Dutch Case – Intervention Time and Evolution of Impacts

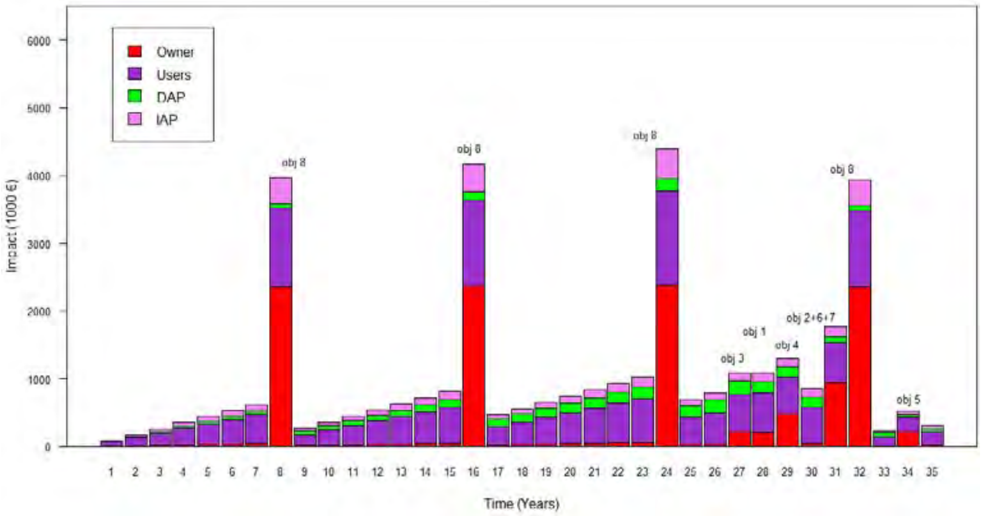


Figure 169 Intervention time and impact evolution (IS-2)

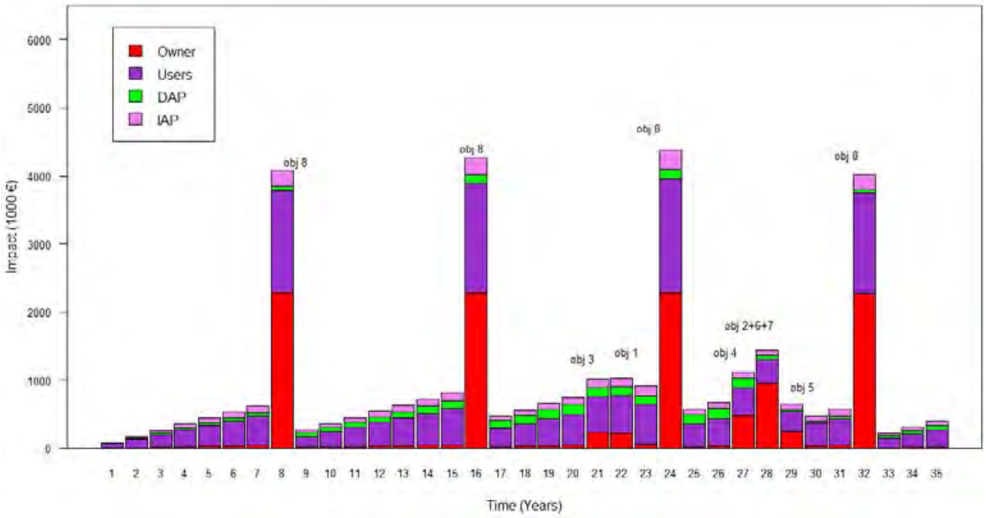


Figure 170 Intervention time and impact evolution (IS-3)

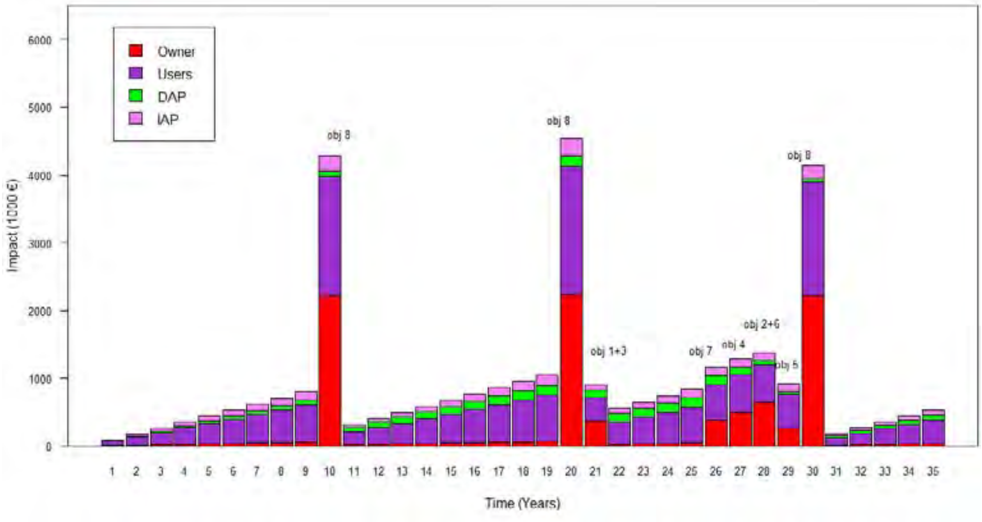


Figure 171 Intervention time and impact evolution (IS-4)

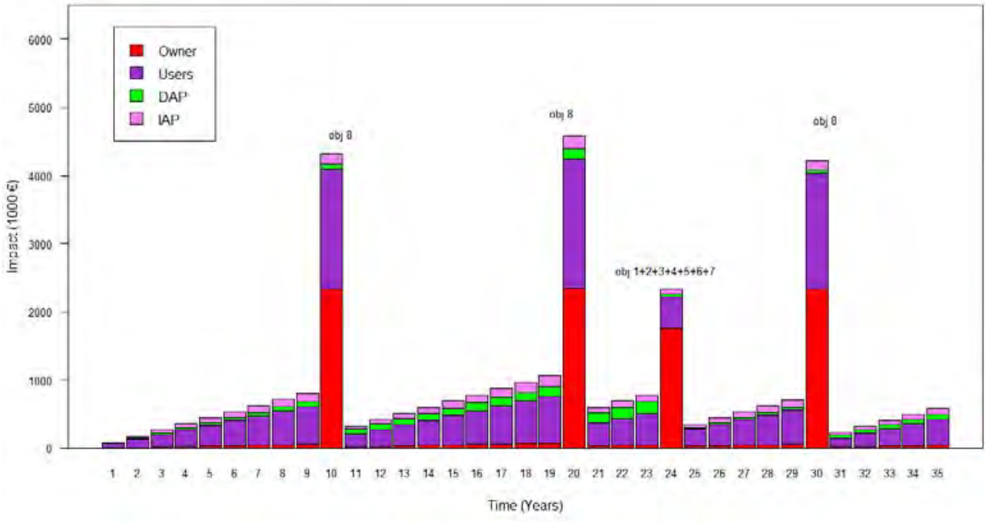


Figure 172 Intervention time and impact evolution (IS-5)

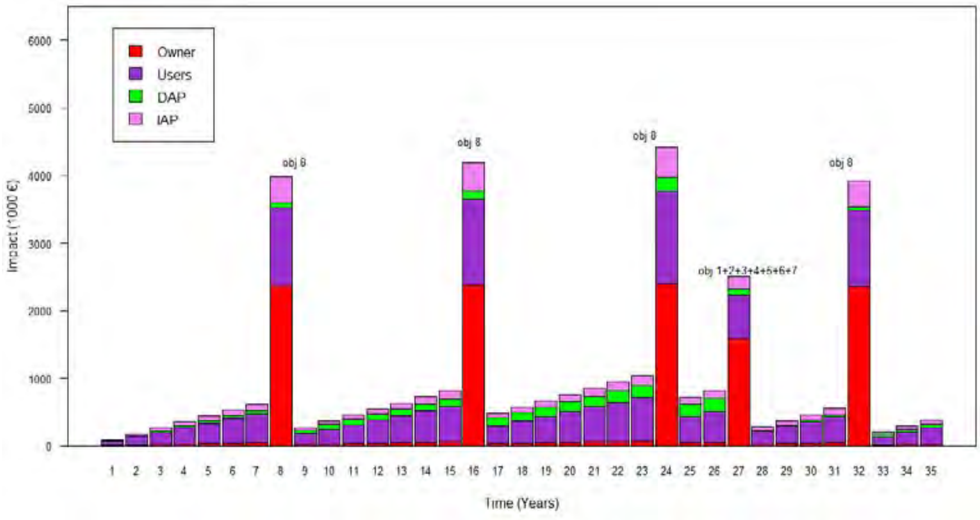


Figure 173 Intervention time and impact evolution (IS-6)

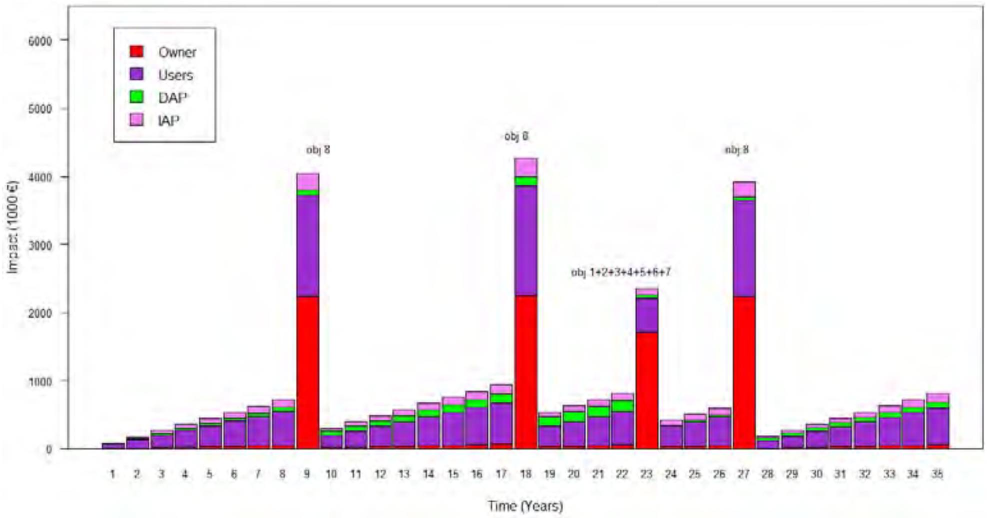


Figure 174 Intervention time and impact evolution (IS-7)

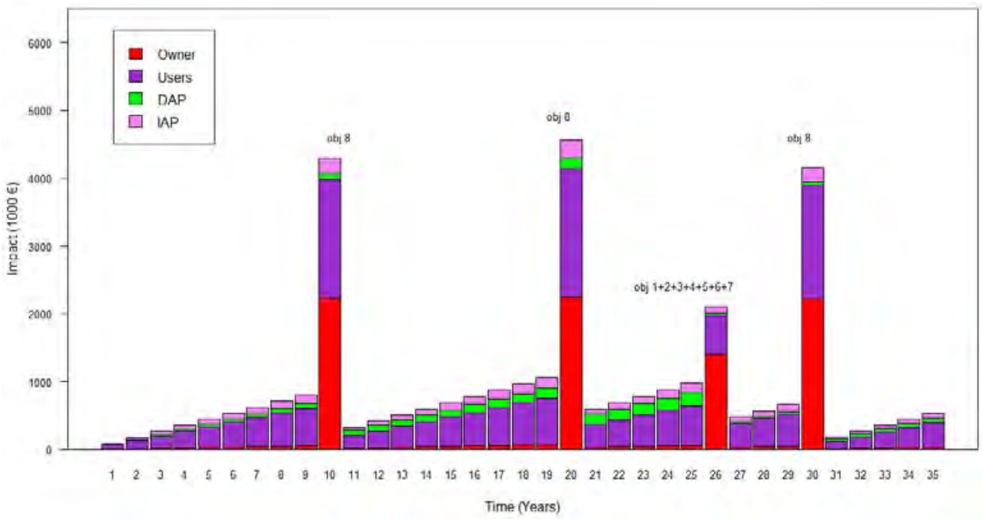


Figure 175 Intervention time and impact evolution (IS-8)

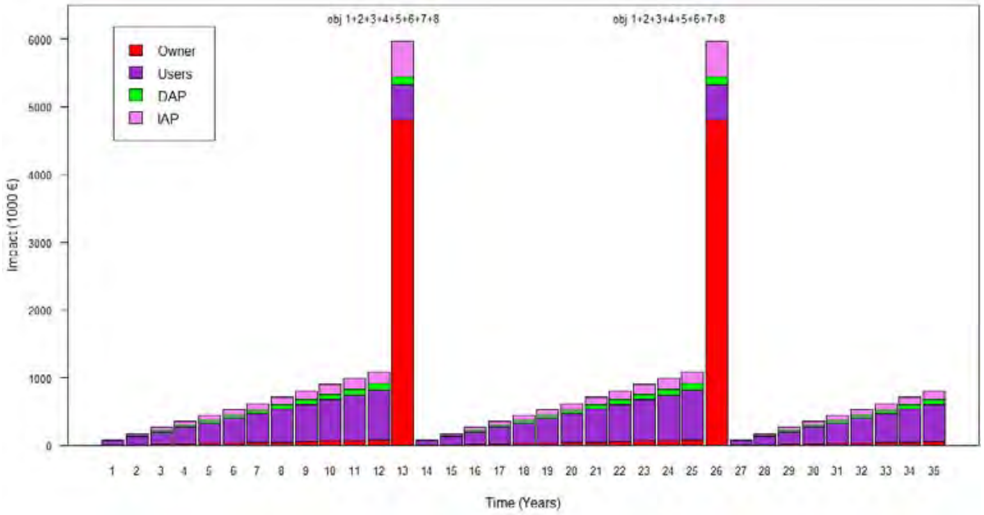


Figure 176 Intervention time and impact evolution (IS-10)

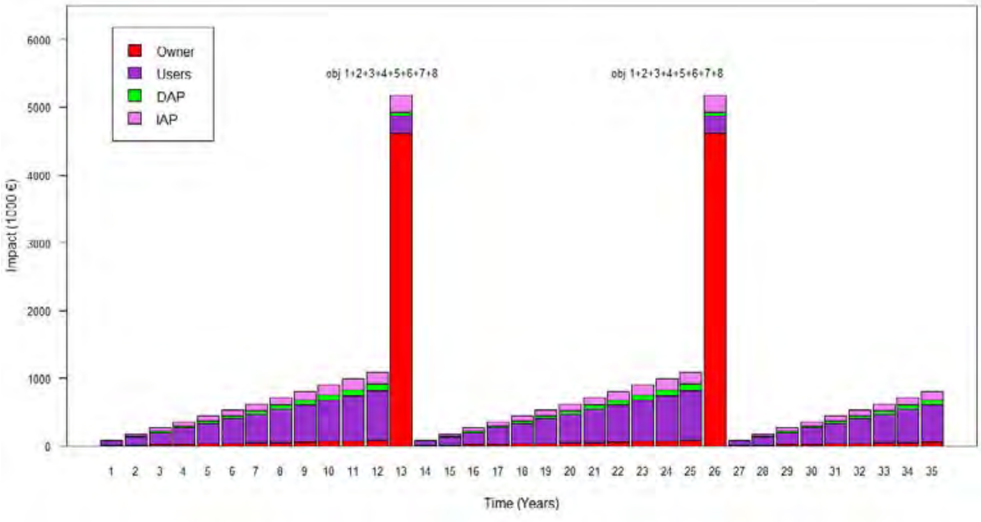


Figure 177 Intervention time and impact evolution (IS-11)

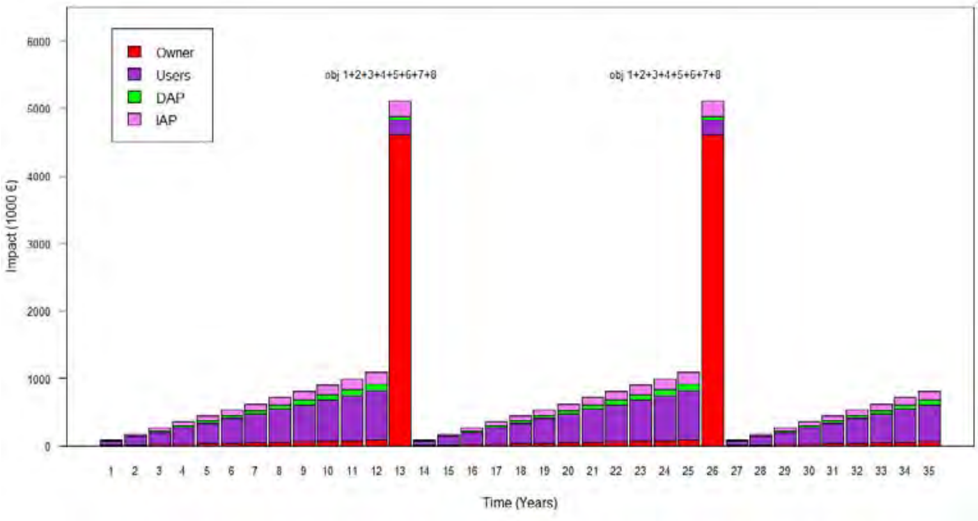


Figure 178 Intervention time and impact evolution (IS-12)

APPENDIX 19: Belgian Case - General Information on E17 Highway Section

Table 43 Section parameters

Line No	Description	Unit	Remark	Infrastructure Objects: object 1	Infrastructure Objects: object 2
I	**General information**				
1	Name of infrastructure object			Road	Road
2	Structural type	type		asphalt	asphalt
3	Number of lanes	lane		8	8
4	Year of construction	year		1970	1970
5	Design length	m		9'700.00	1'800.00
6	Design width	m		3.50	3.50
7	Design thickness of surface layer	cm		NA	NA
8	Design thickness of asphalt foundation	cm		NA	NA
9	KM post			NA	NA
II	**Daily traffic information (All lanes included)**				
1	Recorded year	year		2010	2010
2	Total Daily Traffic Volume (DTV)	vehicles		62'220.00	50'020.00
3	Truck/Freight	vehicles		0,00	
4	Light-weight car (Car)	vehicles		51'000.00	41'000.00
5	Medium-weight car (Truck)	vehicles		11'220.00	9'020.00
6	Heavy-weight car	vehicles			
7	Bus	vehicles		0.00	
8	Shared of diesel power vehicles in total	%			
9	Annual growth rate of traffic volume	%		NA	NA
III	**Deterioration**				
1	Number of discrete condition states	5	for all objects	5	5
2	Threhold condition state for intervention (if applicable)			4	4
3	Before condition state (select from drop list)	states		4	4
4	Before roughness index (enter actual value)	mm/km			
5	Other performance indicator (if applicable)	%	cracking		
6	Other performance indicator (if applicable)	%	cracking		
7	Average survival duration	years		30	30
8	average fatalities rate in Belgium	per billion vehicle-km	3	3	3
9	average injuries rate in Belgium	per billion vehicle-km	11	11	11
10	Average accident rate in Belgium	per billion vehicle-km	30	30	30

APPENDIX 20: Belgian Case – Questionnaire 1

FACULTEIT INGENIEURSWETENSCHAPPEN
CENTRUM VOOR INDUSTRIEEL BELEID
CENTRE FOR INDUSTRIAL MANAGEMENT
CELESTIJNENLAAN 300A BUS 2422
B-3001 HEVERLEE (BELGIUM)

KATHOLIEKE
UNIVERSITEIT
LEUVEN

Geachte heer/mevrouw,

Agentschap Wegen en Verkeer Oost-Vlaanderen is op 28 februari 2011 gestart met grote onderhoudswerken op de E17 tussen het klaverblad in Zwijnaarde en het op- en afrittencomplex in Deinze. Wegens de slechte huidige staat van het wegdek wordt liefst 11 kilometer snelweg in beide richtingen heraangelegd.

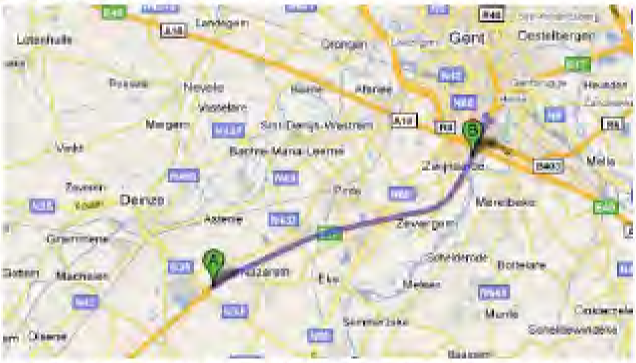
Het wegdek wordt in beide rijrichtingen van de fundering tot de toplaag heraangelegd in beton. Er komt ook een kort stuk asfalt vlakbij de verkeerswisselaar in Zwijnaarde. Daarnaast worden zes bruggen gesaneerd en maakt de middenberm plaats voor een centrale betonnen veiligheidsstootband. Een gelijkaardige stootband is vorig jaar aangelegd tussen Deinze en Kruishoutem.

De werken gebeuren in drie fasen. Vanaf 14 maart tot 30 juni wordt het gedeelte tussen het complex Deinze en het complex De Pinte aangepakt. In juli en augustus wordt er gewerkt aan het gedeelte tussen het complex De Pinte en de verkeerswisselaar in Zwijnaarde.

Wegen en Verkeer Oost-Vlaanderen wil bij wegwerkzaamheden zo min mogelijk hinder veroorzaken voor weggebruikers en de omgeving. Een belangrijk onderdeel van het creëren van minder hinder tijdens wegwerkzaamheden is het luisteren naar de gebruiker en de omgeving. Daarom willen we u, vanuit de KU Leuven vragen deze enquête in te vullen. De enquête richt zich specifiek op de E17 waar groot onderhoud uitgevoerd gaat worden. We willen weten wat voor u belangrijk is tijdens het uitvoeren van het onderhoud en wat u verwacht van het eindresultaat van dit onderhoud.

De enquête bestaat uit vier onderdelen met in totaal 11 (hoofd)vragen en neemt 10 minuten tijd in beslag. Onder de respondenten, die na afronding van de onderhoudswerkzaamheden ook onze tweede enquête willen invullen (per e-mail), wordt ter beloning €50 verloot.

De vragen hebben betrekking op beide rijrichtingen van de E17 tussen knooppunt Deinze en Zwijnaarde, te zien in onderstaand figuur:



Al uw informatie behandelen wij vertrouwelijk. Wij rapporteren niet per individu of onderneming over de resultaten: er wordt geen beeld geschetst van de afzonderlijke bedrijven of personen.

Voor vragen kunt u contact opnemen met tom.ulenaers@student.kuleuven.be.

Bij voorbaat dank voor het invullen van de enquête. We zien uit naar uw reactie!

Enquête Weggebruiker E17

Onderdeel 1 - Algemene Vragen

1.1 **Wat is uw geslacht?**

Vrouw	☐	Man	☐

1.2 **Wat is uw leeftijd?**

18 t/m 25	☐	Tussen de 46 en 55	☐
Tussen de 26 en 35	☐	Tussen de 56 en 65	☐
Tussen de 36 en 45	☐	66 of ouder	☐

1.3 **Hoe vaak rijdt u op de E17 tussen Deinze en Zwijnaarde (zie figuur in brief):**

Dagelijks (5, 6 of 7 dagen per week)	☐
Enkele keren per week (2, 3 of 4 dagen per week)	☐
Eens per week (1 dag)	☐
Enkele keren per maand	☐
Minder dan eens per maand	☐
Nooit (ga door naar onderdeel 2)	☐
Weet ik niet	☐

1.4 De kilometers die u aflegt kunnen worden verdeeld naar verschillende doelen. Wij onderscheiden drie 'hoofddoelen': woon-werk (reizen van en naar uw werk), zakelijk (bijvoorbeeld reizen in het kader van uw werk) en privé. Hoe zijn de kilometers, die u over dit stuk E17 rijdt, verdeeld over de verschillende doelen? **Verdeelt u alstublieft percentages over de drie doelen, zodat deze samen optellen tot 100 %.**

Woon-Werk	____ %
Zakelijk (anders dan woon-werk)	____ %
Privé	____ %
	100 %

Onderdeel 2 - Kenmerken van de E17

Bij het rijden over de E17 zijn er verschillende kenmerken van de weg die voor u als weggebruiker belangrijk kunnen zijn. We willen graag weten welke kenmerken van de E17 belangrijk voor u zijn, zodat hiermee rekening gehouden kan worden bij het plannen van onderhoud.

2.1 Hoe belangrijk vindt u de volgende kenmerken bij gebruik van de E17?

Geeft u a.u.b. met 1 t/m 8 de rangorde van de kenmerken aan. Voor het meest belangrijke kenmerk geeft u een "1" en voor het minst belangrijke kenmerk een "8". U mag ieder getal eenmaal gebruiken.

	Kenmerken E17	Rang 1-8
1	Uitstoot (emissies) veroorzaakt door de E17 (bv. geluid, uitlaatgassen)	☐
2	Bijdrage van de E17 aan de economie (bv. bereikbaarheid bedrijven, werkgelegenheid)	☐
3	Comfort bij het gebruik van de E17 (bv. kwaliteit wegdek, soepelheid van rijden)	☐
4	Visuele kwaliteit van de E17 (bv. schoonheid/fraaiheid omgeving)	☐
5	Veiligheid van de E17 (bv. risico op ongevallen en schades door ongevallen)	☐
6	Kosten aan voertuig veroorzaakt door de E17 (bv. schade door asfalt, benzine)	☐
7	Verbruik van middelen voor uitvoeren onderhoud E17 (bv. onderhoudsmateriaal, energie)	☐
8	Reistijd bij gebruik van de E17	☐

2.2 **Hoe belangrijk vindt u elk kenmerk van de E17 op basis van uw gemaakte rangorde (vraag 2.1)?**

Geeft u a.u.b. de belangrijkheid van elk kenmerk op een schaal van 0% (zeer onbelangrijk) tot 100% (zeer belangrijk) aan! U mag per kenmerk één vakje aankruisen.

	Kenmerken E17	Zeer onbelangrijk 0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	Zeer belangrijk 100%	Geen mening
1	Uitstoot (emissies) veroorzaakt door de E17 (bv. geluid, uitlaatgassen)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
2	Bijdrage van de E17 aan de economie (bv. bereikbaarheid bedrijven, werkgelegenheid)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
3	Comfort bij het gebruik van de E17 (bv. kwaliteit wegdek, soepelheid van rijden)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
4	Visuele kwaliteit van de E17 (bv. schoonheid/fraaiheid omgeving)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
5	Veiligheid van de E17 (bv. risico op ongevallen en schades door ongevallen)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
6	Kosten aan voertuig veroorzaakt door de E17 (bv. schade door asfalt, benzine)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
7	Verbruik van middelen voor uitvoeren onderhoud E17 (bv. onderhoudsmateriaal, energie)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
8	Reistijd bij gebruik van de E17	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Onderdeel 3 - Verwachtingen over het onderhoud aan de E17

In dit onderdeel vragen we naar uw verwachtingen van de E17 tijdens het onderhoud en naar uw verwachtingen van de uiteindelijke verbetering aan de E17 na het onderhoud. Naast uw verwachtingen stellen we ook vragen over uw wensen met betrekking tot de verbetering van de E17.

3.1 Hoeveel denkt u, als weggebruiker, dat de onderhoudswerkzaamheden u zullen beïnvloeden?

	Zeer weinig beïnvloedt	Weinig beïnvloedt	Gemiddeld beïnvloedt	Veel beïnvloedt	Zeer veel beïnvloedt	Ik heb geen verwachting
Ik denk dat het onderhoud mij als weggebruiker:	☐	☐	☐	☐	☐	☐

→ Indien u geen verwachtingen heeft, kunt u doorgaan met vraag 3.3.

3.2 Hoeveel denkt u dat de kenmerken van de E17 tijdens de onderhoudswerkzaamheden zullen worden beïnvloed? U mag per kenmerk één vakje aankruisen.

		Zeer weinig beïnvloed wordt	Weinig beïnvloed wordt	Gemiddeld beïnvloed wordt	Veel beïnvloed wordt	Zeer veel beïnvloed wordt	Ik heb geen verwachting
	Als weggebruiker denk ik dat tijdens het onderhoud aan de E17:						
1	de **reistijd**	☐	☐	☐	☐	☐	☐
2	de **veiligheid** (bv. risico op ongevallen)	☐	☐	☐	☐	☐	☐
3	het verbruik van **middelen voor onderhoud** A20 (bv. onderhoudsmateriaal)	☐	☐	☐	☐	☐	☐
4	het **comfort** (bv. kwaliteit wegdek)	☐	☐	☐	☐	☐	☐
5	de **bijdrage aan economie** (bv. werkgelegenheid, bereikbaarheid)	☐	☐	☐	☐	☐	☐
6	de **uitstoot** (emissies) (bv. geluid, uitlaatgassen)	☐	☐	☐	☐	☐	☐
7	**kosten aan voertuig** (bv. schade door asfalt, benzine)	☐	☐	☐	☐	☐	☐
8	de **visuele kwaliteit** (bv. schoonheid/fraaiheid omgeving)	☐	☐	☐	☐	☐	☐
9	anders, namelijk ______	☐	☐	☐	☐	☐	☐

3.3 **Hoeveel denkt u, als weggebruiker, dat de E17 verbeterd zal zijn na het onderhoud?**

	Zeer weinig verbetert	Weinig verbetert	Gemiddeld verbetert	Veel verbetert	Zeer veel verbetert	Ik heb geen verwachting
Als weggebruiker denk ik dat het onderhoud de E17:	☐	☐	☐	☐	☐	☐

→ Indien u geen verwachtingen heeft, kunt u doorgaan naar vraag 3.5.

3.4 **Hoeveel denkt u dat de kenmerken van de E17 verbeterd zullen zijn na het onderhoud?** U mag per kenmerk één vakje aankruisen.

		Zeer weinig verbetert	Weinig verbetert	Gemiddeld verbetert	Veel verbetert	Zeer veel verbetert	Ik heb geen verwachting
	Als weggebruiker denk ik dat door het onderhoud aan de E17:						
1	**de reistijd**	☐	☐	☐	☐	☐	☐
2	**de veiligheid** (bv. risico op ongevallen)	☐	☐	☐	☐	☐	☐
3	het verbruik van **middelen voor onderhoud** E17 (bv. onderhoudsmateriaal)	☐	☐	☐	☐	☐	☐
4	het **comfort** (bv. kwaliteit wegdek)	☐	☐	☐	☐	☐	☐
5	de bijdrage aan **economie** (bv. werkgelegenheid, bereikbaarheid)	☐	☐	☐	☐	☐	☐
6	**de uitstoot** (emissies) (bv. geluid, uitlaatgassen)	☐	☐	☐	☐	☐	☐
7	**kosten aan voertuig** (bv. schade door asfalt, benzine)	☐	☐	☐	☐	☐	☐
8	**de visuele kwaliteit** (bv. schoonheid/fraaiheid omgeving)	☐	☐	☐	☐	☐	☐
9	anders, namelijk ______	☐	☐	☐	☐	☐	☐

3.5 **Hoeveel zou u, als weggebruiker, willen dat de E17 ten opzichte van de huidige situatie verbetert na het onderhoud?**

	Zeer weinig verbetert	Weinig verbetert	Gemiddeld verbetert	Veel verbetert	Zeer veel verbetert	Ik heb geen wensen
Als weggebruiker wil ik dat het onderhoud de E17:	☐	☐	☐	☐	☐	☐

→ Indien u geen wensen heeft, kunt u doorgaan naar vraag 4.1.

3.6 **Hoeveel zou u, als weggebruiker, willen dat het onderhoud de kenmerken van de E17 ten opzichte van de huidige situatie verbetert?** U mag per kenmerk één vakje aankruisen.

		Zeer weinig verbetert	Weinig verbetert	Gemiddeld verbetert	Veel verbetert	Zeer veel verbetert	Ik heb geen wensen
	Als weggebruiker wil ik dat door het onderhoud aan de E17:						
1	**de reistijd**	☐	☐	☐	☐	☐	☐
2	**de veiligheid** (bv. risico op ongevallen)	☐	☐	☐	☐	☐	☐
3	het verbruik van **middelen voor onderhoud E17** (bv. onderhoudsmateriaal)	☐	☐	☐	☐	☐	☐
4	**het comfort** (bv. kwaliteit wegdek)	☐	☐	☐	☐	☐	☐
5	de **bijdrage aan economie** (bv. werkgelegenheid, bereikbaarheid)	☐	☐	☐	☐	☐	☐
6	**de uitstoot** (emissies) (bv. geluid, uitlaatgassen)	☐	☐	☐	☐	☐	☐
7	**kosten aan voertuig** (bv. schade door asfalt, benzine)	☐	☐	☐	☐	☐	☐
8	**de visuele kwaliteit** (bv. schoonheid/fraaiheid omgeving)	☐	☐	☐	☐	☐	☐
9	anders, namelijk ______	☐	☐	☐	☐	☐	☐

Onderdeel 4 - Betrokkenheid bij het onderhoud aan de E17

Dit laatste onderdeel focust op uw gewenste betrokkenheid bij het onderhoudsproject.

4.1 Hoeveel zou u, als weggebruiker, betrokken willen worden bij de planning van de werkzaamheden voor het onderhoudsproject aan de E17?

	Zeer weinig betrokken worden	Weinig betrokken worden	Gemiddeld betrokken worden	Veel betrokken worden	Zeer veel betrokken worden	Ik heb geen wens
1 Als weggebruiker wil ik bij het plannen van het onderhoud:	☐	☐	☐	☐	☐	☐

4.2 Hoeveel zou u, als weggebruiker, geïnformeerd willen worden voor aanvang van de werkzaamheden?

	Zeer weinig geïnformeerd worden	Weinig geïnformeerd worden	Gemiddeld geïnformeerd worden	Veel geïnformeerd worden	Zeer veel geïnformeerd worden	Ik heb geen wens
1 Als weggebruiker wil ik voor het onderhoud:	☐	☐	☐	☐	☐	☐

4.3 Hoe zou u, als weggebruiker, voor aanvang van de werkzaamheden geïnformeerd willen worden?

	Ja	Nee		Ja	Nee
Als weggebruiker wil ik geïnformeerd worden door:					
1 informatiebrieven	☐	☐	6 informatiebijeenkomst	☐	☐
2 informatie in kranten	☐	☐	7 twitter/hyves/facebook	☐	☐
3 informatie op websites	☐	☐	8 sms (vrijwillig)	☐	☐
4 informatielijn met vraag en antwoord	☐	☐	9 persoonlijk gesprek	☐	☐
5 anders, namelijk ______	☐	☐	10 anders, namelijk ______	☐	☐

Hartelijk dank voor het invullen van de enquête. Het doel van het onderzoek is om na het onderhoud te onderzoeken of de verwachtingen over het onderhoud overeenkomen met de beleving van het onderhoud. Daarom zouden we graag nog eenmaal een tweede enquête willen toesturen na het onderhoud. Zou u daarom uw e-mail adres hieronder willen invullen?

Uw e-mail adres: ______

Uw e-mail adres wordt enkel gebruikt voor het versturen van de tweede vragenlijst en eventueel een bericht over de prijs die we verloten onder de respondenten die beide enquêtes invullen.

[verstuur deze enquête per e-mail - hier drukken]

APPENDIX 21: Belgian Case – Questionnaire 2

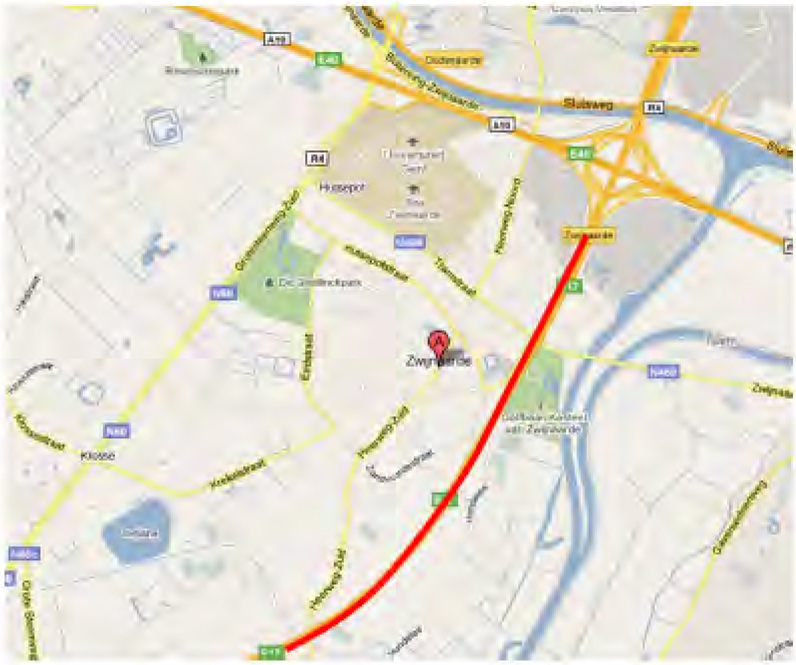
FACULTEIT INGENIEURSWETENSCHAPPEN
CENTRUM VOOR INDUSTRIEEL BELEID
CENTRE FOR INDUSTRIAL MANAGEMENT
CELESTIJNENLAAN 300A BUS 2422
B-3001 HEVERLEE (BELGIUM)

KATHOLIEKE
UNIVERSITEIT
LEUVEN

Geachte heer/mevrouw,

Onlangs hebben we u gevraagd om een enquête in te vullen waarin we naar uw verwachtingen ten aanzien van het onderhoud aan de E17 vroegen. We hebben veel respons ontvangen op deze enquête, hartelijk dank hiervoor! Inmiddels hebben de onderhoudswerkzaamheden tussen Zwijnaarde en Deinze plaatsgevonden en deze eindigden op 1 september. Zoals we in de eerste enquête al aankondigden, zouden we u graag nog eenmaal naar uw ervaringen met betrekking tot het onderhoud aan de E17 willen vragen. Met de resultaten kan het Ministerie van Openbare Werken het onderhoud in het vervolg beter op uw wensen aansluiten.

De enquête bestaat uit drie onderdelen en neemt 10 minuten tijd in beslag. De vragen hebben betrekking op het onderhoud dat is uitgevoerd aan beide rijrichtingen van de E17 tussen tussen Zwijnaarde en Deinze, te zien in onderstaande figuur:



Al uw informatie behandelen wij vertrouwelijk. Wij rapporteren niet per individu of onderneming over de resultaten: er wordt geen beeld geschetst van de afzonderlijke bedrijven of personen.

Bij voorbaat dank voor het invullen van de enquête. We zien uit naar uw reactie!

Onderdeel 1 – Kenmerken van de E17

1.1 Hoe belangrijk vindt u de volgende kenmerken als weggebruiker van de E17?

We willen u vragen om de volgende kenmerken van de E17 nog eenmaal te ranken, omdat u de kenmerken nu kunt bekijken vanuit uw ervaringen tijdens en na de werkzaamheden aan de E17.

Geeft u daarom a.u.b. met 1 t/m 8 de rangorde van de kenmerken aan. Voor het meest belangrijke kenmerk geeft u een "1" en voor het minst belangrijke kenmerk een "8". U mag ieder getal eenmaal gebruiken.

	Kenmerken E17	Rang 1-8
1	Uitstoot (emissies) veroorzaakt door de E17 (bv. geluid, uitlaatgassen)	
2	Bijdrage van de E17 aan de economie (bv. bereikbaarheid bedrijven, werkgelegenheid)	
3	Comfort bij het gebruik van de E17 (bv. kwaliteit wegdek, soepelheid van rijden)	
4	Visuele kwaliteit van de E17 (bv. schoonheid/fraaiheid omgeving)	
5	Veiligheid van de E17 (bv. risico op ongevallen en schades door ongevallen)	
6	Kosten aan voertuig veroorzaakt door de E17 (bv. schade door asfalt, benzine)	
7	Verbruik van middelen voor uitvoeren onderhoud E17 (bv. onderhoudsmateriaal, energie)	
8	Reistijd bij gebruik van de E17	

Onderdeel 2 – Evaluatie onderhoudswerkzaamheden

2.1 Hoeveel hebben de onderhoudswerkzaamheden u als weggebruiker beïnvloed?

	Zeer weinig beïnvloed	Weinig beïnvloed	Gemiddeld beïnvloed	Veel beïnvloed	Zeer veel beïnvloed	Weet ik niet
Het onderhoud heeft mij als weggebruiker:	☐	☐	☐	☐	☐	☐

2.2 Hoeveel zijn de kenmerken van de E17 volgens u als weggebruiker tijdens de onderhoudswerkzaamheden beïnvloed? U mag per kenmerk één vakje aankruisen.

	Zeer weinig beïnvloed is	Weinig beïnvloed is	Gemiddeld beïnvloed is	Veel beïnvloed is	Zeer veel beïnvloed is	Weet ik niet
Als weggebruiker heb ik tijdens het onderhoud aan de E17 waargenomen dat:	☐	☐	☐	☐	☐	☐
de reistijd	☐	☐	☐	☐	☐	☐
de veiligheid (bv. risico op ongevallen)	☐	☐	☐	☐	☐	☐
het verbruik van middelen voor onderhoud E17 (bv. onderhoudsmateriaal)	☐	☐	☐	☐	☐	☐
het comfort (bv. kwaliteit wegdek)	☐	☐	☐	☐	☐	☐
de bijdrage aan economie (bv. werkgelegenheid, bereikbaarheid)	☐	☐	☐	☐	☐	☐
de uitstoot (emissies) (bv. geluid, uitlaatgassen)	☐	☐	☐	☐	☐	☐
kosten aan voertuig (bv. schade door asfalt, benzine)	☐	☐	☐	☐	☐	☐
de visuele kwaliteit (bv. schoonheid/fraaiheid omgeving)	☐	☐	☐	☐	☐	☐
anders, namelijk ________	☐	☐	☐	☐	☐	☐

2.3 **Heeft u door deze onderhoudswerkzaamheden uw reisgedrag aangepast?** <u>U kunt meerdere antwoorden geven.</u>

☐	ja, ik ben eerder of later gaan reizen
☐	ja, ik heb een of meerdere geplande reizen niet gemaakt (bijv. door thuis te werken)
☐	ja, ik heb een andere bestemming/locatie bezocht voor mijn bezigheden
☐	ja, ik heb een ander vervoermiddel gebruikt, namelijk
☐	ja, ik heb een andere route genomen
☐	nee, want …………………

Onderdeel 3 – Evaluatie onderhoudsresultaat

3.1 Hoeveel vindt u, als weggebruiker, dat de E17 verbeterd is na het onderhoud?

	Zeer weinig verbeterd is	Weinig verbeterd is	Gemiddeld verbeterd is	Veel verbeterd is	Zeer veel verbeterd is	Weet ik niet
Als weggebruiker vind ik dat de E17:	☐	☐	☐	☐	☐	☐

3.2 Hoeveel zijn volgens u als weggebruiker de volgende kenmerken verbeterd na het onderhoud? <u>U mag per kenmerk één vakje aankruisen.</u>

		Zeer weinig verbeterd is	Weinig verbeterd is	Gemiddeld verbeterd is	Veel verbeterd is	Zeer veel verbeterd is	Weet ik niet
	Als weggebruiker heb ik na het onderhoud waargenomen dat:						
1	de reistijd	☐	☐	☐	☐	☐	☐
2	de veiligheid (bv. risico op ongevallen)	☐	☐	☐	☐	☐	☐
3	het verbruik van middelen voor onderhoud E17 (bv.	☐	☐	☐	☐	☐	☐
4	het comfort (bv. kwaliteit wegdek)	☐	☐	☐	☐	☐	☐
5	de bijdrage aan economie (bv. werkgelegenheid, bereikbaarheid)	☐	☐	☐	☐	☐	☐
6	de uitstoot (emissies) (bv. geluid, uitlaatgassen)	☐	☐	☐	☐	☐	☐
7	de kosten aan mijn voertuig (bv. schade door asfalt, benzine)	☐	☐	☐	☐	☐	☐
8	de visuele kwaliteit (bv. schoonheid/fraaiheid omgeving)	☐	☐	☐	☐	☐	☐
9	anders, namelijk ________	☐	☐	☐	☐	☐	☐

Onderdeel 4 – Evaluatie informatievoorziening en algemene tevredenheid

4.1 Hoeveel bent u geïnformeerd voor aanvang van de onderhoudswerkzaamheden aan de E17?

		Zeer weinig geïnformeerd	Weinig geïnformeerd	Gemiddeld geïnformeerd	Veel geïnformeerd	Zeer veel geïnformeerd	Weet ik niet
1	Als weggebruiker ben ik voor het onderhoud:	☐	☐	☐	☐	☐	☐

4.2 Op welke manier bent u geïnformeerd over de onderhoudswerkzaamheden? U mag meerdere vakjes aankruisen

☐	Informatiebrief	☐	Informatielijn met vraag en antwoord
☐	Informatie in krant	☐	Twitter/hyves/facebook
☐	Informatie op website	☐	Borden langs de weg
☐	Anders, namelijk	☐	Anders, namelijk ....

4.3 Kunt u aangeven per onderstaande vraag hoe tevreden u bent.....

		Zeer ontevreden	Ontevreden	Noch tevreden noch ontevreden	Tevreden	Zeer tevreden	Weet ik niet
1	met de invloed van de onderhoudswerkzaamheden op u als weggebruiker?	☐	☐	☐	☐	☐	☐
2	over de mate van verbetering van de E17 na het onderhoud?	☐	☐	☐	☐	☐	☐
3	over de mate waarin u geïnformeerd bent over de onderhoudswerkzaam- heden	☐	☐	☐	☐	☐	☐
4	over de manier waarop u geïnformeerd bent over de onderhoudswerkzaamheden?	☐	☐	☐	☐	☐	☐
5	over de gehele onderhoudswerkzaamheden aan de E17 in zijn totaliteit?	☐	☐	☐	☐	☐	☐

Hartelijk dank voor het invullen van de enquête.

[verstuur deze enquête per email - gelieve hier te drukken]

APPENDIX 22: Belgian Case – Respondent Characteristics (Questionnaire 1)

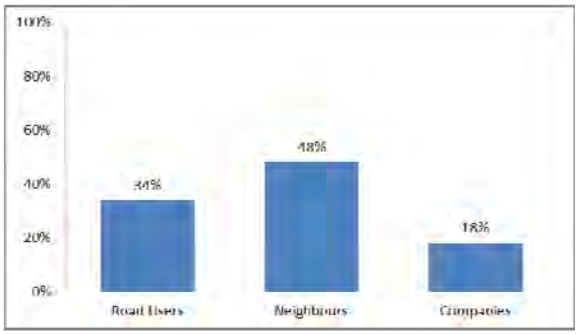


Figure 179 Stakeholder group

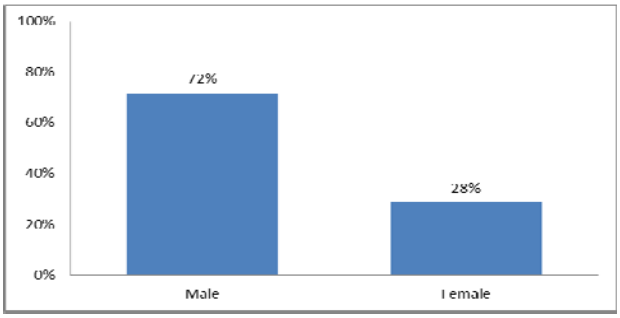


Figure 180 Gender (road user and resident)

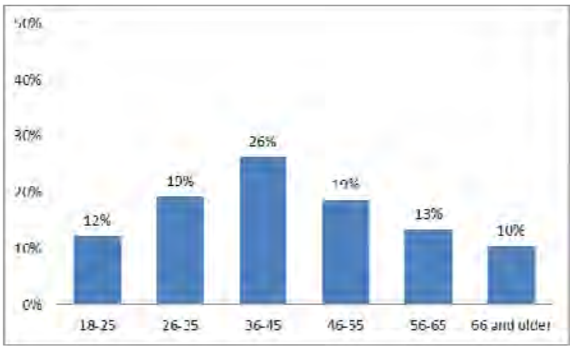


Figure 181 Age (road user and resident)

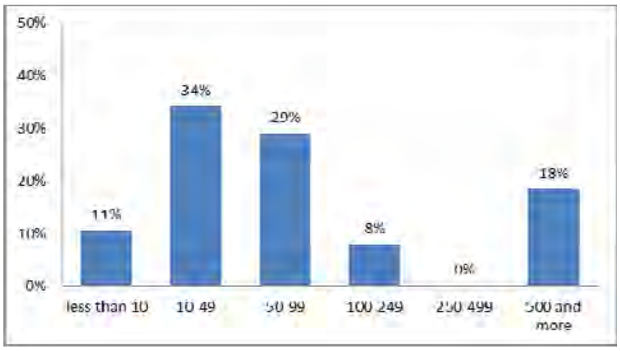


Figure 182 Size (company)

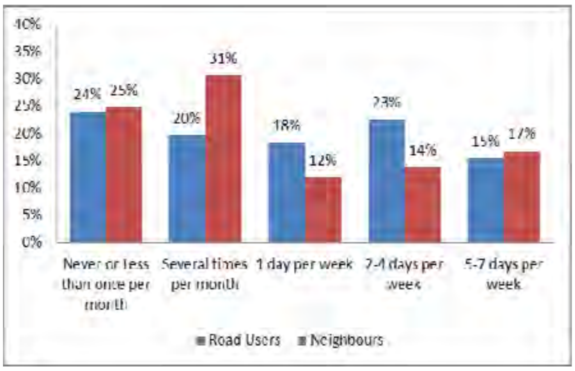


Figure 183 Frequency of road use (road user and resident)

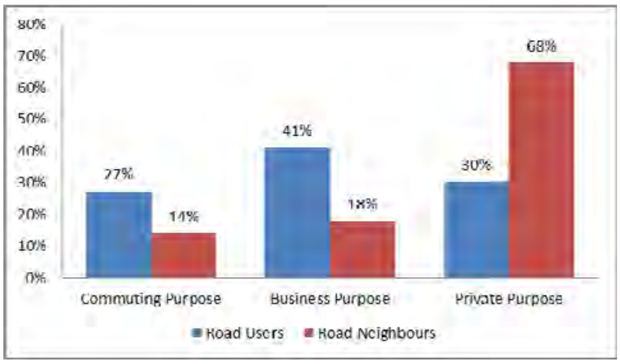


Figure 184 Travel purpose (road user and resident)

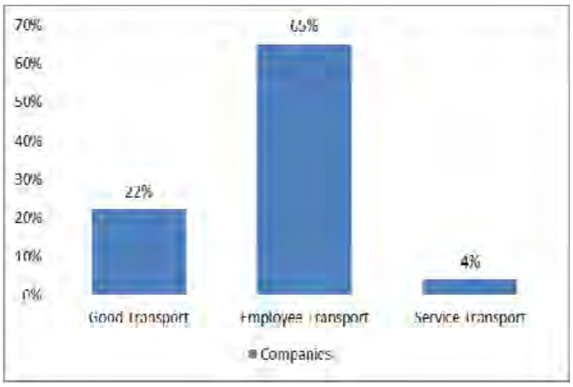


Figure 185 Transportation purpose (company)

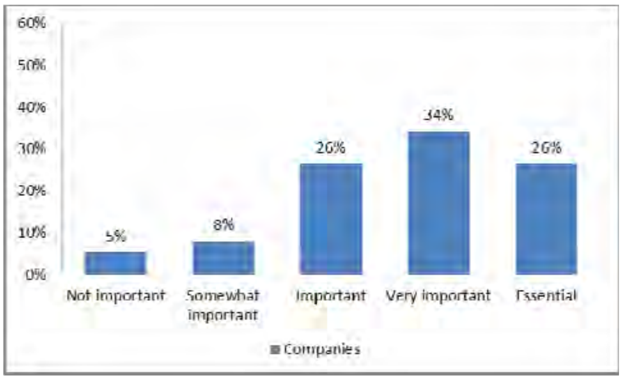


Figure 186 Road importance (company)

APPENDIX 23: Belgian Case – Traffic Flows Generated

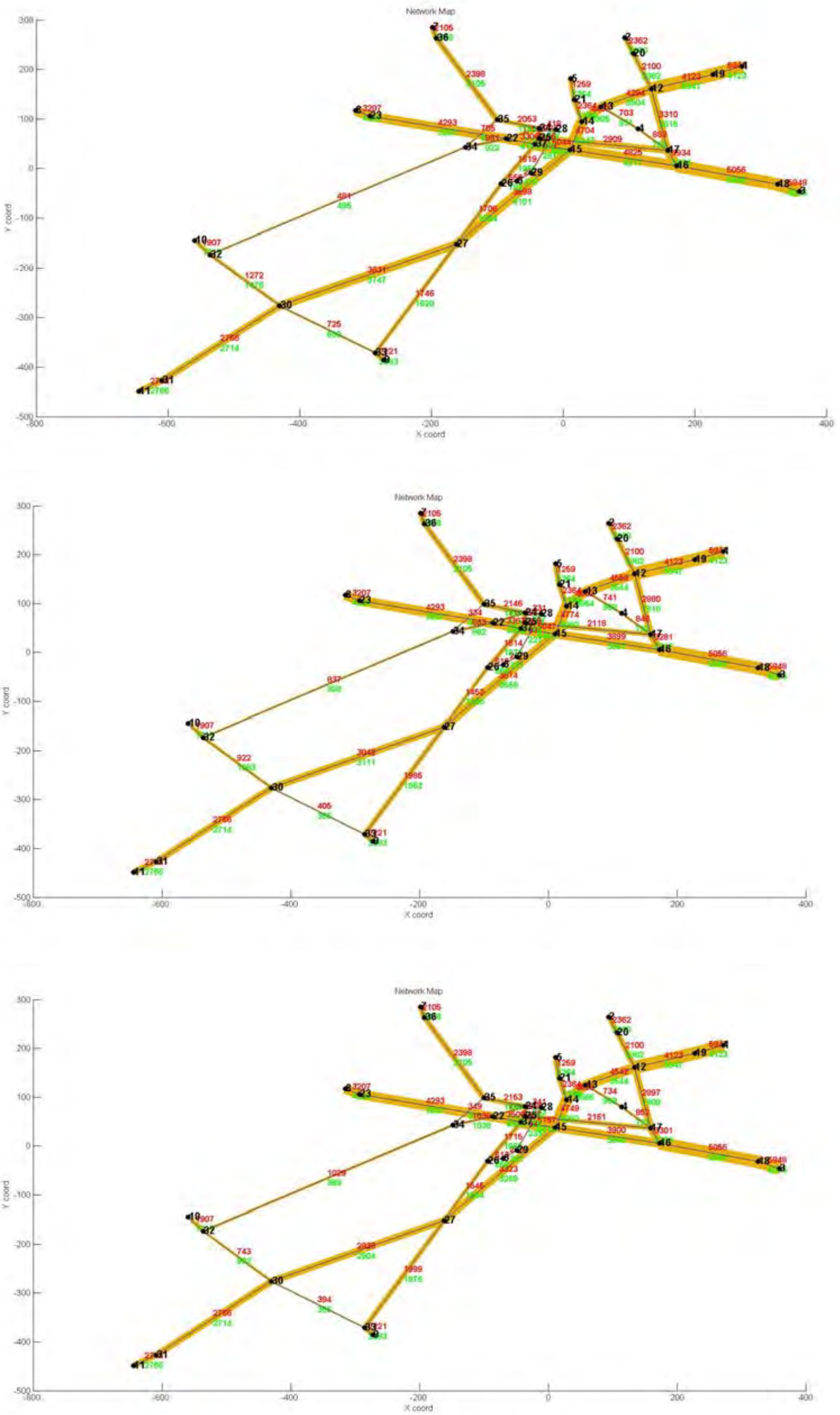


Figure 187 Flows generated in the Gent network; a) no intervention, 2) strategy 1.1, 3) strategy 1.2

APPENDIX 24: Belgian Case – Impacts During Interventions

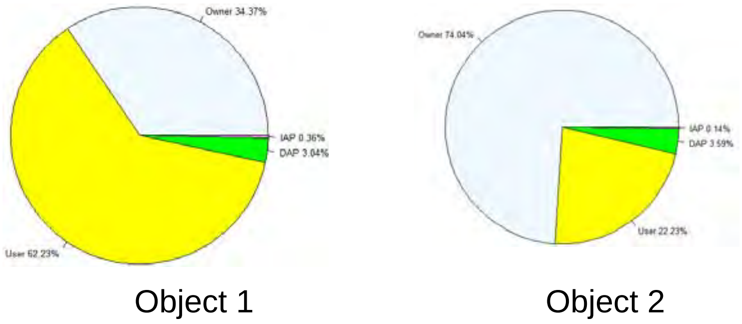


Figure 188 Impacts during intervention period (traffic configuration 1)

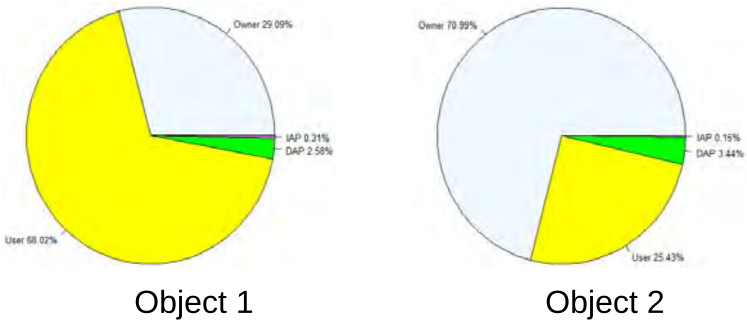


Figure 189 Impacts during intervention period (traffic configuration 2)

APPENDIX 25: Belgian Case –Impact Development Between Interventions

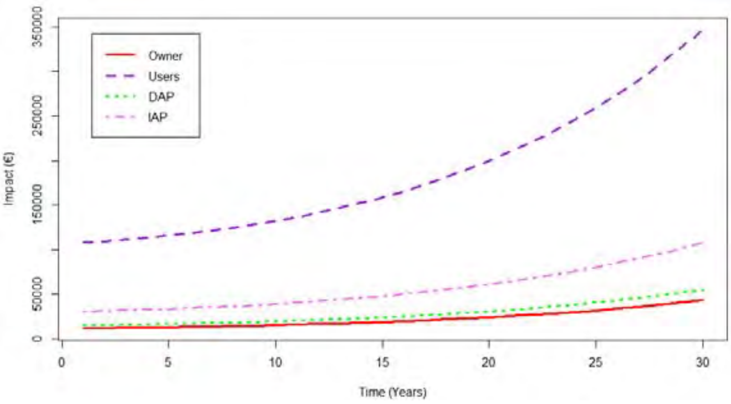


Figure 190 Impacts in between intervention (object 1)

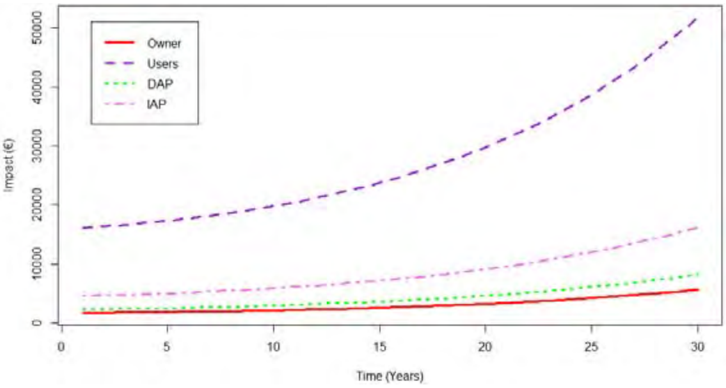


Figure 191 Impacts in between intervention (object 2)

APPENDIX 26: Programme of Workshop with Dutch Highways Agency

Workshop
"Stakeholder Benefit and Road Intervention Strategies" (SABARIS)
13 September 2012
09.00 – 13.00
Parkhotel (Park Room)
Den Haag

09.00 – 09.15	Welcome (*Andreas Hartmann*)
09.15 – 9.30	Introduction SABARIS project (*Andreas Hartmann*)
09.30 – 09.50	Presentation of project results I (*Andreas Hartmann*) - Stakeholder identification, analysis and management - Case A20
09.50 – 10.00	Discussion (*All*)
10.00 – 10.20	Presentation of project results II (*Bryan Adey*) - Optimisation of intervention strategies - Case A20
10.20 – 10.30	Discussion (*All*)
10.30 – 10.45	Break
10.45 – 12.00	Working in groups (*All*) - Which project results would provide added value to RWS when implemented? - Which added value would be provided? - Where should the results be implemented to add value? - What is required to implement the results?
12.00 – 12.45	Lunch presentation and discussion of group work (*All*)
12.45 – 13.00	Wrap up and conclusion (*Andreas Hartmann*)

Participants

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Jaco van der Werf	Rijkswaterstaat
Inge Schipper	Rijkswaterstaat
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