COBRA Cooperative Benefits for Road Authorities

ERA-NET ROAD

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Getting the most out of Intelligent Infrastructure

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Revision and history chart

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1.3	2013-04-17	MvN – Business Model descriptions added
1.4	2013-06-06	MA, KM – Example of Country-specific analysis added

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1 Introduction

The COBRA project aims to help road authorities to position themselves to optimally benefit from changes in the field of cooperative systems. It does so by providing insight on the costs and benefits of investments, both from a societal perspective and a business case perspective. These insights will be given based on a decision support tool that allows for the comparison of costs and (monetised) benefits of cooperative services in various contexts.

This document presents the user requirements for the decision support tool, and the feasibility and scope. It also shows the architecture of the tool. Finally the methodology to determine impacts and translate those to costs and benefits is reported. Figure 1 shows a schematic overview of that methodology, which is further explained in this document. The methodology consists of two main parts. The first part is the impact assessment. The impacts of the systems are determined in terms of the maximum effectiveness at 100% penetration of equipped vehicles, the actual penetration in the assumed scenario and the current situation in terms of traffic indicators for safety, efficiency and environment. The second part is the benefit cost analysis. It includes the deployment scenarios, societal benefit cost calculations and calculations of the business case for the road authority. The figure also shows whether a component is calculated in the decision support tool, whether is it is input by the user of the tool, or whether it is a parameter included at the development of the tool.

The following elements are addressed.

- Categorization of the cooperative systems (CS) by the role of the road authority in the multi-stakeholder environment, its technical components, and by the driving task that it aims to influence.
- Process flow from inputs to the desired outcomes. The inputs are the scenarios and the effects in terms of costs, traffic effects and/or monetized benefits.
- Combining inputs. The data collection from literature may deliver multiple results for one CS that may or may not be fully consistent. This step develops a method to combine all inputs in one process flow.
- Method for handling reliability. The reliability of the outcome is influenced by the reliability of the inputs and the variance of the different inputs. A method will be designed for characterizing the reliability of the inputs and outputs and for the relation between them.
- Method for handling combinations. A scenario may involve multiple CS and a method will be developed to handle combinations. This method will make use of the categorization of CS to avoid double counting of costs or benefits.
- Architecture of the knowledge database: what data needs to be recorded and how. This follows from the previous step.

Based on this document, an initial setup of the decision support tool in Excel will be made. It shows, based on fictional data, the output and input options in terms of scenario choices set by the user of the tool. This will give insights into how the tool can be used.

The document consists of five chapters. Chapter 2 describes the user requirements and feasibility. It is followed by a chapter on the Impact Assessment and a chapter on the Benefit Cost Calculations. The final chapter explains the implementation of the methodology in the tool. Five appendices contain more detailed information on specifications of technologies and costs of cooperative systems, estimating the costs of in-vehicle equipment and infrastructure, an explanation of hotspot calculations, and the Netherlands-specific analysis of existing roadside infrastructure for traffic management and its relation to the cooperative systems investigated in COBRA

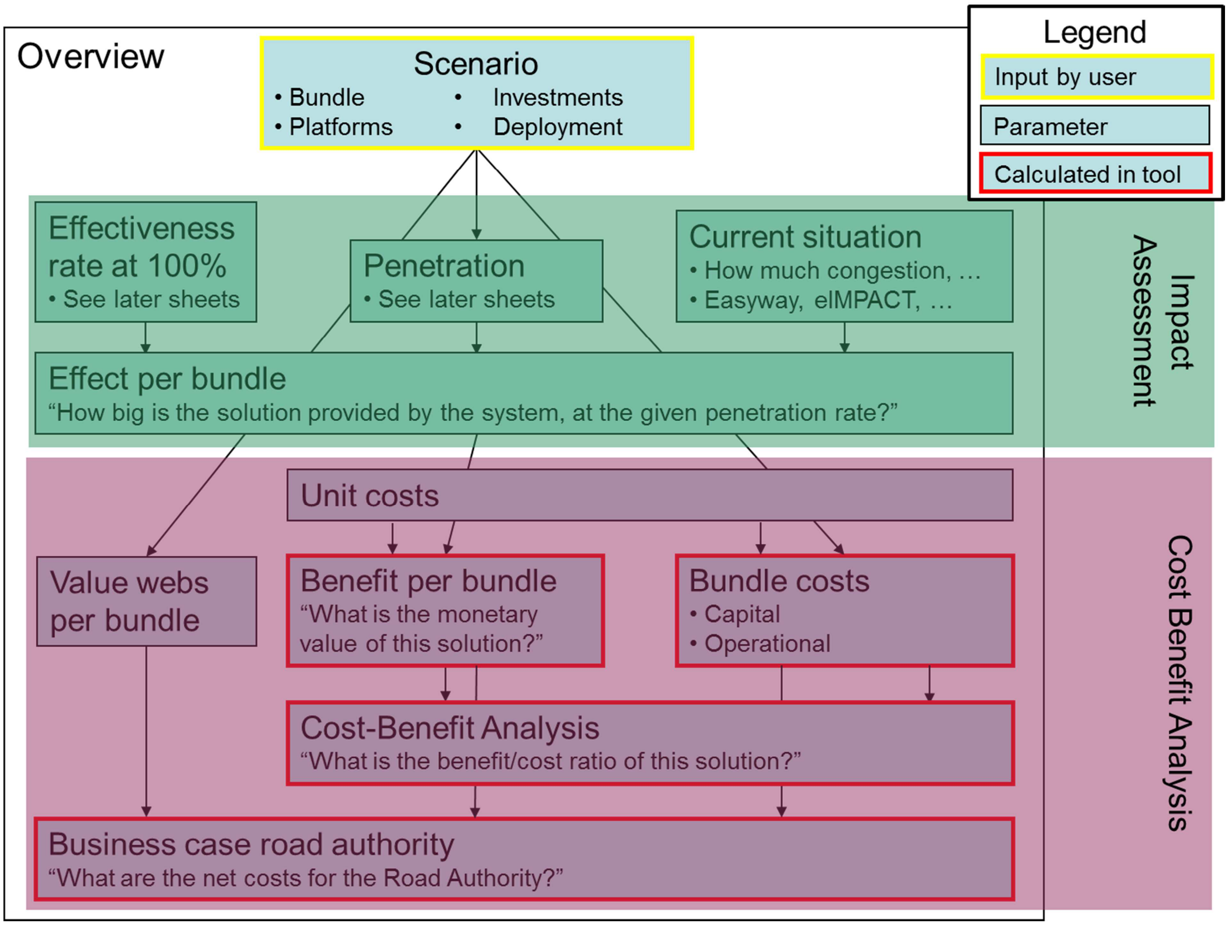


Figure 1: Methodology overview

2 User requirements and feasibility

2.1 User requirements

The requirements of road authorities regarding the type of outcomes delivered by the tool, the cooperative systems to be considered, and the scenario choices made by users of the tool have been identified. This was done in an initial stakeholder workshop with road authorities at the CEDR Working Group 14 on January 19, 2012 in Brussels. In this workshop the ideas for the decision support tool were presented, and the roles, the challenges and a prioritisation of cooperative system were discussed.

The tool should be able to:

- Compare societal cost and benefits, and costs (savings) for National Road Authorities (NRAs)
- Compare cooperative platforms
- Select policy priorities for safety, efficiency and environment
- Accommodate different roles for the NRA (infrastructure provider, service provider) so that it can be used by NRAs from different countries with different relations with road operators.

Two participants wanted to see a role as service provider of information and safety services. Even when not providing cooperative services themselves, the large majority do want to ensure cooperative systems, either by providing regulation, contributions to standardisation or cooperation within industry.

Roland Schindhelm, in his stakeholder analysis for an eSafety working group, defined three potential roles of the road operator in operating selected cooperative services: Owner, Content provider, Service provider and User. About half of the CEDR WG participants have mentioned one of these operational roles, mainly the owner (infrastructure provider) and service provider. The other half described their role in terms of ensuring regulation or standardisation, so they participate but do not have an operational role in the process of service delivery.

Based on the roles listed by the participants, the tool will define a business model for each platform. The focus will be on the operational roles, since these roles require investment decisions.

<u>Challenges in relation to cooperative systems</u>

The most frequently listed challenge is the cooperation with private partners, such as defining an agreed common business case with the car and service industry. The COBRA consortium will provide several business models for each cooperative platform example in the decision support tool.

The second most listed challenge is facing increasing budget pressure, for instance due to increased maintenance costs, budget cuts and increasing traffic. The intention to include costs (savings) for the road authority in the decision support tool was supported.

Other identified challenges are:

- how to manage network/traffic without being in control of the information provided to individuals,
- how to avoid investing in 'losing' standards (i.e. ageing or about to be superseded)/ buyer lock-in/obtain common standards,
- who should be the owner of the infrastructure and
- how to deal with security.

<u>Questions related to CS and the COBRA project</u>

Many different questions related to cooperative systems were listed, overlapping strongly with the challenges. The following question was directed at the COBRA project, and is answered here:

Who will the customer be for the decision support tool that is being developed (operators or road authorities)?

The view of the COBRA consortium is to develop a strategic tool for long term investment decisions, so it is intended for NRAs that also have a road operator's responsibility.

An added value of the decision support tool would be to address cost (reductions) for road operators, alongside the CBA. It was recommended that the tool should support, next to a cost minimisation perspective also a profit maximisation and service maximisation perspective. NRAs are organised differently and have different perspectives, which also change over time.

2.2 Feasibility

The main questions to be answered in this section are which of the user requirements are feasible to include in the decision support tool, and what inputs are needed. This chapter will provide a system requirements document and an input requirements document. This reflects the possibilities to include the user requirements in the decision support tool (i.e. which requirements can be fulfilled?).

Within the project scope it has been necessary to limit the number of cooperative functions to be assessed, the geographical scope (which countries are covered), and the scenarios that can be selected by the user. These are discussed in the sections below.

2.2.1 Research questions

The following research questions are defined that can be addressed by the decision tool.

- Should current transport schemes go ahead? Is it feasible to cut costs on current road side equipment?
- What are possible societal costs and benefits of investments in cooperative systems to improve road safety, traffic efficiency and the environment? Which cooperative systems have benefits under which conditions?

2.2.2 Selection of bundles of cooperative functions

A cooperative system dedicated to one function is expected to be economically unfeasible. A cooperative system with several functions to support the driver is much more realistic and desirable. However it is not yet clear how services will be bundled together for deployment, For this purpose of this tool, a number of logical bundles of functions have been defined. These could be deployed together because they can operate on the same platform. These logical bundles should be considered as illustrative examples of possible implementations.

The societal benefit cost calculations will be performed on these bundles. Based on the 'day one' applications as defined by CEDR and ASECAP, and preferences of the members of CEDR working group 14, the bundles listed in Table 1 have been defined. The first three have been selected to be assessed in the decision support tool.

Table 1: Bundles of cooperative functions

Local dynamic event warnings
In-vehicle speed and signage
Information services
Critical safety and operational driving
Road user charging

Table 2 shows the functions in each of the bundles and the priorities assigned by the CEDR working group. The bundles selected are based on

- Responsibilities of road authorities: traffic management, safety warnings, enforcement
- Infrastructure requirements: Cellular communication infrastructure, WLAN (802.11p WiFi based) infrastructure – wireless beacons
- Legal perspective: warnings vs. mandatory traffic regulation vs. time critical warnings (automated driving not included)
- Business case perspective: communication costs vs. infrastructure costs, savings in VMS, savings in static routing signs

As a user of the tool it is possible to select one of the bundles. Since the effect of the functions in a bundle is dependent on the presence of other functions, it is not possible to add or select individual functions. This is because the impacts of the systems on safety, efficiency and the environment depend on the bundle. The interaction effects between the impacts of different functions make it impossible to make a tool that facilitates all combinations of functions, so only the selected combination of the bundles can be used. This means that selecting cooperative functions based on policy priorities in terms of safety, efficiency and the environment is possible only to a limited extent.

Table 2: Functions per bundle

Functions	Priorities of participants
Hazardous location notification (incl. slippery road, fog, obstacles, car breakdowns etc.)	23
Road works warning	16
Traffic jam ahead warning	14
In-vehicle signage	11
Intelligent Speed Adaptation	10
Traffic information and recommended itinerary	9
Wrong way driving warning	8
Dynamic speed limits	8
Road user charging	8
Requested green (in a cooperative way)	7
Multimodal travel information	7
Post crash warning/eCall	6
Automatic access control	5
Parking information and guidance	4
Emergency vehicle warning	2
Emergency brake light	2
Cooperative intersection collision avoidance	1
Dedicated Lanes	0

2.2.3 Geographical scope

The geographical scope is initially limited to the UK and The Netherlands as examples. This has been done to limit the effort of data collection. The tool will be useable for other countries and facilitates different situations in terms of equipment of the existing infrastructure with detection loops and VMS. This data will have to be included by these countries themselves before they can use the tool.

2.2.4 Scenarios

The number of possible scenarios for the deployment of cooperative systems is endless. To make it easier for the user of the tool, and also for the developer, the range of possible scenarios has to be limited. For this reason a number of logical deployment scenarios have been predefined by the developers. These can be selected by the user of the tool.

The scenarios consist of the following elements (with a number of scenario options for each element):

- Communication platform (cellular, wireless beacons)
- Bundle of cooperative functions (Local dynamic event warnings, In-vehicle speed and signage, Travel information and dynamic route guidance)
- Market penetration of in-car systems (low, middle, high market uptake)
- Business model (public, private, one or more public & private)

Table 3 shows which functions can be deployed on the different communication platforms. When a function cannot be deployed on a platform, obviously the benefits and costs of this function are excluded from the calculation in that scenario. For instance, the benefits of an intelligent speed adaptation function will not be included in a wireless beacon based scenario.

Table 3: Feasible combinations of functions and communication platforms

	Communication platform	
Functions	**Cellular**	**Wireless Beacons**
Hazardous location notification (incl. slippery road, fog, obstacles, car breakdowns etc.)	1(0)	1
Road works warning	1(0)	1
Traffic jam ahead warning	1(0)	1
In-vehicle signage	1	1
Intelligent Speed Adaptation	1	
Traffic information and recommended itinerary	1	
Wrong way driving warning	1	1
Dynamic speed limits	1	
Road user charging	1	1
Requested green (in a cooperative way)		1
Multimodal travel information	1	
Post crash warning/eCall	1	
Automatic access control	1	1
Parking information and guidance	1	
Emergency vehicle warning		1
Cooperative Adaptive Cruise Control (C-ACC)		1
Cooperative intersection collision avoidance		1
Dedicated Lanes	1	

More explanation about the definition of the scenarios and the assumptions can be found in section 4.1.

3 Impact assessment

The project aims at assessing the impacts relevant for road operators in order to provide support for decision makers on cooperative systems. The indicators selected are therefore related to assessable outputs that can be used for cost-benefit analyses directly. The impacts determined in the assessment stage are evaluated in monetary terms in order to provide decision support for the COBRA tool.

The impacts are grouped as follows:

- **Safety**: The safety potential of cooperative systems is of major importance for road operators. It comprises the effect on numbers of accidents, fatalities and injuries.
- **Traffic efficiency**: The primary efficiency indicator is traffic flow, which is affected by traffic density, volume and vehicle velocities.
- **Environment**: Environmental effects are assessed regarding emissions and fuel consumption.

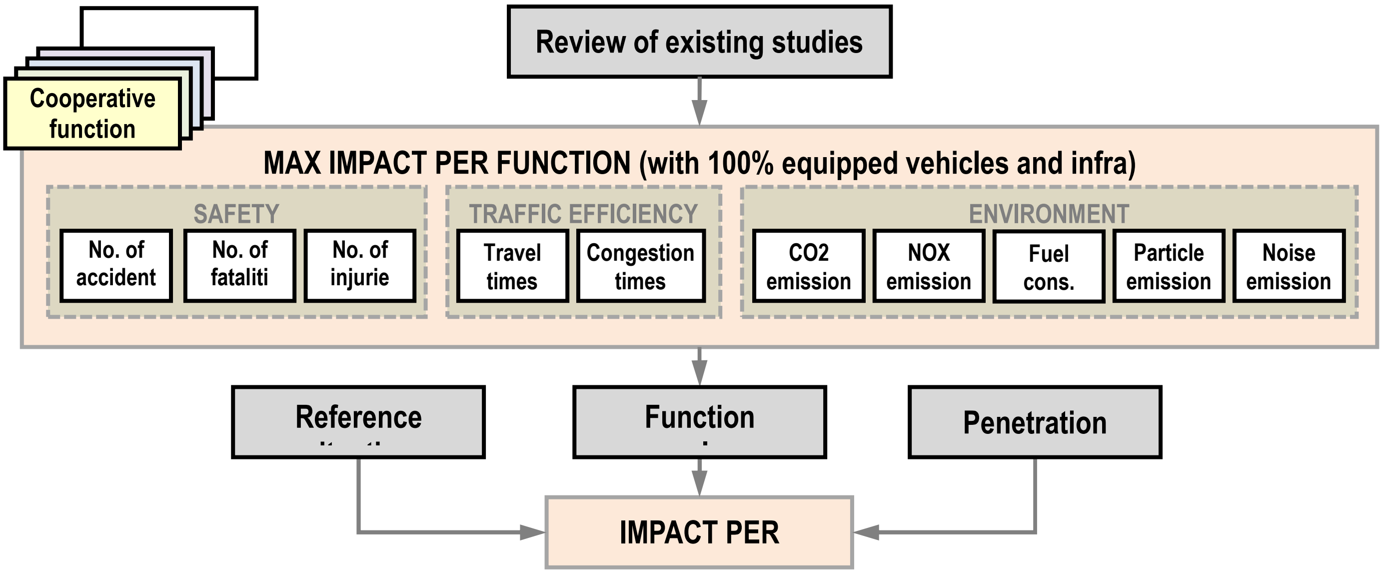


Figure 2: Methodology for assessing the impacts

The concept of impact assessment is depicted in Figure 2. This impact assesment consists of four parts. The first task will be the assessment of impact indicators at a 100% cooperative system penetration for each function. In COBRA, these safety, efficiency and environment indicators are identified from the literature review and data collected in previous studies.

The second task is to determine the ovelap between the functions. This allows us to determine the impact per bundle. Then the relation between in penetration of equipped vehicles and infrastructure, and the actual impact needs to be determined. Finally the current size of the traffic (safety, efficiency and environment) problems are defined as a reference case.

Chapter 3.1 describes the indicators. The impacts are assessed for each function, but are later combined to calculate the impact for each bundle. Chapter 3.2 deals with this issue and explains how overlaps between functions are taken into account. The idea of how to relate the expected impact to different penetration scenarios is described in Chapter 3.3.

3.1 Impact indicators

The impact assessment is based on findings and results from previous studies and projects. In COBRA, no particular simulations of traffic flows or emissions will be carried out. Instead, the following studies provide relevant information about impact indicators (see Table 4). A cross (X) labels the corresponding impact group that was investigated in detail.

Table 4: Data sources for the impact assessment

Name of study	Year	Where	Safety	Efficiency	Environment
2DECIDE	2011	EU	x	x	x
ACAS FOT	2006	USA	x		
ADVISORS	2000	EU	x	x	x
CLIMATE	2011	AUT			x
CODIA	2008	EU	x	x	x
COOPERS	2009	EU	x	x	
CVIS	2009	EU	x	x	
ECORYS/COWI	2006	EU	x	x	x
eIMPACT	2008	EU	x	x	x
euroFOT	2012	EU	x	x	x
FESTA	2008	EU	x	x	
Freightliner FOT	2003	USA	x	x	
Full Traffic	2008	NL	x	x	x
HEATCO	2006	EU	x	x	x
ICCS FOT	1999	USA	x		
Mack FOT	2006	USA	x	x	
ROSEBUD	2005	EU	x		
SAFESPOT	2009	EU	x	x	
SEiSS	2005	EU	x	x	x
TAC Safe Car	2006	AUS	x	x	x
TeleFOT	2012	EU	x	x	x
Volvo FOT	2007	USA	x	x	

All data gathered from these studies, as well as assumptions made by the COBRA team, needs to be transparent. This allows assessment results to be updated in the future with better knowledge about indicators and penetration rates. Therefore, a “literature matrix” is used to incorporate review results and data from previous studies. This is done for each cooperative function and for each indicator selected for impact assessment.

The following indicators are used for assessing the impacts of

Safety:

- **Number of injury accidents**: Number of road accidents resulting in personal injuries.
- **Number of fatalities**: Number of lethally injured people caused by a road accident.
- **Number of injuries**: Number of people, who have been slightly or seriously wounded in a road accident.

Traffic efficiency:

- **Travel times**: Measured difference between departure and arrival times of vehicles on a specific road site (corridor).
- **Fuel consumption**: The consumption of fuel (gas or diesel) is typically measured in litres per 100 kilometres. It must be noted that COBRA will not assess the impacts on energy consumption of electric vehicles, since there is still a lack of reliable research studies.

Environment:

- **CO_2**: Carbon dioxide; Measure in grams per kilometre.
- **NO_X**: NOX is a generic term for mono-nitrogen oxides NO and NO2 (nitric oxide and nitrogen dioxide). Measured in grams per kilometre
- **Particles**: The burning of fossil fuels in vehicles generates significant amounts of particles with different chemical compositions. They can be seen as small localized objects, depending on the scale. Particles are commonly noted as particulate matter (PM) suspended in air, followed by a number that refers to a maximum particle size. For example, $PM_{2.5}$ refers to particles with an aerodynamic diameter of up to 2.5 µm. The PM emissions will also be measured per kilometre.

This list contains high-level indicators, referring to impacts that can directly be converted into monetary units for cost benefit analysis. If none of these indicators can be found in literature, they will be derived from low-level indicators, e.g. traffic density, average vehicle speeds, time-to-collision etc.

Review results may vary due to different assumptions, regions of interest or methodology. The challenge will be to harmonize the indicators estimated in different studies. In case of different impact values for one and the same function and penetration, a weighting regime/algorithm will be used to access a harmonized assessment result. The function weighting will be based on several impact factors such as study design, sample size, analysis method etc. By doing so, one gains an impression of how meaningful it is to generalise a set of findings of evaluation studies in terms of a weighted average result. One way of checking whether a weighted mean estimate of effect makes sense is by conducting a meta-analysis. This method refers to an analytical procedure focused on contrasting and combining results from different studies, in the hope of identifying patterns among study results. In its simplest form, this is normally by identification of a common measure of effect size, of which a weighted average might be the output. In order to conduct a meta-analysis, two basic requirements need to be fulfilled:

- Results of several studies dealing with the same topic/bundle
- A common basis, i.e. the studies should use the same indicators (e.g. road fatalities, fuel consumption etc.). Otherwise, the research results cannot be combined to a single (mean) value.

It must be considered that driver behaviour changes and adapts to systems. It is likely that drivers change their behaviour due to novel cooperative traffic systems, but how drivers will adapt their driving is a matter that is hard to predict. For example, some systems may influence attention, mental load or headway distances. Moreover, drivers may get used to systems. Behavioural changes will depend on the duration of system usage. For example, drivers may change their behaviour after system integration, but fall back in their normal driving when they are used to the system. Such effects are considered in previous works, e.g. eIMPACT, where nine different mechanisms for assessing the impacts are used. The assessment in COBRA will be based on such existing estimations without conducting additional analysis.

3.2 Combining the impacts for each bundle

One of the main difficulties in assessing the impacts of cooperative systems in this approach is to bundle the results per functions according to the three identified bundles: *Local dynamic event warnings; In-vehicle speed and signage; Travel information and dynamic route guidance*. The previous chapters explained how the effects of each function are judged and valued. The next step before calculating the benefit/cost ratio (see Chapter 4) is to estimate the impact per bundle.

Different technologies and/or systems might affect each other. To cope with this, the interrelation between different cooperative functions is included in the assessment methodology. This requires assumptions to be made about the extent of overlaps between systems. One option is to split the effect by situation, then assume full overlap of functionality for similar situations and no overlap in functionality for different situations. Situations are defined by the intended effect of the function. This can be characterized by e.g. road type, accident type (for safety), etc. For example, two systems that address rear-end collisions may have full overlap, but have no overlap with a system that addresses frontal collisions. An example list of situations for each functions is given in Table 5.

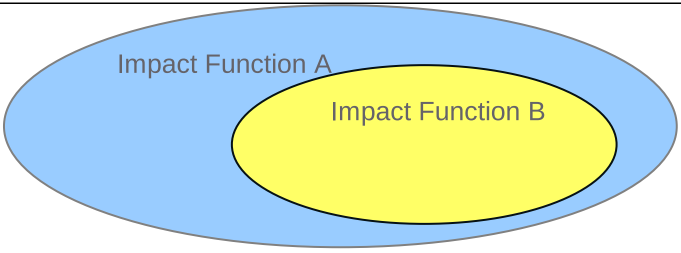
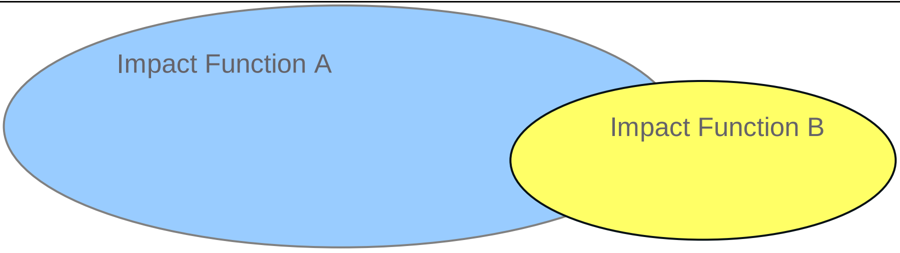
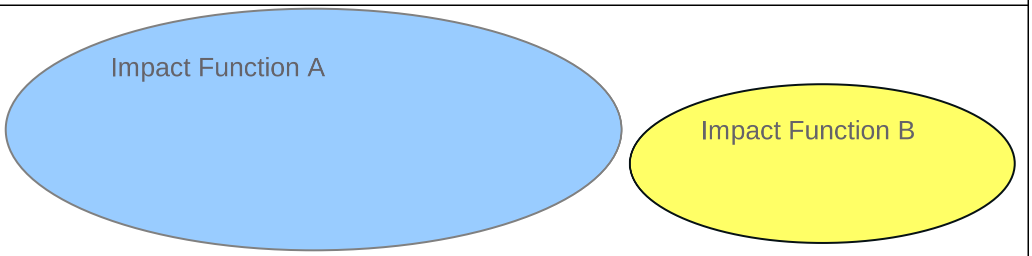
Table 5: Example situations for each function

Bundle	Function	Problem Situation
Local dynamic event warnings	**Hazardous location notification**	Approaching icy road section Approaching oily/slippery road section Approaching road section with poor surface condition Approaching fog
	Road works warning	Approaching a road works zone
	Traffic jam ahead warning	Approaching traffic jam
	E-Call	Having a crash
In-vehicle speed and signage	**In-vehicle signage**	Approaching sharp curve Approaching roundabout Approaching pedestrian crossing
	Intelligent speed adaptation	Over-speeding
	Dynamic speed limits	Approaching fog Approaching icy road section Approaching oily/slippery road section Congestion shock wave occurs Exceeding emission limits
Travel information and dynamic route guidance	**Traffic info and recommended itinerary**	pre-trip route choice on-trip route choice after incident …
	Multimodal traffic information	pre-trip route choice on-trip route choice after incident …
	Truck parking information and guidance	Truck parking

In order to not overestimate impacts per bundle, a simple addition of impacts is only realistic if the individual functions' impacts are not overlapping. For most of the functions within a bundle, this is not the case (e.g. *hazardous location warning* and *traffic jam ahead warning*). Therefore, a distinction needs to be made between full overlap, partial overlap and no overlap, as depicted in Table 6. Therefore, it is necessary to

- identify overlapping functions within a bundle;
- estimate the overlapping range;
- calculate the resulting impact per bundle.

Table 6: Overlapping impacts of cooperative functions within

a.)	Full Overlap	
b.)	Partial Overlap	
c.)	Null Overlap	

The proposed calculation method uses the maximum impact for full overlap (a.), partial added impact (b) and fully added impacts (c):

a) Impact (Bundle) = max (Impact (A), Impact (B), Impact (C),…)
b) Impact (Bundle) = [Impact (A) + Impact (B) + Impact (C)…] – Overlap [Impact (A) + Impact (B)+ Impact (C)…]
c) Impact (Bundle) = Impact (A) + Impact (B) + Impact (C)

The overlap estimation of two functions will be based on the situation analysis (see Table 5) and the target objectives (i.e. target accidents for the function Hazardous location notification or change of mean speed for the function Intelligent Speed Adaptation). Table 7 proposes the corresponding calculation method for each function considering their overlaps. It must be noted that there may be an overlap between bundles, e.g. traffic information affects traffic jams. However, these overlaps are not assessed in COBRA, since the bundles are considered to be independent of each other.

Table 7: Bundles and how to deal with overlaps

Bundle	Function	Proposed calculating method
Local dynamic event warnings	Hazardous location notification	a
	Road works warning	a
	Traffic jam ahead warning	a
	E-Call	c
In-vehicle speed and signage	In-vehicle signage	b
	Intelligent speed adaptation	b
	Dynamic speed limits	b
Trave informatio n and route guidance	Traffic info and recommended itinerary	a
	Multimodal traffic information	a
	Parking information and guidance	c

3.3 Penetration scenarios

In COBRA, the share of vehicles equipped with cooperative in-vehicle devices in a fleet is defined by the term “fleet penetration”. Respectively, the term “RSU penetration” denotes the share of road kilometres equipped with roadside units (RSU) in a road network. For both terms, the penetration rate defines the change of penetration over time, e.g. the yearly development of vehicles equipped.

However, the essential factor is the number of “informed vehicles”, which depends on fleet and RSU penetration. This relation is depicted in Figure 3 for the two platforms, “Cellular” and “Wireless Beacons”. For a certain year, the penetration of informed vehicles equals the percentage of vehicles equipped (fleet penetration) multiplied by the percentage of road kilometres equipped with communications. The yearly change is then added to the penetrations in order to determine the development over time. The COBRA tool will allow the users to choose between various penetration rates in order to strengthen the decision support for road operators. The rates comprise the current market penetration of both in-vehicle and roadside units necessary for the corresponding function and platform.

Platform: Cellular		
Communications penetration rate	In-vehicle penetration rate	
100%	Aftermarket+Nomadic	Low (39% in 2030) Medium (59% in 2030) High (78% in 2030)

Platform: Wireless Beacons		
Communications penetration rate	In-vehicle penetration rate	
User defined (Easyway suggests a realistic scenario for 2030 is <5%)	OEM-fitted	Low (9% in 2030) Medium (29% in 2030) High (61% in 2030)

Figure 3: Penetration of informed vehicles

High, Medium and Low scenarios will be determined based on previous studies (market penetrations of cooperative safety systems from SAFESPOT and intended deployment of cooperative road side infrastructure can be specified by the user of the tool or are taken from EasyWay). The scenario (High, Medium, Low), as well as the relevant platform (Cellular or Wireless Beacons), has to be selected by the user of the tool. This step results from the number of cooperative in-vehicle devices sold and cooperative road side units deployed each year.

All impact indicators are assessed for 100% penetration of informed vehicles. These are then multiplied by the number of informed vehicles.

3.4 Hotspots

The notion of 'black spots' or 'Hotspots' are considered; i.e. these are sections of the road network where more accidents, travel time or emissions occur. Hotspots suggest that the share of the maximum effect is more than proportional to the share of the road network that is equipped with cooperative road side equipment, assuming that Hotspots are equipped first. It is expected that these relationships will vary for the different type of impact.

3.5 Existing infrastructure

The 'reference case' or 'base case' for the planned future deployment of infrastructure-based systems using existing technologies is to be defined by the user. It is assumed that the three bundles of services are currently delivered by existing infrastructure and that on road sections with this infrastructure, no additional benefits are delivered by cooperative systems, so benefits are seen only where the network is not already equipped with such infrastructure. The three infrastructure-based systems are:

- 'Roadside Travel and Routing Information (assumed to deliver the Travel Information and Dynamic Route Guidance bundle using roadside variable message signs)
- 'Queue Protection' (assumed to deliver the Local Dynamic Event Warnings bundle)
- 'Managed Motorways / Variable Mandatory Speed Limits' (assumed to deliver the In-vehicle Speed and Signage bundle).

4 Benefit Cost Analysis

The benefit cost analysis is intended to translate the information on expected impacts of cooperative systems described in Section 3 into monetary terms. This will enable authorities to estimate the scale of benefits and costs arising from a decision to invest in cooperative systems, and if the benefits exceed the costs, whether the benefit cost ratio is sufficiently large for investment to be considered further. To this end, comparison is made with the base case (or reference case) which is intended to represent the situation if road authorities continue with current practice i.e. vehicle detection based on fixed infrastructure (loops), dynamic in-trip information provided by road authorities to drivers via VMS, broadcast etc. and can take account of future plans for such investment.

An assessment of the relative benefits and costs is however just one part of an investment decision. Factors such as policy priorities, distributional effects, political will and synergy with other initiatives are also important influences on investment decisions (and are often more influential than the benefit cost analysis). Such factors are not included in this tool and road authorities will need to weigh up these non-monetised factors alongside the estimated benefits and costs, when making investment decisions. Budgets also play a key role in decision making; the tool enables road authorities to examine the business case as well as assessing the societal benefits and costs.

The tool enables benefits and costs to be assessed over a range of time intervals up to 2030.

It will be possible to refine the base data, or to use the data already included in the tool for two example countries: the UK and The Netherlands. An authority wishing to make a broad comparison between different services or implementation scenarios could do so using the example data.

The user will have the ability to build a number of scenarios which provide a top-level description of the cooperative environment. In building the scenarios, the user will select from:

- Country
- Which bundles are being analysed
- What platform will the services run on
- Business model
- Select penetration curves (high, medium or low)
- Planned investment schemes for roadside infrastructure
- VMS coverage
- Detector loop coverage
- % of network equipped with roadside infrastructure (wireless beacons)

In addition, the user will be able to provide some input parameters to the scenarios, including the discount rate to be used.

All parameters will have default values to be used if the user does not enter values.

Sitting behind the user-entered data will be country specific data on costs, business models, impacts, forecasts on penetration rates etc. This data will generally be hidden, but it will be possible for the user to edit it if required.

4.1 Scenarios

A scenario describes the context, in terms of service, technology, stakeholders' roles and deployment, for which the analysis is made. It is a combination of a bundle (service), a platform (technology), the business model (stakeholders and their roles), and a number of other assumptions about deployment such as market penetration rate of in-car and nomadic devices.

The scenarios can be defined using three key dimensions:

- The services available for analysis and the communications for delivering them
- Assumptions about the rate of penetration of equipment to support these services (along the roadside, within the vehicle fleet or as nomadic devices available for use in vehicles)
- The type of business model which road authorities choose for providing cooperative services, which determines the stakeholders and their roles.

In addition, users may select some refinements of these key dimensions:

- Deployment via aftermarket in-vehicle equipment or smartphones

- Different levels of vehicle costs (full costs, one-third, half or no costs)
- Operational costs
- Phasing out of existing roadside systems, leading to a reduction in societal benefits but also a monetary cost saving to the road authority.

The various services available for analysis are the combinations of bundles and communications platforms which are outlined in Section 2.2.3. Previous studies (CVIS 2010, Intelligent Infrastructure Working Group, 2010) have shown that cooperative services only become feasible if similar services are bundled, and indeed the recent EasyWay I Business Case and benefit cost assessment of cooperative services (2012) takes this approach. Services can be bundled in a number of different ways; for example, EasyWay bundled services by communications requirements into those requiring V2V communications, and those requiring V2I communications. In this analysis services requiring V2V communications are not considered as these services will not incur a cost to the road authorities and hence are not relevant to cost-benefit analysis. For road authorities, the benefits from cooperative services are related to the function of the services, so for example services which provide information into the vehicle may reduce the need for roadside signage. Hence for this analysis the services are bundled functionally into three bundles (as described in Section 3.2):

- Local Dynamic Event Warnings
- Travel information and dynamic route guidance
- In-vehicle speed and signage.

Cooperative services require a communications infrastructure which can be provided by either cellular long range communications or WiFi-like high-speed, short range communications (probably compliant with IEEE 802.11p standards, described here as “wireless beacons”), or both. While WiFi-like communications are crucial to the success of cooperative systems requiring V2V communications, it is not clear at this stage if WiFi-like communications are feasible on the inter-urban road network. In any case, a combination of both seems more realistic in practice. A good estimation of the optimal balance between WiFi-like units and cellular coverage is highly location and traffic dependent and requires prediction about data transmission rates and prices related to traffic density. Current state of the art lacks those predictions, so an optimal balance between wireless and cellular is not available. At this stage the analysis will include only either one or the other of these communication platforms.

The assumptions about the penetration rate are based on work in SAFESPOT and described in Section 3.2; scenarios for high, middle and low penetration rates are available.

The business models that can be selected fall into three main categories:

- Public: road authorities want to guard societal values (like level of service, accident avoidance and emission reduction) and therefore are in control of guidance and control of traffic flows.
- Private: the role for road authorities is limited to enabling market parties to provide cooperative services to end users.
- Mixed: road authorities and market parties cooperate to realize cooperative services, combining optimal individual freedom with guidance where social preconditions are not met.

In a public model, the road authority is responsible for delivering the cooperative service to the end user, and the service is usually paid from tax revenues. In a private model, a market party is responsible for the service delivery to the end user, who usually has to pay a fee. If the private service performs a task for the road authority, then the business model may include quality agreements or level of service specifications. In a mixed model, such agreements may also be put in place to specify the collaboration.

It should be noted that this terminology is not pinpoint correct because the role of road authority can be fulfilled by a private party, like the toll motorway operators in France. Such a road authority will have a different business model than a public one, because his goals are different. Indeed, societal goals are external goals for a private road authority, laid down in contracts or motivated by monetary or public relations concerns (e.g. cost reduction of incident management, or a “safe” image), while for a public road authority they are the internal goals of the organization itself. As the majority of roads is publicly operated, the business models will focus on this setting, and the terms “private” and “public” will be used for brevity. The business models can be adjusted to the case of private road authorities with rather little effort.

It is proposed that the user will be able to select from various “market”, “public” or “mixed” models. The business model determines the distribution of costs and benefits over stakeholders, and hence influences the business case for the road authority and other stakeholders. It is assumed not to influence the *societal* costs and benefits. While this is debatable, as there may be differences in efficiency between the business models, in the absence of clear data this assumption seems a reasonable first approximation. Section 4.5 will describe the business models that can be selected.

4.2 Benefits per bundle

4.2.1 Method

The tool itemises the main benefits in monetary terms for each bundle of services. Monetised benefits can be divided into two categories:

- Direct monetary benefits, where the implementation of a (bundle of) cooperative services leads to a direct saving to the road authority, for example by reducing infrastructure costs; and
- Societal benefits, where the cooperative services provide a monetisable benefit to society as a whole, for example the cost saving of preventing a fatal accident.

As road authorities normally exist to further the aims of government, it is reasonable to combine these benefits, and this will be done in this analysis.

The benefits which will be considered include:

- Reduced infrastructure requirements (both CAPEX and OPEX) once a certain market penetration has been reached – typical examples here include the reduced requirement for non-essential signage like VMS. There are however social consequences which will need to be considered by decision-makers, such as how to serve the remaining non-equipped users, which could offset some of the benefits
- Reduced fatalities and injuries, resulting from free-flowing traffic and improved information
- Reduced accidents, leading to less incident-induced congestion, and hence more reliable journey times
- Reduced travel times
- Reduced fuel consumption from less congestion and traffic management
- Reduced emissions (CO_2, NOx, PM) from smoother traffic flow.

(Note that ideally, noise reduction benefits would also be included, but there is currently insufficient information available to assess the scale of the impacts on the inter-urban road network.)

The benefits from cooperative services will only be those which are derived from V2I based services – V2V based services are assumed to happen anyway without any intervention from or investment by Road Authorities. Further benefits provided by the addition of V2I based services will however be included where appropriate.

The tool works on the principle of making conservative estimates to reduce the likelihood of over-optimistic assessments.

Note that some key types of benefit are not included. These include indirect benefits such as wider economic benefits, for example growth and employment, and distributional effects such as social inclusion. Such benefits are difficult to evaluate and it may be disputed whether these are in fact due exclusively to the package itself and not to other factors. Thus the approach proposed will tend to underestimate the possible benefits from the package rather than overestimate them.

However, there will only be benefits if a sufficient level of both sensing (combination of road side and in-car) and communication is deployed. An assumption in the tool is that sensing and communication equipment will be placed at the same locations. Possibly, a minimum level of sensing equipment will be defined in terms of loops per kilometre and floating car data for each bundle. This makes it possible to define a fraction of the network that is 'equipped' to provide the services in that bundle.

4.2.2 *Sources of data*

These benefits are based on the estimated impacts using expert judgement and data from studies of the impacts of non-cooperative versions of these services (as described in Section 3) and derived from the previous studies listed in Section 3 and summarised in COBRA deliverable 3.

The beneficial effects of installed cooperative services are fundamental to the estimation of benefits and information is derived from existing studies of systems which provide similar services, but autonomously rather than cooperatively.

The benefits are monetised using the standard monetary values used in the two example countries concerned and discounted to 2012. The discount rates used are shown in Table 8 and standard values for benefits are shown in Table 9.

Table 8: Discount rates

Discount rate	UK	NL
Discount rate	3.5 %	4.0 %

Table 9: Unit cost data used for valuing benefits

Type	Description	Units	UK Value	NL Value	Source
Accident unit costs	Fatality - value of prevention (lost output, medical and ambulance, human costs)	Euro/ fatality	2,112,289	2,580,640	UK - DfT WebTAG Unit 3.4.1, Table 1 (Aug 2012), 2010 value NL – EasyWay Both scaled up by GDP to 2012
	Serious injury - value of prevention (lost output, medical and ambulance, human costs)	Euro/ serious injury	237,366	257,529	UK - DfT WebTAG Unit 3.4.1, Table 1 (Aug 2012), 2010 value NL – Easyway (victim in hospital) Both, scaled up by GDP to 2012 value
	Slight injury - value of prevention (lost output, medical and ambulance, human costs)	Euro/ slight injury	18,291	4,767	UK - DfT WebTAG Unit 3.4.1, Table 1 (Aug 2012), 2010 value, scaled up by GDP to 2012 value
	Injury accidents - value of prevention (police costs, insurance and admin, property damage)	Euro/ injury accident	5,724	4,129	UK- DfT WebTAG Unit 3.4.1, Table 3 (Aug 2012), 2010 value, NL – Easyway, property damage only, 2010 value. Both scaled up by GDP to 2012 value
Value of time	Value of time, weighted by working / non-working time	Euro/ vehicle hour	10.77	11.95	Derived using data on distance driven as: - Car, non-working time (Commuting) - Car, non-working time (Other) - Car, working time (Business) - LGV, working time - HGV, working time
	Cars (driver + passengers)	Euro/ hour working time	40.07	37.25	Derived using occupancy data

Type	Description	Units	UK Value	NL Value	Source
		(resource cost)			
	Cars (driver)	Euro/ hour working time (resource cost)	35.69	31.80	UK - DfT WebTAG Unit 3.5.6, Table 1 (Oct 2012) NL – RWS, average of economic forecasts
	Cars (passenger)	Euro/ hour working time (resource cost)	25.57	31.80	UK - DfT WebTAG Unit 3.5.6, Table 1 (Oct 2012) NL - RWS, average of economic forecasts
	Light Good vehicle (driver or passenger)	Euro/ hour working time (resource cost)	13.75	31.80	UK - DfT WebTAG Unit 3.5.6, Table 1 (Oct 2012) NL - RWS, average of economic forecasts
	HGV (OGV) (driver or passenger)	Euro/ hour working time (resource cost)	13.75	43.90	UK - DfT WebTAG Unit 3.5.6, Table 1 (Oct 2012) NL – EasyWay 2010, scaled up by GDP to 2012
	All persons – non-working time, commuting	Euro/ hour non-working time (resource cost)	6.90	9.18	UK - DfT WebTAG Unit 3.5.6, Table 2 (Oct 2012) NL - RWS, average of economic forecasts
	All persons – non-working time, other	Euro/ hour non-working time (resource cost)	6.10	6.34	UK - DfT WebTAG Unit 3.5.6, Table 2 (Oct 2012) NL - RWS, average of economic forecasts
Fuel costs	Petrol (price at pump)	Euro/ litre	1.71	1.758	UK – DECC average retail prices of petroleum products Table 4.1.1 (Nov 2012) NL – CBS, average price 2012
	Petrol (price at pump excluding VAT)	Euro/ litre	1.42	1.453	UK – 20% VAT NL – 21% VAT (19% VAT until October 2012, 21% after; used 21%)
	Fuel duty on petrol	Euro/ litre	0.7296	0.730	UK - https://www.gov.uk/fuel-duty#rates-of-fuel-duty NL – 2012 rate from http://www.rijksoverheid.nl/onderwerpen/belastingtarieven/btw-en-accijns

Type	Description	Units	UK Value	NL Value	Source
	Petrol (excluding tax and VAT)	Euro/ litre	0.70	0.80	UK – Derived NL – EasyWay 2010, scaled up by GDP to 2012
	Diesel (price at pump)	Euro/ litre	1.79	1.444	UK – DECC average retail prices of petroleum products Table 4.1.1 (Nov 2012) NL – CBS, average price 2012
	Diesel (price at pump excluding VAT)	Euro/ litre	1.49	1.193	UK – 20% VAT NL – 21% VAT (19% VAT until October 2012, 21% after; used 21%)
	Fuel duty on diesel	Euro/ litre	0.7296	0.430	UK - https://www.gov.uk/fuel-duty#rates-of-fuel-duty NL – 2012 rate from http://www.rijksoverheid.nl/onderwerpen/belastingtarieven/btw-en-accijns
	Diesel (excluding tax and VAT)	Euro/ litre	0.76	0.76	EasyWay, scaled up by GDP to 2012
Environ mental costs	Damage cost value - CO_2	Euro/ tn	69	69	UK - DfT WebTAG Unit 3.3.5, Table 2a (Aug 2012) NL - UK value
	Damage cost value - NO_x	Euro/ tn	1202	1202	UK - DfT WebTAG Unit 3.3.3, Table 4 (Aug 2012) NL – UK value
	Damage cost value - PM 2.5	Euro/ tn	139,355	13,935.46	Easyway 2010, scaled up by GDP to 2012

The tool will include an explanation of any qualifications and limitations of the data with a “health warning” on the implications for interpreting the results.

Key data issues will need to be addressed, including:

- The need for consistency between countries of definitions, coverage etc;
- The time period of the data;
- Monetary valuations; and
- The impact of other related interventions.

4.2.3 Assumptions

For the estimation of future benefits, certain assumptions need to be made. These include:

- Costs of congestion (calculated on the basis of assumptions about vehicle occupancy and value of travel time), emissions, deaths and injuries etc. are derived from existing studies
- Traffic demand growth (which is driven in turn by population and economic growth) is based on government forecasts
- Market penetration of suitable on-board equipment
- Effects of improved vehicle efficiency, safety etc. to ensure benefits of cooperative systems are not over-estimated are based on government forecasts
- Discount rates to calculate the net present value will be based on those currently used by public authorities (e.g. 3.5% in the UK, 4.0% in The Netherlands).

4.3 Bundle costs

4.3.1 Method

The tool itemises the main cost elements in providing each bundle of services:

- In-vehicle equipment costs for OEM, after-market and nomadic device fitment
- Infrastructure costs, including detection, signage, control equipment (both CAPEX and OPEX)
- Communications costs
- Back office and data processing costs

The tool works on the principle of pessimistic estimates of the costs (as well as cautious estimates of benefits) to reduce the likelihood of over-optimistic assessments.

4.3.2 Sources of data

The monetary values are derived from the EasyWay study. Other sources examined such as the US DOT RITA ITS Costs Database and the 2Decide on-line ITS Toolkit, did not provide suitable data. Appendix B summarisesthe values used and explains how these were derived.

The EasyWay study base year was 2010 and it projected impacts for 2030.

The documentation for the tool will also include an explanation of any qualifications and limitations of the data, with a “health warning” on the implications for interpreting the results.

4.3.3 Assumptions

The tool assumes that the costs will be the same in different organisations.

It also assumes that organisations using the tool will need to collect their own data as input to the tool.

Some assumed costs and cost forecasts include:

- In-vehicle equipment costs for OEM, after-market and nomadic device fitment
- Infrastructure costs (capital costs)
- Communications costs
- Maintenance costs
- Operating costs
- Installation costs

4.4 Cost Benefit analysis and sensitivity

4.4.1 Cost Benefit analysis method

Societal cost benefit analysis (CBA) is based on the principle of welfare economics which assesses whether or not society as a whole is expected to be better off as a result of introducing a measure, so that the estimated benefits are greater than the estimated costs incurred. The resource savings made (capital equipment, labour, time, fuel etc.) are assumed to be deployed elsewhere in the economy at least as productively as before the measure was introduced. CBA is a tool that allows those who gain from an intervention to compensate the losers if that is considered desirable.

The method used in the tool is based on recommended techniques for benefit cost analysis developed in European projects. A review of approaches to *ex ante*[1] assessment has indicated that several different methodologies are used throughout Europe (Mackie and Kelly, 2007).

Benefit - Cost Analysis has faced two particular problems:

- It aims to reduce all impacts to a single monetary metric; and

[1] Assessment prior to implementation

- Distributive effects are not taken into account within the analysis.

The introduction of ITS systems will generate a wide range of impacts, many of which are not easily monetised, for example due to the lack of a market-based pricing mechanism, but which need to be identified and, if possible, measured according to an acceptable scale. In addition the distributional impacts will vary according to location, activity, social group etc. These differences need to be recognised in any analysis.

The European norms are set by the HEATCO (Developing Harmonised European Approaches for Transport Costing and Project Assessment) recommendations which were developed to act as a standard in evaluation of TEN project, although ITS assessment decisions are not specifically addressed (HEATCO 2004). At present, evaluation of investments and policy measures takes place in a highly pragmatic manner.

National guidelines exist in a number of countries. For example in the UK the New Approach to Transport Assessment (NATA) is a body of advice, software and data products that the UK Department for Transport provides to support those developing business cases for Government funding or approval. However ITS is not specifically covered and NATA is probably inappropriate for assessing the impacts of its introduction. The national approaches differ widely in terms of their methodologies, level of detail and indicators. These differences are partly due to a natural bias of guidelines towards state level economic and social objectives. They were not developed for assessing international projects. In part, however, there are also differences in assumptions between countries in terms of the economic valuation of impacts.

Other European studies have also attempted to standardise assessment methodologies. FESTA (Field opErational teSt supporT Action) is an approach to assess the impacts of ICT systems on driver behaviour, both in terms of individual (safety) benefits and larger scale socio-economic benefits applying common methods for field operational tests in EC funded projects (FOT-NET 2011). The 2DECIDE (Toolkit for sustainable decision making in ITS deployment) project is currently developing an ITS toolkit for decision support for transport authorities and operators in the road and public transport sectors by providing easy access to information and knowledge on ITS.

KonSULT (the Knowledgebase on Sustainable Urban Land use and Transport) is designed to help policy makers, professionals and interest groups to understand the challenges of achieving sustainability in urban transport, and to identify appropriate policies (including implementing ITS systems). It provides detailed information on individual policy instruments and comparable assessment from first principles based on case studies. It also enables users to identify the individual policy instruments which may be of most relevance to their needs, and to combine these into effective policy packages.

One assessment methodology that does not require monetary valuations of impacts but does allow for the consideration of distributional impacts is the (Planning Balance Sheet) PBS approach. This involves identifying costs and benefits by different sectors (e.g. operators, residents, businesses etc.), measuring them in monetary terms wherever possible but, as a minimum, identifying the impact and the distributional effects.

The assessment method developed for the project will build on the most appropriate elements from HEATCO, FESTA and cost benefit analysis while recognising that some elements will not be able to be monetised, yet will need to be included in any decision support approach.

The tool uses a 'lifecycle' approach which enables road authorities to assess benefit-cost ratios for any year up to 2030 (the timeframe covered by the tool), and takes account of the varying lifecycles of different items of equipment involved in cooperative systems. This will enable road authorities to visualise how the return on any potential investment is expected to change over time. (Note this is different from the approach used in some European projects on cooperative systems such as EasyWay and CODIA, which take a 'snapshot' approach, calculating benefit cost ratios only for specific years.)

The term 'unintended impacts' is used in the tool to denote impacts which may be seen as negative (such as increasing journey times). For the purpose of calculating a benefit: cost ratio (BCR), such impacts are often treated as a negative benefit to be subtracted from other (positive) benefits. However this can result in a negative benefit: cost ratio (when there are no actual benefits) or a BCR less than 1:1, which was felt to be confusing; to avoid this, unintended impacts have been treated as additional costs for the purpose of calculating the benefit: cost ratio in the tool. This tends to bring the

BCR closer to 1:1. However, using this alternative method has no effect on the overall conclusions about investment decisions. Similarly, negative costs, i.e. cost savings, are treated as benefits.

Like the other components of the tool, the benefit cost analysis method will be tested as part of the development process to ensure that it is operating as expected; it will be refined to eliminate any errors and inconsistencies identified during this testing phase.

The results for the example countries included in the tool will be presented and discussed in D4.1 (the report accompanying the tool).

4.4.2 Benefit Cost analysis assumptions

The main assumptions relate to:

- Discount rate
- Traffic forecasts (which take into account changes in vehicle ownership and mileage)
- Accident forecasts
- Forecasts for emissions and energy use
- Forecasts of investment in infrastructure

The assumptions are derived from EasyWay (2011) which were validated by national representatives for the countries concerned; the basis of assumptions can be summarised as follows:

- Discount rates for public investment decisions vary between countries and average 5% across the EU; the rates in the two example countries included in the tool are 3.5% (UK) and 4.0% (Netherlands)
- Traffic forecasts for 2030 are based on available national forecasts
- Accident forecasts for 2030 are based on available national forecasts for the UK
- Forecasts for emissions and energy use are based on national forecasts for the UK)
- Forecasts of investment in infrastructure are based on information from national policies; EasyWay estimates that the maximum proportion of the network expected to be equipped with wireless beacons is 5% for most countries (but 40% in The Netherlands) (EasyWay 2012).

4.4.3 Sensitivity analysis method

For each scenario, sensitivity analysis (to investigate the robustness of the study) enables users to estimate the sensitivity of the results to:

- a range of possible impacts (either from the data available in the tool or by users varying the parameters)
- a range of estimates of bundle costs
- varying estimates of market penetration levels.

Sensitivity analysis will be undertaken after the baseline analysis to act as a check on the initial results and to investigate which variables have the greatest impact. Most likely it would be traffic growth or variations in the discount rate, but there may be other factors that will also have a noticeable impact.

It is anticipated that a graphical representation of sensitivity analysis will be incorporated into the graphs of results as an output of the tool.

By analysing which parameters are most sensitive, road authorities will be able to determine which aspects are most important to consider when making policy decisions.

4.5 Business models and Value webs

This section describes the business models that can be selected for the cooperative bundles. A business model describes the way in which the stakeholders exchange value for money. A business case describes the size of the monetary flows. A positive business case is the situation in which this business model results in a positive cash flow for at least the commercial stakeholders in the value web, without which they are unlikely to participate. Public stakeholders, such as a road authority, can have a different position. They might have budgets to achieve their policy goals in terms of network performance (traffic safety, efficiency and environmental goals). Therefore, societal benefits can take the place of monetary gains for a public stakeholder – in essence, tax revenue is used to buy societal benefits. Depending on how public stakeholders are organised they may have a cost minimisation perspective, a profit maximisation or service maximisation perspective. The public, private and mixed business models reflect some of these differences. Still, it is possible for a road authority to have a positive business case without considering societal benefits, for example when investments in cooperative services are combined with cost savings due to a phase out of existing roadside systems that are made obsolete by these cooperative services.

Business models are visualised in the value webs. A value web is similar to a value chain, but depicts a non-sequential, non-linear set of relationships. It shows the flows of services, money and non-monetised value between the main stakeholders involved in a service (whether as providers or users). The inclusion of flows of societal benefits is a difference from a usual value web as used for private companies' business cases, which only includes flows of money, goods and services. However, since road authorities have a public role, it is appropriate to include societal benefits as well in this case.

The business models and value webs are created on the basis of information on the operation of existing services, data on costs of existing services from the SPITS (2011) and SAFESPOT (2010) projects, and expert judgement.

One of the functions of the value web is to provide the data for estimating the road authority's business case. This is illustrated in Section 4.6, where an example of the output from a value web is included. This shows the percentage of costs borne by the road authority, which is used as a factor in calculating the costs for the road authority's business case.

In each business model the benefits to the road authority are the following:

- The increased service level is expected to result in increased safety and efficiency on the road, resulting in fewer societal costs for the road authority. Also monetary costs (e.g. of incident management) may decrease because of this (this monetary benefit is not considered in the COBRA tool).
- There is an expected savings in replacement and operation of the existing road side equipment, if this equipment is phased out when information and warnings can be provided via a mobile application.
- The road authority will be able to access enhanced traffic data for traffic management if he receives FCD. This is an option in most of the business models.

While each business model gives rise to these three components, there may be quantitative differences in the size of the benefits between the business models. The first of the three benefit types is a societal benefit, expressing that society as a whole will benefit from the services provided by the road authority, traffic control centre and private parties via a behavioural change of the drivers. These societal benefits are denoted as 'virtual €' in the value webs.

In these descriptions and value webs, some relations are a mandatory component of the business model, while others are optional. The optional relations concern the transfer of floating car data or traffic information from one stakeholder to another. The differences are noted in the text for each business model and different symbols are used to indicate mandatory and optional components in the value webs. Furthermore, the value webs indicate whether a flow comprises goods or services, money, or societal benefits. Table 10 shows the legend of the value webs.

In the COBRA tool, optional relations will not be taken into account. Furthermore, in the tool the role of the traffic control centre is merged into the role of the road authority for simplicity of presentation and because in reality they are often the same organization.

Table 10: Legend of the value webs.

Flow	Mandatory	Optional
Money	→	- - →
Services and goods	→	- - →
Societal benefits	→	- - →

A value web will be created for each of the available business models. This will enable road authorities to analyse their roles in the various scenarios. The following subsections 0–0 describe the business models one by one. The concept of a value web is illustrated in more detail for the first case.

Not every business model is applicable for each bundle, and each business model applies to only one communication platform. A summary of this and other key parameters of the business models can be found in Table 11.

Table 11: Overview of the business models that can be selected, showing who pays which costs (both capital and operational). Costs are attributed to RA = road authority, O = other party, - = not applicable.

Business model	Type	Platform	Bundles	In-vehicle device	Wireless beacons	Back office	Application development
BM1	Public	Cellular	All	O	-	RA	RA
BM2a	Mixed	Cellular	All	O	-	RA	O
BM2b	Mixed	Cellular	All	O	-	O	O
BM3	Mixed	Cellular	3	O	-	O	O
BM4	Private	Cellular	3	O	-	O	O
BM5	Public	Beacons	1, 2	O	RA	RA	RA
BM6a	Mixed	Beacons	1, 2	O	O	RA	RA
BM6b	Mixed	Beacons	1, 2	O	RA	RA	O
BM7	Private	Beacons	1, 2	O	O	O	O

The cost of wireless communication is handled differently for wireless beacons and cellular communication. The wireless beacon road side communication infrastructure is assumed to be dedicated to cooperative vehicle systems. The investment costs and operational costs are taken into account in the societal cost benefit calculation. In contrast, the cellular communications infrastructure is already in place with full coverage in most countries, and is already used for several services such as mobile telephony and mobile internet. Thus it is assumed that the cooperative service is an additional use of this existing system, and the societal cost is the cost of expanding the capacity of the existing network. This cost will be modelled as an annual fee.

4.5.1 Business model 1: Free road authority app

Business model 1 is a public business model and applies to the cellular platform and all bundles. It describes a road authority that controls all aspects of information and warning provision. The value web is shown in Figure 4. In this value web, flows of goods, services, money and societal benefits are indicated by arrows, and stakeholder roles are shown in boxes. A single organization may perform multiple roles. In this model the road authority is investing in an application, helpdesk and service. These services are provided to drivers, in this figure via a traffic control centre. The traffic control centre is providing warnings and the application itself to drivers for free. The communication provider is providing the driver with the necessary cellular data communication bundle. The drivers pays for this (e.g., a monthly fee). Optionally the traffic control centre receives floating car data (FCD) from the drivers in return for the free application and warnings.

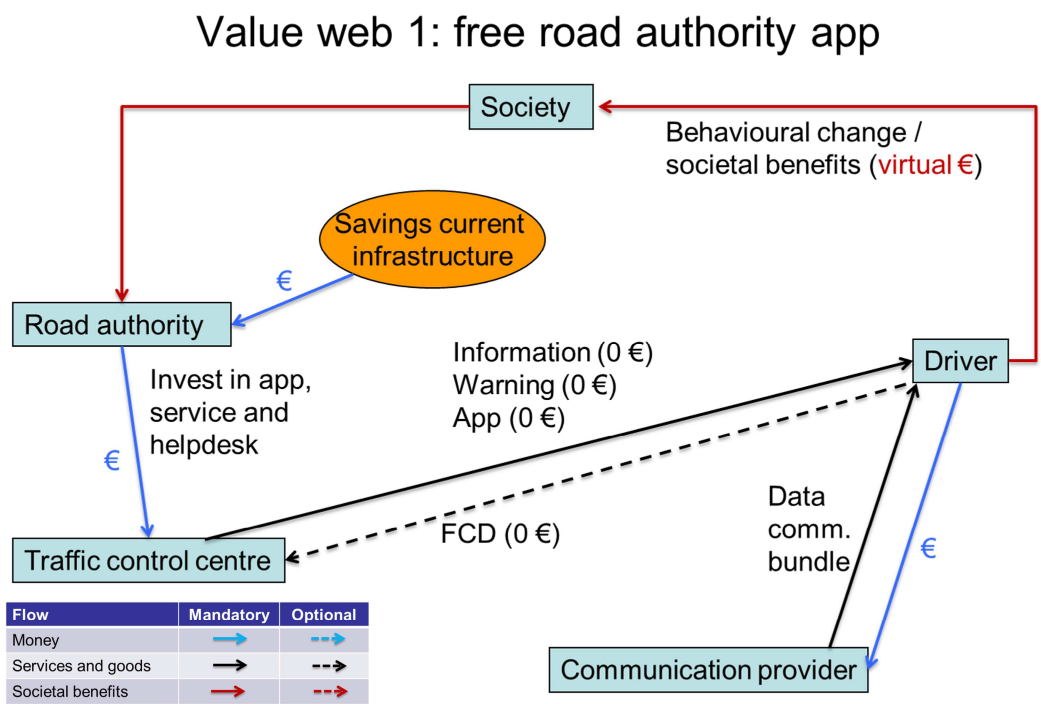


Figure 4: Value web for business model 1, applicable to all bundles and to the cellular platform.

A value web shows the relations between the stakeholders. In this business model the relationships between the stakeholders are as follows:

Between road authority and Traffic control centre

The road authority invests in the development of an app, and in the underlying service and the helpdesk. The app is able to receive the warning messages and show it to the driver when approaching a local dynamic hazard. The service generates and sends out the warning messages. It uses traffic data from detection loops and FCD to do this.

Between Traffic control centre and Driver

The traffic control centre provides and app and warnings to the drivers for free. Drivers can download the app through the app store from the different smart phone providers. In return, the floating car data that is collected through smart phones is sent to the traffic control centre.

Between Driver and Communication provider

The communication provider is a telecommunication operator, operating a cellular network (CN scenario). In this scenario the communication required for the service is assumed to fit within the driver's data communication bundle. The driver pays a monthly fee and can use the network to transfer a certain amount of data.

4.5.2 *Business model 2a: 1€ commercial app*

Business Model 2a is a mixed business model and applies to a cellular platform and all bundles. In this value web, see Figure 5, the road authority invests in an application, helpdesk and service. These services are provided to drivers via a traffic control center and a commercial application provider. The app provider provides an inexpensive app to road users. The road authority provides an information and warning service to drivers for free.

The app provider receives floating car data from the drivers and optionally enriches this data into traffic information for the road authority, in exchange for a fee. The delivery of floating car data from drivers to the app provider can be seen as delivering value in kind. The communication provider is providing the driver with the necessary cellular data communication bundle. The drivers pays for the data communication bundle (e.g., a monthly fee).

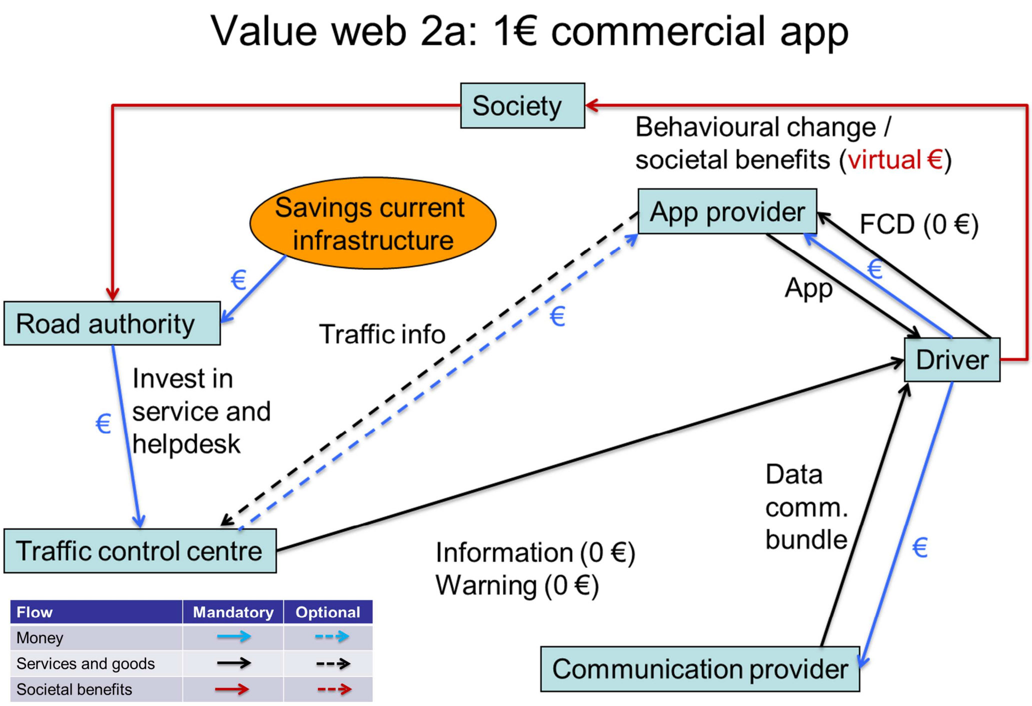


Figure 5: Value web for business model 2a, applicable to all bundles and to the cellular platform.

4.5.3 Business model 2b: Extended navigation

Business Model 2b is a mixed business model and applies to a cellular platform and all bundles. This value web, see Figure 6, is very much like business model 2a, except that the navigation service provider replaces the commercial app. provider. In this value network the road authority invests in a helpdesk and service. Information and warning services are provided to drivers via a traffic control center and a navigation service provider. The navigation service provider provides a service via nomadic or aftermarket devices to road users, and includes the road authorities' warnings and information in this service.

The navigation service provider receives floating car data from the drivers and optionally enriches this data into traffic information for the road authority/traffic control center, in exchange for a fee (in kind and/or monetary). The delivery of floating car data from drivers to the navigation service provider can be seen as delivering value in kind. The navigation service provider delivers value to the driver by providing the road authorities' warnings and information. The communication provider is providing the driver with the necessary cellular data communication bundle. The navigation service provider pays for this communication bundle (e.g., a monthly fee).

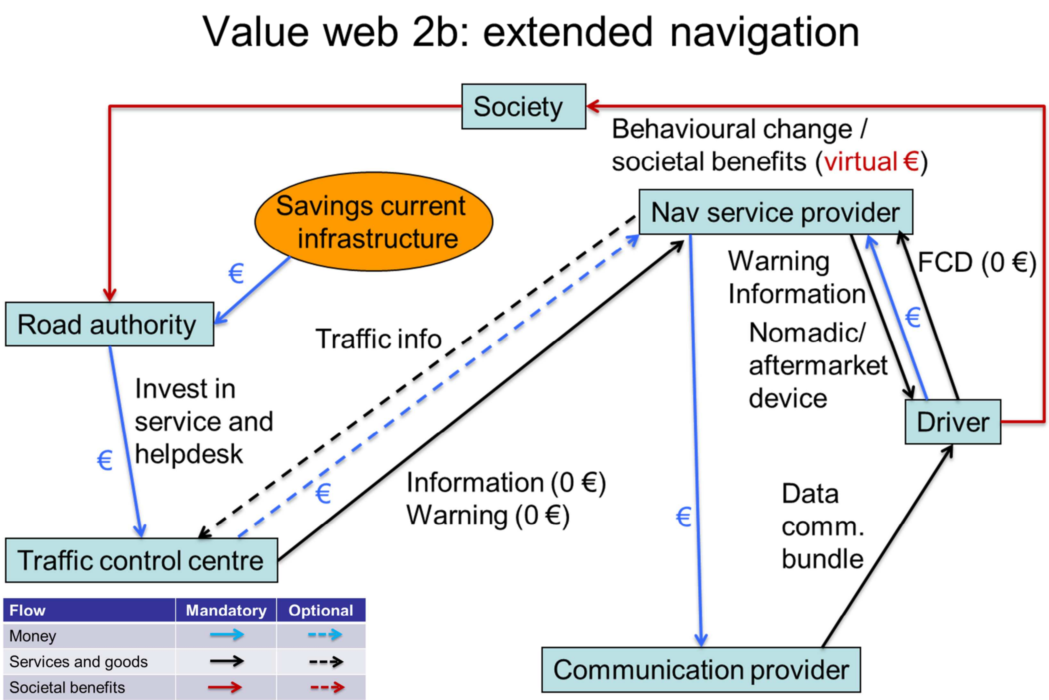


Figure 6: Value web for business model 2b, applicable to all bundles and to the cellular platform.

4.5.4 *Business model 3: Public travel time information*

Business Model 3 is a mixed business model and applies to a cellular platform and bundle 3. The value web, see Figure 7, is very much like business model 2b, except that the road authority (via the traffic control center) provides real time travel times rather than information and warning messages to the navigation service provider. The navigation service provider uses these travel times to provide a route advice service via nomadic or aftermarket devices to road users. As the road authority only provides travel times and no warnings or information messages, this business model applies only to bundle 3.

The navigation service provider receives floating car data from the drivers and optionally enriches this data into traffic information for the road authority/traffic control center, in exchange for a fee (in kind and/or monetary). The delivery of floating car data from drivers to the navigation service provider can be seen as delivering value in kind. The navigation service provider delivers value to the driver by providing route advice. The communication provider is providing the driver with the necessary cellular data communication bundle. The navigation service provider pays for this communication bundle (e.g., a monthly fee).

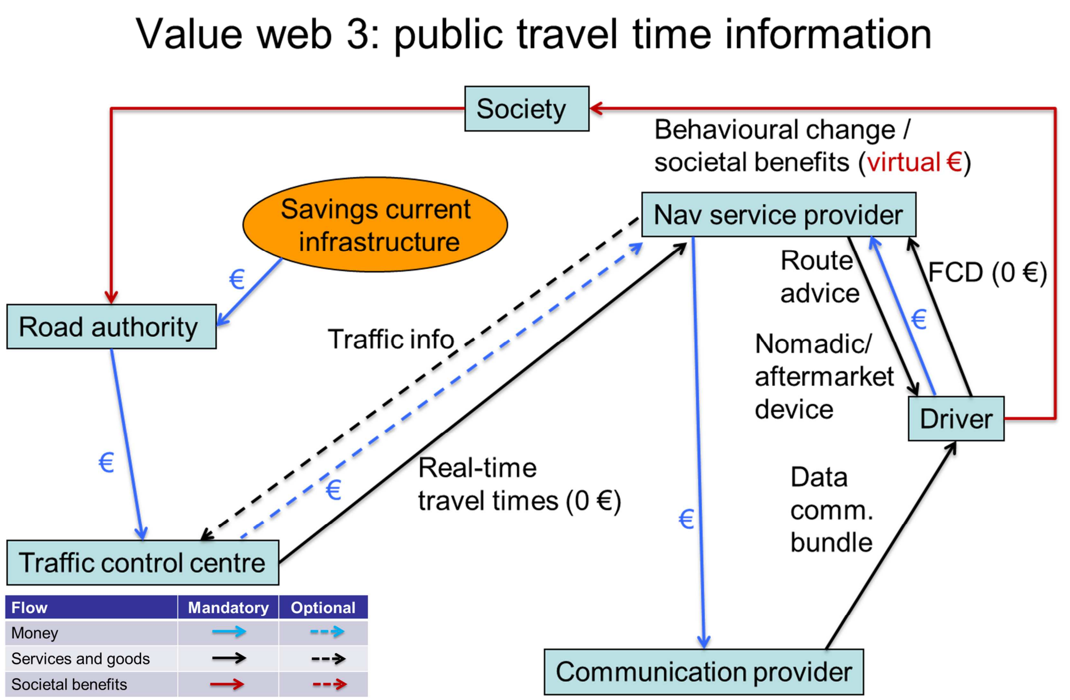


Figure 7: Value web for business model 3, applicable to bundle 3 and to the cellular platform.

4.5.5 Business model 4: Private dynamic navigation

Business Model 4 is a private business model and applies to a cellular platform and bundle 3. The value web, see Figure 8, describes a variant of an existing business model for traffic information provision by private navigation service providers. Via the traffic control center, the road authority provides loop detector data to the navigation service provider. The navigation service provider gives route advice to drivers. As no warnings or information messages are provided by the road authority, this business model applies only to bundle 3.

The drivers provide floating car data to the navigation service provider. This data is used by the service provider to enhance its route advice service. The delivery of floating car data from the drivers to the service provider can be seen as delivering value in kind. The communication provider is providing the driver with the necessary cellular data communication bundle. This bundle is paid for by the navigation service provider (e.g., a monthly fee).

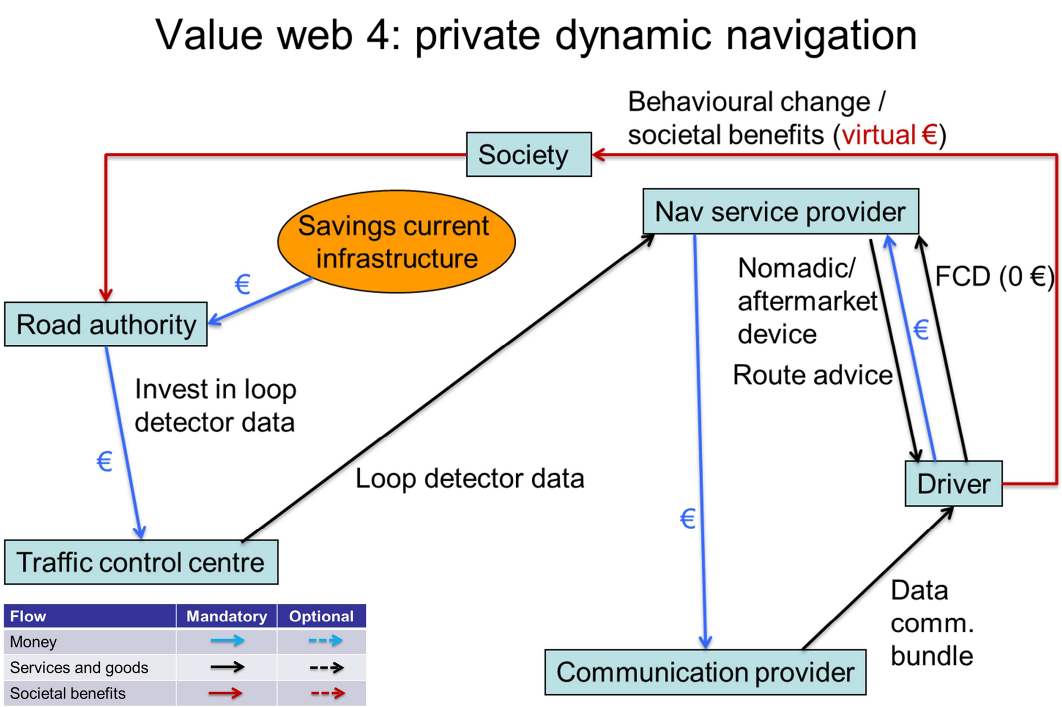


Figure 8: Value web for business model 4, applicable to bundle 3 and to the cellular platform.

4.5.6 Business model 5: Public roadside WLAN

Business Model 5 is a public business model and applies to a wireless beacons platform and bundles 1 and 2, see Figure 9. It represents the situation that the road authority installs, operates and maintains the roadside equipment (wireless beacons) for cooperative systems, and invests in the helpdesk and the cooperative warning and information services. These services are provided to the drivers by the traffic control center, while the wireless beacons are managed by the road infrastructure provider (this may be the road authority itself). In return, the drivers provide the road authority / traffic control center with floating car data, via the cooperative device built-in to the cars. Drivers buy these cars from vehicle manufacturers who deliver the car including the built-in cooperative module. Data communication is for free for the driver, and takes place between road side infrastructure and driver, and between road side infrastructure and traffic control center.

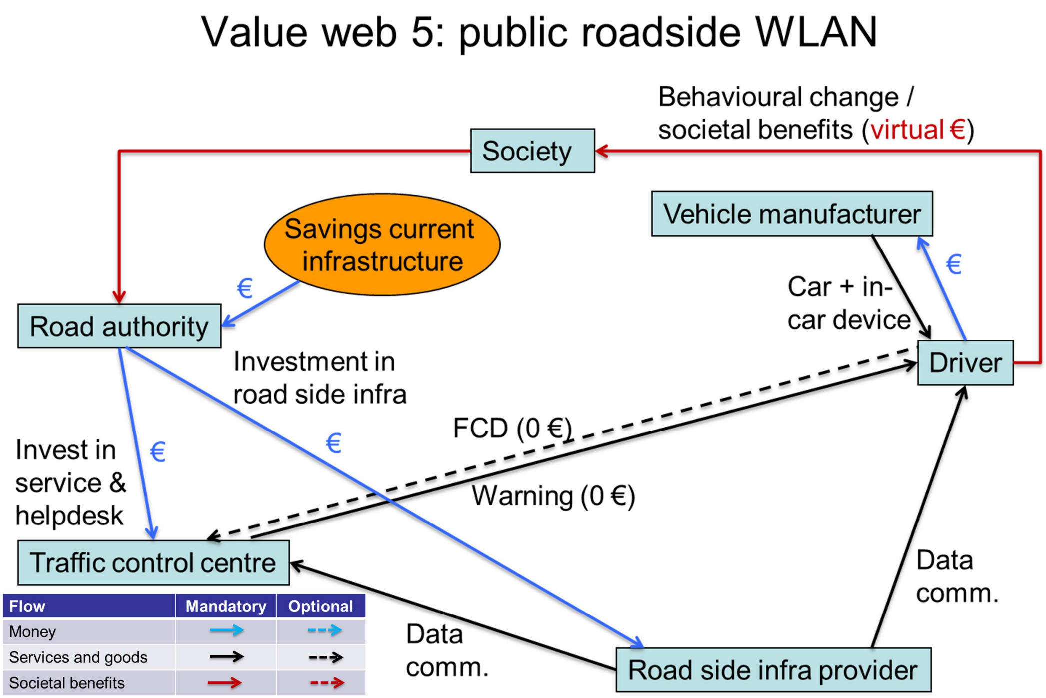


Figure 9: Value web for business model 5, applicable to bundles 1 and 2 and to the wireless beacons platform.

4.5.7 Business model 6a: Mixed with private roadside WLAN

Business Model 6a is a mixed business model with a privately operated roadside WLAN, and applies to a wireless beacons platform and bundles 1 and 2, see Figure 10. In this model, a privately owned company (e.g. a telecom provider) invests in road side WLAN infrastructure (802.11p based Wireless Local Area Network), while the road authority invests in a mobile application, service and helpdesk. The road authority provides a warning service towards drivers, while drivers optionally provide the road authority with floating car data in return, via a built-in platform in their cars. Drivers buy these cars from vehicle manufacturers who deliver a car including the built in platform. Data communication is for free for the driver, and takes place between road side infrastructure and driver, and between road side infrastructure and traffic control center.

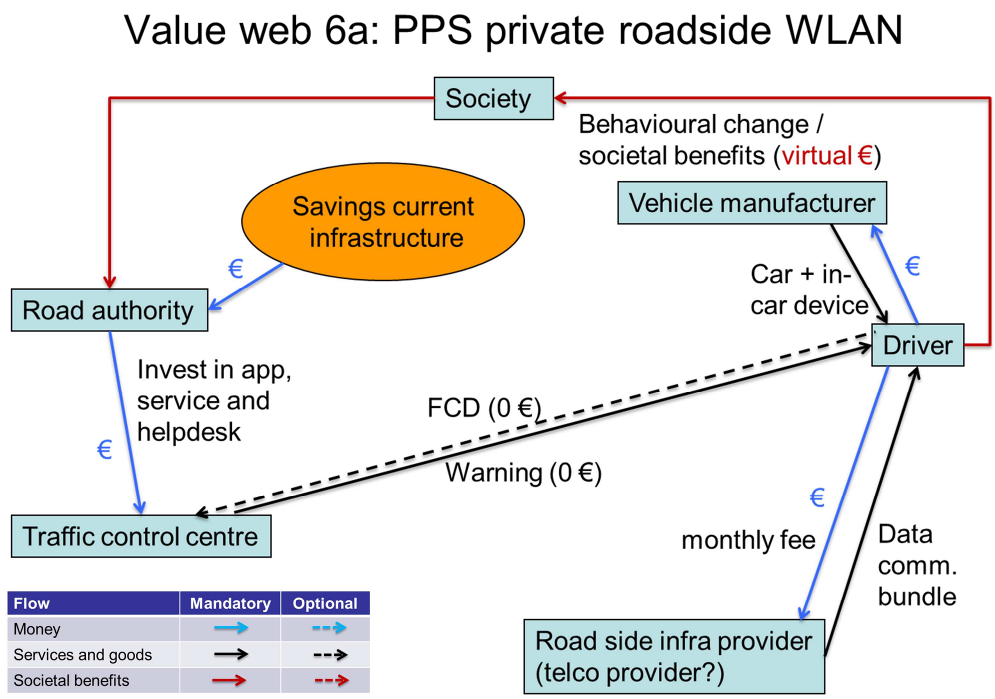


Figure 10: Value web for business model 6a, applicable to bundles 1 and 2 and to the wireless beacons platform.

4.5.8 Business model 6b: Mixed with public roadside WLAN

Business Model 6b is a mixed business model with a publicly operated roadside WLAN, and applies to a wireless beacons platform and bundles 1 and 2, see Figure 11. In this model, the road authority invests in road side WLAN infrastructure (802.11p based Wireless Local Area Network), service and helpdesk. A privately owned company invests in a mobile application which is open to messages from the road authority. The road authority provides a warning service to drivers on this application. Drivers provide their app provider with floating car data, which can be considered as payment in kind. Optionally the app provider can sell this data to the road authority. Data communication is provided by a public road side infra provider to both drivers and the traffic control center, at no cost to the driver.

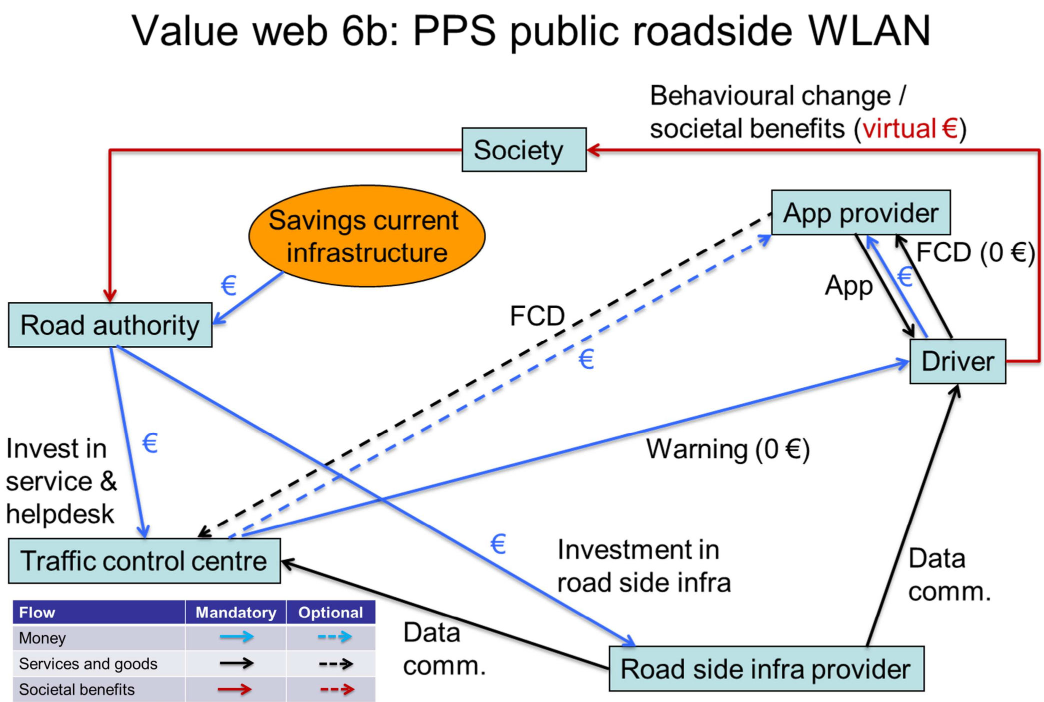


Figure 11: Value web for business model 6b, applicable to bundles 1 and 2 and to the wireless beacons platform.

4.5.9 Business model 7: Free road authority app

Business Model 7 is a private business model and applies to a wireless beacons platform and bundles 1 and 2, see Figure 12.

In this model, a vehicle manufacturer sells cars with built-in cooperative module plus the provision of cooperative services to drivers. Drivers pay a fixed price for the car and a monthly fee for the cooperative services to the manufacturer, who will in turn pay a monthly fee to a road side infrastructure provider in order for drivers to receive a data communication bundle, and a monthly fee to a navigation service provider who will provide information and warning services to drivers.

The road side infrastructure provider is a private party (e.g., a telecom provider) investing in road side WLAN infrastructure (802.11p based Wireless Local Area Network).

This could be run as a purely private model, without any involvement from the road authority. However, if this model is to replace the existing regulatory functions of bundles 1 and 2, then the road authority needs to be involved. This is indicated as an optional extension, where warnings and information from the road authority is provided to the driver via the navigation service provider. In return the navigation service provider provides his data to the road authority. These information flows could be paid for (in one direction or the other), or could be considered as a fair exchange without further payments. In this setting, the traffic management centre (or a separate entity) could act as a common back office for the generation of warnings and enriched data. The road authority may have to invest in the traffic management center to make this happen.

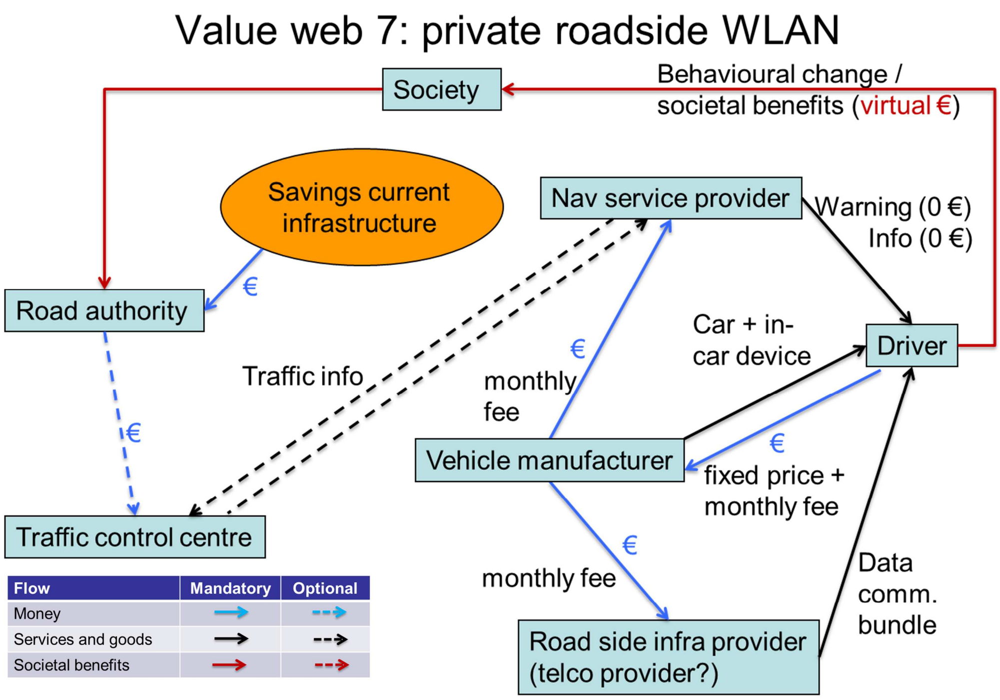


Figure 12: Value web for business model 7, applicable to bundles 1 and 2 and to the wireless beacons platform.

4.6 Business case for a road authority

In the calculation of the business case for the road authority, the costs and benefits are applied to the arrows in the value webs (described in Section 4.2). Based on the value webs, the various cost components can be assigned to either the road authority or other stakeholders, as shown in the example in Table 12. This provides estimates of the costs borne by the road authority and the cost savings which the road authority is expected to make.

It is important to note that this is a financial assessment, which does not take account of the wider benefits of the services being assessed.

Table 12: Example of costs and cost savings for the road authority

Cost component	**CAPEX**		**OPEX**		**Comments**
	Cost (EUR)	**Contribution NRA (%)**	**Cost (EUR)**	**Contribution NRA (%)**	
Data collection					
Traffic data from a National Data Warehouse	…	100%	…	100%	Already exists, so no cost
FCD from NRA app		0%		x%	Payment of data value to end user
FCD from private app		0%		y%	Payment of data value to serv. prov.
Data processing					
Data fusion		100%		100%	NRA back office
Message generator		100%		100%	NRA back office
Data communication					
messages NRA -> end user		0%		0%	End user pays
messages NRA -> serv. prov.		0%		0%	Serv. prov. pays
traffic data end user -> NRA		0%		z%	Payment of comm. cost to end user
traffic data end user -> serv. prov.		0%		0%	Serv. prov. pays
User interface					
NRA app		100%		100%	Development, maintenance and upgrades
private apps		0%		0%	Serv. prov. pays
NRA help desk (for end users)		100%		100%	Extension of existing help desk, investment for training and facilities
Savings on VMS		-a%		-b%	Fewer VMS needed; savings on installation, replacement, running costs and maintenance
Total:	**A EUR**	**B EUR**	**C EUR**	**D EUR**	

5 Specification of the decision support tool

5.1 How does the tool work?

In short, the tool determines the benefits and costs of an alternative versus a reference[2]. In the reference, there is no deployment of any cooperative bundle. In the alternative, one of the cooperative bundles can be selected and can be deployed at a varying level over time. The deployment of the corresponding existing roadside system (defined in section 3.5) can develop over time both in the reference and in the alternative, and along different deployment paths. The benefits and costs can therefore be due to a difference in deployment of the existing roadside system and to the cooperative bundle.

This section gives a mathematical description of the calculations performed in the tool. The following subsections will clarify the notation used in this section, the results (outputs) of the tool, the inputs, and the calculations.

5.1.1 Notation

The quantities listed in Table 13 are used throughout this document. For monetary quantities, we use € to denote values discounted towards the base year.

Table 13: Notation, units and definitions of quantities used in the calculations. The type is either a dummy variable (D), calculated (C), a fixed parameter or function supplied by the tool (P), or a value supplied by the user (U)

Notation	Unit	Range	Type	Definition
N	Year	-	D	Year for which costs, benefits and impacts are calculated.
N_0	Year	-	P	First year of the deployment scenario and reference year for monetary values. In the tool this is fixed to 2012.
CCBR(N)	-	≥ 0	C	Cumulative cost-benefit ratio up to year N (incl.), discounted to year N_0. A value above 1 means that the benefits are higher than the costs, a value below 1 means that the costs are higher than the benefits. Negative costs are counted as a benefit; Negative benefits are counted as a cost.
CBD(N)	€	-	C	Annual cost-benefit difference in year N, discounted to year N_0. A positive value means that the benefits outweigh the costs.
CCBD(N)	€	-	C	Cumulative cost-benefit difference up to year N (incl.), discounted to year N_0. A positive value means that the benefits outweigh the costs.
B(N)	€	≥ 0	C	Annual benefits (monetary and societal) in year N, discounted to year N_0.
CB(N)	€	≥ 0	C	Cumulative benefits up to year N (incl.), discounted to year N_0.
C(N)	€	≥ 0	C	Annual costs (monetary and societal) in year N, discounted to year N_0.
CC(N)	€	≥ 0	C	Cumulative costs up to year N (incl.), discounted to year N_0.
$B_{<0}(N)$	€	< 0	C	Annual societal dis-benefits (negative) in year N, not discounted.
$B_{\geq 0}(N)$	€	≥ 0	C	Annual societal benefits (positive) in year N, not discounted.

[2] It actually does this for two different scenarios (i.e., two references and two alternatives), to allow users to easily compare scenarios. Since these are computed independently from each other, this specification will for simplicity describe the calculation of a single scenario.

Notation	Unit	Range	Type	Definition
$C_{<0}(N)$	€	< 0	C	Annual monetary cost savings (negative) in year N, not discounted.
$C_{\geq 0}(N)$	€	≥ 0	C	Annual monetary costs (positive) in year N, not discounted.
$CP_{<0}(N)$	€	< 0	C	Annual monetary cost savings $C_{<0}(N)$ received by the NRA, not discounted.
$CP_{\geq 0}(N)$	€	≥ 0	C	Annual monetary cost $C_{\geq 0}(N)$ paid by the NRA, not discounted.
CP(N)	€	-	C	Net annual monetary costs of the NRA, discounted to year N_0. A positive value means a cost, a negative value means a savings.
$CCP_{<0}(N)$	€	< 0	C	Cumulative monetary cost savings $CC_{<0}(N)$ received by NRA, not discounted.
$CCP_{\geq 0}(N)$	€	≥ 0	C	Cumulative monetary costs $CC_{\geq 0}(N)$ paid by NRA, not discounted.
CCP(N)	€	-	C	Net cumulative monetary costs of the NRA, discounted to year N_0. A positive value means a cost, a negative value means a savings.
R	-	∈ (0,1)	P	Discount rate for discounting future monetary values, as a fraction. This has to be less than 1 (=100%), otherwise future values are discounted to 0 or less.
J	-	-	U	Type of system component for which cost and deployment are calculated. This can be a roadside component or an in-car component, and can belong to the existing roadside system or to the cooperative bundle. The user decides the bundle, which determines the types J to consider. See Table 15 further below for a list of values of J.
L(J)	Years	> 0	P	Functional lifetime of type J (This assumes that the functional lifetime is not limited by a final year, for example a year when the system is phased out).
AI(J, N)	-	≥ 0	C	Number of freshly installed units of type J in year N. If 0, then no units are installed and possibly units are being phased out.
AR(J, N)	-	≥ 0	C	Number of replaced units of type J in year N.
S(J, N)	-	≥ 0	C	Total number of units of type J that is active (that is, has been deployed and not yet phased out) in year N.
CICI(J)	€	≥ 0	P	Upfront capital investment cost of fresh installation of one unit of type J, not discounted.
CICR(J)	€	≥ 0	P	Upfront capital investment cost of replacement of one unit of type J, not discounted.
PC(J)	-	∈ [0,1]	P	Fraction of monetary cost or cost savings of item J attributed to NRA.
TAC(J, N)	€	≥ 0	C	Total annual cost for the capital investment of all units of type J deployed in year N (either new or replaced), not discounted.
OC(J)	€	≥ 0	P	Annual operational cost of one unit of type J, not discounted.

Notation	Unit	Range	Type	Definition
TOC(J,N)	€	≥ 0	C	Total annual operational cost of all units of type J in year N (either existing, new or replaced) , not discounted.
G(J,N)	-	∈[0,1]	C	Deployment rate of type J, that is, the fraction of vehicles or road kilometres equipped with type J in year N.
SP(N)	-	∈[0,1]	U	Number of deployed smart phones as fraction of all deployed after-market devices (smart phones and aftermarket)
Y	Years	≥ 0	D	Vehicle age, measured in full years, rounded down (like for humans)
A(Y)	-	≥ 0	P	Fraction of vehicles on the road of age Y.
D(Y)	km	≥ 0	P	Average annual distance driven by a vehicle of age Y.
V(N)	-	≥ 0	P	Total number of vehicles on the road in year N.
Q(J,N)	-	≥ 0	U	Fraction of new vehicles that is equipped with type J in year N (the market penetration).
RL(N)	km	≥ 0	P	Total road network length (unidirectional) in year N.
F(J)	unit/km	≥ 0	P	Number of units of type J needed per kilometre of road (unidirectional) for the road to be considered equipped. This is only applicable to roadside types J.
U	-	∈{0,1}	D	Reference case (0) or alternative (1).
SC	-	-	P	Societal cost category (e.g. travel time, or fatalities)
D(SC,U,J,N)	-	≥ 0	C	Problem coverage by item J. Fraction of the instances of societal problem category SC where type J is present in year N in the reference or the alternative (depending on U).
F(SC,J,p)	-	∈[0,1]	P	“Hotspots” function that maps the deployment rate p to the problem coverage by item J, for societal cost category SC.
E(SC,U,N)	-	∈[0,1]	C	Problem coverage, i.e. the fraction of the societal problem category SC covered by the reference (U=0) or the alternative (U=1) in year N.
B(SC)	-	≥ -1	P	Relative change in societal cost category SC in each instance of problem situation U where all types J are present that are needed for the bundle under consideration, compared to the case where they are not. B(SC)=0 means no change, >0 means an increase (i.e. it gets worse), <0 a decrease. The change is relative, that is, B(SC)=1 means an increase by 100%, and B(SC)=-1 means the societal cost is reduced to 0.
M(SC, N)	€	≥ 0	C	Amount of societal cost of category SC in year N in the (hypothetical) case that no system (existing roadside or cooperative bundle) is present, expressed in monetary values, not discounted.
M_0(SC, N)	€	≥ 0	C	Amount of societal cost of category SC in year N in the reference case (no bundle, but with an existing roadside system), expressed in monetary values, not discounted.
A_0(SC, N)	unit	≥ 0	P	Amount of societal cost of category SC in year N in the reference case (no bundle), expressed in natural units (e.g. hours of travel time, or number of fatalities).

Notation	Unit	Range	Type	Definition
V(SC, N)	€/unit	≥ 0	P	Monetary value of one unit of societal cost of category SC in the year N, not discounted.

5.1.2 Results

The results are presented on the “Output” sheet in the decision support tool. There is output for the cost benefit analysis (CBA) and for the business case for road authorities (BC).

The output for the CBA consists of five graphs and the payback year.. The first graph shows the break-down of total costs and benefits by category. The second one shows the total costs and benefits and the difference. The third one shows the annual costs and benefits over time, while the fourth graph shows the cumulative costs and benefits over time. The fifth graph shows the cumulative benefits divided by cumulative costs, that is, the benefit-cost ratio.

The output for the business case shows the financial effects for the road authority, excluding societal costs and benefits. The output consists of four graphs and the payback year. The first and second graphs show the break-down of costs, similar to the CBA, but only for costs and cost savings related to the NRA. The third graph shows the cumulative costs and benefits to the NRA over time. The final graph shows the net financial result for the road authority over time, in terms of a net cost..

The underlying data for all the graphs can be found on the “Cost_benefit_analysis” and “Business_case_for_the_NRA” sheets of the tool.

5.1.3 Inputs

The tool is set up so that the user can easily consider costs and benefits for a limited number of countries, functions and scenarios (which determine the input variables). The input options are not only limited to make it easy to use, but also to limit the effort to build the tool.

For more in-depth use of the tool, in principle, everything in the tool can be adjusted. A number of parameters can be easily changed. The tool is Excel-based, so it is fairly transparent on how it works; it is also possible to change parts of the tool, even the more structural elements, such as the services in a bundle or the business models.

5.1.4 Calculations

Cost-benefit ratio

The cumulative cost benefit ratio is one of the outcomes of the CBA. If CC(N) ≠ 0, this ratio is defined by

$$CCBR(N) = \frac{CB(N)}{CC(N)} \qquad (1)$$

Otherwise the ratio is undefined.

Cost-benefit difference

The (cumulative) cost-benefit difference is another one of the outcomes of the CBA. These differences are defined by

$$CBD(N) = B(N) - C(N) \qquad (2)$$

$$CCBD(N) = CB(N) - CC(N) \qquad (3)$$

Costs and benefits

Societal benefits can be both positive and negative. The latter will be called dis-benefits. Monetary costs can be both positive and negative. The latter will be called cost savings. The benefits in the cost-benefit analysis consist of positive societal benefits and cost savings. The costs consist of societal dis-benefits and monetary costs.

The (cumulative) cost is one of the outcomes of the CBA.

The cumulative costs CC(N) are calculated as

$$CC(N) = \sum_{k=N_0}^{N} C(k) \tag{4}$$

The annual costs consist of (positive) monetary costs and (negative) societal dis-benefits, and are discounted towards year N_0 at rate R:

$$C(N) = (1+R)^{N_0-N}(C_{\geq 0}(N) - B_{<0}(N)) \tag{5}$$

The (cumulative) cost is one of the outcomes of the CBA.

The cumulative benefits CB(N) are calculated as

$$CB(N) = \sum_{k=N_0}^{N} B(k) \tag{6}$$

The annual benefits consist of (positive) societal benefits and (negative) monetary cost savings and, and are discounted towards year N_0 at rate R:

$$B(N) = (1+R)^{N_0-N}(B_{\geq 0}(N) - C_{<0}(N)) \tag{7}$$

Monetary costs and cost savings

Annual monetary costs consist of investment costs and (annual) operational costs for all types for which this is positive:

$$C_{\geq 0}(N) = \sum_{J} \max\{0, TAC(J,N) + TOC(J,N)\} \tag{8}$$

The “max” function selects the positive cost terms. A similar formula holds for monetary cost savings, where only the negative terms are selected:

$$C_{<0}(N) = \sum_{J} \min\{0, TAC(J,N) + TOC(J,N)\} \tag{9}$$

In the tool, all terms TAC(J,N) + TOC(J,N) are positive except for one, namely the cost savings associated to a reduction in deployment of existing roadside systems.

Cost elements are divided into the categories listed in Table 14. The index J runs over specific instances of these categories. The table shows all possibilities for J, but for a specific bundle this can be restricted to some subset.

Table 14: cost element categories

Infrastructure or in-vehicle	Capital or Operational	Cost element category	Type (J)
In-vehicle	Capital	Equipment	• OEM built-in • After market • Smart phone
		Installation	
	Operational	Subscriptions	
		Cellular communications	
		Maintenance	
Infrastructure	Capital	Equipment	• Existing roadside system • Short range communication infrastructure (wireless beacons)
		Installation	

		App development	• Long range communication infrastructure • Back office, traffic management centre • App development
	Operational	Maintenance	

Capital costs for a unit are incurred in the year that this unit is acquired:

$$TAC(J,N) = CICI(J)AI(J,N) + CICR(J)AR(J,N) \tag{10}$$

For the existing roadside systems, equipment costs are incurred for fresh installations and for replacements, but installation costs are incurred only for fresh installations. Hence, typically CICR(J) < CICI(J) for types J that are part of the existing roadside system. For the cooperative bundles, the same equipment and installation costs are incurred for fresh installations as for replacements, so CICI(J) = CICR(J) for the corresponding types J.

The operational costs are assumed to be proportional to the number of active units of a type:

$$TOC(J,N) = OC(J)S(J,N) \tag{11}$$

It is assumed that the upfront unit capital investment costs CICI(J) and CICR(J) and the unit annual operational costs OC(J) do not depend on the year. Since equations (10) and (11) calculate non-discounted costs, this means that we assume that the nominal costs are constant over time. The number of acquired units equals the number of fresh installations plus the number of replacements. The number of fresh installations equals the change in the total number of active units, or zero:

$$AI(J,N) = \begin{cases} \max\{0, S(J,N) - S(J,N-1)\} & \text{for } N > N_0 \\ 0 & \text{for } N \leq N_0 \end{cases} \tag{12}$$

The replacements have no influence on the number of active units, they just replace one active unit by another. The number of replacements is calculated differently for the cooperative bundle and the existing roadside system, reflecting the fact that there is no installed base of the cooperative bundle in the starting year N_0, while there is an installed base of the existing roadside system. For the existing roadside system, the number of replacements is

$$AR(J,N) = \frac{S(J,N)}{L(J)} \tag{13}$$

For a cooperative bundle, it is assumed that each fresh install is replaced exactly after its lifetime:

$$AR(J,N) = \begin{cases} AI\big(J, N - L(J)\big) + AR(J, N - L(J)) & \text{for } N \geq N_0 \\ 0 & \text{for } N < N_0 \end{cases} \tag{14}$$

(For technical reasons, AR and AI are defined also for years before the base year N_0. Indeed, this ensures that equation (14) is well defined. The implementation in the tool is slightly different but with the same effect.)

The values R, CICI(J), CICR(J), OC(J), S(J,N) and L(J) are inputs for the cost calculation, while C(N) and CC(N) are outputs. Except for L(J) they can be country-specific. The values R, CICI(J), CICR(J), OC(J) and L(J) are default input values, but can be modified by the user if better data is available. The user can make a choice for the modelling of S(J,N), as explained in the section below on deployment models.

Costs to the NRA

The business model specifies for each term in the cost and cost savings equations (8), (9) a fraction PC(J) of the cost or cost savings of item J that is attributed to the NRA. Then the annual costs covered by the NRA are

$$CP_{\geq 0}(N) = \sum_{J} PC(J) \max\{0, TAC(J,N) + TOC(J,N)\} \tag{15}$$

The annual cost savings of the NRA are

$$CP_{<0}(N) = \sum_{J} PC(J)\min\{0, TAC(J,N) + TOC(J,N)\} \tag{16}$$

The net annual costs of the NRA are discounted towards year N_0 at rate R:

$$CP(N) = (1+R)^{N_0-N}\left(CP_{\geq 0}(N) + CP_{<0}(N)\right) \tag{17}$$

The cumulative costs (not discounted), cost savings (not discounted) and net costs (discounted) of the NRA are given by

$$CCP_{\geq 0}(N) = \sum_{k=0}^{N} CP_{\geq 0}(k)\,;\; CCP_{<0}(N) = \sum_{k=0}^{N} CP_{<0}(k)\,;\; CCP(N) = \sum_{k=0}^{N} CP(k) \tag{18}$$

If they are negative, then there is a cumulative cost saving.

Types of equipment to support cooperative services

The types of equipment included in the tool are as follows:

1. In-vehicle, OEM: an in-car component that is built in in the car by the OEM in the factory.
2. In-vehicle, aftermarket: an in-car component that is included into the car after the car has left the factory.
3. In-vehicle, smartphone: a handheld device that is used by drivers in their vehicle.
4. Roadside, existing VMS: only used in the cost savings part of the model
5. Roadside, wireless beacons: short range communication infrastructure, fibre optic backbone.
6. Roadside, sensors: sensors are not currently included in the model, although there is a blank space to include them in a future version
7. Back office, traffic management centre
8. Back office, app development

They are also shown in Table 14 above.

Deployment model

There are several ways in which the level of deployment S(J,N) of units is modelled. The following deployment models are used:

- Linear deployment model for after-market devices (OEM and smart phones), with a choice between three deployment levels.
- Nonlinear deployment model for OEM in-car devices, with a choice between three deployment levels.
- Linear deployment model for short range communication infrastructure, with free choice of start and end years, and final deployment level.
- Piecewise linear deployment model for existing roadside systems.
- Fixed deployment for long range communication infrastructure, back office and app development.

After-market devices

The deployment rate is modelled as a linear uptake:

$$G(J,N) = a(J) + b(J)\,(N - N_0) \tag{19}$$

Here the parameter a ≥ 0 is the deployment rate in the base year N_0, and b ≥ 0 is the annual increase. These parameters cannot be chosen directly by the user. Rather, the user can select between three deployment levels (low, medium, high), that specify the values of a and b. These are chosen such that G(J,N) ≤ 100% in the study period (starting at N_0 and up to some future year; in the tool this is 2030).

This deployment is split between aftermarket devices and smart phones. The number of vehicles equipped with a smart phone is

$$S(J,N) = V(N) * G(J,N) * SP(N) \tag{20}$$

The number of vehicles equipped with an after-market device is

$$S(J,N) = V(N) * G(J,N) * \left(1 - SP(N)\right) \qquad (21)$$

OEM in-car devices

An OEM in-car device can be deployed only when a new vehicle is sold. This mostly concerns replacements of existing vehicles, and since vehicles have a wide lifetime distribution, and annual mileage depends on age, this requires a more elaborate model than after-market devices.

The deployment rate is given by

$$G(J,N) = \sum_{Y=0}^{+\infty} Q(J,N-Y) * A(Y) \qquad (22)$$

That is, the deployment is the average of all past market penetrations, weighted by the presence of their age class in the vehicle fleet. The number of vehicles equipped with an OEM in-car device is

$$S(J,N) = V(N) * G(J,N) \qquad (23)$$

The values of A(Y) are fixed by the tool, while the user can select between three deployment levels (low, medium, high) for the values of Q(J,N). For all three, Q(J, N) = 0 for $N < N_0$, that is, there are no equipped vehicles before the base year.

Remarks:

- Typically A(Y) < A(Y-1) for all Y because vehicles are taken out of the fleet, and possibly also because the fleet grows. However, the SafeSpot numbers that are used by the tool show that this is not always the case.
- This model is not fully consistent with the assumption of a fixed lifetime L(J). Indeed, that assumption implies that a unit reaching the end of its lifetime is replaced, and then the new one will again work a full lifetime. But in the case of OEM in-car devices, the lifetime of the device is limited by the lifetime of the car, and thus it is typically not equal to L(J) or an integral multiple thereof. Hence the investment cost is usually spread over fewer years than L(J). This effect could be taken into account in the future, in an improved version of the tool.

Short range communication infrastructure

The deployment rate is modelled as a linear uptake between two boundary years, starting at 0:

$$G(J,N) = \begin{cases} 0, & N < N_{\text{start}} \\ \dfrac{N - N_{\text{start}}}{N_{\text{end}} - N_{\text{start}}} G_{\text{end}}, & N_{\text{start}} \leq N \leq N_{\text{end}} \\ G_{\text{end}}, & N > N_{\text{end}} \end{cases} \qquad (24)$$

Here the years N_{start}, N_{end} and the final deployment rate G_{end} can freely be chosen by the user.

The number of equipped roadside locations is the road length times the number of units per km times the deployment rate:

$$S(J,N) = RL(N) * F(J) * G(J,N) \qquad (25)$$

Existing roadside systems

The deployment rate is modelled as a piecewise linear increase or decrease:

$$G(J,N) = \begin{cases} 0, & N < N_2 \\ G_j + \dfrac{N - N_j}{N_{j+1} - N_j}\left(G_{j+1} - G_j\right), & N_j \leq N < N_{j+1};\ j = 2, \dots, k-1 \\ G_{\text{end}}, & N \geq N_k \end{cases} \qquad (26)$$

The user can choose the years N_2, N_3, …, N_k and the deployment rates G_2, G_3, …, G_k. Different deployment rates can be chosen for the reference and the alternative.

The number of equipped roadside locations is

$$S(J,N) = RL(N) * F(J) * G(J,N) \qquad (27)$$

Long range communication infrastructure, back office and app development

Long range (that is, cellular) communication infrastructure is assumed to be available already, at no additional cost, so this is not taken into account on the cost side: S(J, N) = 0.

The number of back offices is fixed and set by the user: S(J, N) = constant.

The number of apps that need to be developed is fixed to 1: S(J, N) = 1.

Societal benefits and dis-benefits

The societal benefits that will be considered are:

1. Traffic safety: fatalities, injuries, accidents
2. Traffic efficiency: travel time savings
3. Fuel consumption: price paid at petrol pump, excluding tax
4. Environment: greenhouse gas emissions, pollutants.

Other types of benefits may exist but are not taken into account.

Benefits are calculated as follows. For a benefit category, there is a fixed, given benefit if all vehicles and at all locations are equipped with the cooperative bundle or the existing roadside system. The benefit is expressed in terms of an impact (like number of fatalities), which is translated to monetary values by multiplying with a unit cost. If the problem coverage is partial, that is, not all vehicles and locations are equipped, then the benefit is decreased in proportion to the coverage.

The coverage depends on the coverage of the individual items J that are needed. Coverage is obtained if either the roadside system is present, or the cooperative system. To express this in formula, we will use the values for J listed in Table 15.

Table 15:Item types for which cost and deployment are calculated

Item	**Value of J**
Any roadside system (“x”, “beacon” or “cell”)	“a”
Existing roadside system	“x”
Short range communication infrastructure	“beacon”
Long range communication infrastructure	“cell”
Any in-car device (smart phone, after-market or OEM)	“c”

We also need to distinguish between the reference and the alternative because they may have different levels of coverage. Let U be the reference (value 0) or the alternative case (value 1). Let D(SC,U,J,N) be the coverage of item J, that is, the fraction of all societal problems of type SC where item J is present. Then the coverage E(SC,0,N) in year N for the reference case is given by

$$E(SC,0,N) = D(SC,0,\text{"x"},N) \tag{28}$$

The coverage E(SC,1,N) in year N for the alternative case is given by

$$E(SC,1,N) = \big(D(SC,1,\text{"a"},N) - D(SC,1,\text{"x"},N)\big) * D(SC,1,\text{"c"},N) + D(SC,1,\text{"x"},N) \tag{29}$$

This means that the coverage from the cooperative roadside components is multiplied with the in-car coverage, and then added to the coverage from the existing roadside system. The calculation of D(SC,U,J,N) is discussed below in the section on problem coverage.

Let B(SC) be the relative change in societal cost of category SC due to either the cooperative bundle or the existing roadside system (they are assumed to have the same benefit), compared to the situation without any equipment. Let M(SC,N) be the societal cost of category SC in year N in monetary values (not discounted), in the absence of the cooperative bundle and the existing roadside system.

Then the change in societal cost of category SC, taking into account the deployment level, equals

$$\big(E(SC,1,N) - E(SC,0,N)\big)B(SC)M(SC,N) \tag{30}$$

A positive value means a decrease in societal cost (hence an improvement), while a negative value means an increase (i.e., deterioration).

The value of M(SC,N) is typically not available because there already is an installed base of the existing roadside system. Hence M(SC,N) needs to be derived from M_0(SC,N), which is the societal cost of category SC in year N in monetary values (not discounted), with the reference deployment of the existing roadside system. They should satisfy the relation

$$M(SC,N) - M_0(SC,N) = E(SC,0,N)B(SC)M(SC,N) \tag{31}$$

Hence M(SC,N) can be calculated as

$$M(SC,N) = \frac{M_0(SC,N)}{1 - E(SC,0,N)B(SC)} \tag{32}$$

The cost M_0(SC,N) is the cost in natural units times the monetary value of one unit: $M_0(SC,N) = A_0(SC,N)V(SC,N)$.

Hence in monetary terms the total positive societal benefit of the bundle is

$$B_{\geq 0}(N) = \sum_{SC} \max\{0, -\big(E(SC,1,N) - E(SC,0,N)\big)B(SC)M(SC,N)\}, \tag{33}$$

where the sums range over all problem situations of the bundle and all societal cost categories. The minus sign is there because negative values of B(SC) correspond to a decrease in cost, and hence to a positive benefit B(N).

The total negative societal benefit of the bundle is, in monetary terms, given by

$$B_{\leq 0}(N) = \sum_{SC} \min\{0, -\big(E(SC,1,N) - E(SC,0,N)\big)B(SC,U)M(SC,N)\}, \tag{34}$$

Problem coverage

The problem coverage D(SC,U,J,N) is not necessarily equal to the deployment rate G(J,N). The tool accounts for two ways in which a difference between D(SC,U,J,N) and G(J,N) can come about:

- Newer vehicles drive more per year than older ones, and the presence of OEM in-car devices is skewed towards newer vehicles.
- Roadside systems are typically placed at locations where more problems occur.

Below, the calculation of the problem coverage is discussed in turn for:

- After-market devices.
- OEM in-car devices.
- Existing roadside systems, short and long range communication infrastructure.
- Back office and app development

After-market devices

It is assumed that these are equally likely to be installed in vehicles of any age, and that there is also no correlation with the locations where the vehicles drive. Hence D(SC,U,J,N) = G(J,N). This formula does not depend on SC and is only used for U = 1.

OEM in-car devices

The problem coverage D(SC,U,J,N) is given by

$$D(SC,U,J,N) = \frac{\sum_{Y=0}^{+\infty} Q(J,N-Y) * D(Y) * A(Y)}{\sum_{Y=0}^{+\infty} D(Y) * A(Y)} \tag{35}$$

This is similar to the formula (22) for G(J,N), except that the contributions are further weighted by D(Y), the annual driven distance of a vehicle of age Y. This means that the past market penetrations are now weighted by the presence of the age class on the road rather than in the fleet. It is assumed that there is no correlation with the locations where the vehicles drive. This formula does not depend on SC and is only used for U = 1.

Formula (35) can be understood as follows.

The vehicle age distribution A(Y) describes the number of vehicles of each age. To be precise, A(Y) is the fraction of the vehicle fleet that is of age Y, and satisfies A(Y) ≥ 0 and $\sum_{Y=1}^{+\infty} A(Y) = 1$*. It is assumed that the age distribution does not change over the years.*
The average annual distance driven by a vehicle of age Y is given by D(Y).
The market penetration Q(J,N) is the fraction of all new vehicles entering the market in year N that is equipped with device type J.
Thus, the denominator of (35) calculates the average annual distance driven with the equipment, while the numerator calculates the average annual distance driven in total, both calculated as an average per vehicle.

Existing roadside systems, short and long range communication infrastructure

For roadside equipment, it is likely that the most effective locations will be equipped first. A roadside location is considered equipped if it has an existing roadside system or short range communication, or if there is long range communication. Thus the fraction of roadside locations equipped with any system G("a", N) is given by

$$G(\text{"a"}, N) = \max\{G(\text{"x"}, N) + G(\text{"beacon"}, N), G(\text{"cell"}, N)\}. \quad (36)$$

The calculation of the values on the right hand side has been discussed in the section on the deployment model, further above. Observe that if cellular communication is available, then G("a", N) = G("cell", N) = 100%.

The relation between the deployment rate G(J,N) and the coverage D(SC,U,J,N) is modelled by a map F:

$$D(SC, U, J, N) = F(SC, J, G(J, N)). \quad (37)$$

Thus, F(SC,J,p) is the coverage if a fraction p of all roadside locations is equipped. Clearly, F has to satisfy F(SC,J,0) = 0, F(SC,J,1) = 1, and F(SC,J,p) is a non-decreasing function of p. If all locations are equally effective, then F(SC,J,p) = p. If not, and the most effective locations are equipped first, then F(SC,J,p) ≥ p.

If all locations are equally effective, this simplifies to

$$D(SC, U, J, N) = G(J, N). \quad (38)$$

Annex E discusses the shapes of the function F that are used in the tool. This function will typically depend on SC.

Back office and app development

The coverage of these items is supposed to be 100% whenever they are needed, and hence they do not enter into equations (28), (29).

5.2 Open issues

See Section 6 of D4.1 for a discussion of open issues.

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Annex A Cooperative systems: specification of technologies and costs

Local Dynamic Event Warnings

This bundle of applications will provide warnings to the driver of upcoming potential or real hazards. The hazards could be static (accident black spots), short term known (e.g. road works), or transient (accidents, breakdowns, weather, congestion, etc.). Post-crash warnings from eCall to other drivers are included.

The bundle is available in the tool for delivery via cellular networks or wireless beacons and will require the following technologies/costs:

- In the vehicle:
  - Location measurement (GNSS)
  - Communications (cellular in aftermarket and smartphones, 802.11p in OEM equipment)
  - In-vehicle processing unit (could be OEM, nomadic, retro-fit, owner supplied or part of a service)
  - HMI (could be part of above, both could be nomadic e.g. smartphone)
  - In-vehicle sensors (temperature, Electronic Stability Control sensors).
- Road-side sensor network (for the wireless beacons version):
  - Incident or congestion detection (using existing loops, machine vision sensors, microwave sensors etc., or floating vehicle data, with no additional sensor costs)
  - Roadside equipment for communications (wireless beacons); in the tool it is assumed that this is used for equipping 'hotspots' by selecting an average density of beacons per km which is equivalent to a certain proportion of the network.
- Back-office
  - Operations and processing centre (office rental, computing facilities, communications facilities, staffing)
  - Road works database
  - Interface with the Public Safety Answering Point for the eCall service to provide crash detection
  - Weather forecast data
  - Communications Interface (Cellular/802.11p as appropriate) and costs.

In-vehicle speed and signage

This application bundle displays the information normally found on road-side static and variable signage to the driver. This information can then be used for intelligent speed adaptation (ISA) where the driver is actively encouraged to adhere to posted permanent or temporary speed limits. ISA itself can be **"advisory"** (over speed alarms in vehicle), **"encouraging/voluntary"** (using haptic feedback like a "heavy throttle pedal to encourage adherence) or **"mandatory"** (vehicle will not be able to exceed posted limit). The options available in the tool cover the haptic throttle and warning versions of advisory ISA but not mandatory ISA.

This bundle is available in the tool for delivery via cellular networks (the advisory version) or wireless beacons (encouraging/ voluntary version) and will require the following technologies/costs:

- In the vehicle:
  - Location measurement (GNSS)
  - Communications cellular in aftermarket and smartphone, 802.11p in OEM equipment)
  - In-vehicle processing unit (could be OEM, nomadic, retro-fit, owner supplied or part of a service etc.)
  - HMI (could be part of above, both could be smartphone nomadic)
  - Vehicle interface (where haptic feedback is supported).
- Road-side sensor network:
  - Incident or congestion detection (using existing loops, machine vision sensors, microwave sensors etc. or floating vehicle data, with no additional sensor costs) if the system supports variable speed limits for incidents

    - Roadside equipment for (wireless beacons); in the tool it is assumed that this is used for equipping 'hotspots' by selecting an average density of beacons per km which is equivalent to a certain proportion of the network.
- Back-office
    - Operations and Processing centre (office rental, computing facilities, communications facilities, staffing)
    - Speed limit database (both static and dynamic)
    - Communications interface (Cellular/ 802.11p as appropriate) and costs
    - Variable speed limit database, with possible interface to incident monitoring if speeds are limited by incident.

Travel information and dynamic route guidance

This application provides information and travel services to travellers, which allows them to make informed choices on travel modes, as well as providing dynamic route guidance to optimise travel times in changing road conditions. Truck parking information and guidance is included.

The bundle requires the following technologies/costs:

- In the vehicle:
    - Location measurement (GNSS)
    - Communications: Cellular – for a centralised system with no local roadside intelligence. Communication via wireless beacons is not considered
    - In-vehicle processing unit (could be OEM, nomadic, retro-fit, owner supplied or part of a service etc.)
    - HMI (could be part of above, both could be smartphone nomadic).
- Road-side sensor network:
    - Journey time sensors (Automatic Number Plate Recognition cameras, floating vehicle).
- Back-office
    - Operations and Processing centre (office rental, computing facilities, communications facilities, staffing)
    - Speed limit database (both static and dynamic)
    - Communications Interface (Cellular) and costs
    - Live traffic situation/journey time database
    - Incident management interface
    - Interface to other modes of travel
    - Interface to parking providers.

Annex B: Estimating in-vehicle equipment costs

General approach

The tool itemises the main elements involved in providing each bundle of services:

- In-vehicle equipment costs for OEM, aftermarket and nomadic device fitment
- Infrastructure costs, including detection, signs and control equipment (covering both capital and operating costs)
- Communication costs
- Back office and data processing costs.

The monetary values are based on data from the EasyWay study (which in turn are based on a several projects in Europe), and the UK Highways Agency (converted to Euros using the prevailing exchange rate). An element of expert judgement was used to adjust some of the cost data to match the specification of the COBRA service bundles.

The original intention was to include data from the costs of ITS in the 2Decide on-line ITS toolkit and the US DOT RITA ITS costs database. However on careful inspection these proved to be unsuitable for various reasons: not all of the cost elements required for this study were included as separate items, and where they were, they were not considered to be sufficiently robust for use in the tool due to age (pre-dating the technologies available now) the number of studies on which they were based, or the lack of documentation on their scope.

Pessimistic estimates of costs are used, by selecting values towards the upper limit of ranges. Values are rounded to avoid giving a spurious impression of precision

Values estimated

The estimates for in-vehicle equipment costs are based on EasyWay figures (which were derived from SAFESPOT); the cost of the ISA bundles are adjusted to take account of the additional functions provided.

Vehicle fit	Bundle	Component	Euros	Description
OEM	Local dynamic event warnings, wireless beacon	In- vehicle unit	100	Sum of maximum cost of all components with display quality similar to a satnav. Lifespan = 12 year life of car (Easyway average for Europe)
		Annual operation & Maintenance	20	Subscription for software updates
OEM	In-vehicle speed and signs (haptic throttle ISA), wireless beacon	In- vehicle unit	250	Haptic throttle version estimated at twice the cost of advisory ISA and equivalent to the highest value in the range of in-vehicle unit costs estimated in SMART 63. Lifespan = 12 year life of car (EasyWay average for Europe)
		Annual operation & Maintenance	20	Subscription for software updates
Aftermarket	Local dynamic event warnings, cellular	In- vehicle unit	100	Sum of maximum cost of all components with display quality similar to a satnav, and including installation. Life span = 10 years (assume 2 years less than life of car and upgrade to OEM fit when replace car)

Vehicle fit	Bundle	Component	Euros	Description
		Annual operation & Maintenance	20 10	Subscription Communications Together totalling low point of Easyway range (30 – 110)
Aftermarket	In-vehicle speed and signs (advisory ISA), cellular	In- vehicle unit	120	Assumed to cost 20% more than basic unit to cover: • Connection to the vehicle • Higher specification display for speed information • CAN bus connection and signal decoding to ensure operation when out of GPS reception • Additional software to decode and display speed warnings and manage the speed database required in early years
		Annual operation & Maintenance	20 10	Subscription Communications Together totalling low point of Easyway range (30 – 110)
Aftermarket	Travel information and dynamic route guidance, cellular	In- vehicle unit	100	Sum of maximum cost of all components with display quality similar to a satnav, and including installation. Life span = 10 years (assume 2 years less than life of car and upgrade to OEM fit when replace car)
		Annual operation & Maintenance	20 10	Subscription Communications
Smartphone	Local dynamic event warnings, cellular	Equipment	0	Assumed to be already owned and fitted by user 5 year maximum renewal period
		Annual operation & Maintenance	20 10	Subscription Cellular communications – to cover incremental cost of additional data
Smartphone	In-vehicle speed and signage (advisory ISA), cellular	Equipment	0	Assumed to be already owned and fitted by user 5 year maximum renewal period
		Annual operation & Maintenance	20 10	Subscription Cellular communications – to cover incremental cost of additional data

Vehicle fit	Bundle	Component	Euros	Description
Smartphone	Travel information and dynamic route guidance, cellular	Equipment	0	Assumed to be already owned and fitted by user 5 year maximum renewal period
		Annual operation & Maintenance	20 10	Subscription Cellular communications – to cover incremental cost of additional data

Annex C: Estimating infrastructure costs

The estimates for infrastructure costs are based on EasyWay figures and data for the Highways Agency in England. They do not vary with the service being supported.

Infrastructure	Component	Euros	Description
Existing VMS	Equipment / sign	94000	Replacement cost for a large sign displaying text and pictograms (MS4) – the type expected to be included in future plans (source Highways Agency MOMM) HA average 1 VMS/3km (all VMS), range every 0.5 – 1.5km on managed motorways to sparse elsewhere – user can set density of signs in 'Parameters' page of the tool
	Installation / sign	315000	Installation or renewal of cantilever post including closing 1 lane
	Annual operation & maintenance / sign	1000	This figure is for an MS4, double it for a gantry mounted sign
Communications platform – 802.11p wireless beacon	Equipment/ beacon	6000	EasyWay estimates for equipment (basic ITS station plus additional traffic monitoring sensors) Assume equip critical points only - users of tool select % of km to be equipped; default value 5% EasyWay assumes 5% of km equipped as 'hotspots' (EasyWay 2012) 300m range results in 3.333 per km of equipped network default value; user can select other values[3] – see note below Assume life of 10 years (as in EasyWay) because once the technology is common in vehicles, it will be difficult to upgrade; note that some countries assume a longer lifetime.
	Installation	10000	EasyWay estimate
	Annual operation & Maintenance	500	Operational and maintenance costs include data, cabling etc – estimated at 5% of capital cost plus data
Sensors	Equipment/ km	26000	Based data in a recent HA tender total cost per km of MIDAS loops 264000, of which 10% assumed to be equipment HA data - 7 year life (source MOMM spreadsheet)
	Installation/ km	238000	See equipment cost
	Annual operation & Maintenance	3000	Based on HA data on cost per loop pair/ year, assume 16 pairs/km

[3] The upper bound on range is normally quoted as 1000m based on the latency requirements, but 300m allows a higher bit rate and a more reliable connection to be achieved, and this is the range often quoted

Infrastructure	Component	Euros	Description
Back office	Equipment	200000	Additional infrastructure at traffic centres - EasyWay estimate 500 per ITS Station to integrate it into an existing traffic centre, including 5.9GHz 802.11p communications and cable or wireless connection to traffic centre Assume life of 10 years
	Annual operation & Maintenance	20000	Assumed to be 10% of capital cost
App development	Development	200000	Cost of developing an existing app
	Annual operation & Maintenance	20000	Assumed to be 10% of capital cost

Annex D: Hotspots calculation

This annex describes the calculation of the relation between the fraction of equipped *road* locations and the fraction of equipped *problem* locations, hereafter simply referred to as the *hotspots relation*. The first is the fraction of road kilometers that is equipped with either the existing roadside system or the cooperative system. The second is the fraction of all problems addressed by the system (i.e. travel time losses, accidents) that takes place at the equipped locations.

In formula this becomes

$$D(SC, U, J, N) = F(SC, J, G(J, N)). \quad (39)$$

If each road location has the same amount of problems, then the hotspots relation is trivial: F(SC, J, p) = p. More typically, some locations will be more prone to problems than others, and then F(SC, J, p) ≥ p with reducing marginal gains: F''(SC, J, p) ≤ 0 for all p, where the derivative is taken with respect to p.

This is calculated on the "Hotspots" sheet of the tool.

The fraction of equipped road locations equals the fraction of road locations equipped with the existing roadside system plus the fraction of road locations equipped with the cooperative system.

It is assumed that either system is deployed first at those locations where the problem that the system addresses is worst, and that there is no overlap between the locations of the existing roadside system and the cooperative system, that is, the cooperative system is deployed only at locations where there is no existing roadside system.

The hotspots relation depends on the type of problem considered. In the tool, two indicators are used to cover all problem types, namely accidents with fatalities or severe injuries, and driven kilometers. The first type is used for all safety related benefits, while the second type is used for benefits on travel time, fuel consumption and emissions.

The hotspots relation also depends on the country. The tool uses the UK relation for safety and the Dutch relation for driven kilometers. This could be made country specific in a second version of the tool.

This annex describes how the Dutch relations have been obtained. The UK relations have been derived using a similar method. For the Netherlands, relations have been obtained for the following problem types:

- Driven kilometers.
- Travel time loss[4].
- Injury and fatal accidents.
- Damage only accidents.
- All accidents.

For each problem type, location based data on the problem size is available. For the first two this data is obtained from loop detectors and consists of measured speeds and intensities. The last three are based on police reports. Roads or road segments without loop detectors or where the loop detectors are not functioning properly have been removed from the network[5].

The hotspots relation is now obtained by cutting the network into small segments, and sorting these segments by problem size per km, as follows. First a segment length is chosen, and each road in the network is divided into segments of this length. The final segment may be shorter.

In formula, number the roads from 1 to N, and let road j have segments 1 to N_j. Each road is assumed unidirectional (so a dual carriageway is considered as two roads). Let segment k have length $L_{j,k}$ and problem size $S_{j,k}$. Define the problem density as the problem size per km: $D_{j,k} = S_{j,k} / L_{j,k}$. Sort all segments of all roads by descending density, and call the resulting sequence D_i, i = 1, …, M, with associated length L_i and problem size S_i. Then $D_{i+1} \le D_i$ and $D_i = S_i / L_i$ for all i.

[4] In the Netherlands, travel time losses are calculated by comparing the realized speed with a reference speed of 100 km/h which is considered to represent the free flow speed on all motorways, independent of the actual speed limit.
[5] Strictly speaking, this selection is not necessary for the safety related problem types.

Let L be the total length, that is, $L = L_1 + L_2 + \ldots + L_M$. Let S be the total problem size, that is, $S = S_1 + S_2 + \ldots + S_M$. The hotspots relation is a curve passing through the points (x_i, y_i), $i = 1, \ldots, M$, where $x_i = (L_1 + L_2 + \ldots + L_i)/L$ is the cumulative fraction of equipped roads and $y_i = (S_1 + S_2 + \ldots + S_i)/S$ is the cumulative fraction of covered problem locations, and the segments with highest density are added first.

Figure 13 shows the resulting relations. They depend on the chosen segment length, and clearly show reducing marginal gains. As would be expected, they also show higher curves for shorter segment lengths – indeed, with a shorter segment length the spots with high problem density can be covered more efficiently. For the driven kilometers relation in the tool, a segment length of 100m is used.

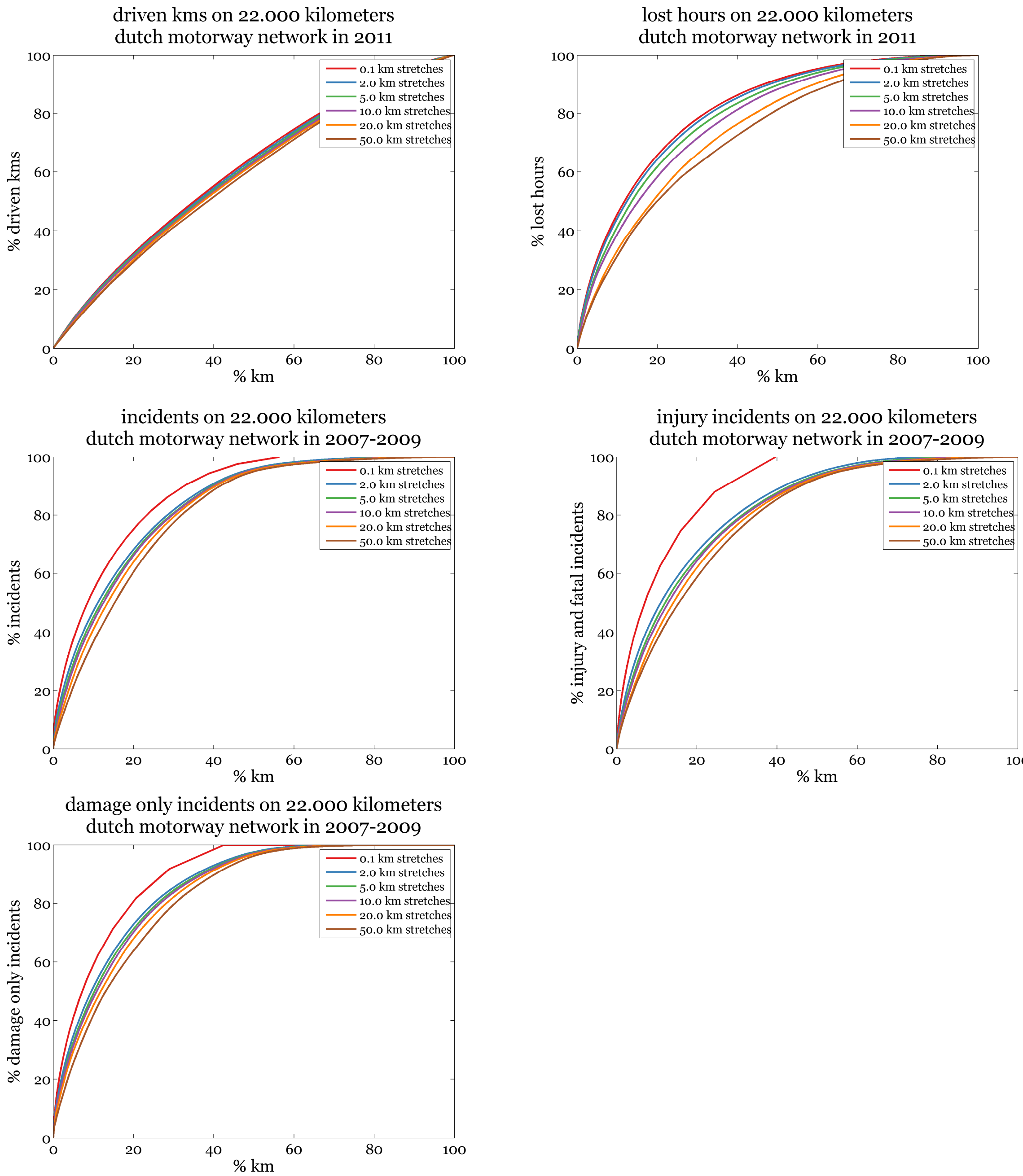


Figure 13: hotspots relations for five indicators, namely driven kilometers, vehicle lost hours, accidents, injury (or fatality) accidents, and damage only accidents. The relation depends on the segment length (called "stretch" in the legend).

Annex E: Example of Country Specific Analysis: the Netherlands

During the COBRA project, differences between countries in implementation of existing road-side infrastructure for traffic management became evident. TNO carried out a country-specific analysis for the Netherlands in order to get a better understanding for how specific analysis would need to be in order to support decision making on cooperative system deployment. It begins by describing the current functions carried out by existing road-side infrastructure, the actual infrastructure used to carry out the function and the average equipment rate (units / km) on equipped sections of the motorway in the Netherlands. This is followed by an analysis of the functions covered by the three bundles investigated in COBRA: to what extent do each of the bundles carry out the functions currently carried out by existing road-side infrastructure? Finally, an analysis of which bundles can replace the current actuators on the motorway network in the Netherlands.

This Appendix begins with a general explanation of traffic management systems and applications, followed by how these are implemented in the Netherlands. Section 2 describes the equipment of the Dutch network. This chapter concludes with an assessment of how well the COBRA bundles cover the current functions of the existing roadside equipment.

1 Traffic management systems and applications

1.1 Variable Message Signs

Definition

A Variable Message Sign (VMS) is a sign for the purpose of displaying one of a number of messages that may be changed or switched on or off as required.

VMS comprise two types, Continuous and Discontinuous signs:

- Continuous signs are similar to fixed signs, the only difference being that they can show various messages by some electromechanical means.
  For example rotating prism signs, roller blinds, etc.
- Discontinuous signs create messages using individual elements that can be in one of two states (or more) and can thereby create various messages on the same sign face.
  For example flip-disk signs, fiber optic signs, LED signs, etc.

Purpose

In Dynamic Traffic Management, VMS can be used for the following purposes:

A. Control, further to be divided in:

Lane Control:	- lane change/closure
	- lane merge by use of crosses and arrows
Speed Control	- speed funneling
	- speed harmonization by using speed indications, with or without red border
Prescriptions	- “no overtaking” etc.

VMS for lane and/or speed control purposes are in most cases positioned over the traffic lanes. Prescription signs are usually placed between two adjacent lanes or at the side of the road.

B. Danger Warning Messages, further to be divided in:

Weather Conditions	- fog

	- snow - ice - rain - wind
Incident / accident	
Congestion / queue	
Road works ahead	
Road status	- closures - slippery road - icy road (black ice)

C. Informative Messages, further to be divided in:

General Informative Messages	- useful traffic information
Informative Link Messages	
Informative Network Messages	
Informative Rerouting Messages	

1.2 Queue protection

Definition

Queue protection on motorways is an automatic traffic management system used to detect sudden traffic disruptions and warn upstream traffic heading for the congested area.

Purpose

The primary purpose of queue protection is to increase traffic safety on motorways by reducing rear-end collisions in queue tails.

1.3 Variable speed limits

Definition

Variable speed limits on motorways are speed limits depending on daytime period, weather conditions, actual traffic conditions or environmental conditions.

Purpose

There are different kind of purposes for implementing variable speed limits:

- Increase traffic safety by reducing speed;
- Improve traffic flow by smoothing traffic;
- Limit environmental impact by reducing speed;
- Improve user acceptance regarding road layout by increasing speeds during off-peak hours.

1.4 Peak hour lanes

Definition

A peak hour lane is a temporary extra lane replacing the hard shoulder at the left or right side of the motorway during periods of congestion. Use of the hard shoulder is indicated by roadside or overhead signals.

Purpose

The purpose of peak hour lanes is to temporarily create extra capacity in order to reduce congestion. Another purpose of peak hour lanes is to buffer traffic in order to prevent queues spilling back too far upstream.

1.5 Managed motorways

Definition

A managed motorway is a particular example of combining several traffic management applications in one integrated system, which is used by the national Highways Agency on motorways in England. The system in England has two main elements in it: variable speed limits and hard shoulder running.

Purpose

The variable speed limits keep traffic moving by controlling the flow of vehicles when the route is congested. A computer system is used to calculate the most appropriate speed limit based on the volume of traffic.

The hard shoulder is used as an additional live traffic lane during periods of congestion. When traffic builds up road users will be instructed to use the hard shoulder as an extra traffic lane, increasing the motorway's capacity, reducing congestion and keeping traffic moving.

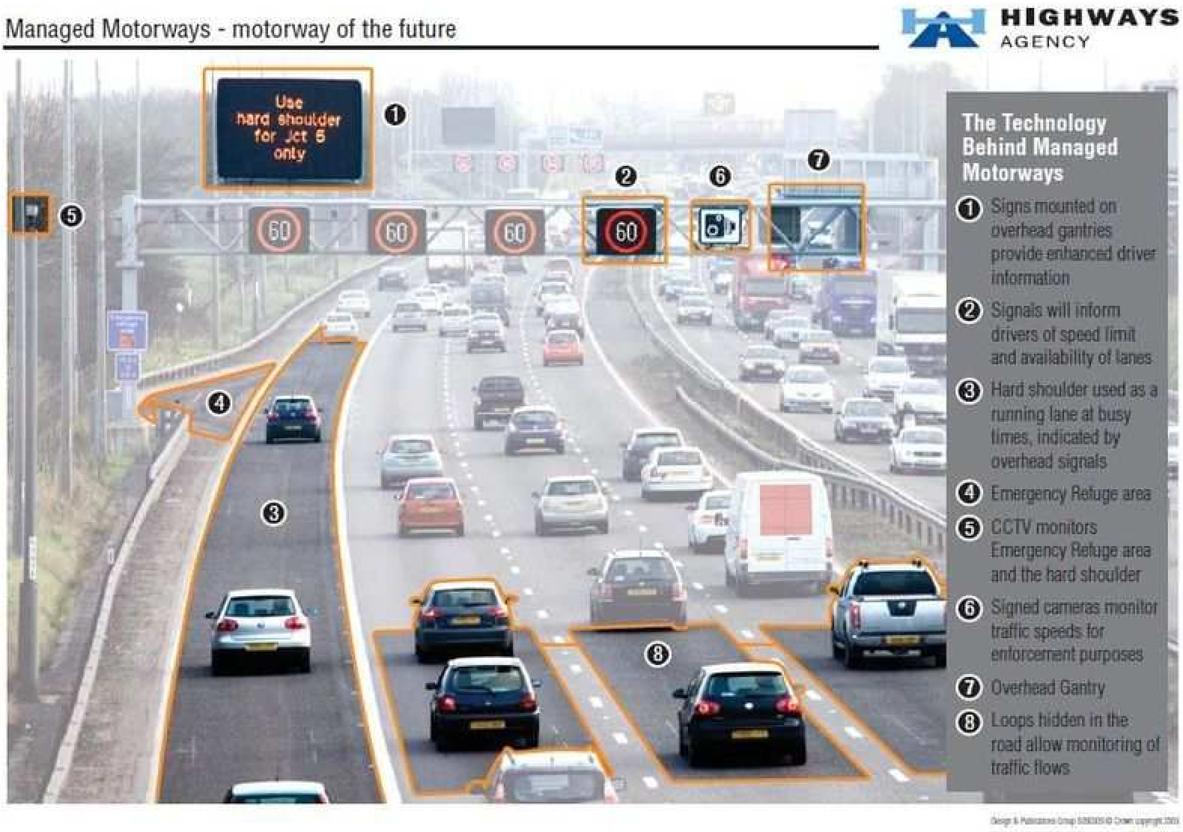


Figure 1.1 Managed motorway in England.

Road side systems

These particular managed motorways consist of several infrastructure systems or applications:

1. VMS driver information panels;
2. VMS speed and lane instruction panels above each lane;
3. Hard shoulder lane;
4. Emergency bays;

5. CCTV monitoring cameras;
6. Speed limit enforcement;
7. Overhead gantries;
8. Detector loops for each lane.

2 Traffic management systems and applications in the Netherlands

2.1 Variable Message Signs

For the Dutch situation there is a distinction in different types of Variable Message Signs. Three main categories can be found:

- Road signs;
- Information panels;
- Other VMS applications, like dosing traffic.

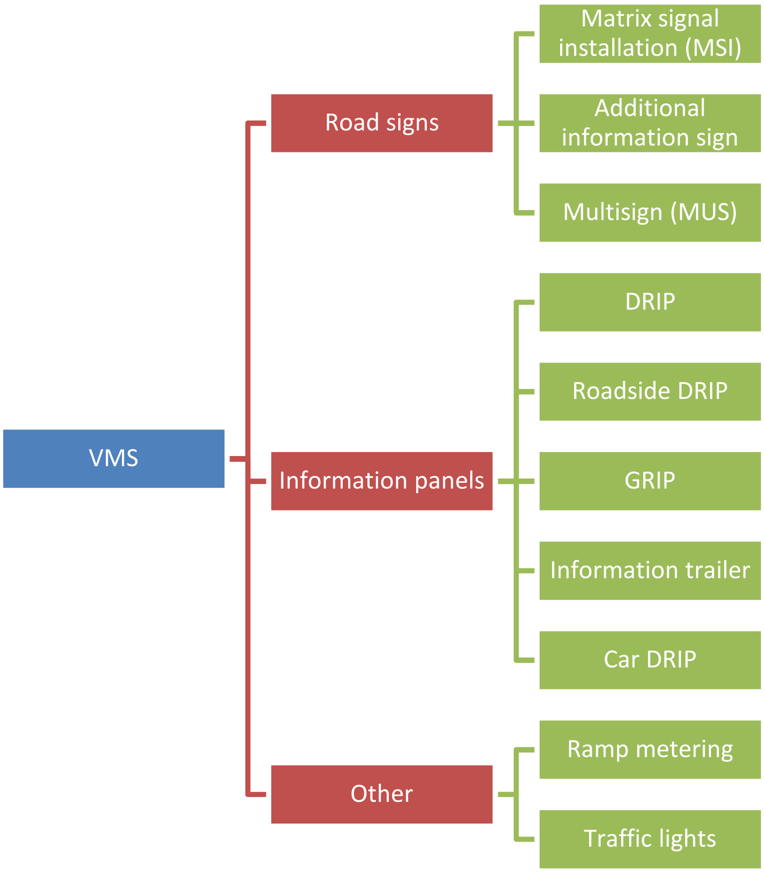


Figure 2.1 Distinction in different types of VMS applications in the Netherlands.

Road signs

The VMS in this category are connected to the Dutch motorway traffic management (MTM) system. They can show a predefined set of road signs dynamically, like lane specific speed limits or arrows, and other road signs considering warnings and prohibitions.

Information panels

The VMS in this category are in most cases matrix panels that can display any kind of text or pictures. They can display for example route information, advices, alternatives or other messages or warnings, either automatically from connected systems or manually from an operator. This category can be split into fixed and mobile panels alongside or above the road.

Other

Other types of VMS are ramp metering (to dose traffic to the motorway at on ramps in order to keep the main road flowing) and traffic lights (to halt traffic on the motorway in front of an open bridge or closed tunnel).

2.1.1 Matrix signal installation (MSI)

Figure 2.2 Example of two MSI mounted on a viaduct.

Large parts of the Dutch main road network are equipped with actuators for each lane called matrix signal installations (MSI) mounted on gantries or viaducts or below route panels above the road. In some cases a MSI is mounted on a post alongside the road. A MSI can only show a limited set of images. These MSI show lane specific mandatory speed limits and indicate the availability of lanes by means of arrows or crosses. An operator can send all signals to the MSI, whereas the automatic incident detection can only display some speeds (50 and 70) and two pairs of yellow flashing beacons in the four corners of the display.

Sign	Meaning	Explanation
120	Limit 120 km/h	Not used as speed limit.
100	Limit 100 km/h	Used for variable speed limits, in combination with a red circle.
90	Limit 90 km/h	Used at road works with limited disturbance or when opening peak lanes.
80	Limit 80 km/h	Permanently used in 80 km/h-zones, in combination with a red circle.
70	Limit 70 km/h	Used as first signal when entering a queue or used at road works.
50	Limit 50 km/h	Used as second signal when entering a queue.
30	Limit 30 km/h	Exception. Only used at congestion in sharp turns.

Sign	Meaning
	Red cross: lane closed.
	Green downward arrow: lane open.
	White arrow pointing downward diagonally left: change lane to the left.
	White arrow pointing downward diagonally right: change lane to the right.
	End of all previous prohibitions shown on electronic displays.

Figure 2.3 Set of images and corresponding meaning used on matrix signal installations.

2.1.2 *Additional information sign*

Figure 2.4 Example of two additional information signs (left: traffic jam ahead, right: attention; fog) mounted on gantries above the motorway between MSI with speed limits.

Additional information signs are the same kind of installation as MSI. Additional information signs do not show speeds and arrows though, but they show a limited set of electronic road signs. Some types have a possibility to show short textual messages below the image, like MIST (fog) or FILE (traffic jam). Usually additional road signs are mounted between the MSI on overhead gantries or viaducts. At the moment only a small number of possible images on additional information signs is used, because of the limitations in the MTM system. The focus is more on warning for extreme weather conditions and halting traffic. The images are displayed automatically based on an independent external system (apart from MTM) measuring visibility, wind or temperature for example.

Sign	Meaning	Sign	Meaning
	Overtaking prohibition		Lane narrowing on the right
	End of overtaking prohibition		Lane narrowing on the left
	Overtaking prohibition for trucks		Slippery road
	End of overtaking prohibition for trucks		Oncoming traffic
	Curve to the right		Side wind
	Curve to the left		Traffic lights
	Open bridge		Traffic jam
	Road works		Snow or glazed frost
	Lane narrowing		Attention, combined with FILE (traffic jam), MIST (fog) or ONGEVAL (accident)

Figure 2.5 Set of road signs an additional information sign could show.

2.1.3 Multisign (MUS)

Figure 2.6 Examples of multisigns (rotary prism signs) alongside the road (left) and above the road (right).

A multisign (MUS) is actually the signal from the MTM system that controls the display status for electronic road signs like additional information signs and rotary prism signs. In this document however a multisign is set equal to a rotary prism sign, which is a road sign existing of horizontal or vertical prisms. Each prism consists of multiple (usually three) sides that can rotate in order to show different information to the driver. Multisigns can be used to indicate multiple road layouts and route panels dynamically, for example with peak hour lanes when hard shoulder running is allowed.

2.1.4 DRIP

Figure 2.7 Example of a DRIP mounted on a gantry above the road showing travel times on alternative routes.

A DRIP is a dynamic route information panel, usually mounted above the lanes of a motorway so drivers from all lanes are able to read the information. Most DRIPs can show three lines of text. Each DRIP also has a set of arrows and icons for common words like queue, accident or off ramp available. The message on a DRIP is informative and can have different priorities:

1. Manual text;
2. Road blockage, incident reason and rerouting advice;
3. Road works;
4. Bridge openings;
5. Route choice information on alternative routes;
6. Route information on predefined routes;
7. General (safety) information or slogan

In general a DRIP always shows travel time information for predefined (alternative) routes in the form of the free flow travel time plus the additional delay time. This travel time information is mostly estimated from the loop detectors in the road surface. In case of a free flow situation, the DRIP can show a slogan. In case of an accident or road closure a text message with icons is prepared and send to the DRIP by the operator from the traffic control center.

2.1.5 Roadside DRIP

Figure 2.8 Example of a roadside DRIP showing travel times.

A roadside DRIP is a smaller DRIP mounted on a post alongside the road. Most roadside DRIPs can show different layouts: 1, 2, 3 or 4 lines text with in-line icons, 1 or 2 small or large road signs combined with text and in-line icons, different alignment of signs or text is possible and even graphic files can be uploaded to the roadside DRIP. Roadside DRIPs are mainly meant to show information in case of incidents, events, road works, parking routes etc. Normally these roadside DRIPs are switched off, but nowadays they are used more often to display route information to secondary (urban) roads or as additional information for DRIPs in case of no incident. For roadside DRIPs the same operation and priorities hold as for normal DRIPs, but no slogans are shown in this case.

2.1.6 GRIP

Figure 2.9 Example of a GRIP for the Amsterdam ring road.

A GRIP is a graphical route information panel and is the same panel as a roadside DRIP. The only difference is that the GRIP is always switched on showing a graphical representation of the network (mostly a ring road) with the congested parts indicated in red. This GRIP gives additional route information compared to a normal DRIP with travel and delay times on alternative routes because now the driver can see on which part of the network there is congestion. As for all route information on DRIPs, the information is coming from loop detectors in the road surface of the predefined road stretches.

2.1.7 Information trailer

Figure 2.10 Example of an information trailer displaying textual information.

Besides fixed panels alongside or above the road, there are also mobile information panels in the Netherlands. These are just car trailers with a display that can be folded upwards. Usually these trailers are placed temporarily on a place without a fixed (roadside) DRIP like in case of road works. The information trailers with a display can show several lines of text and icons or arrows and are placed alongside the road. It is also possible to upload graphic files on the information trailer. These trailers are usually not connected to the traffic control center. In most cases there is a wireless connection over the mobile network possible though.

2.1.8 Car DRIP

Figure 2.11 Example of a car DRIP mounted on a road inspector vehicle from Rijkswaterstaat.

In cases where direct security of an incident location is required, the road inspectors from Rijkswaterstaat use their cars to fend off upcoming traffic. Their cars are equipped with small displays that can show short textual information or arrows indicating a lane change. The road inspector can choose the appropriate image from his car. Usually the car DRIP is used as an extra caution to road users, apart from other fixed (electronic) signals.

2.1.9 Ramp metering

Figure 2.12 Example of ramp metering near an on ramp.

Ramp metering in the Netherlands comprises a ramp metering algorithm that calculates the remaining capacity on the motorway and the incoming flow from an on ramp using loop detectors. When the incoming flow will exceed the capacity of the motorway, the flow from the on ramp is dosed onto the motorway by traffic lights. The traffic controller uses very short green times, so only one or two vehicles can enter the motorway. The red time depends on the flows of both the motorway and the on ramp; less remaining capacity means longer red times. This regime is enforced by a camera registering red light running.

2.1.10 Traffic lights

Figure 2.13 Example of traffic lights used at a tunnel (left) and on an intersection at the end of an off ramp (right).

Strictly speaking, traffic lights are also variable message signs. They are implemented on Dutch motorways near objects that are controlled externally like tunnels and bridges to halt traffic in case of bridge openings or calamities in a tunnel. Sometimes the red lights are combined with information on an additional information sign. Traffic lights are also used near objects (mostly tunnels) to halt traffic in case a vehicle that is too high to pass the object is detected. Sometimes there are two height measuring locations, so that the driver can be warned after the first measurement in order to divert to the escape route. In this case there will be a yellow light flashing above the lane on which the high vehicle is detected, together with an additional information sign showing a warning. Some parts of the Dutch motorway network still contain traffic controllers, mostly at intersections on secondary roads maintained by Rijkswaterstaat, interchanges controlled by traffic lights or intersections at the end of motorways or near off ramps.

2.2 Queue protection

2.2.1 Automatic Incident Detection

The Dutch queue tail protection system on motorways is called Automatic Incident Detection (AID). The AID is able to detect queues and shows speed images on the MSI to warn the drivers. This is based on the measured speeds from the double loop detectors. When the moving average speed on a lane drops below a predefined value (usually 35 km/h), the AID system shows speed images on the MSI above the corresponding carriageway. The MSI on the gantry where the queue has been detected will show a speed limit of 50 (km/h). The MSI on one gantry upstream will also show 50, but now with flashers. The MSI on the next upstream gantry will show a speed limit of 70 with flashers. In this way upcoming traffic is warned more than one kilometer in front of the actual disruption or queue giving drivers an opportunity to adapt their speed and reducing rear-end collisions a queue tail. When the moving average speed on all lanes is above a threshold value (usually 55 km/h) the images on the MSI will disappear. The thresholds of 35 and 55 are the result of fine tuning in order to display reliable and credible MSI images in the AID system.

Figure 2.14 Example of MSI above each lane indicating 50 accompanied by flashers to warn for a queue ahead.

2.2.2 Central and local AID

The AID system has two forms: central AID and local AID. The abovementioned process of showing speeds on MSI of three subsequent gantries is the central AID and needs communication with a central system (the traffic control center). When detecting a queue, the outstation at the gantry sends an AID request to the central system for traffic engineering operations. This application checks the request and decides what images to show on which MSI. This signal is then sent to all involved outstations. In this way the AID images can move along with moving queues.

When communication between the outstation and the central system is not possible, the AID operates in local mode. In this case it is still possible for an outstation to calculate the speed on all lanes from the loop detectors. This means the outstation will show 50 with flashers if the speed drops below the threshold value, but now only on the MSI of the gantry with the detected speed drop.

2.3 Variable speed limits

2.3.1 Dynamax

In the Netherlands variable speed limits depending on actual traffic (apart from the AID queue protection), weather or environmental conditions, are not implemented on large scale yet. There have been a couple of test sites on this topic, called Dynamax (Dynamic Maximum speed limits), of which some were successful and recently have been implemented on several road stretches permanently.

There are three main conditions for implementing variable speed limits on road stretches in the Netherlands:

- Weather conditions;
- Air quality;
- Traffic flow.

The reasons for implementing variable speed limits in the Netherlands are:

- Increasing the speed limit (to 120 km/h) in situations with low traffic flows to reduce travel time and increase user acceptance of variable speed limits;
- Reducing the speed limit (to 80 km/h) in situations where the concentration of fine dust in the air is expected to exceed or approaching the daily maximum value to limit the environmental impact of traffic on air quality;
- Reducing the speed limit (to 100, 80 or 60 km/h) in situations with queues moving upstream to improve traffic flow by solving shockwaves;
- Reducing the speed limit (to 100 or 80 km/h) in situations with heavy rainfall to increase traffic safety;
- Increasing the speed limit (to 100 km/h) during peak hours with high traffic flow in urban areas with permanently reduced speed limits (80 km/h) because of local air quality to improve traffic flow;

2.3.2 Time dependent speed limits

Besides variable speed limit regimes based on external conditions, there are also different speed limit regimes solely based on time of day. There are daytime speed limits and speed limits during night, depending on the location of the road (in urban or rural areas for example). This is actually a static version of implementing variable speed limits, because the assumption is that during the night there is less traffic on the road. In this static case there is no system calculating actual traffic flow or external and road conditions.

2.3.3 Actuators

The actuators used to communicate the variable speed limits – and sometimes the reasons behind them – to the road user are the matrix signal installations, additional information signs and multisigns (rotary prism signs alongside the road). It is also possible to show speed limits on a roadside DRIP. The static speed limits are normally communicated to the driver by means of static road signs along the motorway, sometimes accompanied by a corresponding time slot.

Figure 2.15 Examples of actuators to indicate variable speed limits (left: MSI and additional information signs, center: MUS, right: static road sign with time slot).

2.4 Peak hour lanes

Peak hour lanes in the Netherlands are used to temporarily create an extra lane in case of busy traffic conditions to improve traffic flow. A peak hour lane can be a special lane on the left side of the road or the shoulder lane on the right side of the road. The first type is called plus lane, the latter type is called shoulder running. Building a permanent extra lane is more expensive, takes more time running though all legal procedures and is not necessary for off peak periods. There are however limitations for peak hour lanes, based on safety and environmental issues.

2.4.1 Limitations

The criterion for opening a peak hour lane is when the detectors measure a flow per lane of more than 1350 vehicles. When this is the case, the operator from the traffic control center receives a message to open an extra lane. The operator inspects the peak hour lane for obstacles or vehicles standing still using cameras and then activates the signals to indicate the lane is open for traffic. However, in some cases the peak hour lane will stay closed for safety reasons. This is the case for example during extreme weather conditions like fog or snow, or when the operator cannot inspect the whole road stretch with cameras.

2.4.2 Actuators

When the peak hour lane is opened, this is indicated by a green arrow on the MSI above the lane. Alongside the road the rotary prism sign adjusts its image to indicate with white upward arrows and a text message that the peak hour lane is open. Sometimes this is accompanied by a reduced speed limit and overtaking prohibition for trucks because of safety reasons. When the extra lane is closed, this is indicated by a red cross on the MSI above the lane. The rotary prism sign returns to the image with the normal situation.

2.4.3 Plus lanes

Plus lanes are usually added when there is enough space for an extra (sometimes narrower) lane. In case of plus lanes there is no solid line between the leftmost normal lane and the plus lane. In most cases however there is a special line that differs from the normal lane separation lines. Roads with plus lanes still have an emergency shoulder lane at the right side of the road. Continuous monitoring by an operator is not necessary here. At roads with more than four lanes in one direction it is normal that there is a shoulder or emergency lane on the left as well. Sometimes this lane is converted into a plus lane. For traffic safety reasons emergency bays with loop detection are added to the left side of the plus lane to detect vehicles standing still in the bay, possibly causing a dangerous situation for upcoming traffic.

Figure 2.16 Example of a plus lane with rotary prism signs on both sides of the road indicating the use of the narrower lane and the reduced speed limit.

2.4.4 Shoulder running

Shoulder running is usually allowed when there is a need for extra capacity, but when it is not possible to create a plus lane because of a lack of space. Allowing shoulder running is more complicated than on a plus lane. Road users are obliged to keep right as much as possible. In case of shoulder running traffic may therefore cross the solid line between the rightmost normal lane and shoulder lane. Especially at on an off ramps there are complex situations in linings. Because there is no emergency lane anymore once shoulder running is allowed, emergency bays have to be constructed every 500-1000 meters adjacent to the hard shoulder. Loop detectors in these emergency bays warn the traffic operator when a vehicle is present in the emergency bay. The operator then decides to keep the shoulder lane open or to close the lane. Because of the lack of a continuous emergency lane the operator has to monitor the shoulder lane continuously in order to intervene as quickly as possible in case of an incident.

Figure 2.17 Example of shoulder running with a green arrow above the lane and the rotary prism sign indicating the open status of the shoulder lane and the new speed limit.

2.5 Motorway Traffic Management system

The Dutch integrated Motorway Control & Signaling System (MCSS) is nowadays called the Motorway Traffic Management (MTM) system and is implemented from 1981. The reasons for developing this system were:

- Improve traffic safety by warning for rear-end collisions in queue tails;
- Improve traffic safety by closing lanes in order to secure incident locations;
- Reduce maintenance costs at road works by saving road signs.

2.5.1 Functions

There are two main functions of the MTM system:

1. Signaling
2. Monitoring

Signaling

There are different ways to show signals above or alongside the road:

- Speed limitations generated based on local detector information. In case of disruptions in traffic flow the Automatic Incident Detection (AID) shows speed limits of 70 followed by 50 on the matrix signs above the road, both accompanied with flashers to warn drivers for the disruption further downstream.
- Speed limitations, lane specific instructions or end of previous limitations in case of road works, accidents or peak hour conditions based on manual measures from the operator in the traffic control center.
- Speed limitations, stop signs and warnings based on local interventions related to external systems, like tunnels, bridges or sensors measuring visibility.
- Instructions on rotary prism signs, for example situated at peak hour lanes.

Monitoring

From the detectors traffic data like speed, intensity and vehicle classes can be extracted. These data is sent to the central system in the traffic control center. The monitoring function is becoming more relevant nowadays, because more and more traffic data is used for evaluation studies and transport policies. The real-time data is also used to estimate travel times which are shown on DRIPs.

2.5.2 Infrastructure components

The MTM system mainly consists of the following road side infrastructure components:

- Loop detectors
- Detector stations
- Outstations
- Matrix signal installations

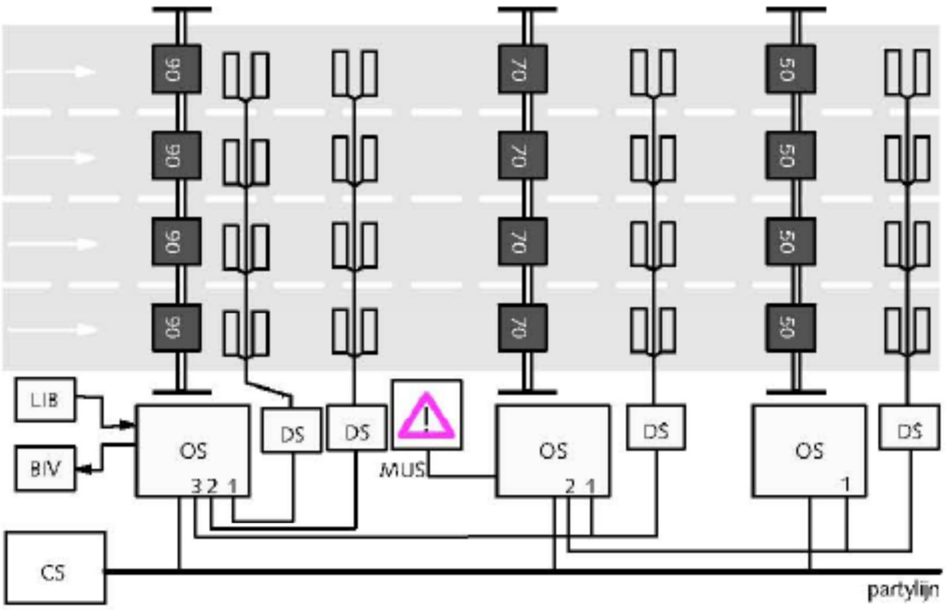


Figure 2.18 Components in the MTM system.

Loop detectors

In the MTM system induction loops are the most used sensors to detect vehicles. The induction loops are placed in the road surface for each lane (and sometimes also for the hard shoulder). Other ways to detect vehicles on the Dutch main road network are infrared and radar detection cameras which are usually mounted above the road on gantries. All loops detect occupancy of that particular road section, which means a vehicle is present above the loop. In most cases two loops are placed close to each other in one lane (a loop pair) in order to calculate the speed and length of the passing vehicle. The detection loops are connected to detection stations (DS).

Figure 2.19 Loop pairs in the road surface on a three lane highway (left) and loop detectors in an emergency bay adjacent to the shoulder lane (right).

Detector station

The detector stations (DS) collect the occupancies and time stamps from each connected loop detector (pair) per lane in a road section. Sometimes emergency bays are equipped with detector loops as well to detect the presence of a vehicle, especially in case of shoulder lane use. The detector station sends this data to the outstation (OS). Detector stations are also implemented on highways without MTM, when only obtaining and monitoring traffic data is needed. In most cases the detector station is placed inside the outstation near a gantry. In case no gantries or outstations are placed near the road, like at connecting roads at interchanges or long road stretches, the detector station is placed alongside the road separately. The detector station spacing is equal to the loop spacing (around 300 meters on important and busy road stretches with peak hour lanes and around 700 meters elsewhere).

Figure 2.20 MTM detector station (left) and a monitoring detector station (right) placed alongside the road.

Outstation

The outstation (OS) is the communication box between the road side systems and the operator from the traffic control center. The outstations are connected to a central system (CS) by party lines (PL), and recently more with fiber optic cables. An outstations has several functions.

An outstation gathers traffic and other data that are received from the detector station. The traffic data is aggregated to speeds and flows per minute and sends this to the central system.

The outstation then processes traffic data internally and intervenes if there is a disruption on the road stretch by showing lower speed limits and flashing lights on the matrix signal installations (MSI) mounted above the road on the overhead gantry to warn upcoming traffic. This is the automatic incident detection (AID) algorithm. For this AID algorithm the outstation communicates with the outstation further downstream to slow down upcoming traffic gradually over larger distance before the traffic disruption. Even when the communication with other outstations or the central system is lost, the AID algorithm keeps running locally on an outstation.

Other systems that could send a signal to an outstation are called local intervention sources (LIB) like an open bridge, closed tunnel, fog detection or emergency bay vehicle detection that warn traffic or the operator for extra attention. Based on the local intervention signals, the outstation can send a visual information signal (BIV) to actuators, like the matrix signal installations (MSI), additional information signs between the MSI above the road or rotary prism signs/multisigns (MUS) alongside the road at peak hour lanes.

The outstation can also receive instructions like the availability of lanes and changes in speed limits manually from the operator in the traffic control center via the central system (CS).

Another function of an outstation is to check its own and other linked systems on operational status and to report this to the central system.

Figure 2.21 MTM outstation near a gantry.

Matrix signal installation

The Dutch MTM system consists of actuators for each lane called matrix signal installations (MSI) mounted on gantries or viaducts above the road. The MSI are part of the group Variable Message Signs (VMS), but only a limited set of images is implemented in the MSI. These MSI inform drivers of traffic conditions ahead, speed limits and the availability of lanes by means of text or images. Some of the signals are defined by the outstation automatically, like in case of the AID algorithm. Most signals come from the operator in the traffic control center, for example in case of lane specific speeds or instructions after an accident or during road works.

Figure 2.22 Matrix signal installations above the road on a gantry.

2.5.3 Relation with other systems and applications

The next figure shows the relationships between the roadside systems in the Netherlands. They are split into sensors, controllers (detector stations and outstations) and actuators. The figure also shows which systems are connected to the traffic control center (TCC). The systems above the dashed line are part of the MTM system.

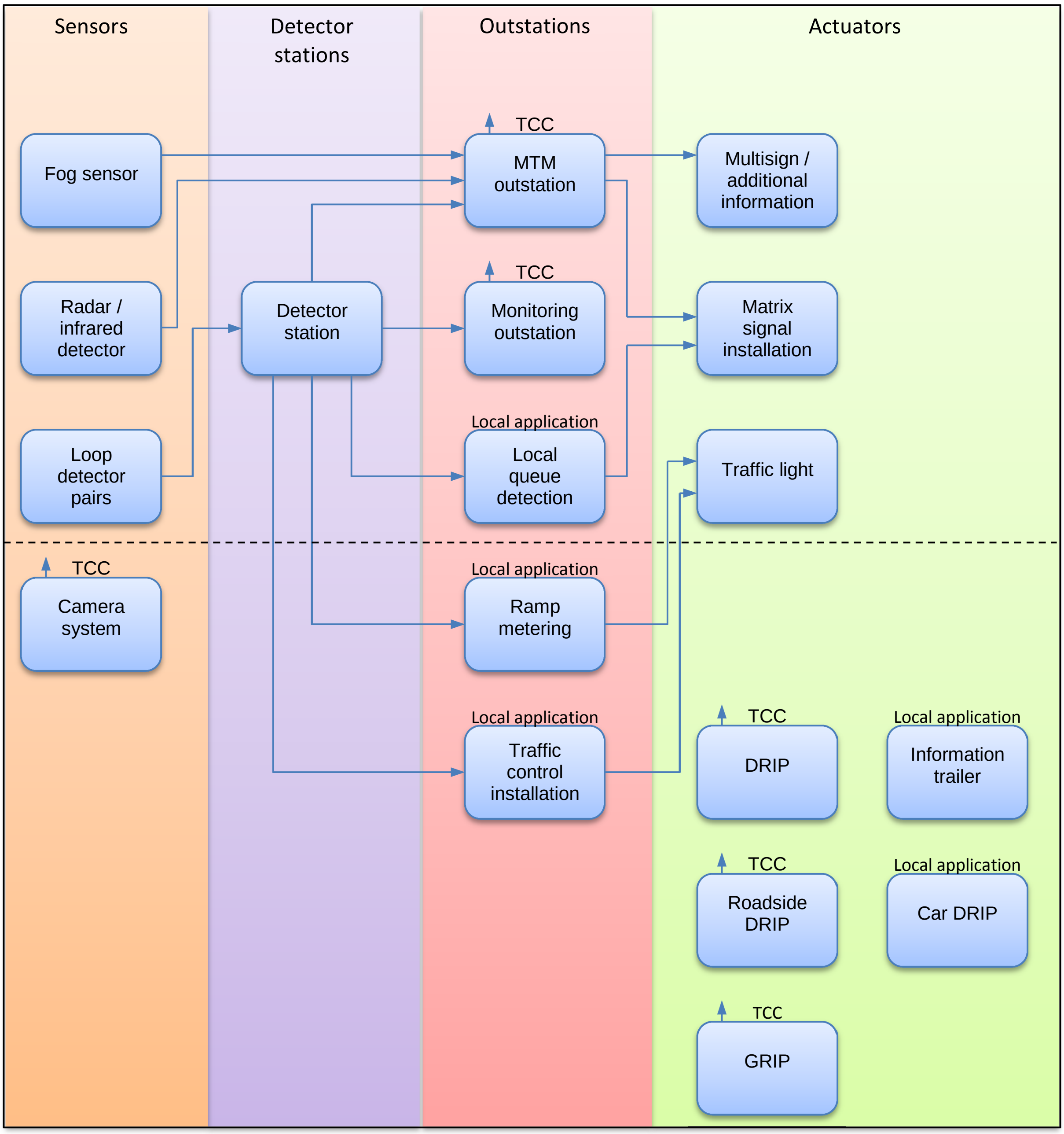


Figure 2.23 Relations between all motorway road side systems and the traffic control center (TCC) in the Netherlands. The systems above the dashed line are in the MTM system.

The advantage of MTM is that it is a flexible system. Just as with managed motorways, the MTM system is an integrated system with different independent parts or modules that can be extended or adapted individually. This makes the MTM system flexible.

Originally MTM consisted only of the AID module and the lane signaling module. The queue protection algorithm AID can still be adjusted and optimized per road stretch individually.

In the beginning MTM only used MSI out of the group of VMS. Later the additional information signs, multisigns and traffic lights near objects were connected to the MTM system via the outstations.

The information panels do use data from the MTM system, but this data is transferred to the traffic control centers via a separate connection. Also the connection from the operators to the different types of DRIPs uses this separate connection, and not the MTM partylines.

Variable speed limits are implemented in the MTM system separately. The algorithms that calculate the necessary signals for MTM come from external and independent systems, for example to calculate the environmental impact or weather conditions.

Peak hour lanes are dependent on the functioning of the MTM system. This is because of the signaling function, indicating the lane use with MSI and MUS. However, the data on which the decision is taken to open or close the peak hour lanes is separated from the MTM signaling function.

2.6 Current equipment of the Dutch motorway network

This section describes the current equipment of the Dutch motorway network with the classes Variable Message Signs, Queue protection, variable speed limits and peak hour lanes

2.7 Variable Message Signs

Figure 2.7.1 Positioning of DRIPs, Roadside DRIPs and GRIPs on the Dutch road network. Some urban and provincial DRIPs are not owned by Rijkswaterstaat but are mapped in this figure as well.

VMS	Number	Average spacing in total network

DRIP	105	Every 70 km
Roadside DRIP	271	Every 27 km
GRIP	1	-

The VMS systems DRIPs, roadside DRIPs and GRIPs are highly concentrated in the western part of the Netherlands (the Randstad area) and around large cities. In most cases these systems are situated near a motorway interchange and display travel time info. The info is mainly focused on routes heading to the large city, or in case of the Randstad between two important interchanges. In parts of the network with multiple routes to a destination these VMSes are also used to influence route choice to spread traffic more evenly over the network.

As the table in the next section will show, the part of the network with a monitoring function (data for the travel times) is around 50%. Since around half of the total Dutch traffic demand is concentrated in the Randstad area, the assumption is that this group of VMSes reaches at least half of the total car travels. Other car trips are made around the bigger cities outside the Randstad, where there are VMSes as well, even when there is no monitoring. Typically these trips are longer in kilometers. A rough estimation is thus that the DRIPs, roadside DRIPs and GRIPs cover around 70% of the trips on the Dutch motorway network.

Other VMS, not shown on map:

VMS	Number
Matrix signal installation (MSI)	15038
Additional information sign	140
Multisign (MUS)	611
Information trailer	157
Car DRIP	360
Ramp metering	105
Traffic light controller	312

The MSI are all placed within trajects with MTM (see next section). Additional information signs usually can be found at tunnels and bridges. One additional exception is a traject equipped with a fog detection system. The multisigns are mostly placed at peak hour lanes (see section 3.4). Mobile VMSes Information trailers and car DRIPs are not fixed but depend on the location of an incident. Ramp metering is placed at some urban on ramps. Traffic lights are either placed in front of a tunnel or bridge, at endings of motorways and at junctions on highways that don't have a motorway status.

2.8 Queue protection

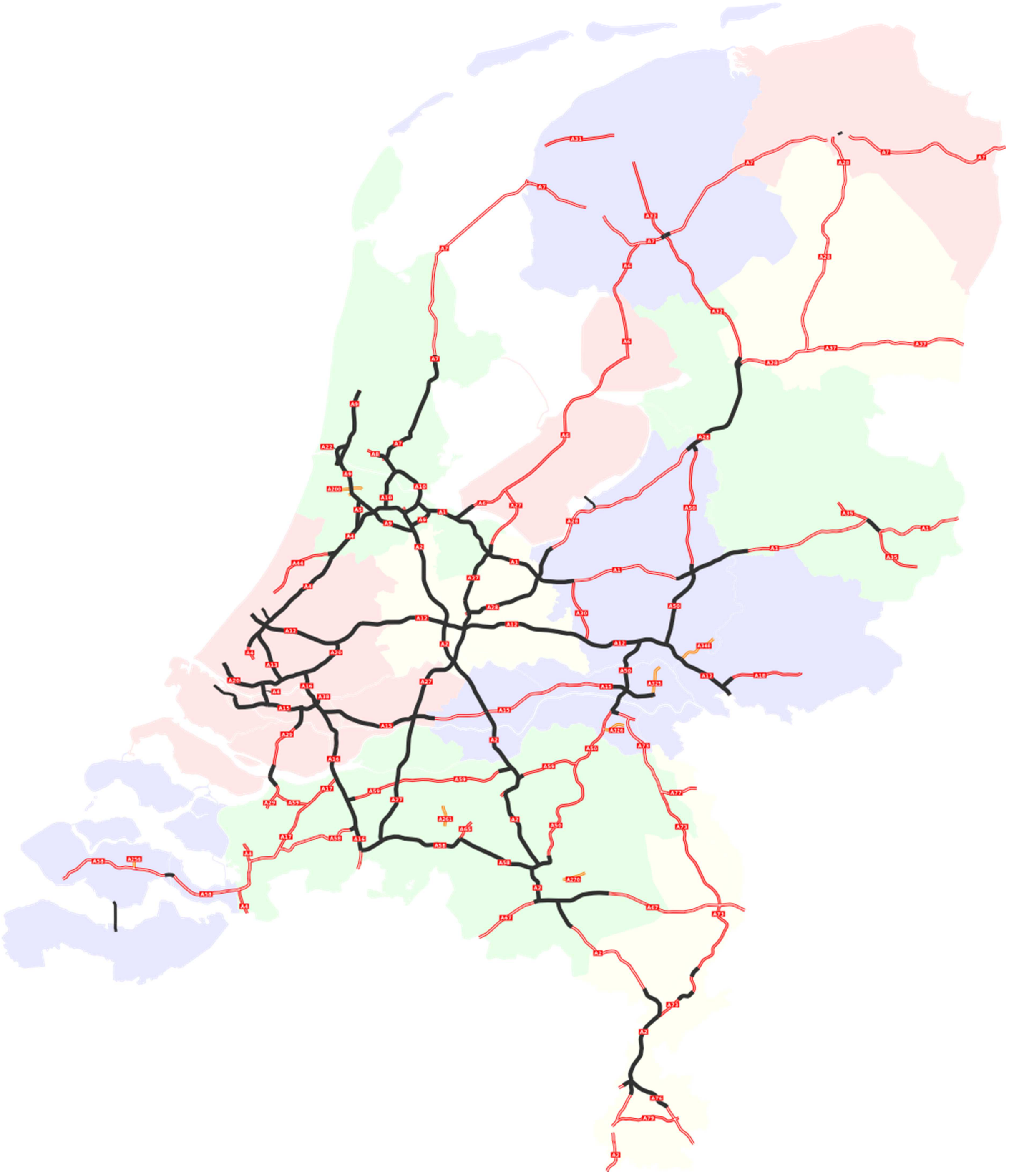


Figure 2.7.2 Motorways highlighted in black are equipped with MSI for queue protection. On the main road network this means MTM.

Characteristic	Length (km)	% of main road network
Main road network	7372.34	100
- Monitoring with signaling (MTM)	2633.10	35.7
- Monitoring without signaling	935.63	12.7
- No monitoring	3803.61	51.6

2.9 Variable speed limits

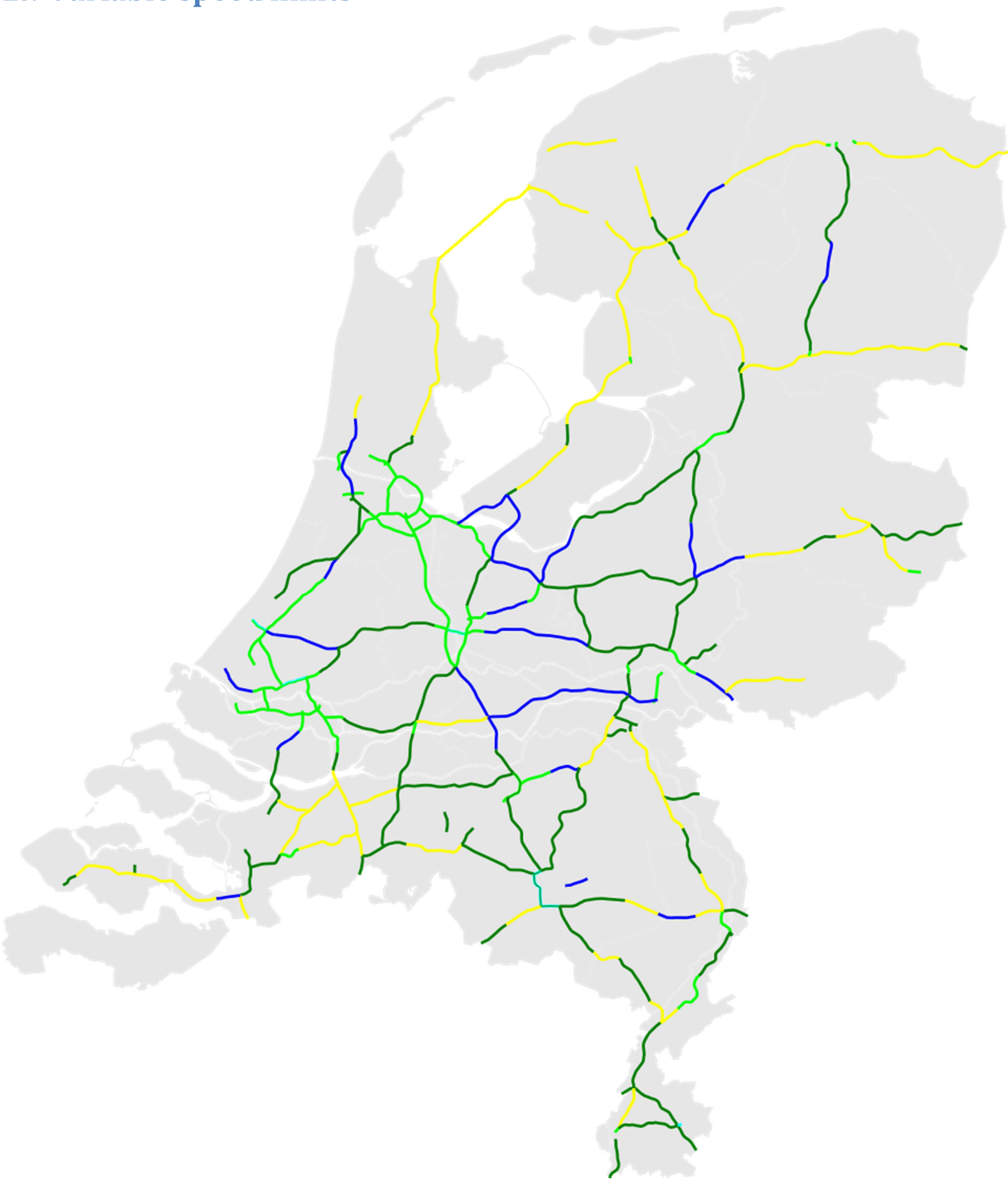


Figure 2.7.3 Overview of Dutch time-dependent speed limits on motorways. The dynamic speed limits in the Dynamax test trajects are not used anymore.

Dutch speed limits per September 2012.

- 130 km/h
- 120 km/h
- variable 100/120-130 km/h

- 100 km/h
- 80 km/h

2.10 Peak hour lanes

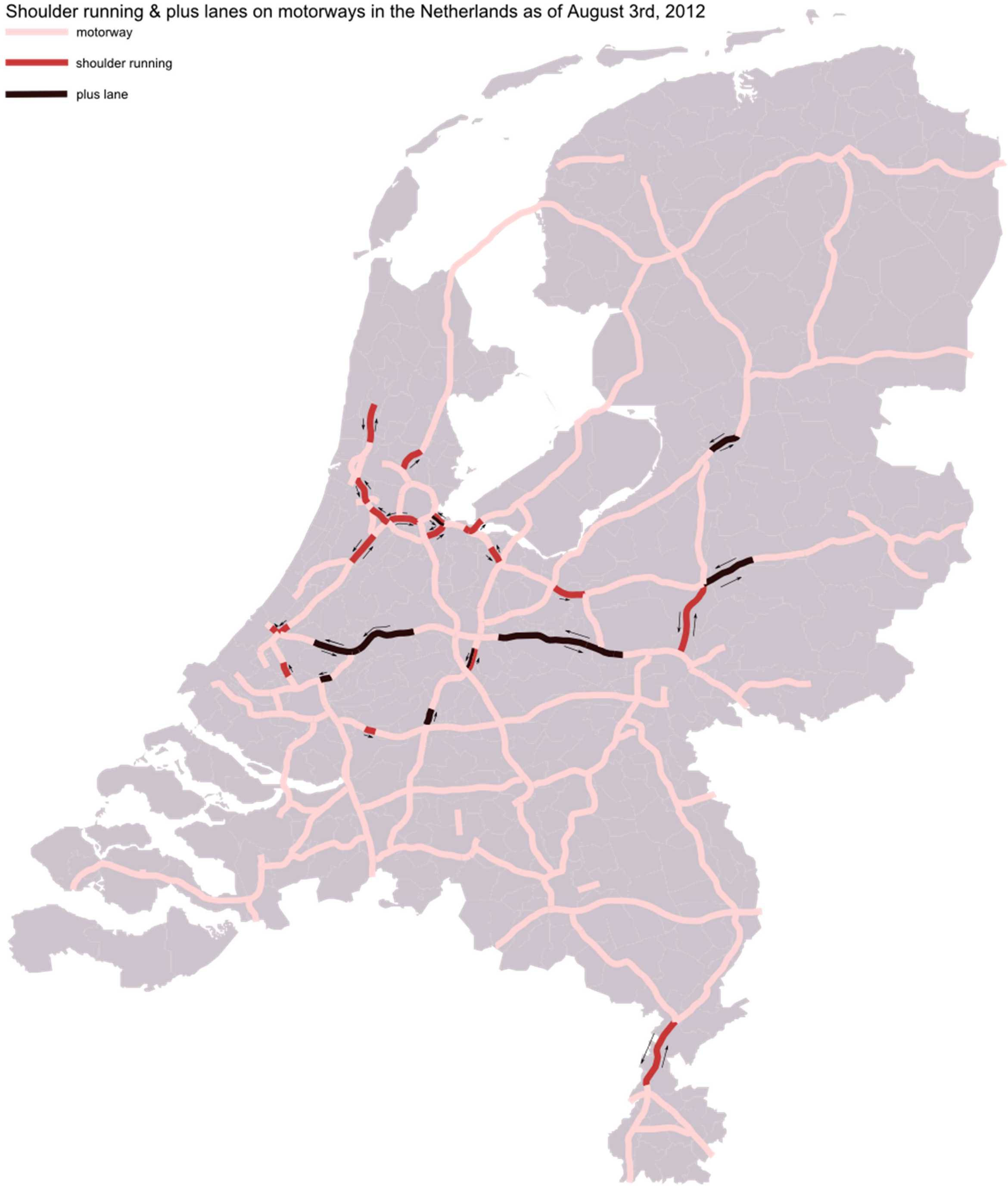


Figure 2.7.4 Overview of trajects with peak hour lanes on the Dutch motorway network.

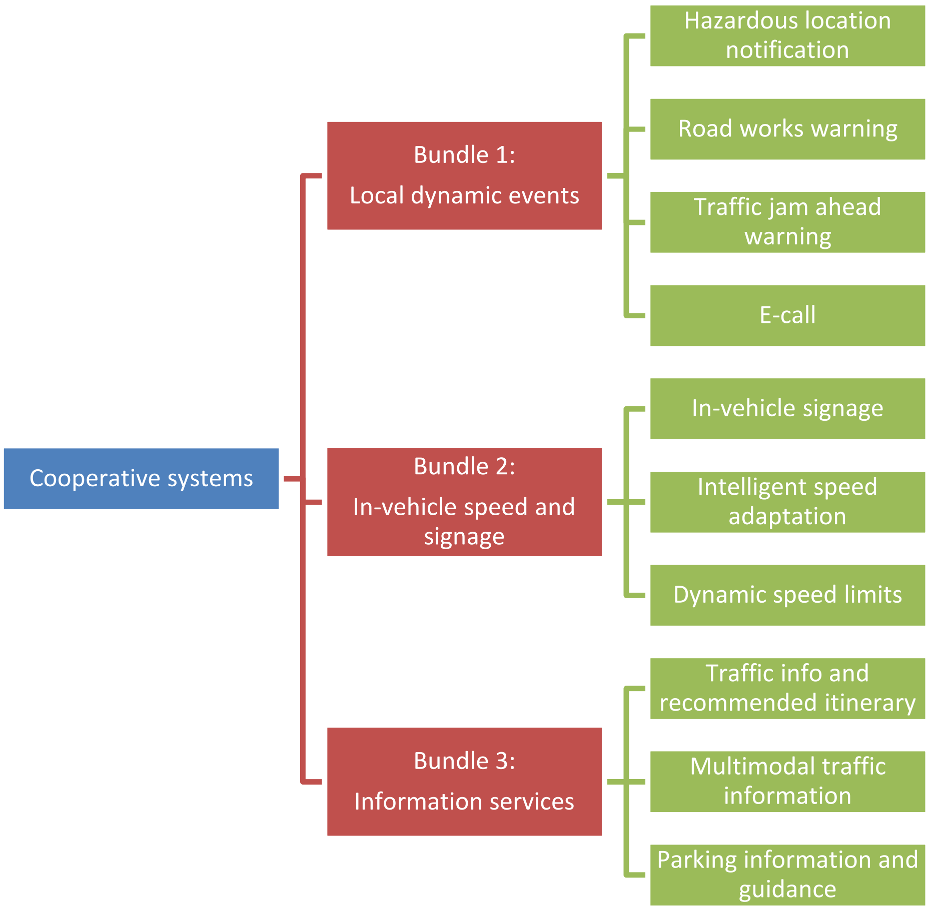
Characteristic	Length (km)	% of main road network
Main road network	7372.34	100
- Shoulder running	187.50	2.5
- Plus lanes	120.95	1.6

3 Implementing cooperative systems in the Netherlands

3.1 Types of cooperative systems

The cooperative systems discussed in this report can be separated in three bundles:

1. Local dynamic events;
2. In-vehicle speed and signage;
3. Information services.



3.1.1 Hazardous location notification

Provides a warning notification about potential hazardous areas when approaching them. These areas statistically have more collisions and incidents, and thus require more attention from the driver. This application would have a particular benefit in dynamic situations such as changing weather conditions.

3.1.2 Road works warning

Carrying out repairs on a live carriageway usually involves temporary speed limits, lane changes, lane merges and contra flow running which are managed by temporary signs and portable physical barriers to divide lanes. A linked vehicle-infrastructure system offers much more flexibility, enabling faster reconfiguring of the work zone and allows precise alerts and instructions to drivers regarding lane choices, speeds, too-close following of preceding vehicles etc.

3.1.3 Traffic jam ahead warning

This function warns drivers when approaching the tail end of a traffic jam. It will cause drivers to be more aware of the situation ahead leading to lower speeds, longer headways and a reduced risk of rear-end collisions.

3.1.4 E-call
If sensors in the vehicle detect that a collision has occurred, the vehicle can automatically make a telephone call to the emergency services to give the incident location, and provide some information about the vehicle and its location. The system opens voice and data channels so that the emergency call centre can talk to the driver or any passengers if they are conscious. The post crash warning part of the application warns drivers when approaching a crashed car either via a message from the crashed car itself or via a following car that detects a crashed vehicle warning ahead.

3.1.5 In-vehicle signage
A vehicle-infrastructure link is used to give information or a warning to a driver of the content of an upcoming roadside sign. This can be extended to inform drivers about other oncoming features of the road such as chicanes, roundabouts, traffic calming installations and road markings such as segregated cycle lanes or bus lanes. This application is often referred to as Visibility enhancement - giving the driver information about situations beyond or outside the direct line-of-sight.

3.1.6 Intelligent speed adaptation
ISA is a system that monitors a vehicle's speed and the speed limit on the road being used and intervenes if the vehicle is detected exceeding the speed limit. An ISA can have additional features to influence driver's behaviour by e.g. haptic gas pedal.

3.1.7 Dynamic speed limits
Speed limits are set on a road segment according to the infrastructure (e.g. geography, road alignment, etc.), type of road, traffic flow and other factors. Dynamic speed limits have the advantage of being more flexible. They take into account traffic flow in different conditions and times of day, weather conditions and other environmental factors.

3.1.8 Traffic info and recommended itinerary
This function recommends a route for the vehicle navigation system to direct the driver around congested locations and dangerous roads and to distribute the traffic load on alternative routes.

3.1.9 Multimodal traffic information
This function aids drivers by providing information regarding travel time, schedules and routing information door-to-door by using different types of sources such as built-in vehicle devices, the internet, mobile devices, etc.

3.1.10 Parking information and guidance
This function is a service provided to drivers who need a parking place. It monitors the number of available places in a parking facility, detects the location of vehicles in real time, finds a parking place and provides routing information on how to reach the reserved place. The payment is organized automatically.

3.2 Overlapping functions with road side systems

3.2.1 Legacy function matrix
The next matrix shows goals and legacy functions, aggregated in seven categories, for each existing Dutch roadside system or application. The matrix also shows which legacy functions are carried out by which cooperative system from the three bundles.

Goal: Management	Goal: Information	Goal: Traffic flow	Goal: Safety	Function	Sensors: Induction loop pairs	Sensors: Emergency bay vehicle detection	Sensors: Fog detection	Sensors: Temperature detection	Sensors: Radar detection	Sensors: Infrared detection	Sensors: Camera	Controllers: MTM detector station	Controllers: Monitoring detector station	Controllers: MTM outstation	Controllers: Monitoring outstation	Controllers: Ramp metering	Controllers: Traffic control	Actuators: Matrix signal installation	Actuators: Multisign	Actuators: Additional information sign	Actuators: DRIP	Actuators: Roadside DRIP	Actuators: GRIP	Actuators: Information trailer	Actuators: Car DRIP	Actuators: Traffic light	Bundle 1: Hazardous location notification	Bundle 1: Road works warning	Bundle 1: Traffic jam ahead warning	Bundle 1: E-call	Bundle 2: In-vehicle signage	Bundle 2: Intelligent speed adaptation	Bundle 2: Dynamic speed limits	Bundle 3: Traffic info and recommended itinerary	Bundle 3: Multimodal traffic information	Bundle 3: Parking information and guidance
			x	detect vehicle	x	x			x	x	x	x	x	v	v	v	v																			
			x	warn for queue ahead	v				v			v		x				x		x									x				x			
	x	x	x	indicate speed limit	v		v	v	v			v		v				x	x			x						x			x	x	x			
		x	x	indicate lane use							v			v				x	x									x			x					
		x	x	indicate lane change							v			v				x	x					x	x			x			x					
			x	indicate lane closure							v			v				x	x									x			x					
		x		indicate end of prohibitions							v			v				x	x			x		x				x			x					
	x			indicate open bridge										v			v			x	x	x				x	+				x (red)					
			x	warn for fog			v							v				v		x		x					x				x (red)					
			x	warn for wind										v				v		x		x					x				x					
			x	warn for slippery road				x						v				v		x		x					x				x					
	x		x	warn for traffic light										v			v	v		x						x	+				x					
			x	warn for road design																x		x						x			x					
x				warn for too high vehicles	v				v		v			v			v	v		v						x	+				+					
			x	halt traffic										v			v	v		v						x	+				+					
		x		dose traffic	v				v			v		v		x	x									x							x			
		x		indicate overtake prohibition for trucks										v					x	x		x									x					
			x	increase driver's attention																x		x		x	x		x	x	x		x	x	x			
	x			inform on approaching congestion	v															x		x									x (red)					
			x	warn for short headway																								x								
			x	warn for wrong direction																											x					
	x			display travel times on predefined routes	v				v	v		v	v	v	v						x	x												x	x	
	x			display congestion in network	v				v	v		v	v	v	v								x											x	x	
	x			inform on road blockages																	x	x		x										x	x	
	x			inform on incidents																x	x	x		x	x		x			x	x (red)			x	x	
	x	x		inform on rerouting																	x	x		x										x	x	x
	x	x		inform on alternative routes																	x	x		x										x	x	x
	x			inform on parking																		x		x												x
	x			display additional information			x							v				v		x	x	x		x	x		x	x					x	x	x	
	x			inform on public transport transfers																	x	x													x	
	x			inform on road works																	x	x		x										x	x	
	x			show (safety) slogans																	x			x												
x				collect traffic data	v				v	v		x	x	x	x																					
x				report system state										x	x																					
			x	draw attention of operator		v					x			x												v				x						

Function categories (row colours):

1	Automatic Incident Detection
2	Traffic signaling
3	Warnings for external conditions
4	Act in operational driving task
5	Network route choice
6	Comfort
7	Other

x	function incorporated in system
x (red)	dynamic signs incorporated in system
v	system necessary for function
+	function could be incorporated in system

Figure 3.1 Legacy function matrix for Dutch roadside systems and cooperative systems

3.2.2 Notes about the matrix

Legacy functions

- A x in a cell means the legacy function is carried out by the cooperative system, for that particular application.
- A v in a cell means that the roadside system is necessary to perform the legacy function.
- A + in a cell indicates that the legacy function is not currently in the definition of the cooperative system functionality, but could be easily incorporated.
- Inform on road works comprises generic information as provided on the radio.
- Display additional information comprises explanation by means of a dynamic road sign or icon, sometimes accompanied by a short text.

Cooperative systems

- Traffic jam ahead warning is assumed to function via infrastructure to vehicle (I2V) communication.
- E-call is assumed to send information to an emergency call centre and to other vehicles approaching the crashed vehicle.
- The cooperative systems in bundle 1 mainly incorporate warning instead of informing functions.
- In-vehicle signage comprises fixed signs, multisigns and matrix signs. It does not directly incorporate dynamic additional information signs which are provided in MTM by external systems like for weather conditions, open bridges or closed tunnels. A red x in a cell indicates this note.
- Dynamic speed limits are assumed to indicate also the reason for the lowered speed.
- Multi-modal traffic information differs from traffic info and recommended itinerary only in that it provides multi-modal transfer information.

3.3 Possibilities to replace road side systems

3.3.1 Sensors

None of the cooperative systems have the legacy function to detect vehicles. Loops or other sensors are still necessary. Another possibility is to use floating car data (FCD) for the wireless roadside equipment scenario.

3.3.2 Controllers

Detector station

Detector stations are not necessary only in case loop data is not used anymore for the signaling function and the monitoring or research function.

Outstation

The outstations report the state of all connected systems within MTM, process data and send signals to actuators. An outstation is the connection between roadside systems and the traffic control center. An outstation therefore is necessary as long there are roadside systems.

Ramp metering and traffic control installation

The systems and algorithms for ramp metering and normal traffic control (on intersections for example) cannot be replaced yet by the discussed cooperative systems.

Conclusion

None of the controllers can yet be removed because there is no cooperative system (bundle) replacing all of their legacy functions.

3.3.3 Matrix signal installation

Replacement by bundle 1

Bundle 1 covers most of the legacy functions of a MSI. It must be noted however that most cooperative systems indicate the signaling functions speed limit, lane use and lane change for specific circumstances (during road works only). The functions indicate open bridge, warn for traffic light and warn for too high vehicles could be implemented in bundle 1, given that the cooperative system is able to communicate between vehicle and the external system connected to the MTM system at the moment. Bundle 1 could also provide weather warnings dynamically, but not accompanied by a speed limit.

Replacement by bundle 2

Bundle 2 is able to show speed limits, lane use and lane change under all circumstances, contrary to the systems from bundle 1. The AID function warn for queue ahead is assumed to be performed by the dynamic speed limit cooperative system. If bundle 2 can cover dynamic signs shown on or with a MSI then it covers the warnings for weather conditions too. However, the function warn for too high vehicles is missing in this bundle but could be implemented in one of the cooperative systems again when it can communicate between the vehicle and object.

Functions not incorporated in bundles

MSI function halt traffic (red cross or sometimes a traffic light above a lane) is not covered by any of the bundles directly. However the assumption is that this function could be incorporated in one of the cooperative systems of bundles 1 or 2, for example indicating lane closures. However there will still remain legal issues.

Conclusion

Bundle 1 and 2 together could cover MSI functions, but neither completely. They both cover more or less the same functions as the legacy systems. Some functions are different though and some functions are missing yet, but could be incorporated in cooperative systems. Bundle 2 covers more functions of a MSI in more situations than bundle 1. Legal issues for the function halt traffic have to be addressed.

3.3.4 Multisign

Replacement by bundle 1

Bundle 1 misses the functions of showing an overtaking prohibition (for trucks). Furthermore the functions of traffic signaling (speed limits, lane use, lane change, lane closure and end of prohibitions) are only carried out during road works and not for other general incidents.

Replacement by bundle 2

Bundle 2 covers all legacy functions for multisigns. However, there is still the legal issue with enforcing the traffic signaling functions.

Conclusion

Bundle 2 is capable of fully replacing multisigns, with remarks however regarding legal issues.

3.3.5 Additional information sign

Replacement by bundle 1

Bundle 1 does not cover the functions indicate open bridge, warn for traffic light, warn for too high vehicles and halt traffic yet. The assumption is that all of those functions could be implemented, for example when communication with external systems is possible. Missing functions are the indication of overtaking prohibitions for trucks and the information on approaching congestion. This last function is partly included in the function for queue ahead warning, but only just in front of a queue not giving the driver an opportunity to change route.

Replacement by bundle 2

Bundle 2 includes all functions of additional information signs, but there are some remarks. The dynamic warnings for external conditions like extreme weather or interventions from object systems are assumed possible to implement in the cooperative systems.

Conclusion

Bundle 2 is able to replace additional information signs, given the remarks on dynamic signals during weather conditions or coming from external objects connected to the current MTM system.

3.3.6 DRIP, roadside DRIP and GRIP

Replacement by bundle 1

Bundle 1 is able to cover the warning functions from the group of DRIP actuators. The functions indicate overtaking prohibition for trucks and inform on approaching congestion are not covered by the systems from bundle 1. Also the informative network route choice and comfort functions are mainly not covered in this bundle.

Replacement by bundle 2

Bundle 2 could also cover warning functions, given that the warnings for external conditions are only given by using a pictogram/icon and no text (blocks). Again, this bundle can also show signs during weather conditions, assuming that the information is sent to the systems by some operator manually just as with the group of DRIPs. This bundle lacks most functions on informative network route choice and comfort functions.

Replacement by bundle 3

Bundle 3 covers all functions in the category of informing on network route choice and showing comfort information. Only the function of showing (safety) slogans are not covered, but this is not assumed a crucial function of the DRIPs group.

Conclusion

Bundle 3 is able to replace all primary information functions from the group of DRIPs. The secondary function of DRIPs is supporting warnings on other roadside actuators, and could be provided by one of the bundles 1 or 2.

3.3.7 Information trailer and car DRIP

Replacement by bundle 1

The traffic signaling function like lane changing is only carried out during road works in bundle 1 and not for all situations. This bundle lacks the (textual) information functions.

Replacement by bundle 2

Bundle 2 offers traffic signaling functions in more situations than only road works. It is for example possible to communicate the exact location to perform a lane change or other attention signals by wireless beacons. This bundle also lacks the (textual) information functions.

Replacement by bundle 3

Bundle 3 only covers the informative functions on network route choice and comfort texts. The function to show safety slogans is not carried out by one of the cooperative systems in this bundle.

Functions not incorporated in bundles

The mobile actuators can be situated at every incident, and furthermore offer some kind of security to people and vehicles behind the physical barrier blocking a lane because they have a crash absorbing function. This aspect is not present in any of the bundles. Showing safety slogans are not implemented in any of the bundles either, but this is less crucial.

Conclusion

Information trailers and car DRIPs cannot be replaced solely by cooperative systems because of the physical presence on the road and their crash absorbing function. Apart from this, bundle 1 and even more bundle 2 cover signaling functions during incidents. Bundle 3 only covers the traffic information functions.

3.3.8 Traffic light

Replacement by bundle 1 or 2

Bundles 1 and 2 cover warning functions for open bridge, too high vehicle, traffic light and halt traffic. Only bundle 2 does not warn the traffic operator.

Functions not incorporated in bundles

The function of dosing traffic in case of ramp metering is not carried out by any of the bundles. Furthermore the function halt traffic is not covered fully (legally) by any of the discussed cooperative systems.

Conclusion

Bundle 1 and 2 can partly cover the function of a traffic light, but only to indicate the driver where and when to stop. There will always be legal issues on enforcement. Replacing ramp metering using one of the bundles is also not possible.

3.4 Conclusion for replacing actuators

	Bundle 1	Bundle 2	Bundle 3	Legal issues	Safety issues
Matrix signal installations	V[bc]	V[c]	-	V	V[f]
Multisigns	V[bc]	V[c]	-	V	V[f]
Additional information signs	V[bc]	V[c]	-	-	-
(roadside) DRIPs/GRIPs	-[d]	-[d]	V[a]	-[g]	-[g]
Mobile DRIPs	V[ab]	V[a]	-[d]	-	V[e]

Traffic lights	V[c]	V[c]	-	V	V

[a] only primary function
[b] only roadworks
[c] with easy additional functions/datasources
[d] only secondary function
[e] no physical protection
[f] in case not everyone is warned/informed
[g] for primary function

Figure 3.2 Conclusions and remarks on replacement of legacy systems by bundles with cooperative systems