DISTRIBUTED TRAFFIC MANAGEMENT ENABLES LOWER INFRASTRUCTURE COSTS AND HIGHER SOCIETAL BENEFITS

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Abstract

Currently road authorities measure network performance and use public signing to influence drivers. This approach is not sustainable due to lack of effectiveness and high costs. With market parties being able to offer more and better data at lower cost, and with in-car systems taking over the role of communication to the driver, there is a big opportunity for road authorities to make traffic management (TM) drastically more efficient and effective. The emerging vehicle automation and communication technologies will change the traditional set-up of infrastructure-based data measurement and public signage towards an increasing in-car system based system, leading to a so-called in-car centric “distributed traffic management” (DTM) approach. In such a system, a new opportunity for in-car devices and services will emerge, supported by wireless communication technologies.

In this paper, we will shortly elaborate on the minimum set of components needed for an effective in-car centric DTM system. Subsequently, we will show that massive introduction of a DTM system is very effective for improving the societal goals of efficiency, safety and environment. We will describe the societal benefits during the transition phase and the potentially avoided TM costs, saving governmental budgets.

Conclusion is that in-car centric DTM is already feasible on short term and has a ROI of 2 to 3 years. But knowing that it is very likely that consumers will in due course take most of the cost, the Return of Investment for a government initiating, supporting or financially stimulating the use of CMD will be much lower.

1 Introduction

Traffic management (TM) is on the verge of a paradigm shift. Real-time TM uses real-time information to make decisions on how to influence the traffic flow with the aim to achieve efficiency, safety and environmental objectives. Traditionally TM employs infrastructure-based sensor information (e.g. via inductive loops) and actuators (e.g. via Variable Message Signs, VMS).

The emerging vehicle automation and communication technologies change the traditional set-up of infrastructure-based sensor information and actuator devices towards an increasing in-car system involvement, where vehicles may act as mobile sensors and traffic actuation may be executed by in-car systems, leading to in-car systems taking over the basis of TM.

There are two main reason for this shift: The high cost of the infrastructure based sensors and actuators, and the decreasing follow-up ratio for public signage as more and more people are informed already via their in-car system.

1.1 In-Car Centric Distributed Traffic Management

Knowing that these upcoming technology innovations are being deployed in future, we need a new wave of TM approaches taking into account and exploiting these new opportunities so that the societal objectives of efficient, safe and pollutant friendly driving is effectively supported. We call this in-car centric Distributed Traffic Management (DTM) as it continues to embrace more elements than just the car and it puts the car centric in the system as sensor and actuator, combined with central back-office functionality and roadside equipment on hotspots.

Knowing this, DTM moves more and more towards a cooperative and decomposed system with potentially much more self-organizing and self-adapting aspects, based on well-informed individuals (Weijer, Rutten, 2012, 2013). This upcoming shift from traditional roadside equipment enabled TM towards in-car systems enabled TM will evolve step by step, probably across hybrid situations, towards a hierarchical cooperative approach with increasing in-car system involvement. Interesting trend to mention here is that emerging countries, without the heritage of an extensive TM infrastructure, tends to choose directly for the in-car DTM approach; just as they have skipped the fixed landlines to go for mobile telephones directly.

The hierarchical approach is necessary because we probably still need a central level to collect information, to interpret it, to build up the integral network traffic state, define TM measures (all real- time) and distribute it back again to all road users who like to or have to use it (Weijer, Rutten, 2012, 2013) In this way vehicles are still enabled to follow automatically any TM decisions that are compulsory for more efficient traffic flow, e.g. in case of emergency situations

1.2 Cooperative Mobility Device

Compared to nowadays system, the big difference is that detectors and actuators are mainly in-car in future, with some help/assistance of roadside equipment. As more and more computer power is introduced into the car, there are arising opportunities for moving central processed data towards local in-car processed data. The main carrier for data and information transfer are the existing 3G cellular networks, in near future 4G, supported with wireless communication technologies in an enhanced cooperation by cellular WLAN based Car2Infrastructure technology and WLAN based Car2Car technology.

TM will more and more be a system of well-informed individuals, acting within widely but strictly defined societal borders. A challenge in this system is to balance public and private interests in how to get optimal traffic flows both from a societal point of view and an individual driver point of view.

This in-car centric DTM approach starts from an individual perspective using an in-car cooperative mobility device (CMD). This can be done respecting societal restrictions and measures that are fully supported in this CMD approach. With this individual approach a high follow-up ratio is reached (Weijer, Rutten, 2012, 2013). This is quite another approach compared to the current way of working, where drivers get advised by Variable Message Signs (VMS), radio bulletins and navigation devices with traffic information, which give many times non consistent and conflicting information as they originate from different sources and service providers, resulting in a low follow-up ratio by the driver.

1.3 Societal Benefits

The question is how the societal benefits of such a system of in-car centric DTM compares to the traditional TM approach.

Road authorities feel that there is a lot to gain but there are hardly any figures available for them on an aggregated level to support decisions to embrace this new in-car centric approach towards the societal goals of more efficient, safe and environmental friendly driving.

Eindhoven University of Technology (TU/e) has combined its strengths in the different disciplines that are needed in Distributed Traffic Management to determine the societal benefits of DTM. These are amongst others ICT research, car tot car communication, traffic prediction, vehicle dynamics, HMI research, behaviour analysis, Transport & Logistics, wireless radio communication, (cyber) security.

In-car centric DTM combines wishes from (local) authorities for managing traffic flows in such a way that negative impact of traffic is minimized, with private and consumer interests of driving smoothly through the network with as less as possible delays. In the Dutch Integrated Test site for Cooperative Mobility (DITCM), public and private parties together with academia and knowledge institutes are developing and testing amongst other topics the DTM concept. The Dutch Minister of Transport has announced a policy change to the Parliament to start with a transition program on travel information and traffic management using these new technology capabilities and making use of DITCM (Schultz, 2013).

One example is dynamic speed advice by displaying variable speed limits no longer on VMS, but on the in-car system; this can be enhanced towards dynamic speed adaptation, possibly coupled to a haptic gas pedal. Another example is getting the measures on road sign equipment like green waves for traffic lights, fully deployed into the in-car (traffic navigation) system, which needs communication links to back offices, road side equipment and car to car.

1.4 Paper Contents

In this paper we shortly elaborate on the minimum set of components needed for an effective in-car centric DTM system. Subsequently, we show that massive introduction of such a CMD containing system is very beneficial for improving the societal goals of efficiency, safety and environment. We describe the transition phase and the potentially avoided TM costs, saving governmental budgets.

2 Components Of An In-Car Centric Distributed Traffic Management System

Basically two types of automotive automation systems can be distinguished, systems for controlling the driving of the vehicle, so called Advanced Driver Assistance Systems (ADAS) and informative systems for advising the driver like car navigation, where the driver reacts on information he receives via an HMI. We focus in this paper on informative systems for advising the driver on traffic and road conditions.

In this paragraph we describe the basic functions of the in-car system, which in a next step can be extended by adding more functionality. The system contains an on-board computer (the CMD) with some pre-installed Apps and services, which have individual benefits for the user and at a certain penetration ratio as a result results in societal benefits (Broek, 2013). This system concept allows adding more Apps in a next step. These Apps are simply downloadable by the user. For a general overview of the system, see Fig. 1, explained in more detail below.

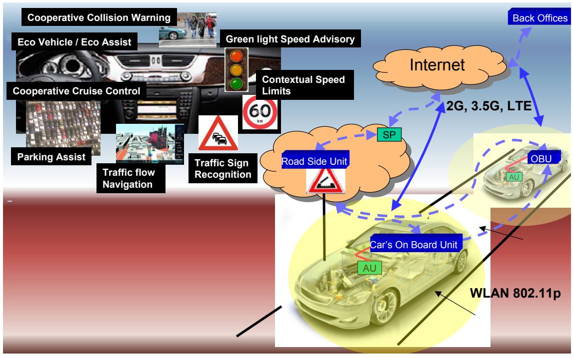

Figure 1. System concept of in-car centric traffic management (SPITS, 2009)]

The central component of the in-car centric DTM system is the CMD (Verbeek, 2013), an in-car computer, connected via the Internet by 3G/4G wireless communication capabilities to a central back-office (BO), and if needed supported by an IEEE 802.11p standard WIFI communication module (WIFI-p) for direct communication between cars (car to car, C2C) and between car and infrastructure (car to infrastructure, C2I). For location positioning it has a GPS sensor and uses if possible other sensors from the car.

This CMD has the following base functionality: it has a navigation App using an on-board map, it has an App for real time traffic information on primary and secondary road network and it has a user interface for visual and auditory speed advice integrated in the HMI for navigation and traffic information.

This in-car computer connects to a central BO (Venrooy, 2013), where the traffic state of the complete road network is available. This central BO is acting as a fully automated DTM centre, and is regionally distributed or has at least the function that regionally collecting and receiving regional data can calculate traffic measures. The software stack for the DTM centre will be deployed in the cloud on a regional base. The regional DTM software has functionality to exchange data between different regional DTM centres. The regional DTM software can be deployed in one physical data centre or in a distributed data centre. With modern cloud computing technology the hosting location is not restricted to any physical location.

The data needed for calculating the traffic state of the complete road network is collected from different sources, mainly measured by the cars themselves, so-called Floating Car Data (FCD) and fused with other available sources, like road side loop detector and camera data. Also extended Floating Car Data from e.g. the CAN bus can bring a wealth of information to be processed locally or centrally and (real time) disseminated to other car users.

The data needed for the actual speed limit is map based, and is fused with real time data, collected by the car from roadside units or made available via the 3G/4G connected cars. The roadside units can also carry speed limit information set by the local road authority. A local computer program, hosted by the local road authority as part of the management software for the roadside units, maintains this speed limit information.

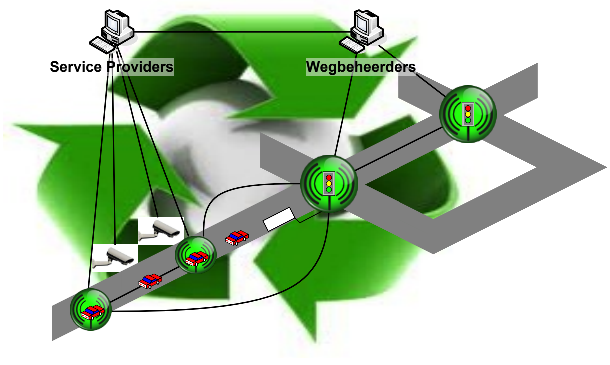

Figure 2. Green wave system with traffic lights connected to CMD via back-office and hybrid wireless connection by 3G/4G and WIFI-p

The speed limit information of the roadside units is applied on hotspots; these are locations with a high need for informing the driver on the speed limit. This can be on motorways on frequently congested road stretches with high dynamic traffic flow like shock waves. This can be also on regional and urban road networks at traffic light controlled junctions. In the latter case, the speed information for a managed set of traffic lights across a set of junctions can be applied as green wave speed information. In this case, the dynamic green wave speed limit is communicated by WIFI-p to the CMD by the local roadside unit or by the 3G/4G connection. In the latter case the BO software of the traffic light control centre is connected with the DTM centre of the service provider, which is connecting to the CMD via 3G/4G. Also hybrid wireless connections are possible, see Fig. 2.

The functionality and hardware of the components as described are partly commercially available off the shelf, like HD Traffic (Cohn, 2009) and navigation by TomTom, and are partly showed successfully as proof of concept in European projects like (FREILOT, 2012), or national projects like (SPITS, 2009). It is all proven technology, but massive rollout is dependent on cooperation between public and private parties, which can stimulate massive adaptation of this technology.

3 CMD Apps Resulting In Societal Benefits

Before we will elaborate the societal benefits gained by massive introduction of an in-car centric DTM system, consisting of millions of cloud connected CMD's, we will describe the pre-installed five Apps: navigable map, turn-by-turn navigation, full coverage real-time traffic information, speed advice and green wave assistant. We call this the base CMD scenario. On top of the base scenario we can extend the functionality with a handful other driver information & advisory Apps, we call this the extended CMD scenario. This scenario is extended with Apps like in vehicle signage, park assistant, intersection assistant, TM measures like blocked lane & road works and driver coaching.

3.1 Description of (Service) Apps in the base CMD scenario

Navigable Map. The navigable map models the complete road network and contains for every road stretch the measured average speed per time window.

The state-of-the-art technology comes from TomTom, called IQ Routes (Rutten, 2008). It also contains information on the network topology (allowed directions on junctions), and has information on most wished for destinations like parking lots, railway stations and other useful landmarks.

Navigation App. The navigation App advises the driver to find his route through the road network. The turn-by-turn navigation App gives instructions to turn left or right on junctions, based on the calculated route towards the destination. In case of dynamic changing network state (like with real time traffic information), the route planner is recalculating the route and in case a faster route is found, it will advise the driver.

Traffic Information Service App. The state-of-the-art traffic information App can be HD Traffic from TomTom. This service is a Pan-European real time traffic service that informs the driver at any moment on the actual traffic situation on its route (Cohn, 2009). The route planner calculates on a continuous base the fastest route at any moment. The driver is requested to confirm for an alternative when it is presented by the system (Rutten, 2007)

Speed Advice App. For the speed advice App we are largely conforming to the description of the SpeedAlert functionality in the exhaustive EU eIMPACT study (Malone, 2008). It is a map and camera based system warning for speed limits. The system informs about static, temporary and variable speed limits. The driver remains responsible for maintaining a safe and proper speed. An HMI informs the driver of the present speed and numeric speed limit, with additional color codes (green = below speed limit, red = above). If the speed limit is exceeded by a certain margin for a prolonged time (in the order of seconds), the driver is warned by an audio signal. The driver may switch off the system. A haptic gas paddle is optionally included (Malone, 2008).

Green Wave App. The green wave App makes happen that the measures on road sign equipment like green waves for traffic lights are fully deployed into the in-car (traffic navigation) system, connected to a BO. An HMI informs the driver of the minimum and maximum advised speed and the present speed. If the speed advise is exceeded by a certain margin for a prolonged time (in the order of seconds), the driver is warned by an audio signal, so that the driver can adapt the speed. The driver can switch off the system.

4 Impacted Traffic Effects By Base CMD System

The societal benefits of an in-car centric DTM system can be distinguished at 3 different topics: better safety, less congestion and less environmental load.

Many studies have been executed on each of these three topics, but the results are quite fragmented and not coupled to a scenario of massive introduction of a base version of a cloud connected CMD used in an in-car centric DTM approach. There are hardly any figures available on an aggregated level.

In the next paragraphs we are extracting relevant information from literature what the societal impact is in terms of societal benefits: less injuries, fatalities and material damage by accidents, less travel time loss and less polluting emissions. Before we present the societal impacts, we summarize the total societal costs of traffic, where we take the Netherlands as example country.

We apply the societal benefits of the CMD system by reducing these societal costs. By monetizing in this way the societal benefits we can compare these with the total investments of a CMD based in-car centric DTM system.

We use the CMD base scenario with navigable map, turn-by-turn navigation, traffic information, speed advice and green wave (service) Apps. More tentative we shortly elaborate on extra benefits and costs of the extended CMD scenario.

4.1 Societal Costs by Traffic in The Netherlands

The Dutch Ministry of Infrastructure and the Environment has studied and published the societal costs by traffic. The latest comprehensive study is showing that in 2009 the yearly societal costs were in total 15.2 to 25.7 billion Euro (Jorritsma, 2009). In this study the congestion costs from 2.8 to 3.6 billion Euro per year have been limited to the motorway network. These costs are monetized from measured time delays and resulting loss of production hours and longer trips caused by rerouting. Also extra fuel costs are included.

For the secondary road network different figures have been reported in different surveys, ranging from doubling to tripling the costs for congestion compared to congestion costs for the motorway network. Tripling of costs is reported in a study by the province of Noord-Brabant on their provincial network (Jacquet, 2006). Doubling of costs is reported in studies on heavily congested corridors, e.g. Schiphol-Amsterdam-Almere (Post, 2005), and in national studies by Central Planning Bureau (Verrips, 2004) and the Ministry of Infrastructure and the Environment (Draijer, 2008). As there is more evidence on doubling the costs, we take this figure.

Table 1. Societal Costs by Traffic in The Netherlands in 2009 in Billion Euro (Jorritsma, 2009). Congestion Costs have been doubled compared to Numbers in (Jorritsma, 2009), due to Congestion Costs on Secondary Road Network (Jacquet, 2006)(Post, 2005)(Verrips, 2004)(Draijer, 2008). Safety Costs Split by Number of Injuries and Fatalities and Corresponding Safety Costs in 2009

Societal costs by	Lower range	Upper range
Safety	10.4	13.6
Congestion	5.6	7.2
Environment	2.0	8.5
Total	18.0	29.3

Safety costs by	Number of people	Lower Range Billion Euro	Upper Range Billion Euro
Fatalities	720	1.7	2.2
Injuries	21,000	4.9	6.5
Material damage	na	3.8	4.9
Total	na	10.4	13.6

We have summarized the results in Table 1. Societal costs in 2009 range from 18.0 to 29.3 billion Euro per year; that is 3.1% to 5.1% of Dutch GDP. The range is caused by some uncertainties in the way the effects have been monetized. This uncertainty range has different reasons. For safety the uncertainty is due to the used method for monetizing the loss of lives and injuries. The uncertainty resulting from this so-called Value Of Statistical Life method reflects the scientific discussion of the different ways the social costs can be monetized (SWOV, 2011). For congestion costs this is due to indirect costs, which are caused by other behavior of travellers like more usage of public transport, causing need for expensive public transport capacity during rush hour (Jorritsma, 2009). For environmental costs the uncertainty range is quite large. The main drivers for emissions are cars, busses, vans and lorries. Cars and buses contribute for 85% to the pollution costs in road person transport, vans and trucks contribute for 90% in road freight transport; societal costs are in terms of CO2, NOx and particles. The uncertainties are partly caused by differentiation in the total vehicle fleet of emission factors per fuel type and motor type (EURO class) (Jorritsma, 2009). The negative effects from pollution show also bandwidth, as some of the effects are long-term and/or hard to estimate, and consequently the many studies do show quite different figures.

4.2 Safety Costs Benefits

In the Netherlands the safety costs can be calculated by combining the results of two studies (Jorritsma, 2009)(SWOV, 2011), reporting the absolute numbers of fatalities and injuries (SWOV, 2011) and using a range in the safety costs (Jorritsma, 2009). This results in an uncertainty in the calculated societal costs and a breakdown per safety cost item as discussed above; results are summarized in Table 1.

In the exhaustive EU eIMPACT study (Malone, 2008) the effects of many stand-alone and cooperative intelligent vehicle safety systems have been studied. The effects of the speed advice App of our base CMD scenario can be extracted from this eIMPACT study. The effects can be distinguished between reduction in accidents, causing fewer fatalities, fewer injuries and less material damage. In the eIMPACT study the effects have been estimated for penetration rates of 26.3% and 39.8%. For reasons of uniform presentation across the different benefits, we are using in this paper the rounded figures of 25% and 40%. The eIMPACT study has calculated the reduction percentage of accidents, fatalities and injuries. We have applied these reduction percentages on the Dutch situation of known number of accidents, fatalities and accidents as well as the total number of societal costs and have monetized the effects. The results are summarized in Table 2. The uncertainty in cost savings is due to the uncertainty in the method of monetizing the safety effects.

Table 2. Safety Cost Benefits for The Netherlands at CMD Penetration Rates of 25% and 40%. Benefits in Reduction Percentage compared to Safety Costs; in Saved Number of People; in Safety Cost Savings

	Reduction % at two CMD penetration rates		Reduced casualties in NL at two CMD penetration rates		Cost savings in million Euro in NL for lower and upper uncertainty range	
Safety costs by	25%	40%	25%	40%	Lower Range	Upper Range
Fatalities	3.6%	5.2%	23	33	60.3	113.9
Injuries	2.8%	4.0%	565	800	138.2	258.2
Accidents	2.3%	3.3%	na	na	87.7	162.3
Total	na	na	na	na	286.2	534.3

4.3 Congestion Costs Benefits

As reported in Table 1 the congestion costs in the Netherlands are ranging from 5.6 to 7.2 billion Euro per year on the motorway and secondary road network. The total number of lost hours due to congestion is 61.6 million hours, twice the number as reported in (Jorritsma, 2009).

Informed dynamic navigation may give quite a reduction in congestion costs, by using a navigation device with a real time traffic information App. In this way, the car driver has always the actual status of travel time delays on the road stretches of his journey and on the road stretches, which might give an alternative less congested route.

Several studies were conducted on the effects of using such a service. The overall conclusion from these studies is that the overall time delays decrease and journey travel times improve up to a certain penetration level of equipped vehicles. Simulation studies show (Matschke, 2007) that up to 20% travel time gains may happen in normal traffic circumstances with 35% penetration rate. Even 40% travel time may be gained in heavy congested situations (Matschke, 2007). On behalf of the Dutch Ministry of Transport and the Environment a study was conducted (Schaaf, 2005), which showed that up to 40% penetration rate the average travel time improved with 11% for equipped drivers and 7.5% for non equipped drivers.

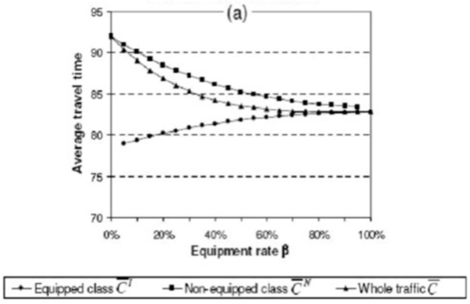

Figure 3. Average travel time versus equipment (=penetration) rate of CMD equipped vehicles (Leurent, 2010). Travel times for equipped cars, non-equipped cars and whole fleet

The latter was confirmed in a network study (Leurent, 2010), Fig.3 shows the main effect, which was reported also in the other studies. This effect is that both the equipped drivers and the non-equipped drivers benefit from massive usage of dynamic navigation. The effect is less with higher penetration rates. The lower line in Fig.3 shows the travel time gain for the equipped drivers; at lower penetration rates these drivers gain a lot. The upper line shows the travel time for the non-equipped drivers, who gain also some travel time at lower penetration rates. At high penetration rates the two lines converge to the same optimum.

In line with the reported figures for safety benefits at 25% and 40% penetration rates, we deduct from Fig.3 the overall travel time benefit for the overall network behavior. This is 6.5% to 8.7% travel time gain on a network level at the 25% and 40% CMD penetration rates. Applying these percentages on the reported congestion costs in Table 1, we calculate the overall congestion cost benefits as shown in Table 3.

Table 3. Congestion Cost Savings for Uncertainty Range and Two CMD Penetration Rates

Calculation of congestion cost savings	Cost savings in million Euro for lower and upper uncertainty range	
Congestion costs by uncertainty range in Billion Euro	5.6	7.2
CMD penetration rate	25%	40%
Congestion cost reduction %	6.5%	8.7%
Reduction congestion cost savings in Million Euro	365.2	626.0

4.4 Environmental Costs Benefits

An extensive study was executed for the European commission on the environmental impact by information and communication technologies (Klunder, 2009). The study focused on CO2 emissions and the way of reported figures is comparable with the eIMPACT study (Malone, 2008): a reduction percentage on the environmental societal costs. Over 50 systems have been assessed; a multi-criteria analysis yielded 15 selected systems for extended analysis in the study (Klunder, 2009). Some of these 15 systems are applicable for implementation in a cloud connected CMD in-car centric DTM approach. These are: (Dynamic) Traffic signalling optimization, Fuel-efficient route choice and Eco-driver Coaching (Klunder, 2009). These measures comply largely with the description of the following Apps: the Green Wave App complies with the (Dynamic) Traffic signalling optimization, and a combination of three Apps (Navigable Map, Navigation App, Traffic Information Service App) complies with the Fuel-efficient route choice. The Eco-driver Coaching measure is supported partly as it takes into account speed advice. From the report it can be concluded that 5% of the reported 15% emission reduction can be assigned to the speed advice. All reported figures are assumed with 100% penetration rates; we have scaled down proportionally with corresponding CMD penetration rates.

In Table 4 we have summarized the emission reduction effects and have these monetized.

Table 4. Environmental Costs Savings at Different CMD Penetration Levels; Costs Benefits by Reduction Percentage and in Million Euro compared to Environmental Costs; the Netherlands; deducted from (Klunder, 2009)

	Reduction % at three CMD penetration rates			Cost savings in million Euro for lower and upper range of uncertainty	
CMD penetration rate	25%	40%	100%	25%	40%
Eco driver coaching, map supported	1.3%	2.0%	5.0%	19.4	117.0
Fuel efficient route choice	0.9%	1.4%	3.6%	13.4	81.9
Green wave at traffic lights	0.5%	0.8%	2.0%	7.5	46.8
Total	2.7%	4.2%	10.6%	40.2	245.7

4.5 Societal benefits summarized

In Table 5 we have summarized the results for the base CMD scenario consisting of navigable map, turn-by-turn navigation, traffic information, speed advice and green wave (service) Apps. The total societal cost savings turn out to be between 0.7 and 1.4 billion Euro per year, dependent on CMD penetration rate (25% to 40%) and uncertainty in societal costs level (10.4 to 13.6 billion Euro). These societal cost savings are 6.7% tot 10.3% of the total societal costs.

Table 5. Summary of Cost Savings per Cost Item by applying CMD at Different Penetration Rates and for Lower and Upper Uncertainty Range of Societal Costs

	Cost savings in million Euro for lower and upper uncertainty range and two CMD penetration rates			
TOTAL societal costs NL (Billion Euro)	10.4	13.6	10.4	13.6
CMD penetration rate	25.0%	25.0%	40.0%	40.0%
Safety	286.2	374.2	408.6	534.3
Congestion	365.2	477.6	478.8	626.1
Environment	40.2	52.6	187.9	245.7
TOTAL avoided societal costs (Million Euro)	691.6	904.4	1075.3	1406.1
Percentage of TOTAL societal costs	6.7%	6.7%	10.3%	10.3%

5 Impacted Traffic Effects by Extended CMD System

On top of the base Apps a handful of the following Apps can be relatively easily added to the system: vehicle signage, park assistant, intersection assistant, TM measures like blocked lane & road works and driver coaching. Conceptually it is like the big IT-players do already with their AppStore and AndroidMarket; just add a new App to the store and the user community will download it. In the same way the in-car centric DTM system can be easily enhanced by adding more Apps on the existing base platform; the IT infrastructure with BO and CMD's is there, it is just adding more functionality.

It means that costs for adding new functionality are relatively low, the main costs have been made by setting up the base scenario of the cloud connected CMD enabled in-car centric DTM system. On the other hand the societal benefits will grow further. Especially Apps like vehicle signage or driver coaching (Klunder, 2009) can add further billions of Euros of monetized societal benefits.

6 Migration Scenario Towards Wished For Situation

The societal cost savings are big especially because the involved system costs are relatively quite low. Core members of the industrial consortium who ran the SPITS project (SPITS, 2009) have made a first assessment on involved system costs for an in-car centric DTM system, including the CMD's. The yearly running costs are much lower compared to the yearly saved societal costs. In Fig. 4 it can be seen, that after the investment period from a societal infrastructure investment point of view the return on investment is very short, about 2 to 3 years. At 40% penetration rate the total investments are about 1,5 billion Euro in 3 years time, the societal benefits are increasing towards a level of about 1,4 billion Euro per year, each year again. Even at the penetration rate of 25% and low estimated societal costs, the pay back period is within 4 years.

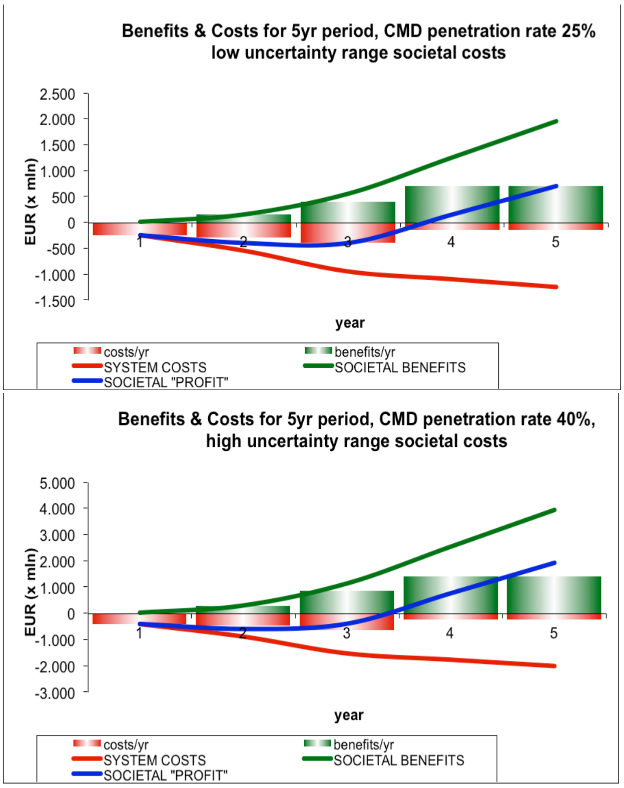

Figure 4. Societal benefits versus system costs for the first 5 years after introduction of the in-car centric DTM system, using CMD's and roadside units and wireless Internet connection

System costs involved for the 25% CMD penetration rate scenario are the investment costs for 2 million CMD's, 5000 roadside units, setting up a central BO with 1000 servers, building software for BO and CMD Applications, support organization, maintenance costs and communication costs.

It is assumed that the build-up period towards the targeted penetration rate will take 3 years, so in the 4th and 5th year the full societal benefits pay off. Investment costs are relatively high in first 3 years, but in 4th and 5th year these are small compared to the benefits.

Fig. 4 is a schematic figure just to show the trade-off between investments and benefits, in reality further evolution will take place during the years following after the first 3 years or even within this first 3 years, by investing in more applications. However this is a scenario where it is assumed that all cost for the device are paid for by the authorities. In real-life it is expected that, because of user benefits, drivers will carry a fair share of the cost themselves. This means that the Return of Investment for a government initiating, supporting or financially stimulating the use of CMD will be much lower.

7 Avoided Traffic Management Costs

Generally speaking, new innovations cause that existing working processes become less relevant and even gradually disappear and become obsolete. When in-car centric DTM is adapted at a large scale, several currently existing and practiced TM working principles are no longer needed. One can think of VMS along the roads for route choice advice, which are fully replaced by personalized information via the HMI of the CMD. But also investments in TM centres must be reviewed. The in-car centric DTM approach results in strong growth of data collection (FCD) produced by the millions of CMD equipped cars, and strong growth of data distribution. This inevitably causes more and more fully automated data processing systems and results in automated set DTM measures instead of human operated TM measures. This saves costs in the central TM centre setup.

The next step at high car penetration rates (over 50%) together with car-to-car communication capabilities and e.g. massive introduction of Adaptive Cruise Control, makes current roadside jam tail signalling systems obsolete, like the motorway traffic management (MTM) system in the Netherlands. Although this will last for some more years than coming 3 to 5 years, at a certain moment these relatively expensive systems are no longer needed anymore, we expect in 10 years from now high in-car system penetration rates between 50% and 100%, knowing the policy change which was taken by the Minister of Transport (Schulz, 2013) and the high investment rates of the automotive industry in in-car systems and partial automation systems.

In 2002 an extensive study was carried out by RWS (Vusse, 2002) on investment and maintenance costs on road-side equipped TM systems. From this study it can be derived that the Dutch government has invested over one billion Euro in road side equipment and signaling systems. The maintenance cost only of these systems adds up to 50 million Euro per year. Most of the functions of these systems will in due course be taken over by in-car systems. Many of the effects of the current system can already be achieved with limited penetration of in-car systems, making road-side equipment obsolete even earlier. In both Germany and the Netherlands (Schultz, 2013) is already been stated that the network of infrastructure based signaling will not be expanded and that it will be largely retrenched. With people fully informed in the future, road-side equipment can limit its activities to communicate legally binding traffic messages.

8 Win For All: Consumers, Society And Industry

We have shown that from a societal perspective the benefits of an in-car centric DTM approach are big. Even when the government invests in all system costs, the perspective is that the societal benefits are so large, that governments make a big societal “profit” when adapting this approach.

But we think the future roadmap must be that the (investments for) system costs must be taken partly by government (society), partly by the consumers themselves, partly by insurance companies and enterprises. As the CMD functionality aims to assist, help and advice the individual driver, the IT- and Service Provision industry will be eager to seduce the consumer to buy a CMD and to subscribe for the services running on it.

We have investigated the societal benefits breakdown per market segment by exploring where costs are made, as reported in (Jorritsma, 2009)(SWOV, 2011). In Fig. 5 we have drawn the results, on the left-hand side the societal benefits by the DTM system at 40% penetration rate, at the top the breakdown amongst user, insurance, enterprise and society, detailed per benefit type environment, congestion and safety. It can be clearly seen, that driver and society have the largest share in benefits (25% to 30%), but also insurance companies and enterprises have quite a big share (15% to 20%).

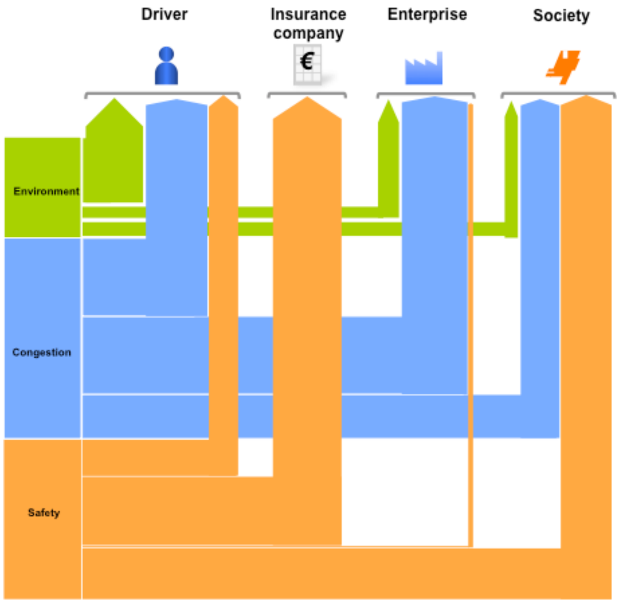

Figure 5. Breakdown towards market segments (consumer; insurance; enterprise; society) of the yearly societal benefits of the in-car centric DTM system; at 40% penetration rate of CMD's and upper uncertainty rate of societal costs.

But there are initial investments needed and cooperation with road operators is also needed to be able to make a success of some of the applications like amongst others the Green Wave App, the Speed Advice App, the In-Vehicle Signage App and Intersection Assistant App.

In other words, public-private partnerships are needed to make happen that common infrastructure like roadside units are rolled out and that the initial investments on Apps and BO software take place. R&D is needed on the HMI for information integration, safe driving and user comfort, on open source software stack for the CMD and BO, on open data exchange standards, on traffic modelling research, primarily based upon real measured FCD, on standards and protocols for interfaces between system components, on certification and evaluation standards and on testing methods on component and system level. Development and testing activities must be executed also in a public private environment like (DITCM, 2013).

However, the largest portion of the investments is the millions of CMD's, which should be paid by the consumers themselves and not by the government. Nonetheless to say that rollout can be boosted by financial governmental incentives to the users and by incentives by insurance companies. The latter could even be leading as insurance companies have costs benefit by customers who are using a CMD system.

9 Discussion

We have shown that an in-car centric DTM approach is revolutionizing the current way of TM. But moreover it brings us large societal benefits. The cloud connected CMD plays a central role in the system. For the Netherlands the estimated societal costs benefits are estimated at 1,4 billion Euro per year at a CMD penetration rate of 40%, meaning 10,3% societal cost savings, at an investment level for the DTM system of about 1,5 billion Euro. In other words, an investment level of only 0,26% of GDP will result every year to societal cost savings of 0,24% of GDP.

The investment costs of traditional road-side equipped TM system with an estimated operational cost level of 400 million Euro per year, can be largely avoided, exact cost saving levels need to be determined in future research as function of in-car systems penetration rates and functionalities offered by the OEM and service industry. These huge potential cost savings for the Dutch road authorities could on their own already be a main driver for choosing of large investments in a car-centric DTM system. On top of these operational cost savings drivers, from a societal perspective the introduction of in-car centric DTM has a societal return on investment of 2 to 3 years.

But knowing that the added value for consumers is high, the main investment will be done by consumers, possibly financially stimulated by the authorities to speed up implementation.

Doing so, a self-fuelled system is introduced that can take traffic management very quickly to a better future. We are convinced that TM is on the verge of a paradigm shift towards in-car centric DTM, which is already feasible on short term.

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