ITS4C Congress
Smart Mobility for Climate
17 - 19 September 2019

Decarbonisation Toolbox
WORKSHOP 3

3 Improving network mode and system efficiency

The ITS for Climate initiative (ITS4C) was established in 2015 during the ITS world Congress held in Bordeaux, under the leadership of the Nouvelle-Aquitaine Region in France to highlight the potential contribution to the reduction of CO_2 emissions of Intelligent Transportation Systems (ITS) and smart mobility innovations. In 2019, 32 Climate and Mobility experts set out to provide a "Decarbonization Toolbox» for cities, regions, national governments as well as for the ITS community and all stakeholders in the transport & mobility sector. This work was presented during the ITS4Climate Congress in Bordeaux.

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Introduction

This ITS4C Topic 3 Briefing Paper looks at the ways ITS and smart mobility can reduce emissions, with a focus on management of traffic, transport infrastructure and public transport.

An increasing demand for transport in urban areas has resulted in chronic congestion, with many adverse consequences such as delays and pollution. In urban areas, traffic is responsible for 40% of CO_2 emissions and 70% of emissions of other pollutants[1]. Many studies have been dedicated to understanding the factors causing excessive fuel consumption and vehicle emissions in road transport. These studies systematically show that about 25% is caused by inefficient deceleration and/or a lack of anticipation. In addition, congestion is responsible for another 15%, whereas excessive speed, inefficient traffic light control and construction sites and/or traffic accidents each account for approximately 10%.

This paper discusses the emission-saving potential of smoother traffic flow, less congestion, better vehicle-infrastructure cooperation and more efficient fleet management. Intelligent Transportation Systems (ITS) for smart mobility, traffic management and traffic control in urban areas is the main interest of this topic. The first sections of this paper will summarize some main principles of fuel consumption and emissions in traffic, to better understand causalities from travel demand to emission volumes and concentrations. The sections thereafter will describe the emission-saving potential of various ITS solutions.

Introduction

Energy consumers and emission generators

Figure 1 summarizes how energy consumption and emissions occur in traffic. The basic principles are relatively simple: fewer vehicle kilometres and cleaner vehicles lead to less fuel consumption and lower emissions. This means that interventions at root causes such as the vehicle engine technology, and travel demand will have the most direct and on the longer term largest impact on environmental targets. Once traffic is generated, interventions aiming at increasing traffic system efficiency through fewer vehicle kilometres travelled, facilitating modal shift to more sustainable modes of transport and optimizing traffic flow (i.e. less congestion and reduced speed and speed variation) have the largest emission-saving potential.

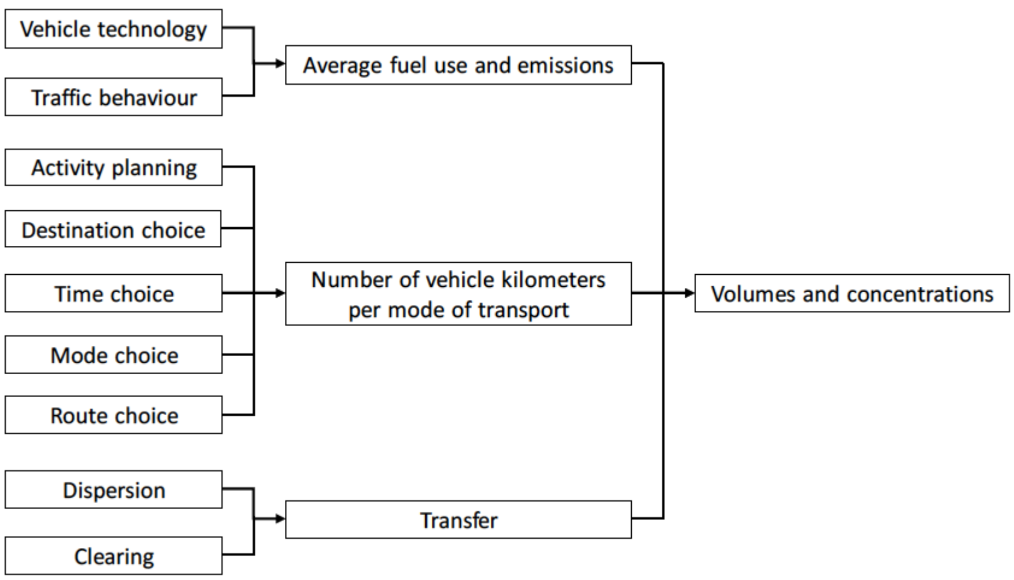

Figure 1 - energy consumers & emission generators

Mobility-related causal relations

Figure 2 shows the causal relation of mobility and traffic related aspects on spatial and temporal scales. It illustrates how short and long term choices, measures and policies generate demand for mobility, thereby vehicle kilometres and traffic characteristics, and thus energy use and emissions. Reversely, policies that e.g. give priority to active modes may, on the longer term, have a considerable (perhaps even large) impact due to second or even third order effects. Traffic management and traffic control typically aim for short term, first order effects, by targeting traffic flow (dynamics), traffic volume and vehicle kilometres.

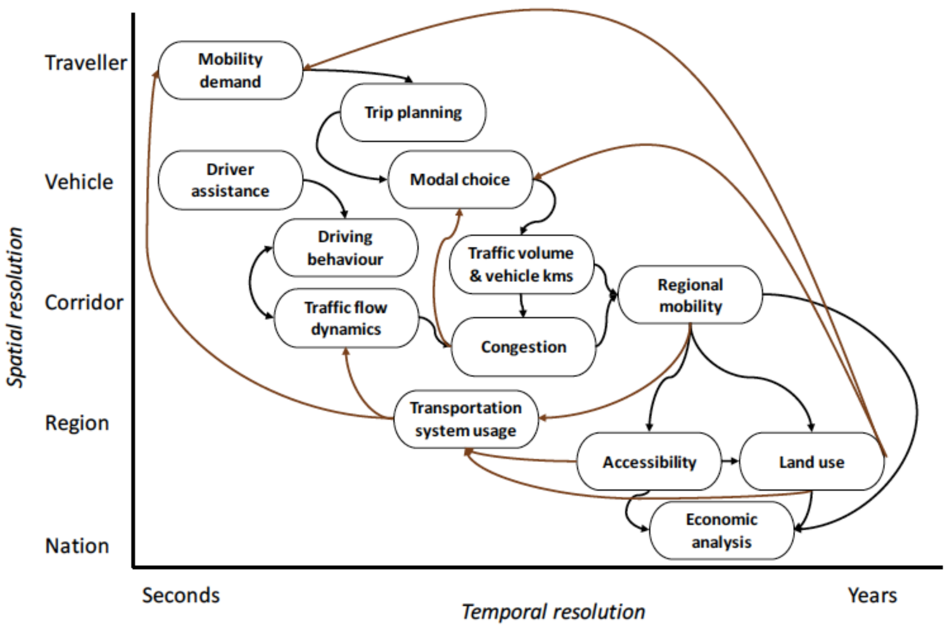

Figure 2 - causal relation of mobility and traffic related aspects

A more holistic approach for an overall sustainable transport system design may entail three pillars, to serve as a way to structure policy measures to reduce the environment impact of transport and thereby improve the quality of life in cities[4] :

• **Avoid/reduce** – referring to reducing the need for motorised travel, and reducing average trip length, through spatial planning.

• **Shift/maintain** – referring to improving individual trip frequency through a modal shift to more active transport (cycling and walking) and public transport.

• **Improve** – referring to vehicle and fuel efficiency as well as the operational efficiency, primarily of public transport. In addition, renewable energy sources must become a basic principle for motorised transport.

[4] - Bongardt, D., Stiller, L., Swart, A. and Wagner, A. (2019). Sustainable Urban Transport: Avoid-ShiftImprove (A-S-I). Deutsches Gesellschaft fur Internationale Zusammenarbeid GmbH.
URL: https://sutp.org/files/contents/documents/resources/L_iNUA/ASI_TUMI_SUTP_iNUA_April%202019.pdf
(accessed: 26 July 2019).

The so-called Avoid-Shift-Improve instruments and agenda is summarised in **Figure 3.**

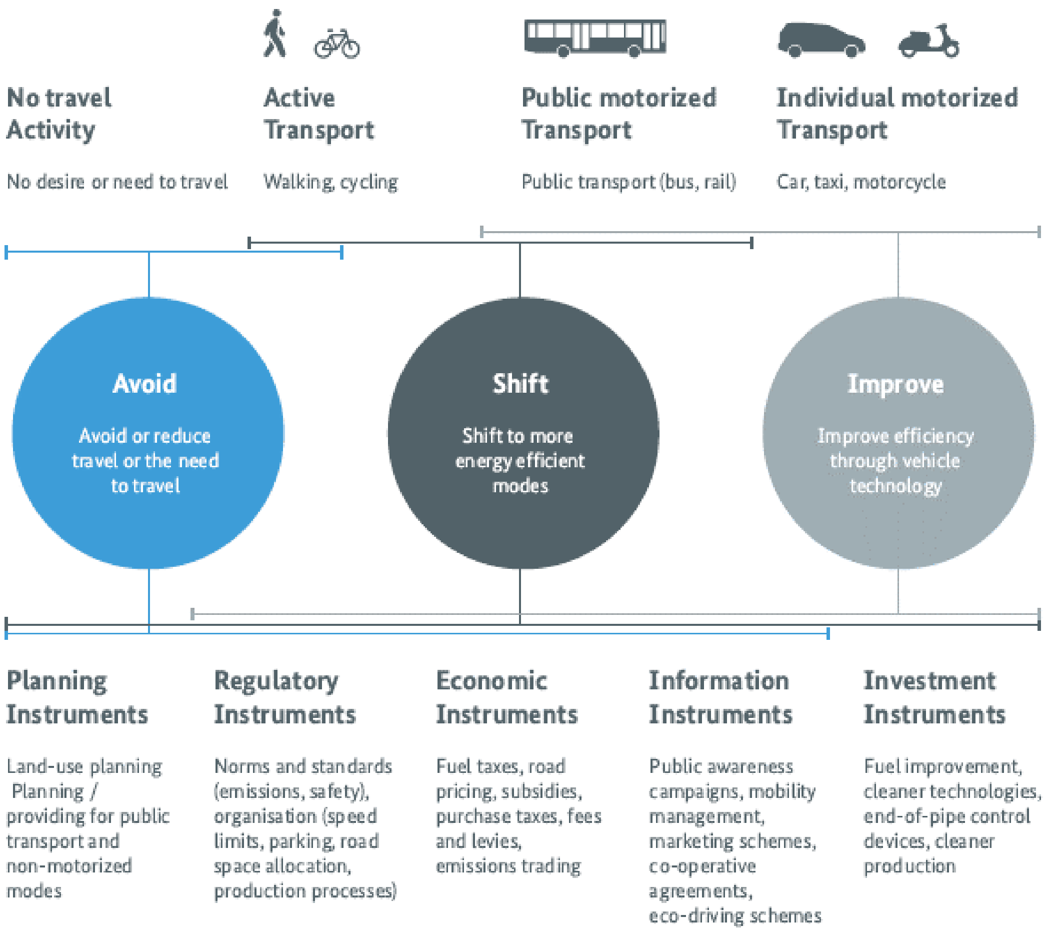

Figure 3 - Avoid-Shift-Improve instruments
Source: Bongardt, D., Stiller, L., Swart, A. and Wagner, A. (2019). Sustainable Urban Transport: Avoid-ShiftImprove (A-S-I). Deutsches Gesellschaft fur Internationale Zusammenarbeid GmbH.

Driving behaviour and emissions

A closer look at driving behaviour and emissions reveals that, as expected, fuel consumption and emissions are highest during acceleration and lowest while idling. **Figure 4** is based on field experiments with measurement of tailpipe emissions[5]. The figure also shows that although acceleration causes a large share of the emissions, its occurrence constitutes only a small portion of the time and distance travelled. The main message from these findings is that of the four driving modes, a reduction of acceleration events and stops in particular, will yield the most significant effect on energy use and emissions.

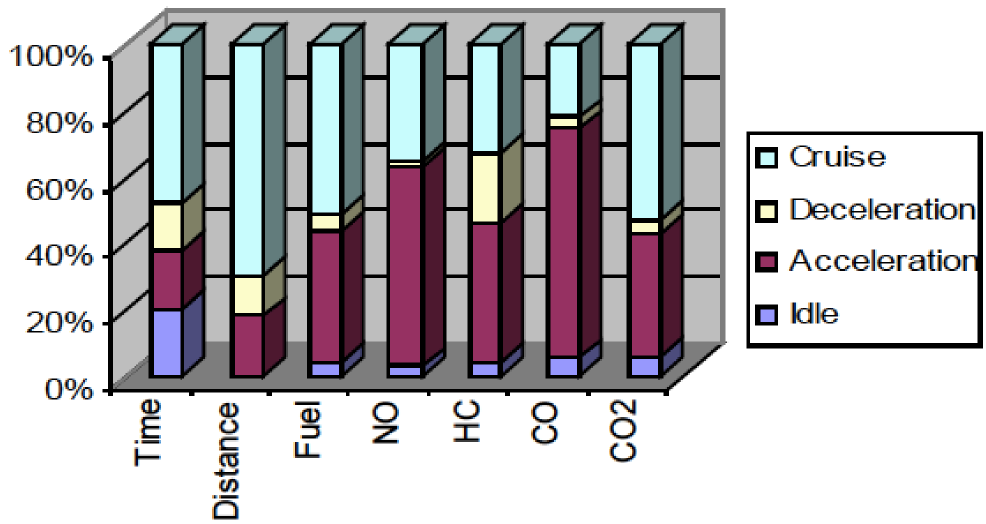

Figure 4 - causal relation of mobility and traffic related aspects
Source: Rouphail, N., Frey, H., Colyar, J., and Unal, A., "Vehicle emissions and traffic measures: exploratory analysis of field observations at signalised arterials," in 80th Annual Meeting of the Transportation Research Board, Washington D.C., 2001.

[5] - Rouphail, N., Frey, H., Colyar, J., and Unal, A., "Vehicle emissions and traffic measures: exploratory analysis of field observations at signalised arterials," in 80th Annual Meeting of the Transportation Research Board, Washington D.C., 2001.

Introduction

Aligning policy objectives to reduce emissions

A challenging task for road authorities and traffic engineers is to balance different policy objectives, including environmental ones. Typically, the three major objectives in traffic operation are to:

- Increase efficiency (i.e. minimize travel times or reduce delays),
- lower environmental impact (i.e. minimize fuel consumption and emissions),
- improve traffic safety (i.e. minimize the number of accidents).

A study on sustainable traffic management measures showed that efficiency and environmental impact are typically aligned, but opposed to traffic safety[6]. If two objectives are aligned it means that solutions exist in which one objective can be met with a neutral or positive impact on the other objective. This is shown in **Figure 5** (left). The finding also implies that there is no combination of measures which results in a situation that is optimal for all three objectives. A helpful lesson from this study is that a change in efficiency has approximately a same-sized effect on environmental targets and vice versa. This means that in the absence of emission data, which is often the case, efficiency indicators can be used as surrogate indicators.

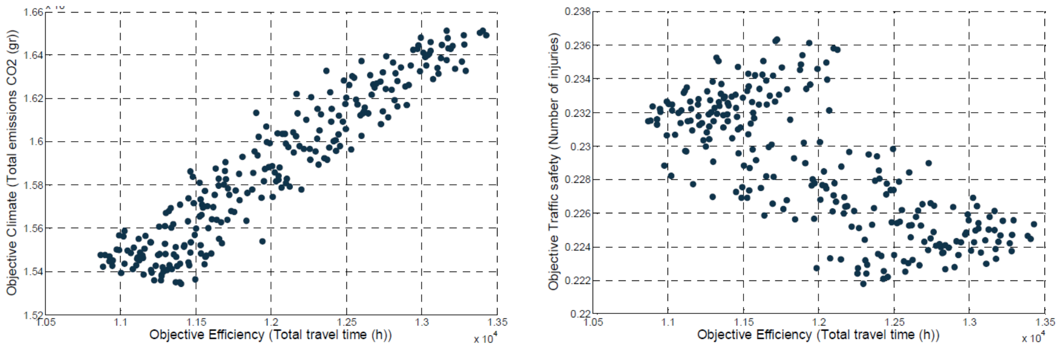

Figure 5 - relation between efficiency and CO_2 emission (left) and efficiency and traffic safety (right)
Source: Wismans, L., "Towards Sustainable Dynamic Traffic Management," Phd-thesis, TRAIL Thesis Series, University of Twente, Enschede, The Netherlands, 2012

Impact assessment

Measuring or modelling

Environmental effects of ITS can be measured, for example emissions, air quality (concentrations of pollutants) and noise levels. Modelling is often easier and cheaper than measuring, as models can provide data for entire road networks (as opposed to just the roads with traffic monitoring), models can provide data for past and future years and models can be used to calculate effects of measures ex-ante. Measurements, however, are often trusted more than models, as nowadays there is much more emission data available, albeit not always as accurately measured but in more natural conditions. Therefore, methods for combining measurements and models have been developed. Today, multiple emission models are available which have been developed using real emission data. Typically, this data is obtained through tailpipe emission measurements from vehicles travelling in the field or vehicles placed on a chassis dynamometer. The resulting emissions database contains data for multiple vehicle and engine types and for various vehicle trajectories and velocity profiles. Microscopic traffic simulation models can then be used to produce traffic data, which the emission model can translate into emission indicators. In addition, propagation and dispersion models allow determination of local noise and air quality indicators, which can be related to health and liveability.

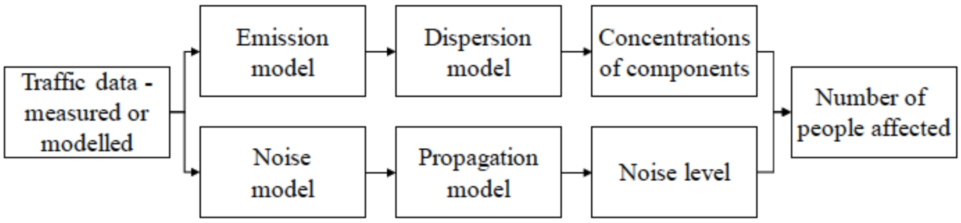

Figure 6 - processs to obtain environmental indicators

Impact assessment

Promising ITS solutions

In 2013, a working group for clean and efficient mobility made an effort to identify the most promising ITS solutions for clean and efficient mobility[7]. They estimated the possible CO_2 reduction on a 3-step scale: 0-5%, 5-10% and +10%. Preferred scenarios were defined by focussing on measures that are ready for implementation or are already (partially) implemented. The recommended measures with the highest potential are shown in **Table 1.**

Table 1 - Recommended measures as identified by the working group 7

Estimated possible CO_2 reduction >10%	**Estimated possible CO_2 reduction 5-10%**
Embedded eco-driving HMI support Traffic light control and signal coordination Cooperative traffic lights (green light optimal speed advisory and green priority) Variable road pricing – distance based Intermodal solutions (synchro modality) Electronic freight exchanges Dynamic trip planning	Intelligent Speed Adaptation (mandatory) Cooperative Adaptive Cruise Control/Automation Smartphone eco-driving HMI support (Eco)-routing / navigation Connected eco-routing (including traffic info) Personalized multi-modal navigation tools Variable road pricing – congestion based Pay-As-You-Drive schemes

Similarly, another assessment of most promising measures looked at the potential CO_2 reduction on the EU level and the ease of implementation of these measures[8]. As can be seen, measures that have a large contribution to CO_2 reduction are not necessarily hard to implement.

[7] - Antonissen T., Dijkstra A., Dreher S., de Haan R., Heiber I., van der Kroon P., Ludeking M., van Muiswinkel K., Pandazis J.-C., Pascotto L., Riederer M., Trommer S., Vreeswijk J., Wilmink I., Johansson H. (2013), Identifying the most promising ITS solutions for clean and efficient mobility, iMobility Working group for Clean and Efficient Mobility (WG4CEM).

[8] - Klunder G., Malone K., Mak J., Wilmink I., Schirokoff A., Sihvola N., Holmen C., Berger A., de Lange R., Roeterdink W., Kosmatopoulos E. (2009). Impact of information and communication technologies on energy efficiency in road transport, TNO report for European Commission.

Table 2 - Ranking of promising measure on potential CO_2 effect

System	Potential CO_2 effect EU	Ease of implementation
Eco-driver coaching	15%	Medium
Eco-driver assistance	10%	Easy
Pay as you drive	7%	Medium
Platooning	6%	Very hard
CC/ACC	3%	Easy
Fuel-efficient route choice	2%	Medium/hard
Dynamic traffic light synchronization	2%	Medium
Automatic engine shutdown	2%	Easy
Trip departure planning (freight)	2%	Medium
Tyre pressure indicator	1%	Easy
Congestion charging	0,5%	Medium
Slot management	0,05%	Hard
Lane keeping	0,008%	Easy
Emergency braking	0,007%	Easy

Aforementioned studies and inventories provide a good first insight of measures with emission-saving potential. Field trials are needed to validate the impact estimates, while compared to already ongoing trials, more effort should be put in collecting emission data. For example, instrumented vehicles can be more often equipped with devices to measure tailpipe emissions. Or speed, acceleration and position data with appropriate frequency and accuracy should be routinely collected to calculate energy use and emissions as explained above.

ITS for traffic management in urban areas

The ITS solutions mentioned in the previous sections are very diverse, covering multiple domains and geographical areas. From here on we focus on ITS for smart mobility, traffic management and traffic control in urban areas. To structure the remainder of this section, measures are categorised as suggested by Ecostand[9], Amitran[10] and Civitas[11] :

1. Navigation, travel and traffic information
2. Traffic management and control
3. Demand and access management
4. Public transport and fleet management
5. Driver assistance
6. Safety and emergency systems

For each ITS category a number of measures will be discussed and their connection with the energy consumers and emission generators as shown in figure 1 will be made.

Navigation, travel and traffic information

Pre-trip and en-route route advice

Findings from a field study with probe vehicles[12], an extensive traffic assignment study using emission models[13] and European-wide desk research[14] indicate an impact of eco-routing functionality of approximately -4% CO_2 emission/fuel consumption. Besides, there are strong indications that at the same time travel time savings of about 10-15% can be achieved.
Noticeably, there is a fuel-saving potential with a conventional navigation system already since study results indicate that the most fuel-efficient route is also the shortest time route in about 80% of cases[12]. This is in line with the earlier notion that efficiency and environmental impact can be aligned. However, vehicle routing may also have negative effects as shown in Rome as part of the HEAVEN project. The HEAVEN evaluation study showed that restrictions on specific roads had a large negative impact on overall emission and fuel consumption. As traffic was redistributed over an already dense network the whole area became congested instead of the one specific road[14]. **The main lesson from this study is not that rerouting cannot have a positive effect (positive effects were for example found for Amsterdam[16]), but that the emission-saving potential also depends on available route alternatives in the network and how close to capacity these roads are operating.**

A study of regional route advice on the motorway network of Rotterdam showed that CO_2 reduction can be achieved on the original route, but emissions increased with the number of vehicles rerouted to the alternative route[16]. Interestingly, a heavier congested original route and a free flowing alternative route together produce less CO_2 emission than the case with both routes equally congested. Similar to the Rome case, local rerouting using the secondary road network showed too negative effects on throughput (and thereby emissions) to even consider activating this measure to reduce emissions.

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[9] - Benz T., Andre M., Boulter P., Castermans J., Driever H., de Kievit M., El Faouzi N.-E., Spence A., Turksma S., Voge T. (2011). Inception report and state-of-the-art review. (European Commission, 2011). Roadmap to a single European transport area – Towards a competitive and resource efficient transport system, White paper, COM(2011)144, Brussels.
[10] - Amitran (2014). D3.1: Methodology for classification of ITS, http://www.amitran.eu/assets/02-March-2015/ AmitranD31Methodology-for-classification-of-ITS.pdf.
[11] - Jonkers, E. and Gorris, T. (2015). Intelligent Transport Systems and traffic management in urban areas. Civitas Policy Note. https://civitas.eu/content/civitas-policy-note-intelligent-transportsystems-and-traffic-management-urban-areas-0
[12] - Ericsson, E., Larsson, H., and Brundell-Freij, K., "Optimizing route choice for lowest fuel consumption - Potential effects of a new driver support tool," Transportation Research Part C: Emerging Technologies, vol. 14, pp. 369-383, 2006.
[13] - Ahn, K. and Rakha, H., "The effects of route choice decisions on vehicle energy consumption and emissions," Transportation Research Part D: Transport and Environment, vol. 13, pp. 151-167, 2008.
[14] - Ludeking, M., Harms, H., Valk, C. and Spanjer, T. (2008). Effect dynamisch verkeersmanagement op de PM10-concentratie in de lucht – onderzoek naar de effecten van zes DVM-maatregelen (in Dutch). Rijkswaterstaat DVS.
[15] - HEAVEN Project, "Healthier Environment through Abatement of Vehicle Emission and Noise - Final Report," Brussels - Belgium2003.

ITS for traffic management in urban areas

Parking guidance and management

The ability to park at a trip destination is a fundamental requirement for using a car, and the price or lack of a parking space can limit car use and encourage use of other modes. Searching for a parking space also accounts for a substantial part of vehicle-km in urban areas. These are promising areas to look for CO_2 emission savings.
Parking guidance systems present dynamic information to drivers about parking in closed parking areas (e.g. with a parking barrier). They are designed to aid in the search for vacant parking spaces by directing drivers to parking garages (e.g. by indicating the number of places available in different garages). The systems combine traffic monitoring, communication, processing and variable message sign technologies to provide the service. The main benefits of this measure are: reduction of kilometres travelled, small reduction in traffic volumes and delay, optimisation of the parking capacity usage, minimisation of the time necessary to locate vacant spaces, and small improvement in air quality locally[11]. State-of-the-art parking guidance systems include smart phone applications, with and without reservation and ticketing options, and combined off-street and on-street systems.

Park and ride facilities

Multi-modal transportation facilities allow car drivers to park their vehicle at designed locations and transfer to public transport. Typically, such park and ride facilities aim to reduce the number of vehicles entering a city centre or passing a heavily congested road section. The public transport connection is usually prioritised to increase the attractiveness of the services, e.g. by means of a designated lane, traffic signal priority or a high frequency.

Travel and traffic information services

Travel and traffic information is a very broad measure that can have various shapes and forms, in the type of information that is provided (static, dynamic), the mode that it provides information about (car, public transport, walking, cycling, multimodal), the way it is provided (mobile phone, road signs), etc.[11]. The primary objective of travel and traffic information services is to increase the awareness of travellers and to steer behaviour towards more sustainable and efficient choices. In some cases, travel and traffic information is combined with social, monetary or material incentives. Such approaches have proven to increase the effectiveness of behavioural change programs, even in the longer term when the incentives are no longer provided[17]. Travel and traffic information generally aims to influence activity, time, mode and route decisions as shown in Figure 1. It is both a policy and a management instrument, with positive effects on air quality (through traffic benefits).

[16] - Klunder, G., Taale, H., Kester, L., Hoogendoorn, S., "Improvement of network performance by in-vehicle routing using floating car data", Journal of Advanced Transportation, vol. 2017, no. 8483750, pp. 1-16.
[17] - Meurs, H., Stelling, C. and Haaijer, R. (2015), Belonen voor spitsmijden: effecten van mobiliteitsprojecten (in Dutch), Tijdschrift Vervoerswetenschap, vol. 51, no. 4, december 2015, pp 63 – 86, ISSN: 1571-9227, www.vervoerswetenschap.nl

ITS for traffic management in urban areas

Traffic management and control

Traffic light control

Traffic light control aims to process traffic at intersections in an efficient and safe manner. The objective is to allow a smooth flow of all traffic at intersections. ITS applications for traffic signals enable signal control systems to anticipate on expected traffic flows and operate with greater efficiency[11]. Usually, traffic lights are optimised to reduce congestion, delay and waiting times. However, if traffic light control would specifically aim to reduce the number of stops, a reduction in CO_2 emission of 8% can be achieved[18]. Signal coordination, i.e. the coordination of traffic lights of a series of intersections, can reduce the CO_2 emission up to 5%, whereas adaptive traffic light control with a network strategy may have an impact up to 10%[19]. Adaptive cooperative green wave control goes another step further, by dynamically coordinating signalized intersections while providing speed advice to create platoons and change signal timing based on these platoons. CO_2 emission reductions up to 14% were found[20].

Vehicle prioritisation

For vehicle priority, traffic control settings are programmed such that stops for e.g. buses, trams or trucks are minimized. The complexity of such a measure increases when the complexity of the design of the intersection increases. For example, when traffic lights also need to consider non-motorised users (pedestrians, cyclists) and impacts on upstream/downstream intersections. Signal priority must be carefully implemented so that it does not create relatively large (negative) impacts on other traffic flows[11]. Evidently, priority vehicles benefit from vehicle prioritisation. Pilots showed that the impact of vehicle priority on the CO_2 emissions and fuel use of priority vehicles is 9-13%[21]. The overall impact of such a measure ranges from 1-6%[22]. Signal priority is most effective in situations with low congestion levels and a limited number of priority vehicles.

Metering

The goal of metering is to minimise speed disruptions to existing flows, usually applied at on-ramps of motorways but also applied in urban areas to reduce the inflow of traffic. Emission and fuel consumption impacts of metering are mixed. Metering causes entering vehicles to stop-and-go, and this behaviour consumes more fuel than free flow driving. Metering also results in smoother vehicle flow on the mainstream road because vehicles enter in a staggered and controlled manner, reducing bottlenecks that would otherwise impede traffic. This results in reduced fuel consumption. These two factors (increased stop-and-go traffic and decreased traffic flow disruption) appear to negate each other[23].

[11] - Jonkers, E. and Gorris, T. (2015). Intelligent Transport Systems and traffic management in urban areas. Civitas Policy Note.
https://civitas.eu/content/civitas-policy-note-intelligent-transportsystems-and-traffic-management-urban-areas-0
[18] - Van Baalen, J., De Koning, A., Voogt, M., Stelwagen, U., and Turksma, S., "ECOFLEX: Improving air quality with green dynamic traffic management based on real time air quality measurements," in 18th Intelligent Transport Systems World Congress, Orlando, United States, 2011.
[19] - Turksma, S. and Vreeswijk, J. D., "Fuel efficiency in cooperative network control systems," in Proceedings of the 14th ITS World Congress, New York, 2008.
[20] - Mahmod, M., "Using Co-operative Vehicle-Infrastructure Systems to Reduce Traffic Emissions and Improve Air Quality at Signalized Urban Intersections," PhD-thesis, TRAIL Thesis Series, University of Twente, Enschede, The Netherlands, 2011.

ITS for traffic management in urban areas

Demand and access management

Access restrictions

Access restriction is the banning or physical blocking of certain vehicles (usually motorized vehicles) on certain roads or areas. The prohibition can also be addressed to certain modes or time periods. Examples of specific restricted access measures are[11] :

- **Restricted access to a city centre.** Can be restricted in time (e.g. no vehicles in the city centre during peak hours) or area (no vehicles in specific zones or on specific roads).
- **Restricted access for certain vehicles** (e.g. freight, weight, length or license plate).
- **Low emission zones** (where only environmental-friendly vehicles are allowed).

The effects on the environment are mostly local and include better air quality and/or lower noise levels, as a result of reduced traffic volumes during the controlled hours or in the controlled area. See for example results from London's ultra-low emission zone[24].

Road pricing policies

Road pricing concerns charging for the use of a road or other road facility (e.g. tunnel, bridge, parking lot), possibly during certain time slots (for example peak hour). Examples are[8] :

- **Cordon area around the city centre,** with charges for passing the cordon line
- **Wide area road pricing,** which charges for being inside an area
- **City centre toll ring,** with toll collection surrounding the city
- **Corridor or single facility road pricing,** where access to a lane or a facility is priced
- **Different tariffs according to the time of day,** with higher charges during peak periods
- **Exception of congestion charging for vehicles using alternative fuels**

Benefits of road pricing include a reduction of vehicle kilometres driven (e.g. 11% in London), less congestion and a modal shift to public transport and active modes[11]. A reduction of CO_2 and PM emissions of more than 10% is common. Road pricing on the toll ring in Oslo led to a reduction of fuel consumption of 35% in Oslo area. Revenues from road pricing can be reinvested to the benefit of travellers who are affected by the road pricing policy, e.g. in better cycling facilities, better public transport, subsidies, etc.

[21] - Koenders, E., Blom, G., and Blanco Lorenzo, R., "Energy efficient intersection control - pilot evaluation results," presented at the 19th Intelligent Transport Systems World Congress, Vienna, Austria, 2012.
[22] - Hirschmann, K. and Fellendorf, M., "A toolbox to quantify emission reductions due to signal control," in 89th annual meeting of the Transportation Research Board, Washington D.C., 2010.
[23] - Shaheen, Susan & Lipman, Timothy. (2007). Reducing Greenhouse Emissions and Fuel Consumption. Institute of Transportation Studies, UC Davis, Institute of Transportation Studies, Working Paper Series. 31. 10.1016/S0386-1112(14)60179-5.

Public transport and fleet management

Dispatch and scheduling

For public transport, better usage of the capacity of the vehicle fleet would, under ideal circumstance, lead to transporting more passengers, with fewer or smaller vehicles and less kilometres driven. On-demand concepts and flexible bus stops are examples of solutions that try to better match demand and supply and improve fleet efficiency. A survey among public transport operators showed that a reduction of empty driven kilometres of 10 %, a reduction of driven kilometres of 7 %, and an increase of the usage of the vehicle capacity by 17 % is feasible with more advanced fleet management[25].

Fuel efficiency

On average per traveller-kilometre, public transport is four times more efficient in terms of CO_2 than private vehicles. And public transport companies are taking additional steps to improve the fuel efficiency of buses[26]. For example by replacing older public transport vehicles with newer, more efficient vehicles, even those with zero exhaust emissions. Other initiatives include eco-driving measures such as the data driving management system, which has the potential to reduce energy consumption by 15%, or actions focussing on smart transmission functionality and fuel-efficient, low rolling resistance tires, which may lead to average fuel savings of 5-10%[26].

Attractiveness

To attract users and to retain users are important aspects in public transportation. Enticing riders to switch from private vehicles to public transport can be achieved through greater, faster, more reliable, more comfortable and safer services. Ensure that existing public transport users do not switch to private vehicles as their income increases might be achieved by keeping public transport as attractive as possible, e.g. by introducing new bus lines or bus rapid transit. Moreover, an increase in the commercial speed of a bus of 5%, e.g. resulting from fewer stops, signal priority, reduced acceleration and less idle time can increase the attractiveness of the services while lowering the energy use and emissions by 20%26.

[24] - Greater London Authority (2019). Central London ultra-low emission zone – first month report. May 2019.
URL: https://www.london.gov.uk/sites/default/files/ulez_-_first_month_report_may_19.pdf (accessed 6 August 2019).
[25] - Bernsmann, A., Kraft, V., Schoneboom, J., Zänker, K. (2006). Konsequenzen von IuK-Technologien für die Logistikprozesse und für die Verkehrswirtschaft. Fraunhofer Institut Materialfluss und Logistik, Bonn/Dortmund.
[26] - UITP (2014). Climate action and public transport - analysis of planned actions. International Association of Public Transport.

ITS for traffic management in urban areas

Driver assistance

Variable speed limits

Traffic regulation to impose a given speed (on motorways and ring roads) according to real-time flow conditions, usually through variable message signs[8], encourages drivers to keep speed moderate and drive smoothly. This system may be combined with dynamic speed limits, dynamic lane assignment, dynamic shoulder use (opening of the hard shoulder for traffic during peak times). Variable speed limits influence speed, headway, and driving dynamics: less braking and acceleration of vehicles is necessary as all drivers run smoothly and at a more homogeneous speed. In addition, it increases traffic flow and systems equipped with warning messages (for congestion, low visibility, road works, etc.) help to avoid incidents that could cause congestion and increase of travel time[10].

Intelligent Speed Adaptation

An Intelligent Speed Adaptation (ISA) system is a system that assists the driver in not exceeding the speed limit[10]. The system can have different forms; it can be an advisory system warning the driver (with an auditory or visual signal) or an intervening system, physically making speeding harder or impossible, for example with a haptic gas pedal. ISA has an influence on:

• The speed of the vehicle since it prevents the driver from speeding. Whether the average speed increases or decreases is difficult to predict, since some drivers will use ISA to drive faster and closer to the speed limit (the system makes them less afraid of exceeding the speed limit).

• The driving dynamics since some ISA systems intervene by braking automatically, or they induce the driver to brake.

• The capacity of the road, since the ISA system can influence the standard deviation of the speed, and the differences between the speeds of different vehicles. In this way traffic can be more homogeneous.

Study results show that significant energy and emission reductions do occur without much penalty to travel time[27]. Moreover, ISA is expected to save up to 33% of accidents on urban roads. Estimates for reduction of CO_2 emissions range from 6-12%[28].

Modifying vehicle trajectories (eco-driving)

Vehicle trajectory influencing systems, also known as (assisted) eco-driving, provide speed and lane advice to anticipate to downstream traffic conditions and can be applied in many situations like traffic lights, ramp meters, traffic jams, lane closures, etc. Information is either provided in the vehicle on a HMI using wireless communication, or at the roadside with electronic signage. Speed advisory at traffic lights has large variety in size and effect subject to spatial, situational and temporal conditions. The range of benefit round was 1% –12% energy savings for all vehicles[29], but impacts up to -17% CO_2 emission/fuel consumption have been noted for specific situations and/or vehicle classes. Speed advisory proves to be less effective with congestion, due to queuing traffic at the intersection. In a scenario analysis for different road types the CO_2 emissions decreased on all road types, with the largest decrease on motorways for trucks[30]. Markedly, the largest effect found was for cars and vans on rural roads. Furthermore, benefits increase with higher market penetration of the system, although benefits are already visible at low penetration[29]. Benefits also increase with longer communication distance due to better trajectory planning, and benefits are greater for corridors on which traffic signals are less coordinated.

[27] - Servin, O., Boriboonsomsin, K., Barth, M. (2006). An energy and emissions impact evaluation of intelligent speed adaptation. In: Proceedings of the IEEE Intelligent Transportation Systems Conference, Toronto, pp. 1257–1262.
[28] - Lai, F., Carsten, O., Tate, F. (2012). How much benefit does Intelligent Speed Adaptation deliver: An analysis of its potential contribution to safety and environment. Accident Analysis and Prevention 48 (63-72).
29. Vreeswijk. J., Barth, M., Salavona Grau, J.M., Blokpoel, R. and Mitsakis, E. (2015). Operational perspectives on eco-traffic signals. Mobil.TUM 2015. International Scientific Conference on Mobility and Transport – Technologies, Solutions and Perspectives for Intelligent Transport Systems. June 30th and July 1st 2015.
30. Jonkers, E., Wilmink, I., Nellthorp, J., Guhnemann, A. and Olstam, J. (2016). D54.1: Costs and benefits of green driving support systems. Version 14, 2016-04-25. ecoDriver project.

Safety and emergency systems

Incident management

Incident management comprises all measures after an incident to clear the road as quickly as possible to restore normal operation[31]. Measures are taking into account the needs of victims, the safety of emergency services, the traffic safety and the minimisation of the damage (e.g. truck loads). The main aim of incident management is to improve traffic safety and throughput. Indirectly, incident management can also help to reduce the environmental effects by helping reduce incident related congestion. In that regard, improvement of incident management has the potential to decrease energy use and emission by reducing delay and congestions resulting from the incident.

Automated speed enforcement

Automated speed enforcement, also known as photo-radar or speed camera enforcement, uses image capturing technologies, to register vehicles and/or drivers at the time of the violation, as evidence in the issuance of fines. Speed enforcement programs have been widely applied, mostly to address speeding-related safety problems. Similar to variable speed limits, automated speed enforcement also has environmental benefits due to lower traveling speeds, more homogeneous traffic flow therefore improved traffic flow and less congestion, and fewer vehicle accidents[23].

Traffic calming

The six most common traffic calming measures (by number of schemes implemented) were found to be 75 mm high flat-top humps, 75 mm high round-top humps, speed cushions, single lane working chicanes, thermoplastic humps ('thumps') and 2-way working chicanes[32]. Studies showed a consistent increase in fuel consumption and emissions of CO2 due to traffic calming, although wide variations in the changes in CO_2 emissions were recorded. In addition, increased vehicle maintenance costs have been reported by some bus companies, but some local authorities have already reduced the severity of ramps to reduce the likelihood of damage.

[32] - Boulter, P. and Webster, D. (1997). Traffic calming and vehicle emissions: A literature review. Transport Research Laboratory. TRL REPORT 307.

Recommendations for strategic integration and management

This section provides considerations for making investment-decisions for the implementation of emission-saving measures and the interpretation of impact figures in general. It discusses the importance of baseline conditions, context-dependent variables, likely consequences of combining measures and possible side-effects.

Reference situation (baseline)

An impact review[3] showed that many different factors play a role in the energy use and emissions of vehicles. Moreover, the interactions between these factors are complex, context-dependent and sometimes unknown, which can make it difficult to replicate the impact of a measure in a different/new situation. Especially the baseline situation can have a large influence on the outcome. For example, smaller benefits will be achieved in already well-performing situations. It is important to consider that it is not necessarily the measure that does not perform well; it could well be the baseline that is already good.

Situational variables

In addition to the reference situation, specific conditions like road topology, a dominant traffic flow, local policies may or human behaviour could hinder a measure from performing optimally. For example, for speed advisory at signalised intersections the large variation in the results can largely be explained by situational variables like: spacing between intersections, traffic volume and density, distribution of traffic over different directions, intersection topology, traffic composition, allowed speed limit and the baseline conditions (e.g. the type of signal control)[29]. This means that when a measure is transferred to a different situation with a different context, it is not guaranteed that the same results are obtained.

Complementarity of measures

Some of the systems mentioned earlier operate in the same domain and address the same fuel and emission related inefficiency. Interaction effects affect the way in which impact estimates of different measures add up. Therefore, a combination of two measures may have a lower impact than the sum of their individual impacts, while in other cases the combination of two measures may accelerate the impact and higher effect sizes may be reached. It is difficult to be certain how each combination of measures will interact in general, let alone being able to predict their effect in specific situations and identify synergies (drawing causal diagrams may help to identify the interactions and interrelations). On the one hand there is a great potential to accelerate the effect of measures by combining those that have synergy. On the other hand, interchangeable effects are likely to exist for measures that operate in the same domain. To design an effective integrated strategy, synergies refer to the interaction effects between measures which is possible in four ways[33].

• **Synergy:** when the simultaneous use of two or more measures gives a greater benefit than the sum of the benefits of using one of them alone. ((A+B) > A + B)

• **Additivity:** when the gain from the use of two or more measures is equal to the sum of the gains of using each in isolation. ((A+B) = A+B)

[33] - May, A., Kelly, C., and Shepherd, S., "The principles of integration in urban transport strategies," Transport Policy, vol. 13, pp. 319-327, 2006.

• **Complementarity:** when the use of two measures gives a greater total benefit than the use of either alone. (A+B > A and A+B > B)

• **Perfect substitutability:** when the use of one application eliminates entirely the benefit from using another instrument. (A+B = A = B, or worse: A+B < A or B)

For example, combined vehicle routing and traffic light control acknowledges the interaction between drivers' route choice and traffic control optimization processes[34]. Rerouting effects induced by control strategies may be greatly accelerated if properly anticipated by traffic light control. Hence, link capacities are no longer fixed but subject to flow-responsive signal settings to respond to traffic flow variations[35]. An extensive simulation study showed that the effect of vehicle routing alone approximately doubles when combined with a traffic adaptive type of control[36]. In this study vehicle routing in combination with fixed time traffic light control reduced the total delay time (and therefore CO_2 emission) by 16%, while a combination with adaptive traffic light control reduced the total delay time by 35%. Exploring the details revealed that the two measures are mainly complementary but that in fortunate cases their effect may even be additive. Similarly, the combination of a green wave measure and speed advisory proved to be 40% more effective together than the sum of their individual impacts.

Tackling air quality hotspots

Where to start one might wonder. A regulation-dictated starting point could be to first address locations or situations where air quality is worst. If it is known how often the concentration of a certain pollutant exceeds the regulatory threshold at a given location and by what amount, a quantitative target can be set for the required reduction. A generic approach can be used to determine what decrease in traffic intensity and what improvement in traffic flow are approximately required to achieve this reduction. Based on the required reduction in intensity and/or congestion, a decision can be made on which measure should be implemented to achieve this goal.

Rebound effects

A positive effect of a measure somewhere, may cause negative effects elsewhere. For example, the redistribution of demand or traffic, in time or space, may have a positive effect locally but lead to higher traffic volumes and new problems in other parts of the network. Under the most unfortunate circumstance, the overall performance of the measure might be worse than the original situation. Similarly, improved traffic flow might in the longer run attract more vehicle traffic, cleaner vehicle technology may lead to more kilometres driven (e.g. in the case of electric vehicles that have low operating costs), public transport priority might lead to disproportionate waiting times for other traffic, metering may lead to more vehicle kilometres due to rat running, etc. For this reason, **it is important to also have a holistic view of the traffic network and the systems operating it.**

[34] - Farhan, M., Stevanovic, A., and Martin, P., "A practical perspective on the benefits of combined traffic assignment and control method," in 89th annual meeting of the Transportation Research Board, Washington D.C., 2010.
[35] - Meneguzzer, C., "Review of models combining traffic assignment and signal control," Journal of Transportation Engineering, vol. 123, pp. 148-155, 1997.
[36] - Farhan, M., Guo, J., and Martin, P., "Combined Traffic Assignment and Control Method: Benefits of Capturing Interaction between Drivers' Route Choices and Flow Responsive Traffic Controls for Traffic System Improvements," in 90th annual meeting of the Transportation Research Board, Washington D.C., 2011.

Recommendations for strategic integration and management

Connectivity and automated driving

Connectivity and automated driving have not been addressed explicitly in this paper. Connectivity is regarded to be an enabling technology that allows the exchange of information between traffic participants and between traffic participants and infrastructure. Thereby it is an enabler for cooperative driving, meaning that single vehicles and drivers act cooperatively within traffic. This implies that single traffic participants are coordinating their aims and actions in the light of improved overall system effects[37]. Automation deals with the execution of processes and procedures without human intervention. Hence automated driving implies that one or more driving tasks are executed without the intervention of human drivers. Automated driving can lead to significant improvements in traffic, as vehicles can be programmed to comply accurately with traffic rules (more so than humans are capable of) and algorithms can be made cooperative and environmentally friendly. This suggests that several of the measures discussed in this paper can be executed more efficiently and effectively with vehicle automation. The precise effect of automated driving on energy consumption is highly uncertain[38]: although automated vehicles are expected to be largely electric and highly efficient (maximum energy reduction of 42% for certain situations and roads, 17% on average[39]), new transportation concepts like robotaxis may lead to a modal shift away from sustainable transport modes, a higher demand for rides with passenger cars, more vehicle kilometres driven and eventually more congestion, which also affects other traffic.

[37] - Kuhn, A. (2018). What's the difference between autonomous, automated, connected and cooperative driving?
URL : https://www.andata.at/en/answer/whats-the-difference-betweenautonomous-automated-connected-and-cooperative-driving.html (accessed: 26 July 2019).
[38] - U.S. Department of Energy (2018). Autonomous Vehicles: Uncertainties and Energy Implications. May 2018.
URL : https://www.eia.gov/outlooks/aeo/pdf/AV.pdf (accessed 26 July 2019).
[39] - Krail, M., Hellekes, J., Schneider, U., Dutschke, E., Schellert, M., Rudiger, D., Steindl, A., Luchmann, I., Wassmuth, V., Flaming, H., Schade, W. and Mader, S. (2019). Wissenschaftliche Beratung des BMVI zur Mobilitäts- und Kraftstoffstrategie Energie- und Treibhausgaswirkungen des automatisierten und vernetzten Fahrens im Straßenverkehr. Fraunhofer-Institut für Systemund Innovationsforschung (ISI).

Conclusion

This ITS4C Topic 3 Briefing Paper looked at the ways ITS and smart mobility can reduce emissions, with a focus on management of traffic, transport infrastructure and public transport. Measure targeting root causes such as the vehicle engine technology and travel demand will have the most direct and on the longer term largest impact on environmental targets. Once traffic is generated, interventions aiming at increasing traffic system efficiency through fewer vehicle kilometres travelled, facilitating modal shift to more sustainable modes of transport and optimizing traffic flow (i.e. less congestion and reduced speed and speed variation) have the largest emission-saving potential. In this paper a portfolio of various classic (e.g. parking guidance, metering and variable speed limits) and modern (e.g. assisted eco-driving and variable access restrictions) measures and techniques was presented. Some can have a substantial (two digit percentage) impact, even though CO_2 reduction was in most cases not the primary goal. **If environmental targets and CO_2 emissions would become a primary policy objective, ITS for traffic management, traffic control and public transport can lead to a reduction of surface transport CO_2 emissions in the order of 10%. This may require a shift of thinking towards an overall sustainable transport system design, and away from optimising travel times, throughput and velocity of individual passenger traffic.**

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Isabel Wilmink obtained her Master's degree in Civil Engineering from Delft University of Technology in 1995. Since then, she has worked as a traffic and transportation researcher at TNO. Between 2009 and 2016, she was also a member of the operational team at TrafficQuest, the "Centre for Expertise on Traffic Management", a cooperation between TNO, Delft University of Technology and Rijkswaterstaat. She has experience with national and international projects in the areas of connected, cooperative and automated mobility, the assessment of traffic efficiency, safety and environmental effects of transport policies, scenario and evaluation studies, and traffic modelling.
Isabel currently works on several projects focusing on the impacts of connected, cooperative and automated driving systems (e.g. L3Pilot, InterCor, Talking Traffic, Practical Trial Amsterdam). She also worked on the EU projects ecoDriver, UDRIVE, eCoMove, ECOSTAND, eIMPACT, and IMAGINE. Other recent projects include the development and application of simulation tools for evaluating the impacts of ITS on sustainability, safety and throughput.

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