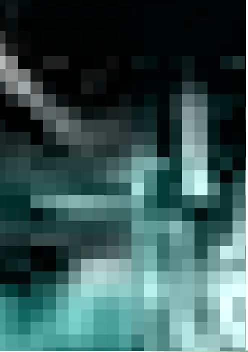


THE ICT-EMISSIONS PROJECT

HANDBOOK

THE WISE WAY TO CUT DOWN ON CO_2

THE REAL-LIFE IMPACT OF THE INTELLIGENT TRAFFIC AND IN-VEHICLE SYSTEMS ON CO_2 EMISSIONS AND HOW TO MAKE THE BEST OF THEM

ICT-Emissions

Co-funded by the European Union

Contents

Our roads, our cars, our transport systems are important for our way of life, our economy and the progress of our societies in Europe. Very much so! In any given day of the year over 300 million people move along our 5.7 million kilometres of road network contributing to a sad 875 million ton load of CO_2 emissions annually.

Even more important though is the quality of the air we breathe and the sustainability of our environment. The more we speed through new technologies and expand their use, the more we ought to care for their repercussions to our natural environment and the global climate.

As we opt for a smart, green and integrated transport, we are developing a wide range of measures -most of them impressively innovative- to reduce car emissions and our dependency on fossil fuels. Such Information & Communication Technologies (ICT) gear our vehicles, regulate our traffic lights, influence our drivers and enrich our policies.

What are they really worth, how to combine them to maximize their benefits or to evaluate and integrate future ones in our transport systems -this is why this book comes in handy.

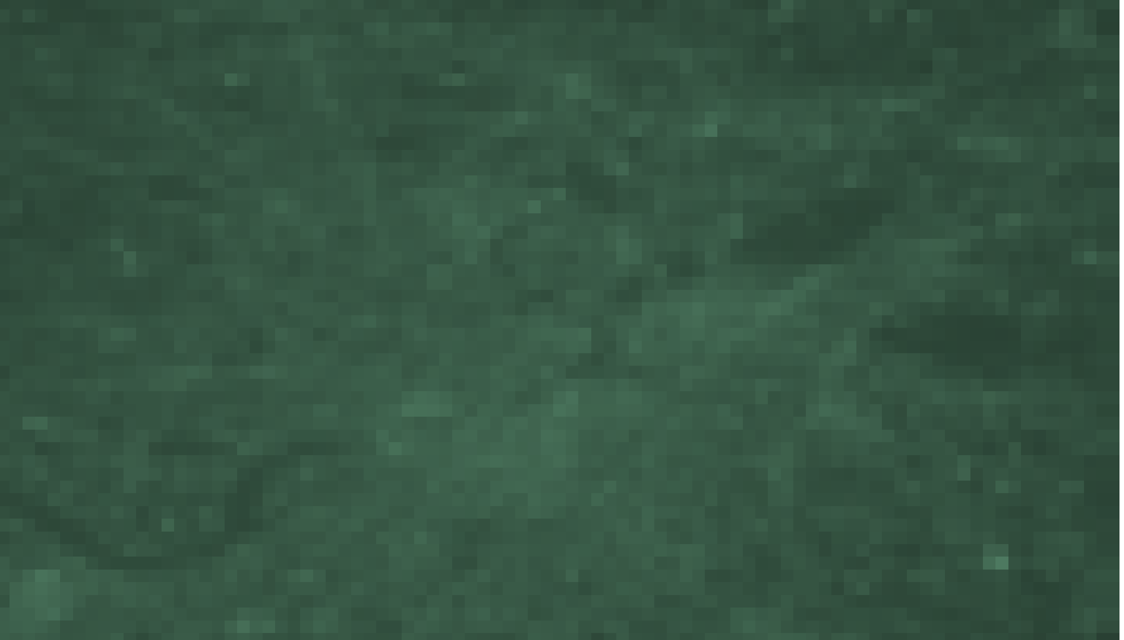
For good reason

The European Commission aims at "a European transport system that is resource-efficient, climate- and environmentally-friendly, that is safe and seamless for the benefit of all citizens, the economy and society". To this end, a host of ICT measures promising reductions of air pollution and fuel consumption are now available for road traffic stakeholders and city authorities to serve their cities, their fleets and their drivers. The real world performance of each measure proposed should be tested under various conditions, and the projected results should be assessed prior to the costly implementation. The ICT-Emissions project provides the science, the methodology and the tools to achieve that.

From different angles

The ICT-Emissions project would not have succeeded without the joint effort of cities, researchers and the industry with the common interest to assess the real-life impact of Information and Communication Technologies on CO_2 emissions and fuel consumption of current and future vehicle fleets. We have used popular traffic and emission models and software tools to simulate second-by-second driving patterns, vehicle speeds and positions, vehicle and network interactions, and finally emissions. This has been performed for different vehicle types and traffic conditions and creates a unique dataset to be used for ICT measures impact evaluation.

Consortium partners: **Laboratory of Applied Thermodynamics [Aristotle University of Thessaloniki] / Centro Ricerche Fiat S.C.p.A. / AVL LIST GmbH / Berner & Mattner Systemtechnik GmbH / Universidad Politecnica de Madrid / Tecnologie Telematiche Trasporti Traffico Torino (5T) s.r.l / POLIS - Promotion of Operational Links with Integrated Services, Association Internationale / CNH-Industrial - IVECO / Agenzia Roma Servizi per la Mobilità Srl / Madrid- Calle 30 / JRC, Institute for Energy and Transport / Heich Consult**

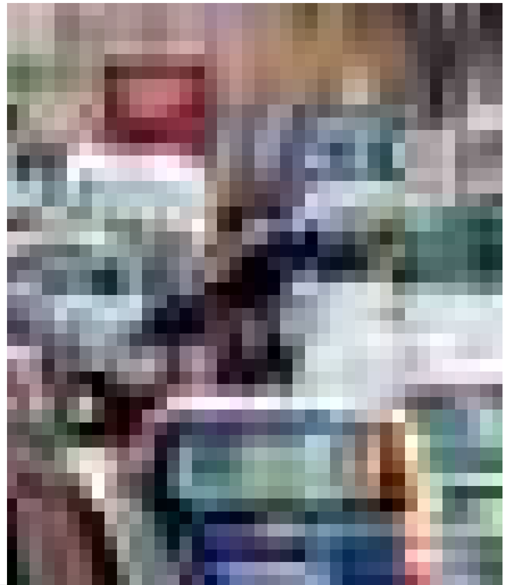


At micro and macro scale

Urban traffic is a complex system spanning the full length and diversity of the road networks and commixing driver behaviours, time schedules and vehicle performances: a measure affecting the behaviour of a single vehicle has an impact on the whole network's operation and vice versa. Therefore, our methodology combines traffic and emission modelling at micro and macro scales and offers the necessary interfaces to shift from one scale to the other.

Tested and validated

Our simulations of the different ICT measures were tested and validated by real-world experiments in the cities of Turin, Madrid and Rome where floating cars collected data in the streets to feed our models. These data were also used to tune the models to meet the complex urban condition to its best.



Into the future

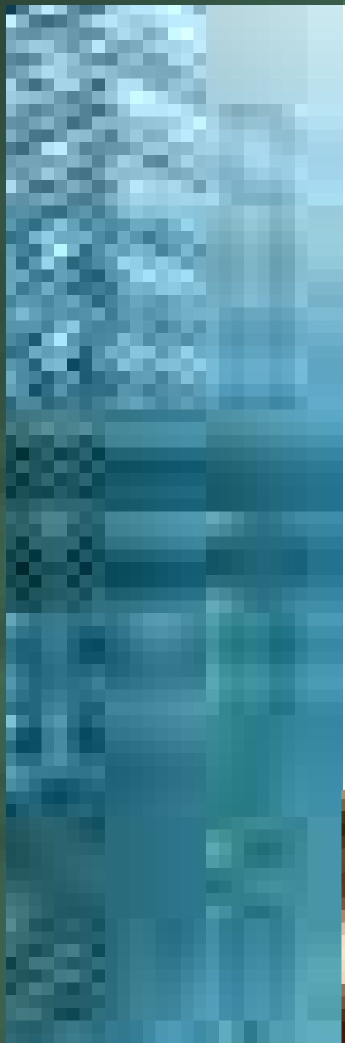
To enable a reliable prognosis of the future developments, the ICT-Emissions Project covers a large number of current and near future technologies such as hybrid, plug-in hybrid and electric vehicles. Moreover, the ICT-Emissions Project provides a standardised assessment methodology to interpret, compare and up-scale different results from related projects and initiatives; the way existing commercial traffic and emission models are defined, interlinked and deployed forms the basis for present and future assessments which truly reflect the real-life conditions in urban areas.

So, if you ask whether to introduce Green Navigation on GPS navigators or how much Adaptive Cruise Control, Urban Traffic Control Systems or Variable Speed Limits can actually reduce emissions in your city, you shall find this booklet useful.

For detailed information on FP7 Project "ICT-Emissions" please refer to ***www.ict-emissions.eu***

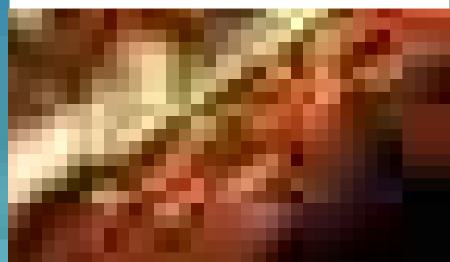
ICT-Emissions Results:

An Overview



The measures under the ICT-Emissions project focus were investigated for different penetration rates and in different traffic conditions (e.g. free flow, congested). The results show sensitivity to these parameters. Several relevant cases have also been modeled with the current and near future fleet compositions.

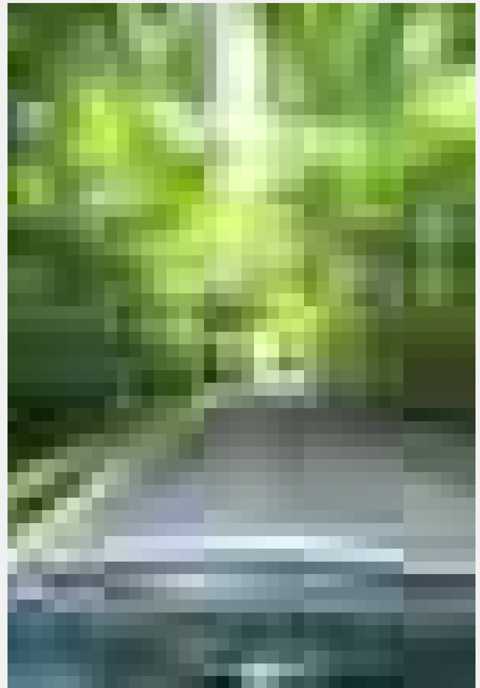
Overall the ICT systems examined exhibited a variable ability to reduce CO_2 emissions, ranging from few to several points, depending on local conditions like traffic, infrastructure and fleet composition. Advanced vehicle types like hybrid and plug-in hybrid vehicles may offer additional benefits when combined with advanced ICT measures.



Vehicle and driving related ICT Systems

(Advanced Driver Assistance Systems, Start and Stop, Eco-driving)

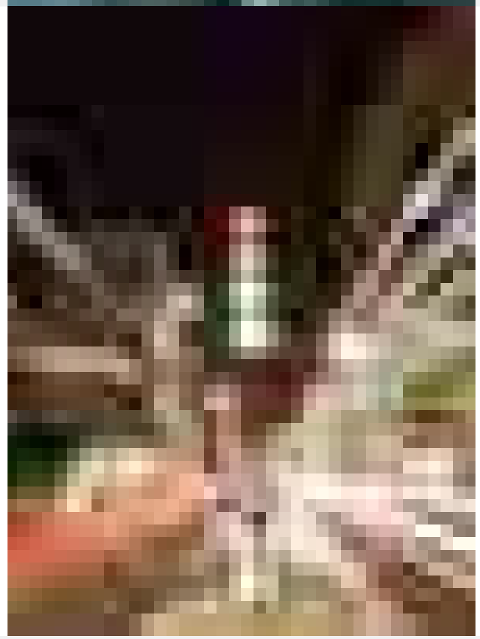
Their effects on a per vehicle basis can be substantial - reductions of CO_2 emissions can exceed 15%. However this CO_2 benefit is constrained by traffic conditions and the penetration rates of the system itself.
Most importantly, effects on a single vehicle basis are not proportionally transferrable to the fleet because of vehicle-to-vehicle interactions. The recommendation from our project is that the true impact of these measures should be assessed not on single vehicles but on a fleet level with a randomization of the vehicles equipped with the particular technology.

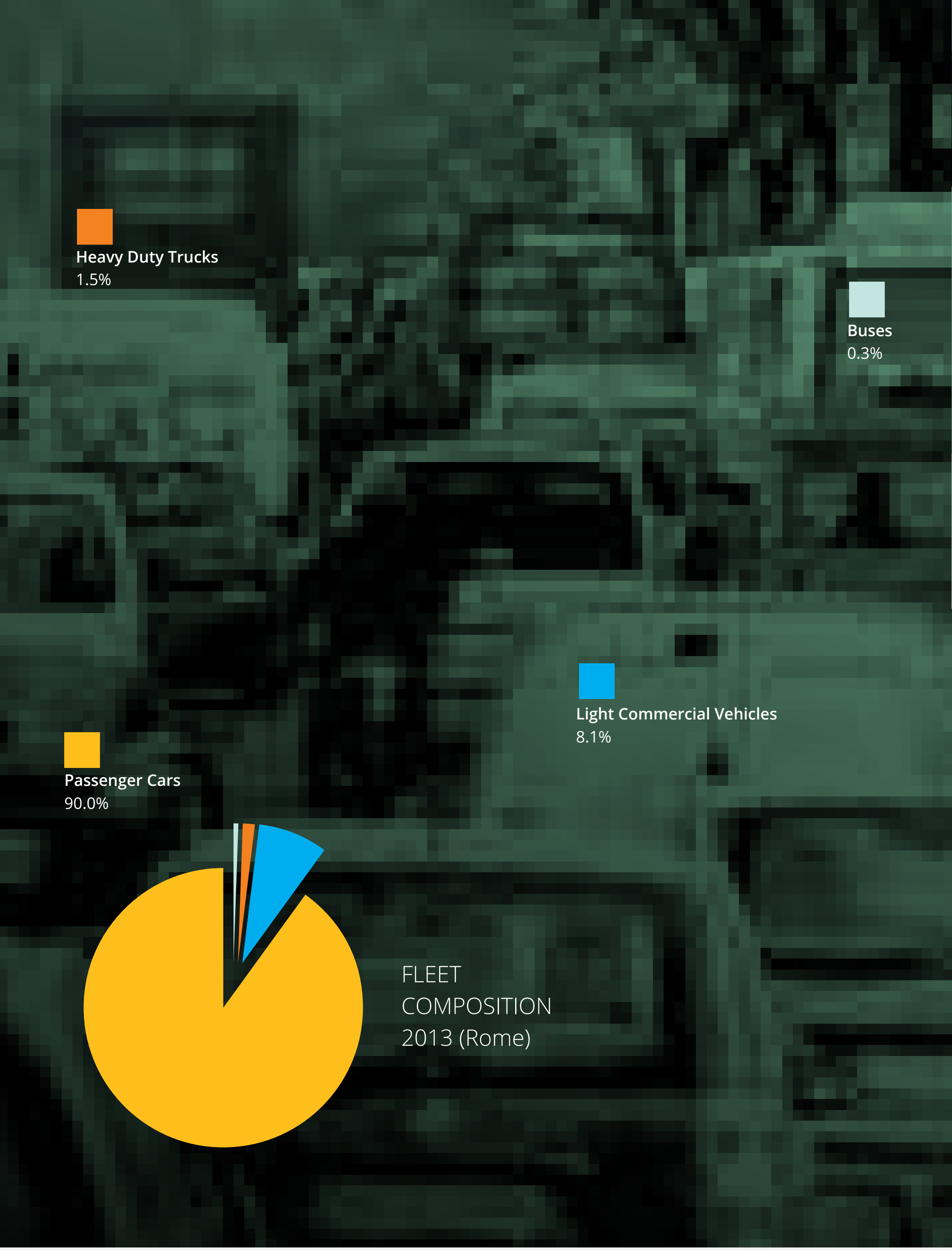


Traffic and Routing related ICT Systems

(Variable Speed Limits, Urban Traffic Control, Green Navigation)

Traffic targeting measures have both a local and a network-wide impact. Changes in traffic lights timing affect the local driving pattern and this affects the capacity of the road which, in turn, has repercussions on the macro scale modelling.
This means that proper methods need to be applied to upscale the local effects to a network level.
Our results show that CO_2 benefits up to 8% at a fleet level can be obtained with such measures.





Now and the future

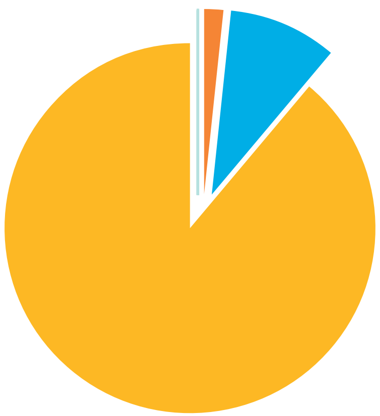
The impact of measures depends on the vehicle fleet structure and its stratification. In ICT-Emissions, we tried to investigate the sensitivity of ICT measures tested in different vehicle fleets.

The basic fleet corresponded to a mix of vehicles representing the average vehicle composition, typical for 2013-2015. In actual implementation of an ICT measure, the exact stratification of vehicles depends on the country and even the city considered. Unique typical vehicle fleets for the Spanish and Italian conditions were constructed due to the corresponding cities tested in this project.

We show the composition of three different fleets examined in this study, taking Turin, Italy as an example:

- Current fleet: The vehicle fleet reflecting the 2013-2015 period.
- Current fleet + Hybrids: Current fleet assuming that 10% of the cars are hybrid. This would correspond to a city that has introduced incentives for the wider introduction of hybrids. In ICT-Emissions, hybrids are further split into full hybrids, mild hybrids, plug-in hybrids, and range extenders.
- Future fleet: Expected composition of the vehicle fleet for year 2030. Further to general trends with respect to fuel change and the penetration of advanced technology vehicles, the average conventional vehicle is considered more efficient than in the 'current fleet' case.

Examining alternative fleets in scenarios is important in order to understand the combined impact of the ICT measures and the vehicle technology. Our recommendation when testing the impact of ICT measures is to meticulously design the vehicle fleet considered, using up-to-date information on the vehicle categorisation. Particular emphasis needs to be given to the contribution of advanced technologies, the split between smaller and larger vehicles, the fuel types, etc. The detail in the fleet should go hand in hand with the detail in the vehicle models available. However, the main message is that the real-world impact of the measures can only be estimated when the detailed vehicle composition is available.



FLEET COMPOSITION 2013 / 2030

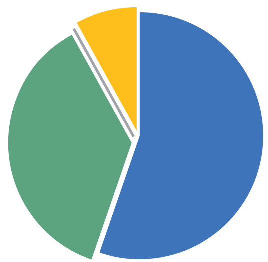
0.2% Buses
1.6% Heavy Duty Trucks
9.4% Light Commercial Vehicles
88.8% Passenger Cars

Key trends

Cars hold the lion's share in a city, representing almost 90% of the total vehicle fleet size. In ICT-Emissions we did not take into account power two wheelers (PTWs), despite their abundance in South Europe, because these do not comply with typical traffic modelling patterns, rather they are often known to defy traffic rules and generally not forming traffic light queues. We hence expect the impact of ICT measures on PTWs to be minimal.

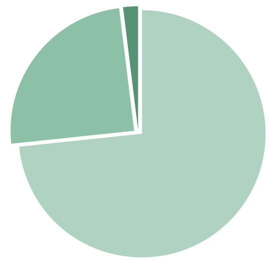
From 2013 to 2030, some major trends are observed for passenger cars. First, the fleet shifts from older vehicle types to Euro 6, which are considered of lower emission levels and superior efficiency. Second, the penetration rate of diesel passenger cars increases, reaching more than 50% in 2030. These are expected to change the absolute impact of ICT measures on CO_2 emission reduction.

Similar trends with regard to the fleets were observed in Madrid and Rome.



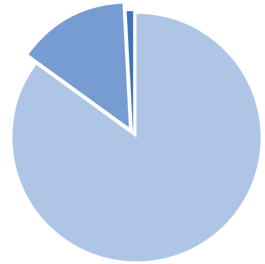
CARS FLEET COMPOSITION 2013

55.4% Gasoline
36.7% Diesel
0.02% Hybrid
7.88% Others



CAR DIESEL TECHNOLOGIES 2013

<= Euro 4
Euro 5
Euro 6



CAR GASOLINE TECHNOLOGIES 2013

<= Euro 4
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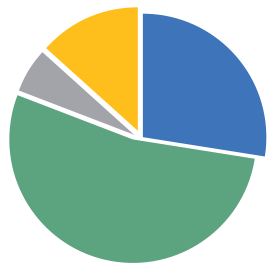
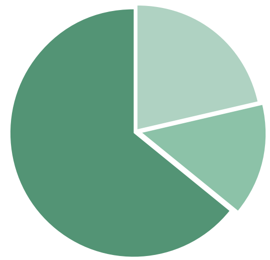
Euro 6



CARS FLEET COMPOSITION 2030

27.5% Gasoline
53.4% Diesel
6.0% Hybrid
13.1% Others



CAR DIESEL TECHNOLOGIES 2030

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Euro 5
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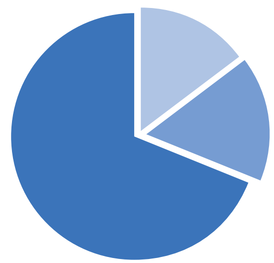


CAR GASOLINE TECHNOLOGIES 2030

<= Euro 4
Euro 5
Euro 6

Put to the test:

Urban Traffic Control *[UTC]*

-8% Normal

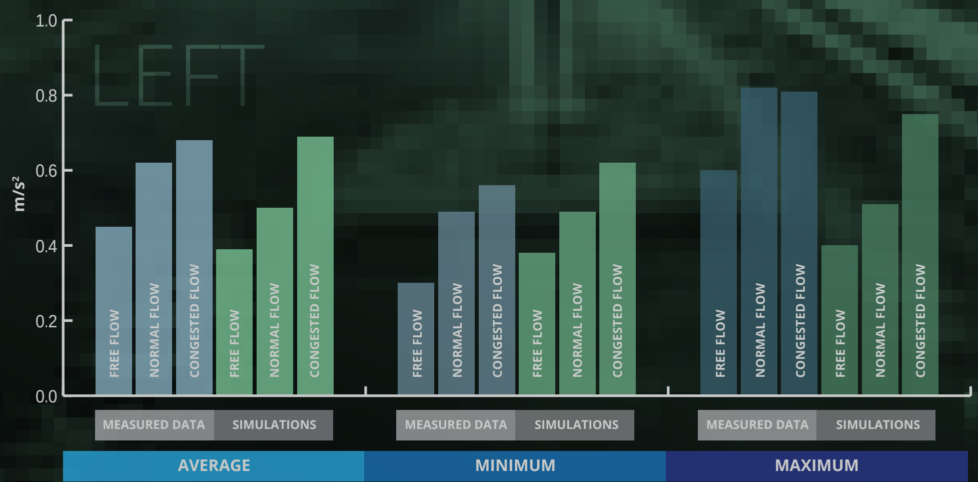
-4.5% Congested

ICT-Emissions studied the impact of traffic-adaptive Urban Traffic Control [UTC] on CO_2 emissions. Such UTC systems are able to measure and forecast queue lengths and adjust green-light phases to optimise efficiency.

UTC was implemented in Rome and Turin, utilising simulations at both micro and macro levels. UTC was implemented in stretches of urban arteries of 1.6 km in Turin (Corso Lecce) and 6.3 km in Rome (Via Appia). The AIMSUN model was used in Turin and VISSIM in Rome. Both models were first calibrated so that traffic parameters such as travelling time, mean stop time, mean acceleration, etc. matched measurements conducted using floating cars at various times of the day, to reflect different congestion levels. Real-world experiments were performed with the UTC system on and off, with the assistance of the traffic control centres in both cities (5T – Turin and Agenzia Roma Servizi per la Mobilità S.r.l. – Rome)

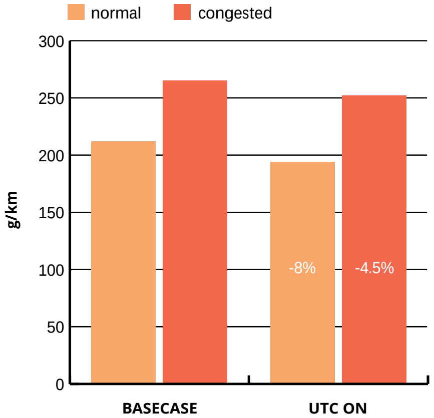
Results presented refer to the micro-level only. At the macro level (city-wide level) impacts are much smaller because of the limited area that the measure was tested. Scaling up effects of UTC measures is therefore a delicate procedure.

Travel time: comparison between measured data and simulations

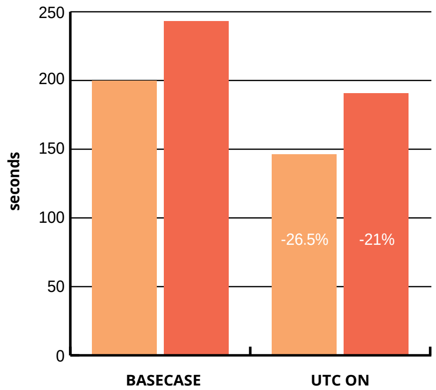


Positive acceleration: comparison between measured data and simulations

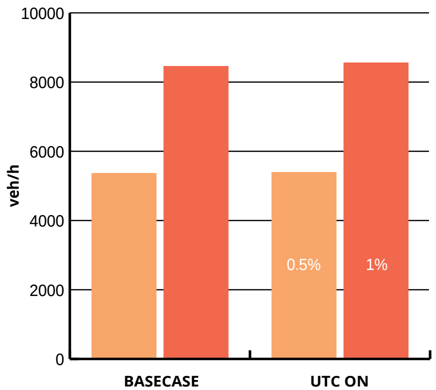
When implementing traffic-adaptive UTC, travel time drops, the percentage of stops decreases and the capacity of the network increases slightly. Effects of the UTC ON scenarios compared with the basecase are shown in the following figures in the case of Turin.



Impact of UTC on average CO_2 emission levels per unit of distance travelled. The values refer to the average vehicle (including passenger cars, light commercial vehicles, buses, and trucks).



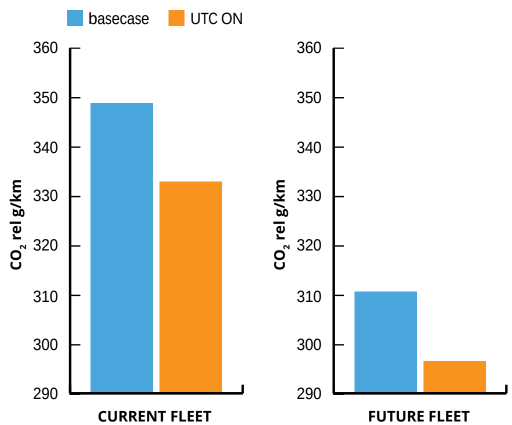
Drop In the travelling time [s] with the UTC system on.



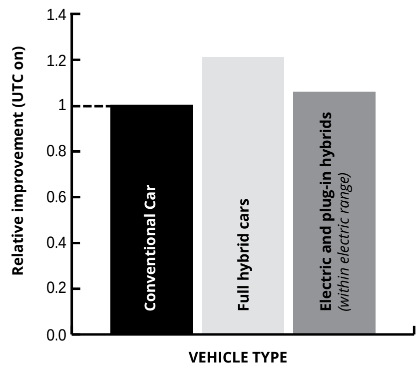
Slight increase in the traffic flow with the UTC system on.

The structure of the fleet is important when UTC is considered because the effect of traffic conditions on emissions depends on vehicle technology. This was examined in the case of Rome, performing scenarios with the current and the 2030 fleets. The future fleet exhibits overall lower CO_2 emissions in g/km (average of the actual vehicle mix in Via Appia) due to the more efficient technologies assumed. Hence, the relative improvement with UTC ON seems to drop from 5% to 4.5%. This is because vehicles become overall more efficient, are equipped with start and stop systems and thus the impact of stop time on average CO_2 emissions is overall lower.

Hybrid and electrified vehicles may also show a different performance when modifying traffic conditions. This is because their technology offers the potential for optimization between different driving modes and to take advantage of the possibility to use either the electric motor or the internal combustion engine. The relative improvement of CO_2 emissions seems to maximize for full hybrid vehicles, even beyond the relative improvement of vehicles with the possibility for external charging, when the latter are used within their electric range.



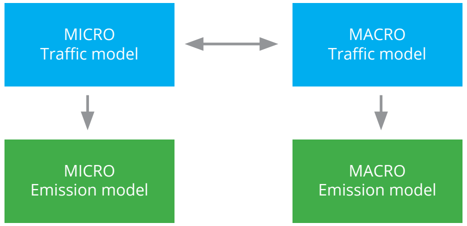
CO_2 Benefits of UTC considering the current (2015) and the future (2030) fleets in Rome, Italy



Relative improvement of CO_2 emissions with UTC system ON for different vehicle types, relative to conventional vehicles. The improvement for conventional cars has been assigned the value of one.

Modelling scale

Urban Traffic Control was simulated both at macro and micro level in the case of Rome while in the case of Turin only at micro level.



UTC: modelling framework

In Turin, the software used was AIMSUN, which includes the possibility of simulating UTC measure with adaptive control interface UTOPIA. In Rome, micro modeling was performed using PTV-VISSIM, while the macro traffic model is developed in Transcad.

Turin

The tested section is a corridor of 1,6 km in Turin with two traffic intensity levels, in the morning rush hour (8-9 h) representing congested conditions and at lunch hour (12-13 h) representing normal traffic conditions.

Traffic model - AIMSUN
Direction 1: corridor in corso Lecce from Corso Regina to Via Lera

Direction 2: corridor in corso Lecce from Via Lera to corso Regina

Turin's UTC test site

Modelling process

We performed a 6-day campaign of car measurements at normal and congested conditions at two traffic system states (UTC OFF and UTC ON), operated by 5T. We built four AIMSUN scenarios at macro and micro level; we inserted the average demand of the campaign days, and we extracted the micro simulation area from the macro scenario. We built and run four scenarios, with combinations of UTC OFF and UTC ON at normal and congested traffic using the Gipps extended car following model. This approach was developed using FIAT eco:Drive data of normal users.

DATA COLLECTION	BUILT SCENARIOS	RUN CALIBRATION SCENARIOS	DATA ANALYSIS CONCLUSION
CAMPAIGN 6 DAYS OF MEASURES TRAFFIC NORMAL CONGESTED STATE UTC ON, OFF	TRAFFIC MODEL AIMSUN 4 SCENARIOS EMISSION MODEL CRUISE COPERT	ON THE CORRIDOR BY FLOW, TRAVEL TIME and OTHER PERFORMANCE INDEXES	COLLECT AND COMPARE THE DATA CONCLUSION

Turin's UTC process followed

The scenario built

Implementation of 5 equipped intersections on the micro simulation model

Traffic demand
Normal 5000 veh/h, congested 7500 veh/h

Fleet composition
92.5% car, 6.9% LDV 0.2% HDV 0.4% BUS

Vehicle attributes
Length, average accelaration

User reaction time
0.5s 30%, 0.75s 45%, 1s 20%, 1.25s 5%
+0.25s HDV, BUS

Scenarios

We considered two traffic conditions, normal and congested driving, involving a demand of 5000 and 7500 vehicles per hour respectively.

Scenario ID	Variables for each scenario			
	Traffic conditions	Penetration level	Number of replication	Fleet composition
112_01	Normal	n/a	10	Turin 2013
113_01	Congested	n/a	10	Turin 2013

UTC: Turin case study. Scenarios considered at micro level

Rome

Rome test case is an important road (Via Appia) 6,3 km long, located in the south-eastern part of the urban area. The itinerary is controlled by 23 traffic lights coordinated by a UTC system. The test case was split in three different scenarios: one refers to the base case condition (UTC OFF) while the other two simulate the effect of UTC-ON as follows;

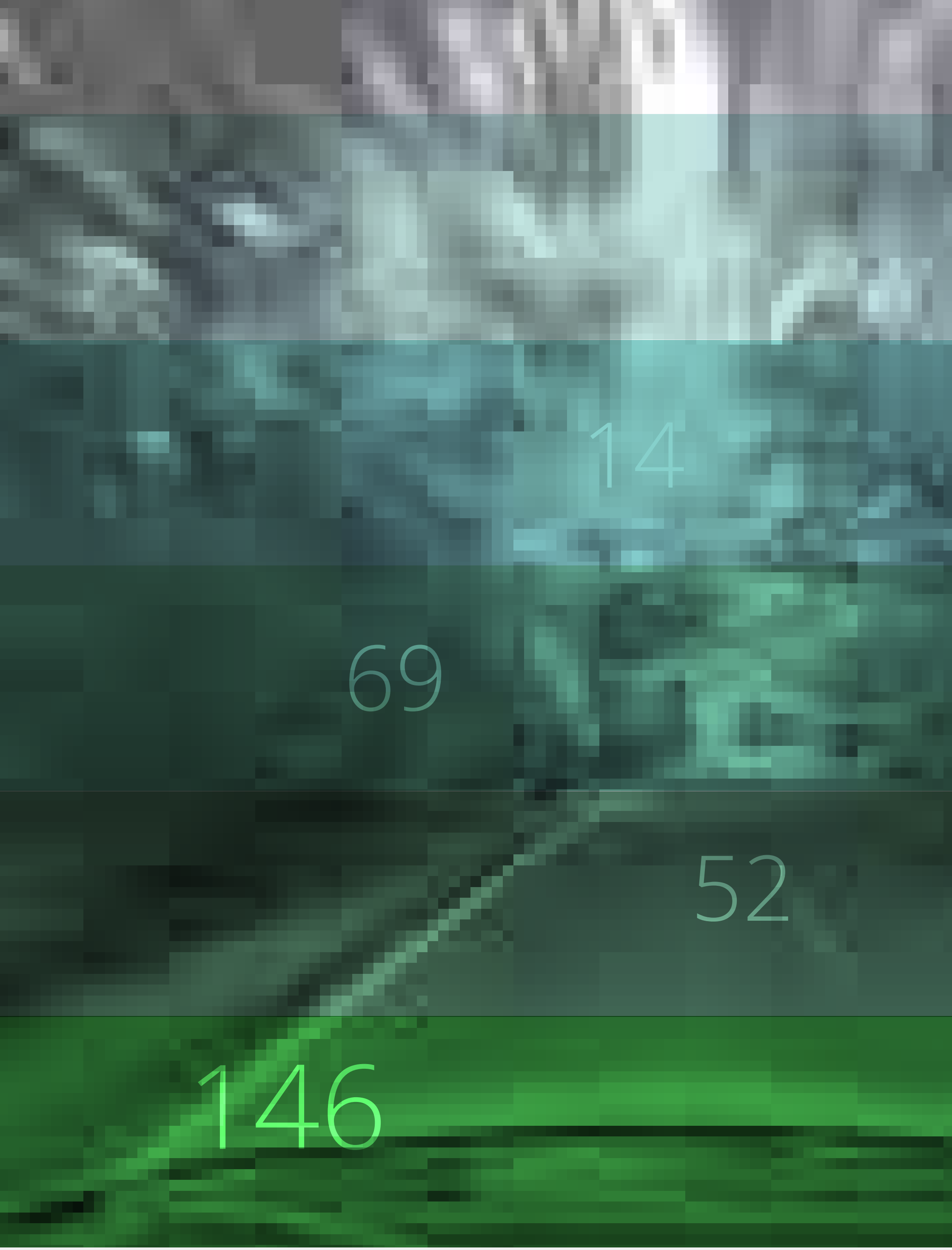
- in the first, the environmental analyses have been carried out on the whole study area, simulating the effects of UTC-ON condition only along Via Appia;
- in the second, the same analyses have been carried out on the whole study area, simulating the effects of UTC ON condition on all the 22 different urban axes under UTC scheme, with a total length of 80 km.

Location of Via Appia within the urban area

Modelling process description

The UTC effects were simulated both at micro and macro scales.
The micro model has been built using VISSIM software that allows to represent in detail the "mobility process" of vehicles on the road since VISSIM uses the psycho-physical driver behaviour model where stochastic distributions of speed and spacing thresholds replicate individual driver behaviour characteristics. Micro-simulation tools allow to model in detail the traffic light controls.

The parameters required to run the models were obtained by an accurate calibration process, that consists of continuous adjustments of the model's parameters and comparison of the modelled data with the observed data, being it traffic or travel times or other significant parameters, until a satisfactory approximation of the observed data by the micro model is reached. For experimental data we used measured (monitored) traffic flows, as well as information from instrumented floating vehicles in an experiment conducted on the particular road with the UTC system ON and OFF.



Put to the test:

Green Navigation

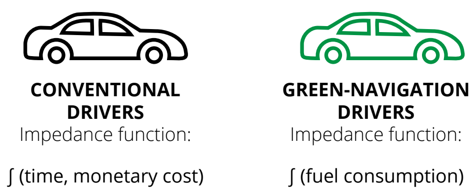
-8.2%
Congested

-4.7%
Normal

With 'green' enhanced navigation systems on-board the vehicle, routing recommendations provided take into account the network traffic conditions and inform the driver on the optimum route to use in order to reduce fuel consumption and, hence, CO_2 emissions.

Green navigation implies routing recommendations based on calculation of environmental impact and real-time traffic situation. This means, in practice, that people follow the route which minimises their fuel consumption and hence CO_2 emissions. The modelling of Green Navigation can only be made at the macro level as we basically need to solve a new optimization problem where the objective function, in this case the traffic impedance function, is not time but fuel consumption. In the ICT-Emissions project, the new impedance function was derived by converting the default fuel consumption function of COPERT (g/km) to an expression as a function of time (g/s).

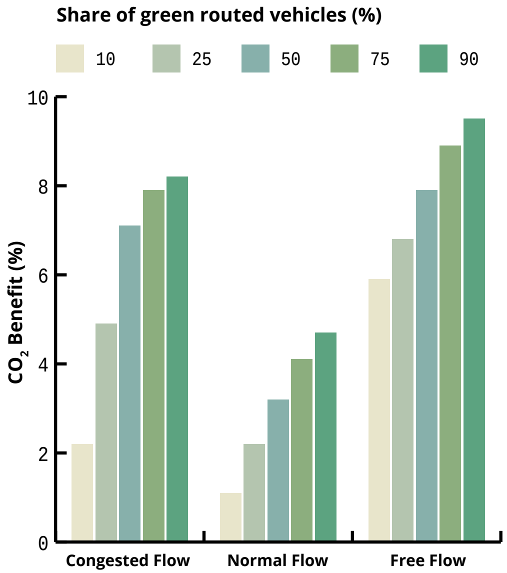
The impact of green navigation depends on the share of vehicles (drivers) in actual traffic for which enhanced routing information is available. Also, relative impacts may depend on the traffic level, i.e. free, normal, or congested. We demonstrate here the impact of Green Navigation in the case of Madrid, using the VISUM modelling framework with the impedance function derived from COPERT as outlined above.



Modelling Green Navigation outline

Results

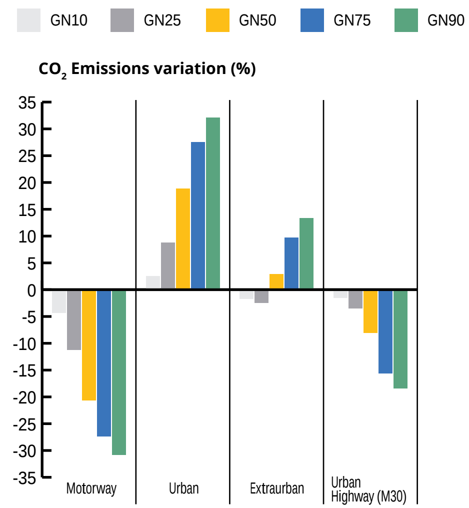
The results with the Green Navigation option are shown in the following figure, as a function of the percentage share of green routed vehicles. Significant benefits are obtained in all traffic levels. However, it is most important to examine green navigation under congested conditions, where it is mostly useful. In this case, there are large benefits up to 50% green routing but then the additional benefit if even more vehicles became green routed becomes smaller. This is because particular short routes which contributed to fuel consumption decrease became saturated as more vehicles were directed to use those and cannot anymore serve the need.

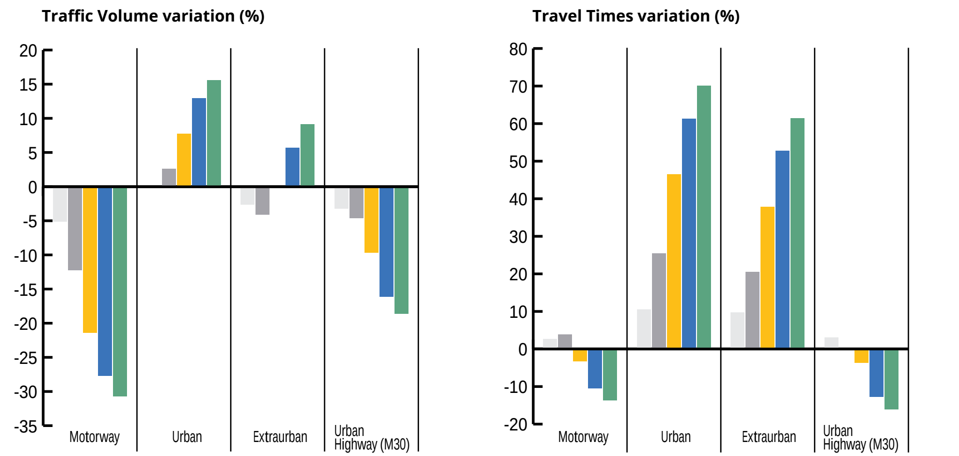


The important message from this figure is that green navigation benefits for a congested network do not change above a certain penetration level, i.e. maximum benefits have been already reached at a 50% penetration. This is because there is no further optimization possible in a congested network, above a certain level.

The following figures show how results differ per road type, with the example of congested traffic. Green navigation entails significant changes on how traffic is routed in the city. It appears that in the interest of fuel consumption, drivers opt for shorter (and busier) routes with a big toll in terms of travelling time.

At 50% green navigation routing, the total activity from the urban highways drops by 10%, while the urban network traffic increases by almost 8%. In reality, it is not certain whether the average driver will accept a 40% increase in travelling time to save approximately 8% on average of fuel consumption. Hence, despite modelling results show a significant benefit, it is difficult to expect full deployment of this benefit in real world conditions.





Example of variation of CO_2 emissions, traffic volume and travel time per road type in the case of congested traffic network in Madrid. To reduce fuel consumption routing shifts traffic from highways to secondary roads which results to significant increase of travelling time.

Methodology

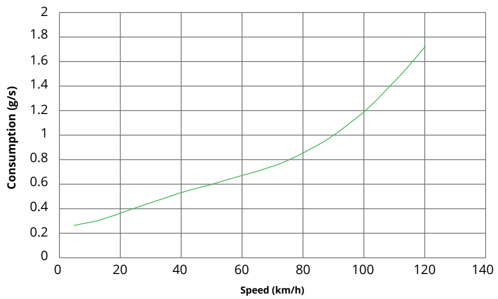
For modelling green-navigation a new transport mode had to be defined in VISUM. This new transport mode, green-navigation drivers, has been assigned a new impedance function defined in terms of fuel consumption (directly related to CO_2 emissions) instead of the typical impedance function for conventional drivers which is based on time and monetary costs.

A percentage of the light vehicles OD matrices will be assigned depending on the green navigation penetration rate. I.e if a penetration rate of 25% of green drivers is considered, then the 75% of the OD matrix will be assigned to conventional drivers under the typical impedance function and the rest 25% to green drivers under an impedance function based on fuel consumption.

Therefore, the new impedance function for green drivers is not only time anymore but total fuel consumption, as follows:

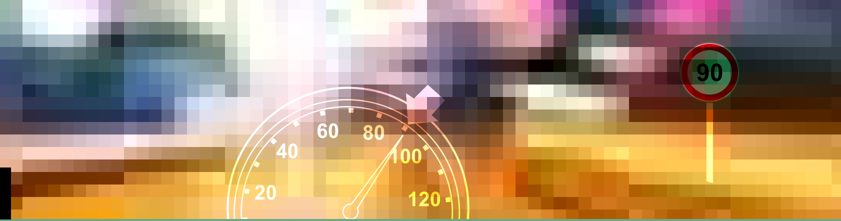
I_{green} [g] = FC(V) [g/s] × t [s]

For this new optimization function, we generated a generalized fuel consumption function for passenger cars as a function of speed. We did not differentiate between fuel or size of vehicle because our aim was to use this function for routing only. After routing was assigned, the fuel consumption functions of COPERT were used to calculate fuel consumption per vehicle type.



Generalized fuel consumption function of speed used in the green navigation routing optimization problem for passenger cars

For optimizing routing, the following considerations were made. Green drivers will select their preferable route depending on the actual traffic conditions, therefore and to capture this effect accurately, the assignment process is divided in two steps or assignment groups. First heavy vehicles and conventional car drivers are assigned to the network and subsequently the impedance function of green drivers is calculated for the new traffic levels and average speeds. By the second assignment group, green drivers are assigned to the network but instead of doing it in a single step, the process is divided in ten stages in order to continuously capture the new traffic conditions. Therefore, a 10% of the OD matrix corresponding to green drivers is assigned in each sub-step and the impedance function is recalculated after every assignment.



Put to the test:

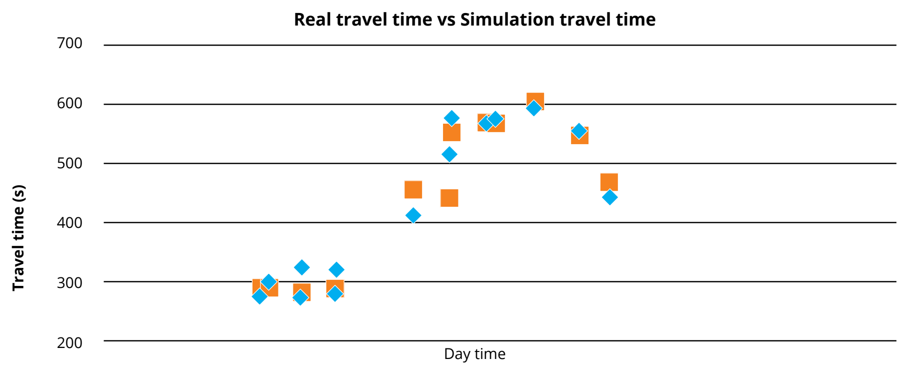
Variable speed limits *[VSL]*

-1.5%
Normal and Congested

Variable Speed Limits (VSL) can be defined simply as speed limit management systems which are time dependant and utilize traffic detectors to determine the appropriate speed.

The results show both absolute and relative CO_2 emissions savings around 1.5%, which are in line with the floating cars measurements. We can observe a significant drop in the stop time percentage, which gives us an idea of more homogeneous traffic flow due to the impact of variable speed limits.

The simulation data [■] were validated with real time measurements [◆]:



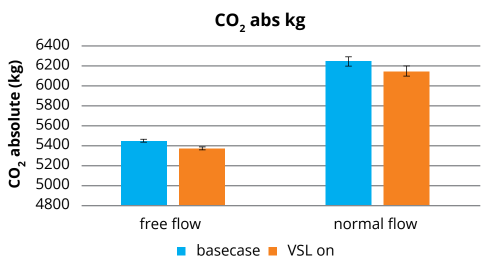
Test on the Madrid ring motorway

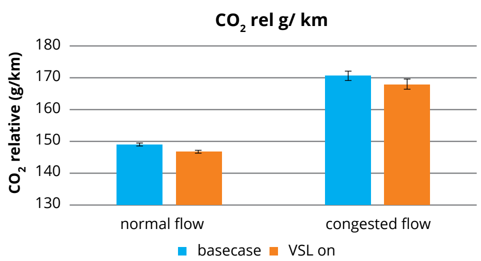
The west section of Madrid is a 3 lanes motorway (southbound) with traffic intensity in the afternoon peak hours reaching 6000 veh/h and with a length of 6.6 km. Most of the section is limited to 90 km/h, except the last 100 m, limited to 70 km/h (tunnel entrance). The congestion is usually caused by the bottleneck situated in the M500 junction, as around 2,800 vehicles merge in the M30 in peak hour.

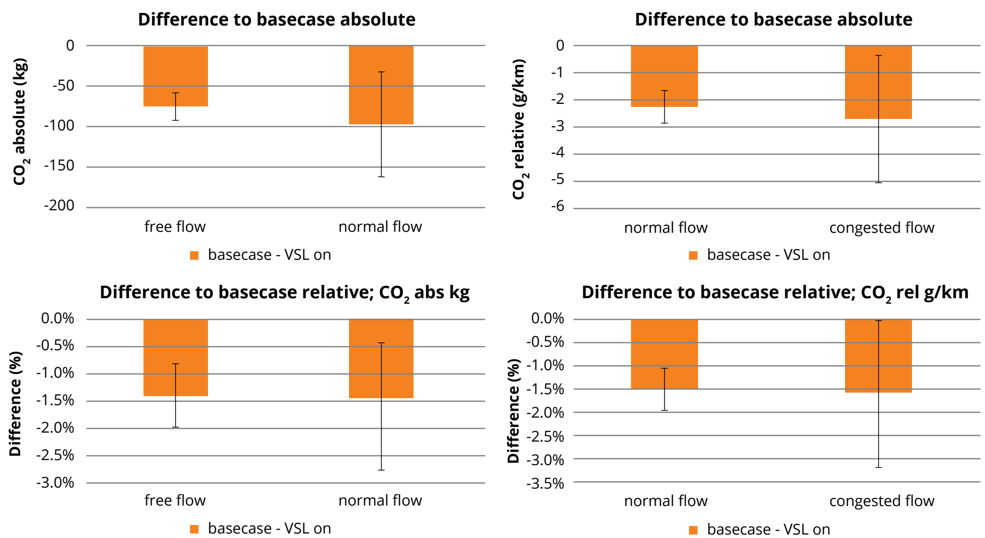
The VSL system is activated at specific points only when there is a certain reduction in speed. The scenarios, therefore, considered are at normal and congested traffic conditions (10 replications each - free flow conditions were excluded).

The analysis of variables related to emissions, traffic and vehicle dynamics shows variations corresponding to the base case scenarios:

Scenario *traffic conditions*	Absolute results			Variation with respect to the base case		
	CO_2 abs kg	CO_2 rel g/km	percent stop time	CO_2 abs kg	CO_2 rel g/km	Percent stop time
	kg	g/km	%	%	%	
normal	5369	146.7	0.85	-1.4%	-1.5%	-19.6%
congested	6143	167.8	3.56	-1.6%	-1.6%	-6.4%







Variable Speed Limits: Madrid case study, Absolute values and Difference basecase.

Modelling scale

Variable speed limits have been modelled at micro level with PTV VISSIM, while the emissions at this level have been calculated with AVL Cruise. Following a micro-to-macro interface procedure, PTV VISUM simulates the traffic at macro level and COPERT the emissions.

Modelling process description

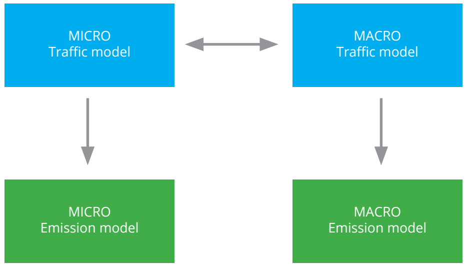
VISSIM software includes the possibility of simulating VSL by adapting the Vehicle Actuating Programming or using the COM Interface. In this particular case the system has been implemented by means of programming the VSL algorithm in Visual Basic. Using this Interface, Visual Basic controls the parameters of VISSIM simulation.

In the case study of Madrid the VSL system consists of a Variable Message Sign situated between A6 and M500 junction, approximately situated half way of the section under study. This VMS (Panel 22241) display a recommended speed limit of 40, 50, 60, 70 or 80 km/h, depending on the control algorithm.

The real traffic speed is obtained from existing induction loops. The speed data is smoothened to avoid instantaneous speed fluctuations.

The algorithm is based on the smoothed speed on the measuring point PM22121, with the following conditions:

- Smoothed speed at or above 85 km/h: recommended speed is not reported.
- Smoothed speed between 84 and 50 km/h: it is posted a recommended speed by subtracting 5 km/h to the smoothed real speed and then rounding down to the nearest ten.

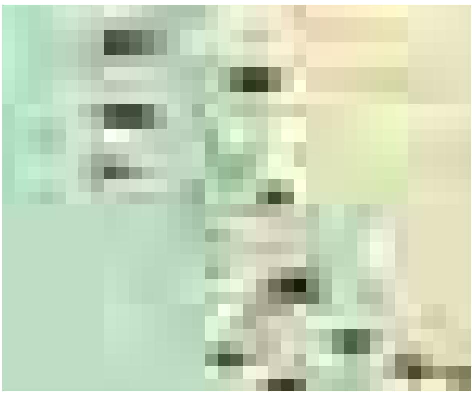


VSL modelling framework

To extend the versatility of the system and its adaptation to complex situations, another condition must be fulfilled: The difference between smoothed velocities in two measurement points is strictly higher than a given configurable value "DV".

Panel	Measur. points		Speed range		Difference between smoothed speeds
			Vmax (km/h)	Vmin (km/h)	
22241	22121	22211	85	40	8

Difference between smoothed speeds value of VSL algorithm.



Location of Variable Message Sign and measuring points in the studied section of the M30 Urban Motorway.

Implementation process and calibration of new desired speed decision

The base case model has been calibrated (see Deliverable 6.2) using traffic and floating car data from the evening of Wednesday March 13th 2013, while the VSL system was not activated. Therefore, it is necessary to calibrate the model for other day in which the system is activated. The day selected has been Wednesday 17th of April 2013.

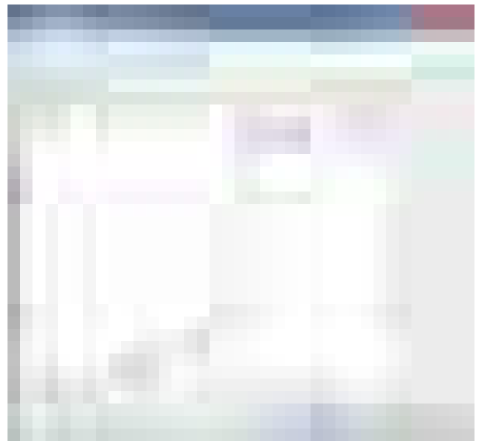
It is important to remind that the posted speed is recommended and, consequently, the effects on the driver behaviour are not as much evident as they would be if the variable speed limits were mandatory.

The algorithm has been implemented in VISSIM using Visual Basic and the COM Interface, which allows to control externally some of the parameters of the model.

Algorithm implementation in Visual Basic through VISSIM COM Interface

The analysis of the speed profiles from floating cars does not show concluding results, so the procedure to obtain the new desired speed distributions is the following:

1. Using the calibrated basecase model, traffic inputs are changed according to the real data from 17th April. The other parameters are kept constant.
2. Routing decisions are adapted to fit traffic data collected from induction loops.
3. Definition of new desired speed distribution affected by recommended speed limits.
4. Programming of Visual Basic code to control VISSIM and simulate the variable speed limits.
5. Adjustment of desired speed distribution to fit travel times data recorded by floating vehicles.



With this procedure, it has been possible to obtain a new desired speed distribution for each possible posted recommended speed limit while achieving good results with regard to travel times

Put to the test:

Adaptive Cruise Control *[ACC]*

-11% Urban Normal

-8% Urban Congested

Adaptive Cruise Control (ACC) is an Advanced Driver Assistance System (ADAS) which controls the velocity of a vehicle by measuring the distance to the vehicle in front. If it is larger than a specified distance, the vehicle is automatically accelerated; as it gets closer to this specific distance, the vehicle is decelerated.

For modelling the impact of ACC, we produced a new interface within ICT-Emissions. The baseline is the speed profile produced by the micro-model and then a specific vehicle-control model corrects this to simulate the impact of ACC. In ICT-Emissions, the vehicle control model has been developed on the MESSINA software platform, maintained by B&M and proper plugin interfaces for its operation have been developed for the Aimsun and SUMO microscopic traffic models.

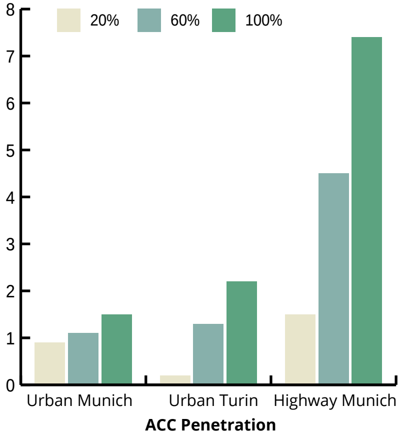
The vehicle control model interacts with the micro traffic model on-line when a simulation is executed and computes the speed profiles of the vehicles in the simulation in real-time. The emissions are computed from the speed profiles by the micro emission model after the simulation has finished.

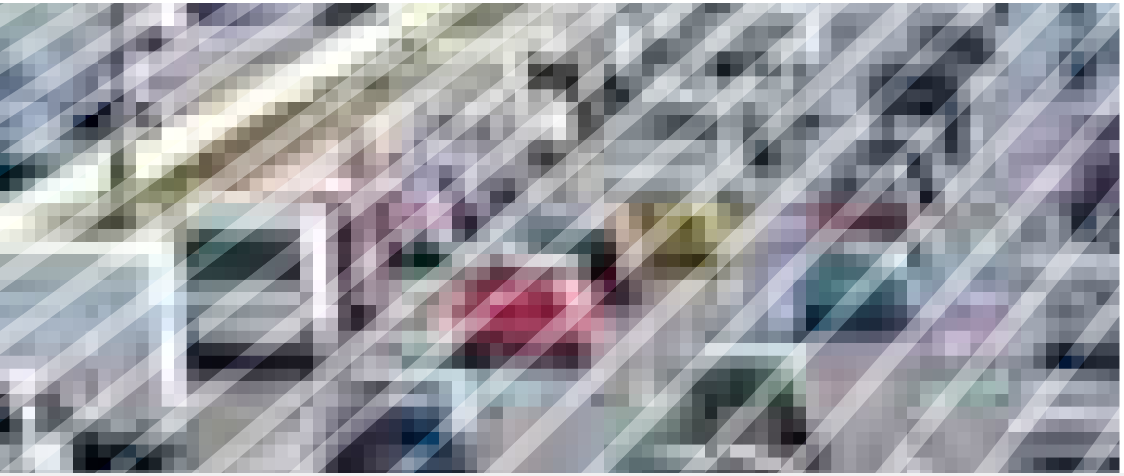
In each simulation step information about the velocities of the vehicles in the traffic simulation as well as about the distances to the preceding vehicles is transmitted to the ACC model in MESSINA. The latter computes from this data the velocities of the vehicles for the next simulation step. Hence, there is a continuous exchange of information between the traffic simulator and the vehicle simulator in MESSINA.

The impact of ACC was examined in the case of Munich for rather light (free flow) traffic conditions in an urban ring road (urban highway) and for a typical urban section, with both examples located in the wider Munich area (Schwabing). Also, ACC results were obtained in the case of Corse Lecce in Turin for free flow normal and congested conditions.

The impact of ACC cannot be considered directly proportional to its penetration because ACC equipped vehicles also affect their surrounding traffic. Hence the end effect is a combination of the impact on traffic behavior of both ACC-equipped and non-ACC equipped vehicles. The results are therefore presented as a function of the ACC-equipped vehicle occurrence in the fleet.
The impact of ACC in free flow conditions maximizes in highways because the ACC equipped vehicles keep a safe distance with the preceding traffic. In this case, most of the benefit comes from the smoother operation of the ACC equipped vehicles rather than the surrounding traffic. In urban free flow conditions, the benefit is less because vehicles still need to stop at traffic lights, which is the main cause of fuel consumption increase.

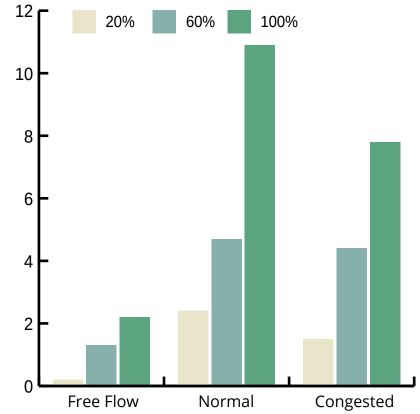
CO_2 benefit (%) for free flow conditions for two different road types as a function of ACC penetration



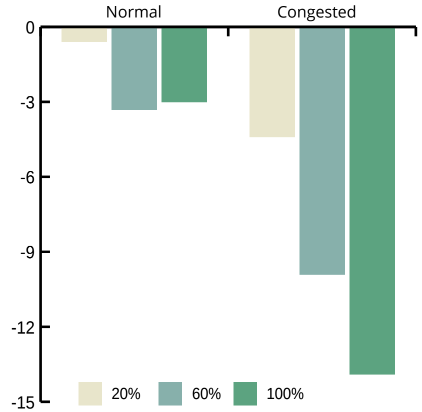


ACC may also offer significant benefits under normal and congested traffic in an urban network. This is the result of short response time of ACC vehicles to changes in the activity in front and early, hence smoother, braking. This improves start up times of queues from traffic lights and also offers less speed variation overall. The following figures show the results in CO_2 emissions and some average traffic parameters in the case of Turin as the fraction of ACC vehicles increases.

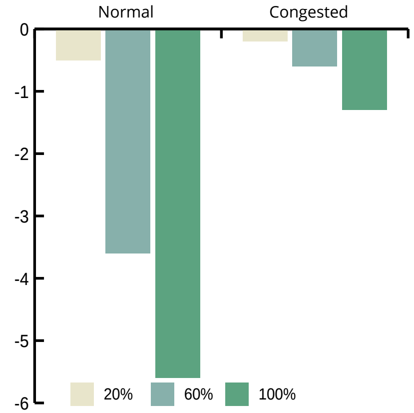
CO_2 benefit (%) at urban roads for different traffic levels and ACC penetration



Percentage (%) drop in average acceleration as ACC vehicles increase, which indicates smoother driving conditions



Percentage (%) improvement in travel time due to ACC introduction

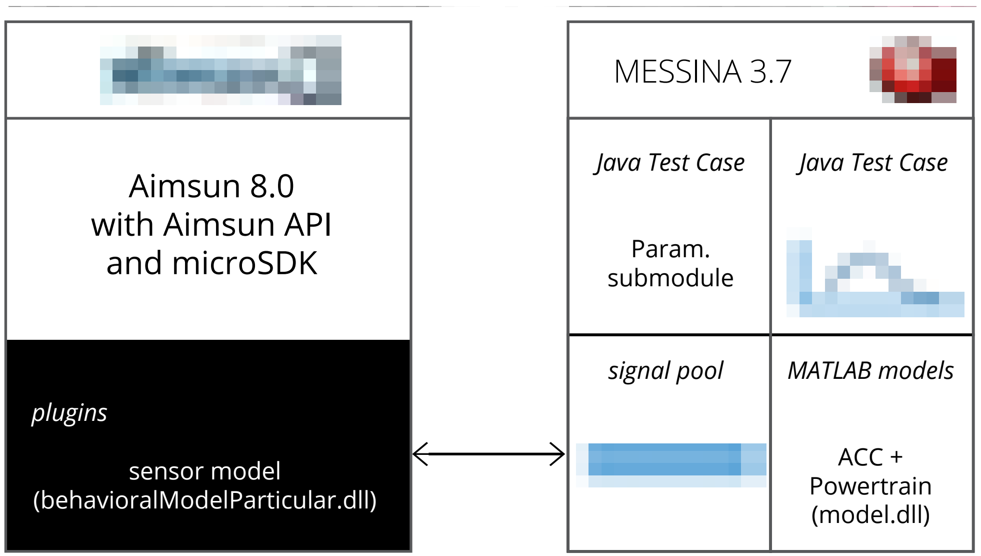


Methodology

For the integration of the ADAS/ Driver Simulator in the ICT-Emissions integrated simulation platform, an interface to the microscopic traffic simulator Aimsun was implemented and then applied in the Turin case. The figure below shows the realization of the general architecture in the tools Aimsun and MESSINA. The data exchange between Aimsun and the signal pool of MESSINA (simulated bus system) is performed via a TCP/ IP connection.

A parameterization submodule is used to set input parameters in the ACC simulations, such as the traffic density in the scenario or the penetration level for ACC vehicles and vehicle types.

The acceleration behaviour of the vehicles without ACC in the simulations is determined by human drivers. It is assumed that there are equal shares of aggressive, normal, and timid drivers. The parameters of the Gipps model, which is used as a human driver model, are set accordingly. The ACC vehicles are randomly distributed over all vehicles in the scenario. Hence, to balance out statistical effects, multiple simulation runs are performed at each penetration level. Thirty repetitions per condition were performed in our case.



Realization of the architecture of the ADAS/Driver simulation framework with Aimsun and MESSINA.

For this framework to operate, the following conditions need to be met:

- The vehicle simulator has to be able to establish a bidirectional (e.g. TCP/IP) connection to the micro-traffic simulator for inter-process communication and data exchange.
- All components in the system must be able to process data from multiple vehicles in a single simulation step to enable the bidirectional communication between the traffic model and the ADAS driver simulator.
- The programming interface (API) of the micro traffic model must provide methods to access data which is required by the sensor model.
- For each vehicle in the simulation the sensor model must be able to detect a target vehicle, which the vehicle should follow. The sensor model has to compute the distance between a vehicle and its target vehicle and the difference in velocity.
- The ADAS driver simulator model must implement a switch which allows the selection of either an ADAS model or a human driver model for the acceleration behaviour of a given vehicle in the simulation.
- The ADAS driver simulator compute an acceleration value based on the distance and the difference in velocity between a vehicle and its target vehicle as well as a defined safe distance which the vehicle should guard with respect to its preceding vehicle.
- A powertrain model should be embedded in the ADAS driver simulator to take into account the constraints of a real-world engine on the acceleration behaviour of a vehicle.
- The parameterization submodule has to offer the possibility for a user to define relevant parameters in the micro-traffic simulation and in the driver simulator. Relevant parameters in the micro-traffic simulation are the traffic scenario (road network) and the traffic density. Relevant parameters in the driver simulator are the shares of different driver types (calm, aggressive etc.), the penetration level of ACC vehicles and the type of vehicle in the powertrain model.

Put to the test:

Eco-driving

-15% Free
-10% Normal
Increase in Congested

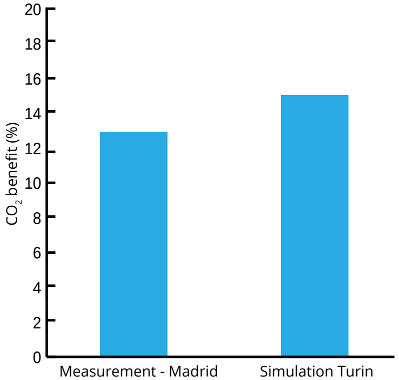
Eco-driving is not an ICT measure per se. It is a set of rules that can lead to decreased fuel consumption by improving the driving style. However, eco-driving can be assisted and promoted by on-board ICT measures like gear shift indicators and other dashboard visual stimuli. Hence, its effects are compared with normal ICT options.

In eco-driving mode, the driver is taught to accelerate and break smoothly, maintain a stable speed as much as possible by anticipating traffic, not operating the engine at high speed and not keeping the engine on long idle operation. Eco-driving also suggests lowering speeds in highways but, generally, eco-driving is most common in urban conditions, where fuel savings can be achieved without substantially lowering average speed and increasing travel times.

Usually in eco-driving, the distance to the preceding vehicle increases to allow room for smoother speed adjustment relative to the surrounding traffic. Speed and distance are parameters that influence, at the macroscopic level, the speed and density of traffic. Therefore micro effects need to be modelled first and the results need then to be scaled up to the macro level.

Eco-driving is a well-known practice to reduce fuel consumption of vehicles on the road. In ICT-Emissions both measurements with actual eco-drivers (Madrid) and simulations in Turin showed that fuel consumption and hence CO_2 emissions may decrease by 13-15% for a single vehicle by just changing the driving style to eco-friendly.

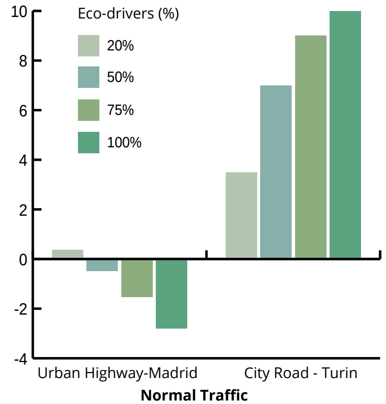
CO_2 benefits (%) of eco-driving.
Single vehicles in an urban free-flow network



Eco-driving results in longer distance from the vehicle in front so that the driver can adjust the speed and behavior to an optimum fuel economy style. Also, the driving style may affect the driving pattern of the following vehicles. As a result, eco-driving of single vehicles affects the surrounding traffic.
In normal traffic flow conditions, simulations on an urban highway in Madrid and in the city network of Turin showed that the CO_2 benefit achieved is not proportional to the fraction of eco-drivers on the road.

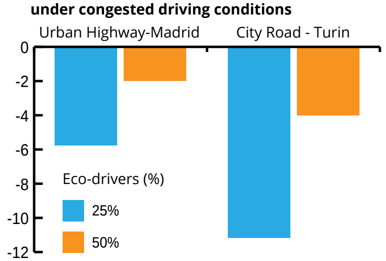
In Turin, while 25% eco-drivers induced 3.5% decrease of total fleet emissions, 100% eco-drivers led to 10% benefits, which is not a proportional benefit. In Madrid's urban highway, increasing the fraction of eco-drivers may actually lead to an increase in CO_2, as the road becomes saturated.

CO_2 benefits (%) of eco-driving
under normal driving conditions



Small or even negative benefits of eco-driving may be likely in congested conditions: eco-driving may lead to an early saturation of the road, as the fraction of eco-drivers increases. This is shown in the following figure.

CO_2 benefits (%) of eco-driving
under congested driving conditions



Note: Negative values denote increase in emissions

To put it in perspective, the stop time percentage doubles from 4.6% to 9% when the share of eco-drivers on the congested urban highway of Madrid increases from 5% to 100%. Therefore, despite each driver attempts to decrease his/her own fuel consumption, the combined result is an overall increase, because of worsening traffic conditions.

It should be stated that emission impacts of eco-driving under congested conditions are difficult to generalize as the roads are close to their saturation and small differences in their capacity may lead to the formation of vehicle queues trying to enter the modelling domain.
Our results showed that eco-driving modelling is a delicate procedure that is much dependent on the exact road conditions and the eco-driving modelling approach that has been adopted. Care should therefore be taken in the simulation parameterization and the interpretation of its results.

In a nutshell, eco-driving is a measure with significant positive impact in reducing CO_2 emissions but should not be practiced under highly trafficked conditions because it seems to worsen congestion, possibly including emissions increase.

The results at the microscale have repercussions on the macroscale as well. The following figure shows the overall drop of speed in the road network of the city of Turin. Basically, under heavy traffic conditions, eco-driving extends congestion to a wider fraction of the total network and mean speed drops by approximately 30%.

Mean speed per link in Turin
area at high traffic conditions.
Eco-driving decreases speed
and leads to worsened traffic congestion

Non eco-driving **Eco-driving**

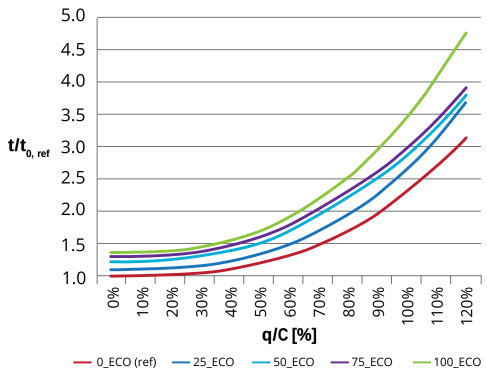
Legend: Mean travelling speed (km/h)
<= 10 <10 <= 20 <20 <= 40 <40 <= 70 >70

One important point refers to the eco-driving and adaptive cruise control comparison. Despite both measures aim at calming driving behavior, the random character of the former could lead to emissions increase on a fleet level. ACC on the other hand leads to a more streamlined behavior as one vehicle tries to follow (mimic) the behavior of the vehicle in front and offers more consistent emissions reductions.

Methodology

The critical point of eco-driving modelling is to calculate the new capacity of the road when this is used by a certain fraction of eco-drivers. In modelling terms, this means determining the new speed-intensity function (fundamental diagram). A new fundamental diagram has been derived for both Madrid (Highway) and Turin (urban network) by using the results of several micro traffic simulations with various degrees of eco-driving penetration.

The following figure shows the new functions derived for urban driving and a summary of key macroscopic parameters is shown in the adjacent table.

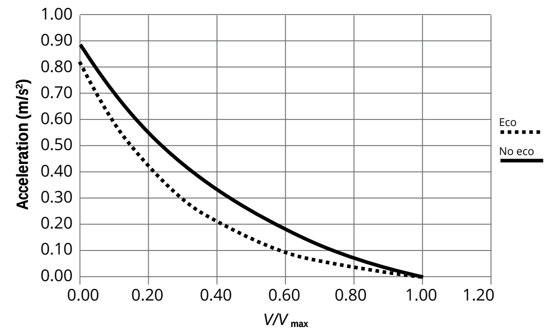


% ECO	Δtime at t_0	Δtime at 100% capacity
0	-	-
25	11%	16%
50	22%	26%
75	30%	30%
100	36%	50%

This step is necessary to link micro and macro traffic assessments of eco-driving. If this step is neglected, then the eco-driving impact cannot be reliably assessed on a fleet level. The fact that eco-driving decreases the capacity of the road, as shown in the example above, explains why the impact of eco-driving on a macro level is not a direct analogous of the results at the micro level.

Producing the new fundamental diagrams also requires careful calibration of the car following law in the micro traffic model. The most widespread models are the Gipps and the Wiedemann ones, which use a completely different logic. In the ICT-Emissions project both models were calibrated using real-world monitored data. The Fiat eco:Drive data fed the revised Gipps function. Detailed information on the approach is given in paper "Traffic Models Enhancements: Assessment of Eco-driving behavior" by Morello et al. (2014) [Journal of Traffic and Transportation Engineering, Vol. 2, pp. 97-106].

In Madrid real-world measurements with floating cars implementing or not the eco-driving principles were conducted. Then the parameters of the Wiedemann model were adjusted to replicate the two different driving styles. The following figure shows an example of the different driving behaviours of eco vs non-eco drivers that need to feed the revised Gipps model.



After the micromodels have been calibrated, then they were executed for various penetration rates of eco-drivers and a number of replications per setting were performed to account for the uncertainty due to the random allocation of eco-drivers in each scenario. Uncertainty analysis showed that 10-20 replications are enough to substantially confine the random error.

In the examples modelled in ICT-Emissions, the Madrid urban highway was modelled in its southbound direction, in a section of 6.6 km of M30 consisting of 3 lanes and with a peak hour traffic of 6000 veh/h. The speed is limited to 90 km/h except for the last 100 m prior to a tunnel entrance where it is limited to 70 km/h. The Turin case was situated in a 1.6 km section of the Corse Lecce with peak hour traffic of 7500 veh/h.

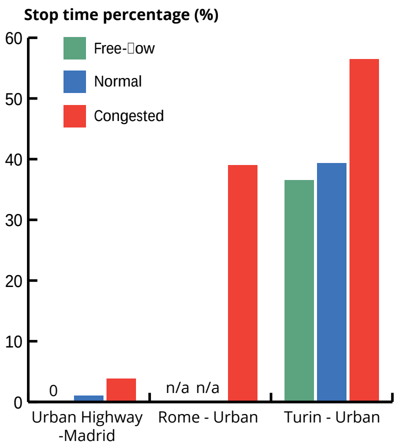
Put to the test:

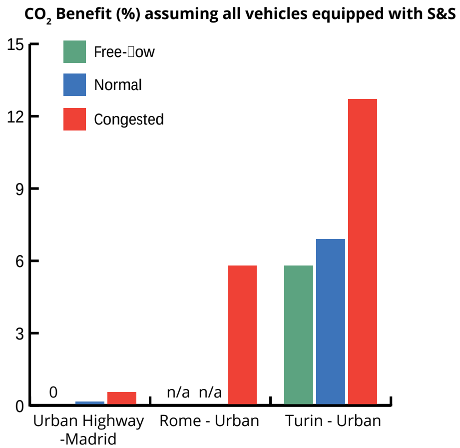
Start & Stop *[S&S]*

-6% – -12%
Urban Driving

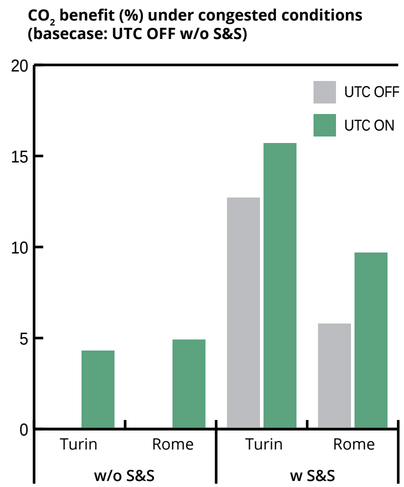
Start and stop is a vehicle technology that switches off the engine while the vehicle is stationary, e.g. at a traffic light. It may offer fuel consumption benefits, especially as stop events increase in frequency and/or in duration.

S&S systems have become popular today in an effort to decrease fuel consumption of passenger cars and most new vehicles are equipped with such a functionality. Although this is primarily a vehicle technology, it is still classified as an ITS system.
In ICT-Emissions we explored the benefits of S&S in three cities (Madrid, Rome, Turin), under various traffic conditions and in combination with other ICT measures. As expected, the impact of this measure is variable but can be significant under congested traffic that induces several stops. This is shown in the two following figures where the impact of S&S is minimal in an urban highway (Madrid) and maximizes for urban congested conditions, where stop time can exceed 50% of total trip duration (Turin)





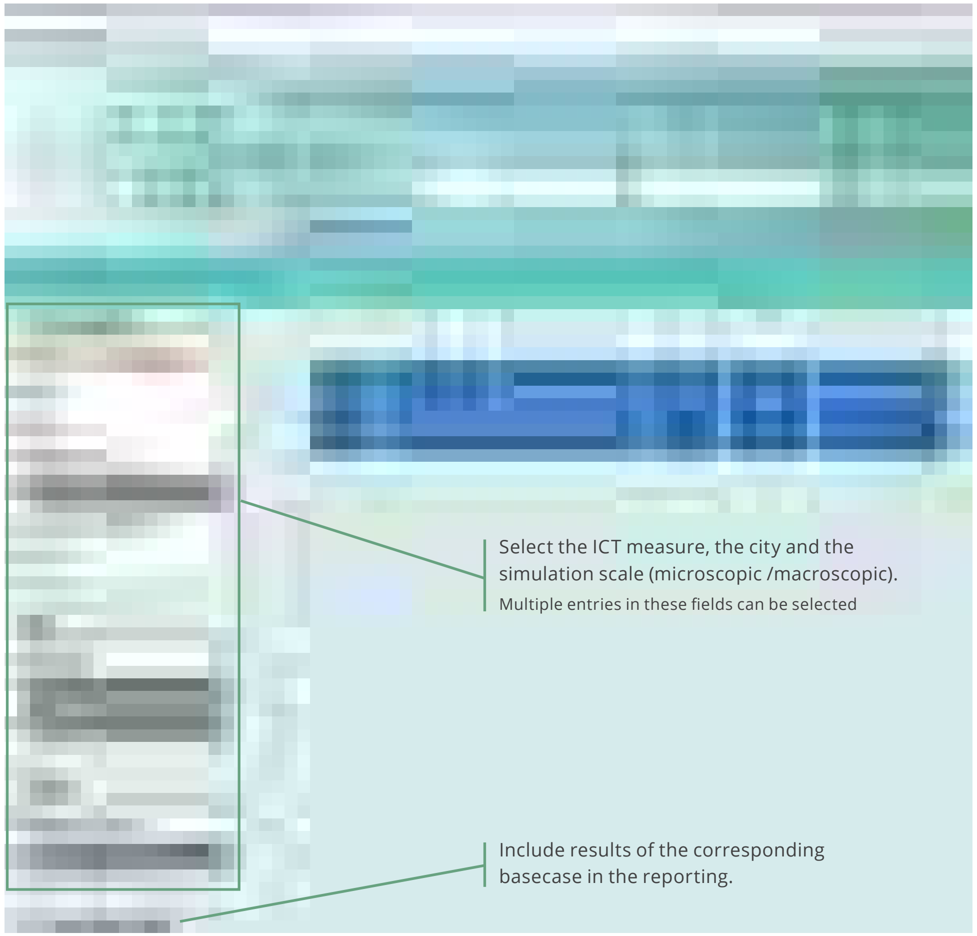
We also examined the combination of S&S together with UTC in two cities. This is a typical example that the combined benefit of two ICT measures is not their arithmetic sum. The following figure shows that UTC and S&S at congested conditions offer maximum benefits, which are though 10% lower of the arithmetic sum of the benefit of both measures. Still, this is a very substantial benefit.

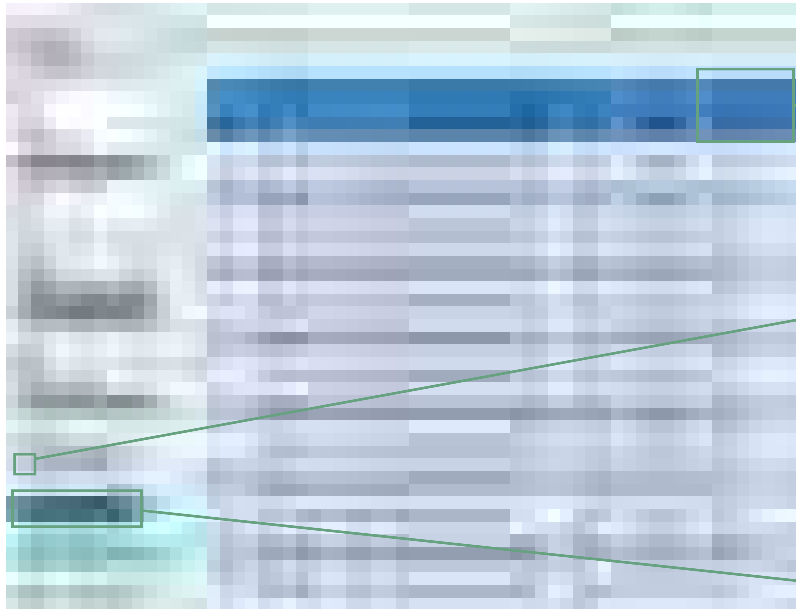


A few words on the methodology
Modelling the impact of S&S requires appropriate vehicle micromodels that are able to switch off the engine at neutral gear and when the speed drops below a certain limit (e.g. 2 km/h). Also, reliable idle consumption values are required as a function of the vehicle type and category. The simulation has then to be executed at the micro scale but S&S does not affect the speed profile. Our results presented assumed 100% S&S penetration for passenger cars. The impact of S&S is directly proportional to its penetration on fleet vehicles.

Database Results

Major results of the project for different scenarios were collected in a public access database, with a web interface at http://ictemissions.meng.auth.gr. The database can be used by authorities and traffic stakeholders to get a reliable value of the CO_2 impact of different measures, under the conditions these were tested. It also provides details on the traffic flow data, vehicle mix (fleet composition) and other parameters for the scenarios executed.





By clicking on the title Benefit [%] the entries in the table are sorted in an ascending or descending order.

By selecting this option, results of associated micro and macro scenarios are both presented.

Summary results of the selection are produced by clicking Generate summary.

Results contain condensed information on the ICT measure simulations stored in the database,

Detailed results, including traffic parameters and values are produced by clicking "Export results to CSV ..."

These data are interesting for researchers that want to study the details of the scenarios. The type of the separator symbol (comma, semicolon etc.) which should be used in the generated CSV file can be selected below the button.

Public Deliverables

ICT-Emissions has produced a list of deliverables with detailed description of the methodology, the modelling and the results of the project. All deliverables may be found at http://www.ict-emissions.eu. A summary list follows.

Outline of the methodological framework and approach for each of the ICT measures considered.
Toffolo et al. (2013) Deliverable 2.1: Methodology

Implementation sites for the methodology and guidelines for implementation of the methodology
Garcia-Castro et al. (2014) Deliverable 5.1: Case studies definition
—
Toffolo et al. (2015) Deliverable 5.2: Manual of procedures for use of the methodology

Details on the vehicle simulators used for micro scale emission modelling and the approach for macro emission modelling
Vock et al. (2013) Deliverable 3.1: Vehicle energy/emission simulator for conventional and advanced passenger cars
—
Vock et al. (2014) Deliverable 3.2.1: Report on the development and use of the vehicle energy / emission simulator.

Validation, assessment and results of application of the methodology
Cocozza et al. (2013) Deliverable 6.1: Evaluation plan
—
Valdes-Serrano et al. (2015a) Deliverable 6.2: Field trials and simulation comparison
—
Valdes-Serrano et al. (2015b) Deliverable 6.2: Results of application of ICT measures in ICT-Emissions partner cities

Description of the modelling of adaptive cruise control and its linkage to traffic micro simulation models.
Schott et al. (2014a) Deliverable 4.1.2: Parameterization submodule
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Schott et al. (2014b) Deliverable 4.2.2: Driver simulator

Description of the structure and operation of the on-line database at http://ictemissions.meng.auth.gr.
Ntziachristos et al. (2015) Deliverable 4.3.2: ICT-Emissions database library

What we have learned

Simulation of ITS measures is a demanding process that requires simulation advancements beyond the current state of the art, with respect to vehicle, traffic and emission modelling. The ICT-Emissions project made a number of steps in this direction. Most importantly:

- ADAS modelling requires a complete new approach so that specific control algorithms are taken into account in the car following submodels of micro traffic models.
- Eco-driving demands a new car following submodule to account for the smoother driving performance of eco-drivers.
- Moving from the micro to the macro scale requires a fully calibrated interface, e.g. through specifically developed speed-intensity functions.
- Macro emission modelling requires improvements so that emission factors take into account the impacts of traffic level, eco-driving and ADAS on a link-by-link basis.

Several measures that primarily have a micro-scale component (e.g. eco-driving, advanced driver assistance systems, etc.) also have repercussions on the macro-scale. This because vehicles operating at those regimes also affect their surrounding traffic. As a result, benefits assessed by simulations or measurements on a single vehicle basis are not proportionally transferrable to the fleet level.

ITS measures can lead to traffic improvement with associated positive CO_2 impacts proven under real-world conditions. Our project examined several ITS measures including, adaptive cruise control, eco-driving, green navigation, start and stop systems, traffic-adaptive urban traffic control, and variable speed limits in several cities.

- The impact of these measures in real traffic ranges from few percentage units up to 15%, depending on the measure, the road network considered, traffic conditions and the on-road vehicle mix.
- Real-world emission benefits at fleet level are almost always less than the benefits obtained on a single vehicle because of the suboptimal conditions that vehicle-to-vehicle interaction results in.
- Precise estimation of the actual benefits can be achieved only accounting for the actual penetration of the measure and traffic and vehicle mix variation with their temporal and seasonal profiles.

We also obtained a number of not expected results. These present an interest for further research and scientific analysis. In particular:

- Eco-driving offers significant benefits in normal and free flow conditions but seems to worsen congestion under heavy traffic. This may even lead to a slight increase in CO_2 emissions at fleet level.
- ADAS, and in particular adaptive cruise control, although implementing principles similar to eco-driving, seems to perform much better even under congested conditions; this is most likely attributed to the more constrained way that vehicles operate in relation to the preceding vehicle.
- Green-navigation, i.e. vehicle routing to save fuel, also offers measurable benefits in terms of CO_2 emissions. However, relative benefits decrease as its penetration to the fleet increases, and is also associated with significant increase in travelling time.
- Relative impacts differ for vehicles of alternative powertrain systems. Advanced vehicle technologies such as hybrids and plug-in hybrid vehicles seem to offer higher reduction potential because of their more degrees of freedom to optimize performance according to traffic situation.

Our main conclusion from this project is that, despite compromises, several ITS/ICT measures can readily be implemented to address total CO_2 emissions of the existing on-road fleet. As a result, they should be seen as a pragmatic option to curtail road transport CO_2 emissions and should be further advanced in the relevant policy and environmental context.

More on ICT-Emissions: Achievements beyond the state-of-the-art

The ICT-Emissions project advanced the current knowledge of traffic and emission modelling by:

- Developing a software suite, using existing commercial tools and newly developed components, that can simulate impacts of specific ICT measures taking into account fleet, traffic, powertrain, and ADAS variables.
- Creating a specific interface to enable microtraffic and adaptive cruise control bidirectional real-time link.
- Simulating the real-world impact of a number of ICT measures and validating this with actual on-road experiments using floating cars.
- Performing thousands of replications to study the impact of ICT measures in various cities and traffic environments, operating at various traffic levels and with a range of vehicle mix and ICT measure penetration rates.

for more information

www.ict-emissions.eu

With a view to the future

The work undertaken, the results obtained and the know-how of the interdisciplinary project team allow a rather clear view of the developments to come:

> ICT-Emissions methodology and toolset will expand beyond CO_2 and passenger cars to include air pollutants and commercial vehicles.

> ICT-Emissions know-how and team of experts can participate in any Smart Cities Solution and assist in deploying effective ICT measures for any particular application.

> ICT-Emissions methodology can serve as a test bench for the assessment and certification of eco-innovations.

> ICT-Emissions can contribute to International Collaborations with a wealth of experiments, test data, case studies and validated methods and tools.

> ICT-Emissions is one major step toward an urgently necessary Standarised Assessment Methodology (SAM) - a system for the interpretation, comparison and up-scaling of different approaches for a Smart, Green and Integrated Transport.

Consortium partners

Coordination and macro emission modelling

Aristotle University of Thessaloniki

Laboratory of Applied Thermodynamics

Assisted in coordination by

Heich Consult

Traffic and Emission Modelling

AVL LIST GmbH

CNH-Industrial - IVECO

Universidad Politecnica de Madrid

European Commission – Joint Research Centre – Unit F08 Sustainable Transport

Advanced Driver Assistance System Modelling

Berner & Mattner Systemtechnik GmbH

Real-world experiments

Agenzia Roma Servizi per la Mobilità Srl

Madrid- Calle 30

Centro Ricerche Fiat S.C.p.A.

Tecnologie Telematiche Trasporti Traffico Torino (5T) s.r.l

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