ICT-Emissions

Evaluation Plan

SEVENTH FRAMEWORK PROGRAMME

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0 Executive summary

ICT-Emissions project aims to develop a comprehensive methodology to assess the impacts of road transport. This assessment will calculate the total efficiency of ITS measurements related to energy consumption and CO_2 emissions in urban environments.

The present document describes the evaluation plan for applying the ICT-Emission road transport impact assessment methodology. For the sake of completeness and in an attempt to help the reader, the document has been written to be as much as possible comprehensive and "stand alone". For this reason, the core chapter 5 "Assessment Framework" is preceded by three chapters providing an overview on potential users, ITS measures and ICT methodology.

The Assessment Framework introduces the objectives, the usage of indexes as methods of assessment, the description of each index used to assess each objective and the foreseen simulation plan.

ICT measure categories	User	Objectives
All	Decision maker and public authorities	1. Capability to simulate an ICT measure; 2. Capability to estimate ICT measure effects on traffic parameters; 3. Capability to test if an ICT measure has positive impacts on CO_2 emissions; 4. Capability to estimate potential reductions in CO_2 emissions.
ADAS, Driver behaviour change and eco driving, Navigation and Travel Information.	Automotive OEMs and suppliers	1. Capability to simulate an ICT measure; 2. Capability to test if an ICT measure has positive impacts on CO_2 emissions; 3. Capability to estimate potential reductions in CO_2 emissions; 4. Capabilities to model vehicle emissions.

Table 1: Users and objectives

Nr	Indicator	Micro	Macro
1	**Capability to simulate an ICT measure**		
1.1	travel time / average speed	X	X
1.2	number of stops	X	
1.3	percentage of stop time	X	
1.4	percentage of constant speed	X	
2	**Capabilities to model vehicle emissions**		
2.1	emission	X	X
2.2	fuel consumption	X	X
3	**Capability to estimate an ICT measure effects on traffic parameters**		
3.1	travel time / average speed	X	X
3.2	number of stops	X	
3.3	percentage of stop time	X	
3.4	percentage of constant speed	X	
4	**Capability to test if an ICT measure has positive impacts on CO_2 emissions**		
4.1	emission	X	X
4.2	fuel consumption	X	X
5	**Capability to estimate potential reductions in CO_2 emissions**		
5.1	emission	X	X
5.2	fuel consumption	X	X

Table 2: Indicators and levels of simulation

1 The ICT Emissions Project

ICT-EMISSIONS aims to develop a new methodology to evaluate the impact of ICT-related measures on mobility, vehicle energy consumption and CO_2 emissions of vehicle fleets at the local scale, in order to promote the wider application of the most appropriate ICT measures. The proposed methodology combines traffic and emission modeling at micro and macro scale. The application of the methodology will be demonstrated using commercially available software. However the methodology is developed in such a way as to enable its implementation by a variety of emission and traffic models. Particular emphasis is given to the correct estimation of driver behavior, as a result of traffic-related ICT measures, the coverage of a large number of current vehicle technologies, including ICT systems, and near future technologies such as hybrid, plug-in hybrids, and electric vehicles. The innovative combination of traffic, driver and emission models produces a versatile toolbox that can simulate the impact of infrastructure measures on energy and CO_2 emissions (traffic management, dynamic traffic signs, etc.), driver assistance systems and Eco solutions (speed/cruise control, start/stop systems, etc.) or a combination of measures (cooperative systems).The methodology will be validated by application in the Torino, Madrid and Roma areas.

1.1. OBJECTIVES

The main aim of ICT-EMISSIONS is to develop an integrated methodology that can be used to quantify the impact of ICT solutions on energy consumption and CO_2 emissions of road transport.

This target and the associated objectives of ICT Emission project re-enter into "**Low carbon multi-modal mobility and freight transport (ICT-2011.6.6)" topic of the call FP7.ICT-2011-7**. In particular, into "**ICT for clean and efficient multi-modal mobility" (area (b))**, and specifically the point described in the call as:

"Methodologies for assessing the impact of advanced ICT in energy efficiency and CO_2 reduction, and in instantaneous emission models which take into account driver behaviour."

The scientific and technical objectives/activities of ICT-Emission can be grouped in the following six categories:

1. Develop a comprehensive methodology to assess the impacts of road transport ICT measures on CO_2 by taking into account the real-world driving and traffic behavior in urban agglomerations.

2. Develop vehicle simulators to calculate the energy and CO_2 emissions of vehicles when operating in ICT regimes, also taking into account advanced vehicle technologies (hybrids, plug-in hybrids, electric, start-stop, etc.).

3. Simulate the impact of various ICT measures by implementing commercial traffic models at the micro and macro scales, and link them to vehicle simulators, following the methodology developed.

4. Validate the methodology on existing real-world ICT applications in three cities.

5. Summarize the impact of ICT measures on traffic, energy, and emissions in a database library.

6. Exploit the results of the project by issuing recommendations and implementation guidelines for use of best-practice ICT measures that can lead to significant energy and CO_2 reductions from road transport.

1.2. STRUCTURE OF DOCUMENT

The deliverable consists of 6 chapters:

1. The ICT Emission Project
2. Users and their needs
3. ITS measures
4. ICT Emission Methodology and Tools
5. Assessment Framework
6. The Turin case – an example

The first 4 chapters represent level 1 devoted to inform public authorities, press and general public. Level 1 provides an overview on users and their needs, on already available measures and on proposed ICT Emission methodology. These chapters have been also introduced in order to have a stand-alone and more comprehensive document.

Level 2 devoted to provide technical implementation details, consists of chapter 5 and 6.

Chapter 5 is the core of deliverable: it describes the “Assessment Framework”, its objectives, its methodology and indexes and provides also the “simulation plan” that will drive most of the activities in WP6.

Chapter 6 has been introduced in order to provide an example of how apply the evaluation methodology to a real case.

2 Users and their needs

Transport planning authorities, local authorities, automotive OEMs and suppliers are on top of the list of potential users of the proposed methodology. More specifically:

2.1. USERS

ICT Emission methodology has been conceived to meet the needs of these potential users:

1. Local authorities such as:
   a. Traffic and transport department
   b. Environment department
   c. Health department
   d. Urban planning department

2. Decision makers such as:
   a. Urban development
   b. Traffic and transport
   c. Environment
   d. Health

3. Automotive OEMS and Suppliers

2.2. USER NEEDS

The awareness of strong impacts of “transport” on greenhouse gas emission is spreading more and more among both national and local authorities and decision makers. ICT technologies has been proven to be able to tackle these issues but their deployment requires investments and nowadays national and local institutions has to face strong financial constraints due to the economic recession. ICT Emission aims at optimizing passenger transport systems by applying ICT measures, while keeping in mind the needs of passengers and ensuring that the impacts of any proposed measures are carbon neutral as far as possible. It is intended to examine passengers’ current travel needs, mobility patterns and business models and to examine how future changes might be used to bring about more sustainable travel patterns. In the end, different sets of strategies and methodologies for optimising passenger transport systems based on ICT options will be created and developed.

This background leads to the following questions:

- How is it possible to reduce CO_2 emissions using ICT measures?
- Which are the ICT measures potentially useful in CO_2 reduction?

- Which are the impacts of a specific ICT measure on CO_2 emission?
- Which are the impacts of a specific ICT measure on traffic?

Authorities and decision makers need new instruments/tools able to drive their choices; to be able to anticipate the possible benefits following the introduction of an ICT measure can be a successful way to reduce emissions and save money.

Automotive OEMS and suppliers are more focused on on-board systems and on what will become a competitive advantage in selling cars. The knowledge of effects of ICT measure on CO_2 reduction would become a competitive asset.

In order to pave the way to these new tools, it is necessary to:

- Develop a comprehensive methodology to assess the impacts of road transport ICT measures on CO_2 by considering the real-world driving and traffic behaviour in urban agglomerations.

- Develop vehicle simulators to calculate the energy and CO_2 emissions of vehicles when operating in ICT regimes, also taking into account advanced vehicle technologies (hybrids, plug-in hybrids, electric, start-stop, etc.).

- Simulate the impact of various ICT measures by implementing commercial traffic models at the micro and macro scales and linking them to vehicle simulators, following the methodology developed.

- Validate the methodology on existing real-world ICT applications in three cities.

- Summarize the impact of ICT measures on traffic, energy and emissions in a database library.

- Exploit the results of the project by issuing recommendations and implementation guidelines for use of ICT measures best-practice that can lead to significant energy and CO_2 reductions from road transport.

3 ITS measures

Intelligent Transport Systems (ITS1) applications can be divided into six categories:

1. Driver behavior change and eco-driving
2. Navigation and travel information
3. Traffic management and control
4. Demand and access management
5. Logistics and fleet management
6. Safety and emergency systems

The list does not claim to be exhaustive, but cover the principal categories of ITS systems based on ICT solutions. As such, it gives an indication of the range of systems which will need to be taken into consideration in the definition of the common methodology. From the above six categories, ICT EMISSIONS will focus on the first four (excluding logistics and fleet management as well as Safety and emergency systems).

3.1. Driver Behaviour Change and Eco Driving

Driver behaviour can have significant impact on fuel consumption. According to the eco-driving literature (Table 3) considering the “average” driver, up to 10% or more of fuel can be saved having an “eco” behaviour. On the other side, a “bad” behaviour could produce extra fuel consumption (50% or more, compared to the average one). So the ***promotion of an energy-efficient style of driving*** is a very important measure for consideration. This can be made after the trip is completed (off line analysis), with the data collected during the trip. More effective is a real time system that suggests the correct behaviour to the driver while he/she is driving. The simplest solution of this type is the ***Gear Shift Indicator,*** that suggests a gear change when the speed of the vehicle is not appropriate (higher or lower) to the current gear.

Eco behaviour could be improved by some vehicle functions like ***Start &Stop system,*** that turn off the engine when the vehicle is stopped. Another one is ***Tyre***

[1] The terminology ITS include the overall set the Intelligent system applicable in the transport context, so they include also the ICT systems and devices installed in vehicles.

pressure monitoring, avoiding travelling with insufficient tyre pressure, condition that produce higher fuel consumption.

Study	Study Type and Size	Short-term	Long-term
Quality Alliance Eco-Drive (2004)			11.7%
	Driving instructors and experts in Switzerland		12% (8 months) 21% (17 months)
	Eco-Drive course		12%
	Simulator course	15%	17%
	Simulator driving		25% (max)
	Eco-training as part of the new driver training		0%
Henning (2008) (Ford of Europe)	German-wide (1998-2000); 300 participants	25% (average)	15% (max) 10% (average)
	Leipzig Motor Show; (74 people trained)	26.1%	
	Frankfurt Motor Show; (765 people trained)	20.65%	
FIAT eco-drive (2010)	Study based on 150 days in 2009 with 428.000 trips done by 5.700 customers with their cars in Italy France Spain UK		6% average 16% maximum
Ford Motor Company (2008)	Intense 4-day class	24% (average)	
Onoda (2009)	Summary of Eco Drive Program in Europe	5 to 15%	5% (no feedback) 10% (w/ feedback)
Vermeulen (2006)	Study by TNO: 24 drivers over predefined route		7% (gasoline) 8 to 10% (diesel)
Taniguchi (2007)	Study of eco driving training	20%	
Beusen and Denys (2008)	VITO study of 8 drivers following training		-1.7% to 7.3%
Beusen et al. (2009)	VITO study of 10 drivers following training	12 to -3% 5.8% (average) (4 months)	
Barth and Boriboonsomsin (2009)	Simulations with limited real-world experiments	10 to 20%	
Bragg (2009) (FuelClinic.com)	620 FuelClinic.com users following driving tips	5.23%	
Saynor (2008) (Ford Motor Company)	Driving trials by Ford Motor Company and Energy Savings Trust: total of 494 drivers	17 to 25%	
Mele (2008)		35% (average)	
WBCSD (2008)	Fuel economy training courses offered by Volkswagen and Naturschutzbund Deutschland	13% (average) 25% (max)	

Table 3: Summary of potential fuel savings identified in the eco-driving literature

3.2. NAVIGATION AND TRAVEL INFORMATION

An automotive navigation system is a satellite navigation system designed for use in automobiles. It typically uses a GPS navigation device to acquire position data to locate the user on a road in the unit's map database. Using the road database, the unit can give directions to other locations along roads also in its database. Dead reckoning using distance data from sensors attached to the drivetrain, a gyroscope and an accelerometer can be used for greater reliability, as GPS signal loss and/or multipath can occur due to urban canyons or tunnels.

The navigation has an impact on fuel consumption since it allows avoiding extra mileage due to mistakes in the route followed to destination. Furthermore the route calculation includes some parameters (shortest distance, fastest road) that can produce fuel saving compared with the route followed without the system.

This is the basic navigation system (***On-Board navigation Systems***). Further benefits in terms of time (and fuel) saving can be achieved if the on board unit has access to real-time information (***Dynamic on-trip routing***): congestions due to traffic, road works or accidents can be avoided.

When historical traffic data are available, based on the collection of information made from the infrastructure or from the vehicle fleet, the routing towards the destination can consider also the expected traffic (and thus average speed) and calculate the best route to reach the destination with the lowest possible fuel consumption (***green enhanced navigation system***). Historical data can be complemented with real time information (traffic, accidents, road works, etc.) to have the most complete solution (***green enhanced navigation system with real time data).***

Some information is useful to avoid unnecessary fuel consumption. Having the information of the parking slot available (***Intelligent Parking***) the navigation system could guide the driver directly to the most convenient one, saving time and fuel.

A benefit can be obtained, in particular, when multiple destinations have to be reached, using (web based) planning tools before the trips start (***Web based pre-trip information system***). This can be useful in particular when the destination is not well defined (a cheaper shop, a good restaurant, etc.). In the near future such a system could also operate in real time on the vehicle, thanks to the mobile connection to a server ***(cloud navigation***).

3.3. TRAFFIC MANAGEMENT AND CONTROL

Under this classification there are all infrastructure based systems that are able to measure (traffic monitoring) the level of traffic on a road network enabling then a management or control of traffic in order to optimize the use of the available road capacity.

One solution is to control traffic lights at the intersections, using traffic sensor information (***Isolated controlled intersections***). This can avoid having traffic stopped on one way while there is no traffic in the other one. The benefits are clear, in terms of traffic flow and fuel consumption, in particular in the rural roads, where stopping a vehicle from a high speed to zero means a lot of energy dissipated.

When traffic lights of several intersection are all controlled by a single system the traffic control could be "plan based" (***Plan based control***). Green wave strategy can be implemented, allowing vehicles that observe the speed limit to find always green at the intersections.

When this plan takes into account the level of traffic (***Traffic adaptive Urban Traffic Control***) the available road capacity is optimized. If the information about the optimal speed to keep can be transmitted to vehicles (***Traffic adaptive Urban Traffic Control + V2I***), an extra saving can be obtained by avoiding excessive speeds compared to the actual traffic flow in that specific traffic condition.

However all the above mentioned measures have an impact on fuel consumption which is generally positive.

All the previous measures are mainly applicable to urban scenarios. On highways one of the most interesting measures is ***Ramp Metering.*** *By* measuring the traffic on the highway it is possible to monitor the level of congestion and calculate the residual capacity of the road stretch, and thus finally to rule the entrance traffic from ramps in order to avoid the trigger of congestions.

Instead of reducing traffic demand, a solution to avoid congestion is to increase road capacity. This is possible with ***Dynamic lane systems,*** i.e. the possibility to open an extra lane when traffic level is higher than a certain threshold. Emergency lane can be used, under defined conditions, as standard lanes. In general, the infrastructure is adapted to dynamically set one or more lanes to a certain traffic direction.

Speed Control (point-to-point), like the TUTOR system in Italy, are solutions to improve the road safety. License plates of vehicles travelling on closed (without ramp) portions of highway are detected at the beginning and the end of the road portion. Average speed on this road portion is calculated for each vehicle and those exceeding the road speed limit are fined. These systems have also impacts on GHG emissions, since the excessive speed is (almost completely) avoided. Furthermore these systems make more effective ***Dynamic Speed Limits,*** in particular when introduced not only for safety reason but also to reduce emission.

There are also other measures that have impact of GHG emissions. One very important is related to intervention on the ***road geometry***. The infrastructure measures can also change the traffic impacts on CO_2 emissions and energy consumption. The measures in some cases include ITS technologies. A typical example is the transformation of an intersection controlled by traffic light into a passive roundabout. This is a very common measure to improve road safety that could have positive or negative impacts on GHG emissions.

3.4. Demand and Access Management

These measures have impacts of GHG emissions since they produce, in general, a traffic reduction, or a modal change (from private car to public transport). It is not guaranteed that the impact is positive (GHG emission reduction) since a traffic reduction in an area could produce an (higher) increase in another area. A typical example is to move the traffic crossing a city to a longer road around the city itself.

The simplest measure is ***infrastructure-use pricing,*** like London congestion charging. If the vehicle is entering in a defined zone, a fee has to be paid. Since all vehicles (typically) pay the same fee this measure could be not very popular, since poor people are more damaged. ***Carbon-credit schemes*** where all people have a certain “credit” before to start to pay are more acceptable by the general public.

Restricted traffic zones are normally introduced for social reason (create pedestrian areas or reduce pollution). The impact on GHG emission could be negative, as already discussed before, since the crossing traffic has to take a longer way to avoid the restricted area.

Pay-as-you-drive strategy could be very effective, since reduces the travelled kms but also the “way” they are travelled. Excessive speed or acceleration can be reduced through an increase of the cost of doing such manoeuvres.

3.5. Advanced Driver Assistance Systems (ADAS)

All systems that support the driver in the longitudinal control of the vehicle (acceleration and braking) have an impact on fuel consumption. The simplest solution, ***Cruise Control***, that keeps constant the vehicle speed, has some benefit on emissions since it avoids unnecessary speed change that produce extra fuel consumption.

Cruise control could consider also the road geometry (***Navigation based cruise control***) and speed limits, using the information available on digital maps and satellite based localisation. When the traffic in front of the vehicle is detected by a radar the speed of the vehicle can be adapted to the traffic (***Adaptive cruise Control, ACC)***.

When the vehicle communicate directly with the infrastructure there is the ACC vehicle with V2I (vehicle to infrastructure communications).

Normally ACC is able only to manage the vehicle speed above a certain threshold; the most sophisticated systems are able also to manage situations of very slow or stopped traffic (queue) (**ACC+STOP&GO**).

If vehicles are able to exchange information between them (thanks to a Vehicle-to-Vehicle communication link) the cruise control could adopt the speed profile of a preceding vehicle (***Cooperative cruise Control***).

All these systems have direct (on the control vehicle) and indirect (on the surrounding traffic) impact on GHG emissions.

3.6. ITS Measures with CO_2 impacts

The following tables summarize the ITS measures proposed to investigate in the ICT-emissions project:

1. ITS 1 - Driver behaviour change and eco driving
2. ITS 2 - Navigation and travel information
3. ITS 3 - Traffic management and control
4. ITS 4 - Demand & access management
5. ITS 5 - Advanced driver assistance system (ADAS) and other measures

Classifica-tion	Name	Brief Description
Driver behaviour change and eco driving	Promotion of an energy-efficient style of driving	Recommendations e.g. on Internet, PC or via on board displays to encourage energy saving driving behaviour
	Gear Shift Indicator	Gear change when the speed of the vehicle is not appropriate (higher or lower) with the gear used
	Start & Stop	Turn off the engine when the vehicle is stopped
	Tyre pressure Monitoring	Avoiding travelling with insufficient tyre pressure

Table 4: ITS 1 - Driver behaviour change and eco driving

Classifica-tion	Name	Brief Description
Navigation and Travel Information	On-Board navigation Systems	Routing recommendations usually based on calculation of fasted route to set destination
	Dynamic on-trip routing	Route recommendation that can be received during trip on PDA or mobile phone taking into account real-time traffic status and/or environmental conditions.
	Green enhanced navigation system based (history data)	Routing recommendations taking into account historical traffic data and real time information
	Intelligent Parking	Provide information on available parking spaces either on parking lots or roadside. Hence drivers spent less time to locate a suitable parking spot.
	Web based pre-trip information system	Route planning for given destination defined before trip start

Table 5: ITS 2 - Navigation and travel information

Classifica-tion	Name	Brief Description
Traffic Manageme nt and Control	Isolated controlled intersections	Generally used for safety. The specific control is different from place to place.
	Plan based control (including green wave strategy)	Synchronization of lights to favor traffic flows on specific routes. Optimisation criteria can be overall minimum delay or minimal number of stops.
	Traffic adaptive Urban Traffic Control	UTC system which is able to measure and forecast queue length and adjust phases to optimize efficiency (not fixed plan).
	Traffic adaptive Urban Traffic Control + V2I	UTC+ V2I services e.g.: the driver is informed about the traffic light cycle so he can adjust the speed before arriving to the traffic light.
	Ramp Metering	Traffic lights to manage influx of vehicles to ring road or motorway system
	Dynamic lane	Opening or closing the assistance lane on highways by means of signs over the lane, depending on traffic conditions.
	Speed Control (point-to-point)	Use consecutive speed cameras and sign recognition to calculate true average vehicle speed of individual vehicles, instead of momentary measurement of speed.
	Dynamic Speed Limits	Traffic regulation to impose a given speed (on motorways) according to real-time flow conditions

	Road Geometry	Changes in the road geometry for better managing traffic

Table 6: ITS 3 - Traffic management and control

Classifica-tion	Name	Brief Description
Demand & Access Management	Infrastructure-use pricing	Form of fee collection
	Carbon-credit scheme	Management of a system based on carbon assessment of trips, which can be bought or sold
	Restricted traffic zones	Entry restriction to given area. Criteria can be vehicle type, socioeconomic necessity, credits
	Pay-as-you-drive strategy	On board black box to charge according to infrastructure use. Can potentially be made very complex, to include dynamic congestion charge functionality, additional fees for environmental zones, time of day etc.

Table 7: ITS 4 - Demand & access management

Classifica-tion	Name	Brief Description
ADAS	Cruise control	Vehicle speed is kept at the value desired by the driver
	Navigation based cruise control	Information about the road geometry is processed by the ACC mechanism to adapt the vehicle speed
	Adaptive Cruise Control (ACC)	Vehicle speed is controlled automatically, based on the desired speed and the distance to the preceding vehicle
	ACC+STOP&GO	A variant of ACC with the capability to stop the vehicle if the vehicle in front stops. After driver confirmation the vehicle restarts again automatically
	ACC+V2I Communication	The ACC mechanism takes into account information about the infrastructure, such as traffic light positions and green phases, in order to adapt the speed of the car
	Cooperative cruise control	Vehicle-to-vehicle communication allows for controlling the speed of the following vehicle, knowing the speed profile of the leading vehicle. The speed profile will not be duplicated but optimised to save fuel, while maintaining an adequate safety level

Table 8: ITS 5 - Advanced driver assistance system (ADAS) and other measures

4 ICT Emission Methodology and tools

4.1. Methodology overview

ICT-Emissions aims at developing a comprehensive methodology to assess the impacts of road transport related ICT measures on energy consumption, and CO_2 emissions by taking into account the real-world driving and traffic behavior in urban environments.

The methodology will provide answers by integrating commercial traffic models at the micro (car-passenger level) and macro scales. Particular emphasis is given to new vehicle technologies with increasing popularity in the coming years (i.e. hybrid, electric vehicles, etc.), including advanced vehicle technologies (hybrids, plug-in hybrids, electric, start-stop, etc.).

The innovative combination of traffic, driver behavior, and emission models produces a versatile toolbox that can help simulating the impact on energy and CO_2 emissions of infrastructure measures (i.e. traffic management systems, dynamic traffic signs, etc.), driver assistance systems and eco-solutions (i.e. speed/cruise control, start/stop systems, etc.) or a combination of measures (i.e., cooperative systems).

The main architecture for assessing CO_2 impact defines the Macro models as the theoretically most suitable ones to provide quantitative and wide results on impacts in extensive area (such as city or county). These models are generally present at the city level and their use is accessible for most of the EU cities. On the other hand, in most cases the ICT measures require to be accurate at the level of the dynamicity of the vehicle, so the correct method of using Micro models is presented together with their connection with the macro models in order to extrapolate the results at the extensive area of study.

Schematically, the architecture of the relations between models and levels is presented in the following graph:

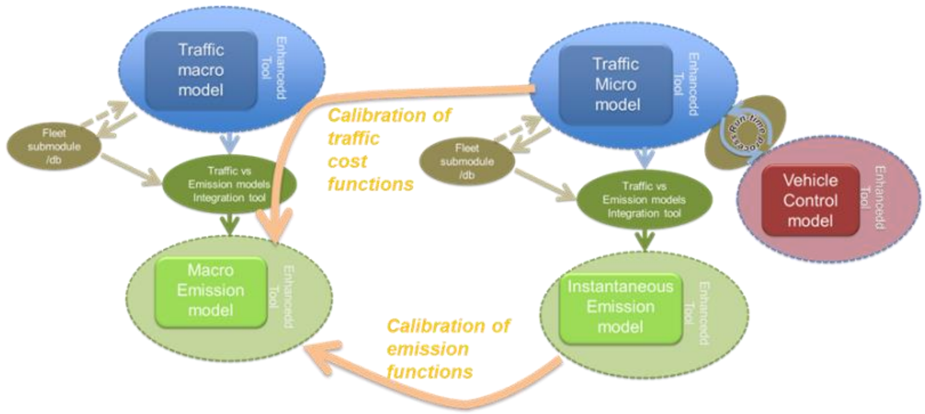

Figure 1: Complete model architecture for CO_2 assessment

The list of potential impacts parameters for ITS systems has been identified according these main subjects: traffic, volume, average speeds, speed dynamics, vehicle dynamics.

The simulation methodological process has a basic structure made of the following steps (Figure 2):

1. The first step is the preparation of the set of the different cases well representing the real use of the measure and there is the need of the definitions of:
   a. Study area with different road types and structures
   b. Traffic levels
   c. Fleet composition
2. For each study area the simulation models have to be calibrated (with available real data). A realistic traffic level and fleet composition has to be selected as representative of the real case (base case / state of reference). These will be the Business As Usual scenarios, in case the measure will be applied in far away in the future, the BAU scenarios will be the calibrated present ones with the forecasted changes to properly simulate the future case in case. This is the first essential step that allow to get the “0 scenarios” or “reference scenarios” to be used as comparison with the scenarios in which the ITS measure are applied: the differences will provide accurate benefit/dis-benefit results.
3. Depending on ITS measure to be simulated and the expected implementation and impact, a selection of the interesting cells of the overall BAU (Business as Usual) scenarios matrix is made.

4. It is useless for each ITS measure to simulate its impacts for each cell of the scenarios matrices, because some ITS can be applied only in given context or it is already know that in certain case the advantage or disadvantage are minimal: for instance the “ramp metering” can be simulated only in an study area which include motorway corridors and ramps.

5. The list of evaluation/future scenarios is now defined taking into account the application case of the specific ITS measure to be simulated.

6. Once the matrices of base scenarios and the list of “future scenarios” have been defined, they have to be simulated with traffic models.

7. If the type of results of the scenarios are not yet ready for the emission models, the integration sub-models have to be run.

8. Running the emission models.

9. At last the value of the benefits/detriments of the measure implementation is quantified comparing the base scenario and the evaluation (future with ITS implementation) scenarios simulation results.

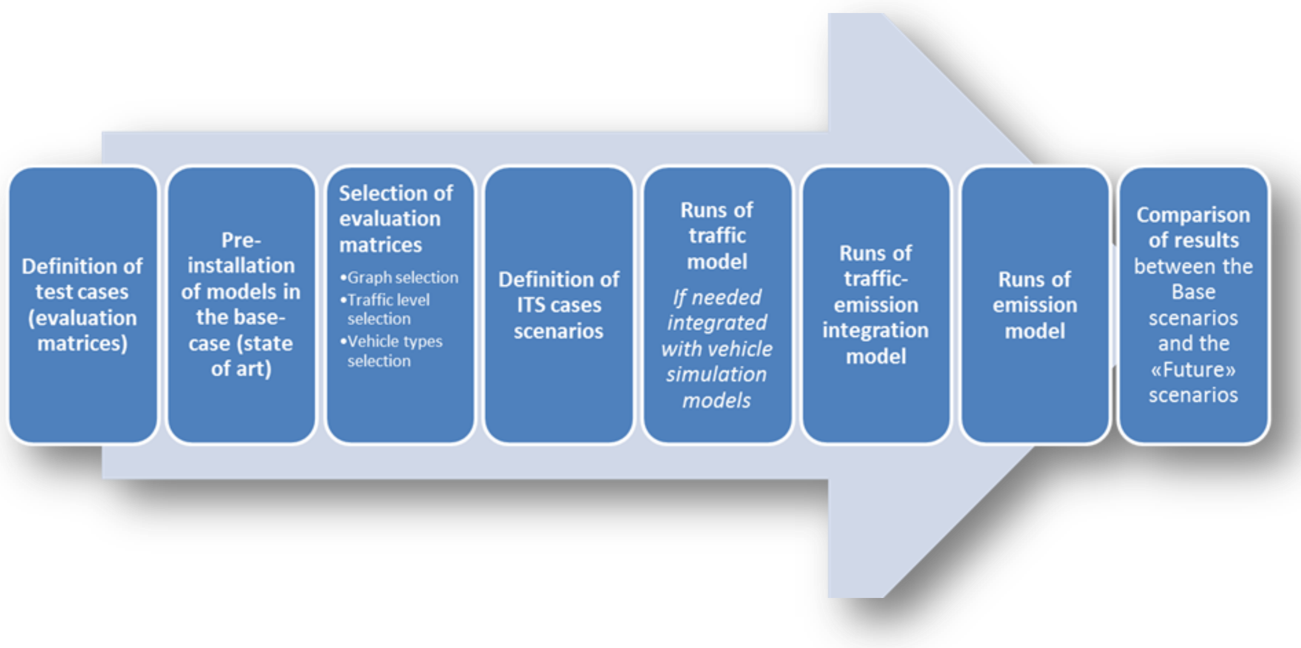

Figure 2: Structure of the methodological process

Figure 3 illustrates the base scenarios matrix. Each scenario is defined according to a Road Context (type of road), one traffic level (according to the level of traffic congestion) and a certain traffic composition. The possible scenarios created according to these three levels of structure (road type, traffic level, fleet composition) determines a multi-dimensional matrix of potential scenarios. According to the study area (urban, extra urban, highway) and the period of time we can get different situations as they are now on the network (according to the day type and the hours there is a variation in mobility demand and consequently in traffic composition and in traffic congestion level).

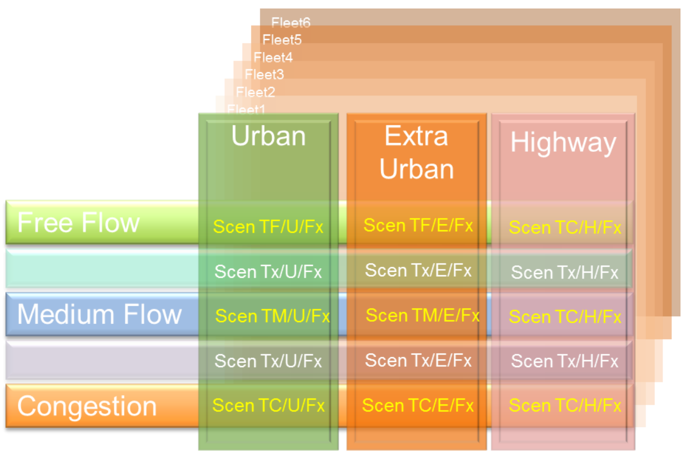

Figure 3: Matrix of assessment scenarios

The methodology is described with details on how to proceed for most of the ITS measures that potentially can have CO_2 impacts and it will be tested in many cases in specific test case cities.

4.2. Tools

4.2.1. Traffic Models

Traffic simulation models are mathematical tools which help to plan, manage and operate road networks. They are able indeed to simulate the traffic at different level of detail and different time scales, depending on the approach followed. Broadly speaking traffic simulation models may be categorized in static models and dynamic models.

Static models describe the steady-state behaviour of the transport system. Though such condition is not actually observable in road networks (it would be observable under specific cases if demand, path choices and supply system remained constant for a sufficiently long period of time), it is assumed as being representative of average system conditions in the simulation period adopted. As in the reality traffic conditions vary over time in a network, different “representative” periods are identified (e.g. morning peak period, free-flow period and evening peak period) for which independent simulations are performed. Such models describe the traffic in terms of macroscopic variables namely flow, speed and density, reason for which they are also referred as **macroscopic (static) models**. Example of these models, in commercial tools, are EMME3, MT.MODEL, MATRIX – static part, VISUM, among others.

Given the level of detail of the output produced and their time invariance such models are generally applied in transportation planning and long term forecasting. Further, the relatively small computational time concerned allows for the simulation of large scale networks (e.g. regional, national or super-national scale). In emission inventory studies, or analyses of environmental impacts of interventions on the transport system, they are generally coupled with average emission models, to which they are able to provide as input the average speed of the traffic flow, within the simulation period, over each link of the network.

Microscopic models describe the movements of individual vehicles as the result of individual disaggregated choices and interactions with other vehicles and with the road environment. Path choice, decisions to accelerate or change lanes, behaviour at intersections etc., of each individual vehicle, are generally explicitly modelled. Moreover, each flow entity has its own characteristics that may include: vehicle characteristics, such as type or access to trip information, vehicle performance, such as maximum acceleration or maximum speed, and driver characteristics, such as reaction time or desired speed. Commercial examples of such models are AIMSUN, VISSIM, PARAMICS, SUMO.

4.2.2. Vehicle Control & Driver Models

Modern driver assistance systems relieve the human driver by taking over automatic control over the acceleration of the car. As with human driver models the case that the vehicle adapts its speed to a target value specified by the human driver in a scenario with a low vehicle density on the road is distinguished from the case where a vehicle has to adapt its speed to other vehicles driving immediately in front of it. To this end, radar technology is used to measure the range in front of the vehicle and to detect targets. Technical solutions for (Adaptive) Cruise Control have been developed by car manufacturers over the past years and are integrated in state-of-the-art middle-class and upper-class vehicles. In simulations these systems can be modelled in terms of control loops and coupled with vehicle dynamics models, which take into account a realistic acceleration and braking behaviour of a given vehicle.

In ICT-Emissions an important issue is the analysis of the effect of advanced driver assistance systems on the fuel consumption of the vehicles. Hence, a comparison between the human driver models outlined in this section and the ADAS models will be performed with respect to vehicle emissions.

Commercial examples of such models are DYMOLA, AMESim, GT-Suite, CRUISE, MESSINA.

4.2.3. Emission Models

Emission estimation is one of the most essential procedures for traffic impact analysis. Emission models are generally developed from emission measurements in reality. The models have gradually been improved, mainly in terms of the amount, type and quality if data available. Given the strong influence of vehicle technology specifications and status on the emissions generation process, emission models are usually calibrated separately for every vehicle make and model, or for homogeneous vehicle categories. In principle, vehicle operating conditions are most relevant inputs to the models, while external environment conditions can be introduced as secondary inputs. Several vehicle emission models are used worldwide to estimate road traffic emissions mainly with those inputs. Analytical emissions modelling divides the whole emission process into different components that correspond to physical phenomena associated with vehicle operation and emission production. Each component of the process is then modelled as an analytical representation consisting of various parameters that can characterize the process. These parameters typically vary according to vehicle type, engine, and emissions technology.

There are different ways of classifying vehicle emission models, although there is a considerable degree of overlap between them. Based on the modelling approach and aggregate levels of emission factors, the models can be classified into the following four types (Table 3.1):

Aggregated emission factor models. Models of this type operate at the simplest level, with a single emission factor being used to represent a particular broad category of vehicle and a general driving condition (e.g. urban roads, rural roads, and motorways). These include NAEI and MOBILE at their normal high level of application, although at a more detailed level these two models also follow the average speed approach.

Average speed models. These are the most commonly used models, based on the assumption that average emissions over a trip vary according to the average speed of the trip. A well-known example of this type is COPERT.

Traffic situation models. This approach incorporates both speed and driving dynamics into emission estimation. Traffic situations are defined qualitatively according to road types and traffic conditions (e.g. urban free flow, urban congested, stop-and-go). Examples of this type include HBEFA and ARTEMIS.

Multiple linear regression models. Models of this type operate at the highest level of complexity. They consist of a set of statistical models for detailed vehicle categories that have been constructed using multiple linear regression analysis. The aim is to find empirical relationships between mean emission factors, including confidence intervals, and a limited number of speed–time profile and vehicle related variables. VERSIT+ is an example of such model.

Modal or instantaneous models. A Microscopic (or instantaneous) model describes individual vehicle movements through the traffic simulation model. It helps capturing the detailed behaviour of drivers and their interaction with traffic environment. In a Microscopic model, each vehicle moves through the traffic network with updated character which is determined by speed, acceleration, time, and individual driver behaviour. The driver behaviour is determined by a set of models such as car following, lane changing, acceleration noise and etc. Some model simulate exactly the vehicle and powertrain system level simulation tool. In this case the models support everyday tasks in vehicle system and driveline analysis throughout all development phases, from concept planning, through to launch and beyond. Its application envelope covers conventional vehicle powertrains through to highly-advanced hybrid systems and pure electric vehicles. Examples of this type include UROPOL, VeTESS, PHEM, MOVES, ADVISOR, VT-MicroModule, CRUISE.

4.2.4. Modelling Levels

Both the traffic and the emissions models work at different level with two of them than can be easily identified in both cases:

- Static-macro: MACRO level

  At macro level both the traffic and the emissions models work with group of vehicle described as a whole in a certain period of time and the description of the data are at more or less the same type of aggregation.

- Dynamic-micro: MICRO level

  At micro level both the traffic and the emissions models works simulating each single vehicle.

The Vehicle control model works for each single vehicle so it has only the MICRO level description.

As a consequence of that traffic-emission models are generally integrated when used at the same level.

In synthesis

1. **at macro level:**

   - Traffic macro models: the so called Static-macro traffic models that are represented by the commercial suites EMME3, MT.model, VISUM, etc.

   - Emission models the so called Average speed models that are represented by the commercial suites COPERT.

2. **at micro level**:

   - Traffic micro models: the so called Micro simulation models models that are represented by the commercial suites AIMSUN, VISSIM, etc.

   - Emission models the so called Average speed models that are represented by the commercial suites CRUISE, PERFECT, etc.

   - Vehicle Control model: that are represented by the commercial suites CRUISE (dynamic vehicle simulation part), MESSINA, etc.

At the micro level, the single vehicle is simulated and its instant emissions are estimated, while at the macro level a global effect is assessed.

The micro models are precise but need many detailed inputs, therefore they can only be used for small areas, while the macro models need more "easy to get" data inputs and they can be used also for bigger areas of study.

Consequently the integration of micro and macro models is one of the cornerstones of the project.

4.3. SIMULATION OF ICT/ITS SOLUTIONS

4.3.1. ARCHITECTURE OF METHODOLOGY

4.3.1.1. Macro-simulation

According to what has been said in the previous chapter about the need of using a macro level simulation approach, in principle, this high level approach is the most reasonable, also if, in some cases, it needs integration with micro models.

The macro architecture has also a good secondary benefit: most cities has already implemented a macro traffic model and they have the input data necessary for using it. So this approach is easy feasible for cities and therefore needs to be deeply studied.

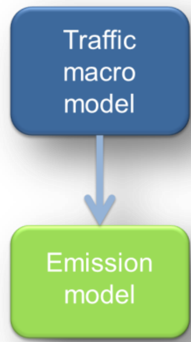

Figure 4: Macro Architecture

According to this architecture the first step is simulating the traffic using the macro-simulation tools and their main results. In this case the main output of the traffic macro-simulation tool is the input of the emission model.

The emission model quantifies the CO_2 impact. An intrinsic approximation derived by this process is that only the main traffic, the one using the “main” road-network considered in the traffic model is taken into account. It is important that the modelers are aware of this fact: if too many vehicles and traffic are out of the modelled network also CO_2 emissions are underestimated. It is care of a correct modelling of an urban area to avoid that this happens: the not-estimated traffic must be a residual part of the overall one. Too much aggregated or “too-macro” models have to be avoided or the not-modelled traffic needs to be taken into account somehow.

The main output of the standard traffic macro-simulation tools are for each main road of the network: the number of vehicles, the average speed and the congestion level (flow/capacity or density).

The needed inputs of the emission model are the output of traffic simulation tool subdivided by fleet composition.

So the fleet composition will be an additional integration sub-module connected with traffic tool or will be a specific database usable as input of the emission model.

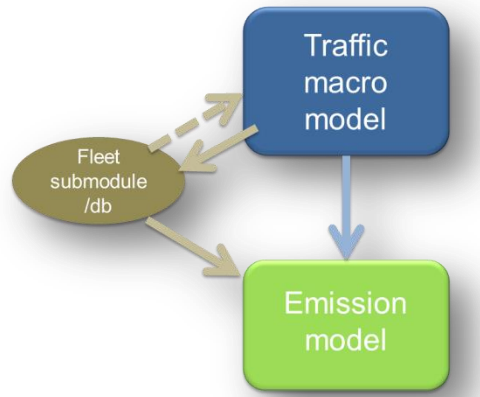

Figure 5: The macro-simulation and the additional sub-model

There is an obvious need of categorizing the vehicle in the traffic models if the data need to be used at the level of the Emission model. Focusing at the level of a “urban” cases the use a specific fleet composition is important because it can determine big differences in terms of emissions.

As a consequence it is necessary to differentiate at least the percentage of vehicle categories using the different roads for the specific urban area of study, in order to associate the different speed and congestion level to the correct type of vehicle and correctly provide the Emission tool with the different km driven for each type of vehicle for each different speed use.

This means:

- an enhancement of the traffic-simulation tool in order to get at last some main categorization of vehicles at the level of macro traffic results[2].
- an enhancement of the emission model in order to be able to get contemporarily different speed and km driven for each vehicle type with adoption of algorithms suitable for working at hourly time periods and for road length of hundreds of meters.

[2] Most of the macro traffic models refers their output to the private vehicles, for assessing the CO_2 emissions of traffic it is important to consider also Public Transport vehicles.

- a new submodule (fleet submodule) that using detailed fleet composition data interrelate the aggregated the traffic data with the disaggregate fleet composition as needed for the Emission models.
- a new submodule (Traffic vs Emission Integration tool) that prepares the output data of the traffic model plus the outputs of the new Fleet-submodule in suitable input data for the Enhanced Emission tool.

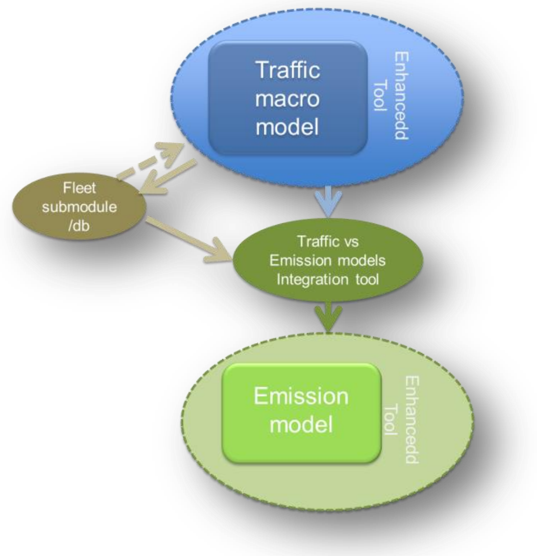

Figure 6: Final Architecture of MACRO-simulation for CO_2 assessment

4.3.1.2. Micro-simulation methods

The Macro Assessment architecture that has been described is suitable for most of the ITS systems which have an already known global effect on traffic (such as Access Restriction, rerouting systems, etc), in other words to the policies that mainly affect traffic distribution and traffic volumes.

Some of the ITS systems and in particular the ICT devices installed on a vehicle, provide impacts at the level of speed dynamics or at the level of “vehicle” dynamics. In these cases the emission impacts cannot be obtained if the assessment is done at the level of the classic macro models as described in the previous chapters. Actually, it is necessary to use micro-traffic models which provide the speed variation for each vehicle and micro emission models which provide the calculation of emissions by driveline simulation.

The emission quantification in these cases can be precisely provided by the instantaneous emission models which are quite accurate in calculating fuel consumption for each specific vehicle when they are fed with the actually driven speed profile, road gradient and vehicle load.

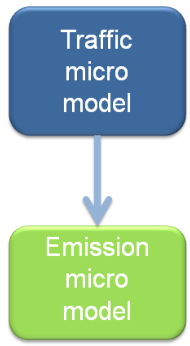

Figure 7: MICRO models architecture

In the traffic simulation tools each vehicle is simulated according to typical characteristics which influence the traffic behaviour (such as the length of the vehicle, the expected maximum speed, the acceleration value etc). Typically the vehicles are gather in two categories: light and heavy.

The network is described in detail with physical and performance characteristics: lanes, turning manoeuvres, length, width and speed limit for each link and type of device (traffic light with their customisation etc.).

Using the constraints due to network, the desired and feasible speed of each vehicle moving in the network is obtained considering the algorithms for simulating the behaviour (such as “free” plus “following” plus “lane changing” conditions) and the congestion and the constraints due to traffic. The traffic model provides the traffic status on the network.

The above means that, similar as in the macro case, the micro case requires to enhance the traffic model as well, in order to provide results in line with the emission model demands, such as providing the “not standard” output of speed profile. Furthermore, an effort from the modellers is needed in order to improve the type of vehicle distribution. On the other hand, the instantaneous emission model needs to be enhanced also to provide “more aggregated” results for feasible and reasonably obtainable data at urban level (such as accept as input characteristics for "types" of vehicle and not only specific for "each" single vehicle).

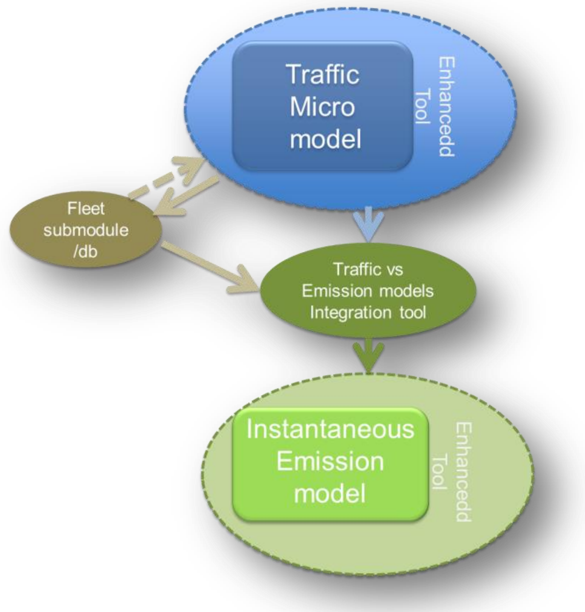

Figure 8: Micro models Integration Architecture

Since the instantaneous emission tool looks at the real dynamics of the vehicle, the provided speed profile should be in line with the really existing vehicle present in those areas: as we said to be fully congruent with the vehicle dynamics was not the main objective of the traffic simulation tool. The algorithm inside the microsimulation tool can be improved to be more aligned with the "real" dynamics (nowadays, many data of measured speed profiles exist, so that there is the possibility to modify in a suitable way the existing algorithms to better simulate reality also for this parameter).

Another interesting and precise solution is to integrate the traffic model with a Vehicle Control model: this integration will allow extracting part of the calculation done by the simulation tool and will ensure that this is done by a vehicle simulator tool that is more accurate in providing the vehicle dynamics.

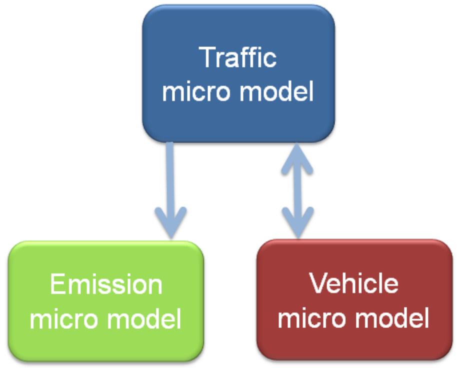

Figure 9: MICRO models enhanced architecture

This integration is useful for better simulating the classic vehicles and provides the optimal solution to the previous issue of the vehicle dynamic accuracy.

This integration is mandatory for simulating the “future equipment” of specific vehicles such as Adaptive Driver Assistance Systems (ADAS), in which most of the driven features are automated and the vehicle response is quicker and more accurate than the one of the human driver. In this case, the response of the vehicles needs to be simulated in a detailed and specific way.

Because the variation in vehicle dynamics can, in some cases, influence the variation in the speed and the position at each step of the traffic simulation tool, this enhancement has to be fully integrated in the traffic simulation tool as an enhancement of the traffic tool or as an external module running in real time with the simulation tool.

This consideration leads to the final version of the Micro architecture, see following figure.

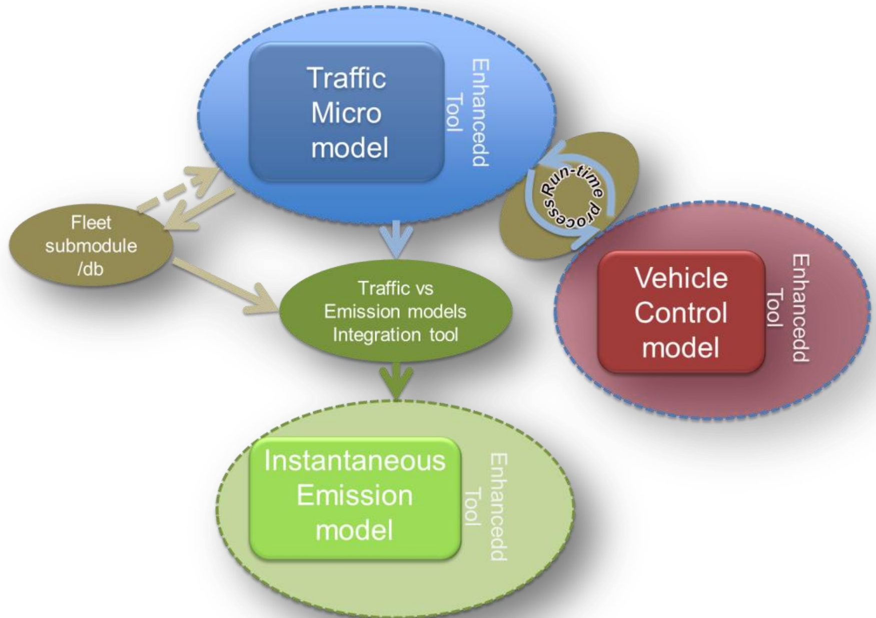

Figure 10: Final MICRO Architecture

5 Assessment Framework

5.1. Assessment Objectives

The ICT emission assessment objectives have been defined starting from users and their needs as briefly stated in chapter 2.

ICT measure categories	User	Objectives
All	Decision maker and public authorities	1. Capability to simulate an ICT measure; 2. Capability to estimate ICT measure effects on traffic parameters; 3. Capability to test if an ICT measure has positive impacts on CO_2 emissions; 4. Capability to estimate potential reductions in CO_2 emissions.
ADAS, Driver behaviour change and eco driving, Navigation and Travel Information.	Automotive OEMs and suppliers	5. Capability to simulate an ICT measure; 6. Capability to test if an ICT measure has positive impacts on CO_2 emissions; 7. Capability to estimate potential reductions in CO_2 emissions; 8. Capabilities to model vehicle emissions.

Table 9: Users and objectives

1. <u>Capability to simulate an ICT measure</u>

A key point of ICT Emission methodology is to simulate ICT measure using “commercial” Micro and Macro traffic simulators. This will be a technical assessment focused on main traffic parameters based on the comparison of traffic simulation outcomes against real traffic measurements.

2. <u>Capabilities to model vehicle emissions</u>

The ICT methodology should be able to model vehicle emissions starting from driving cycles and traffic parameters. This will be a technical assessment focused on fuel consumption and CO_2 emission based on the comparison of simulation outcomes against real measurements.

3. **Capability to estimate ICT measure effects on traffic parameters**

This assessment objective is crucial for decision makers in order to estimate ICT impacts on traffic. This will be a technical assessment focused on simulation of main traffic parameters in an “on” and “off” scenario.

4. **Capability of test if an ICT measure has positive impacts on CO_2 emissions**

The main objective ICT Emission project is to estimate if a specific ICT measure is able to reduce CO_2 emissions. This will be a technical assessment focused only on CO_2 parameter, carried out simulating an “on” and “off” scenario.

5. **Capability of estimate potential reductions in CO_2 emissions**

The knowledge of potential reduction of CO_2 emission due to a measure is quite crucial for decision makers. This will be a technical assessment focused on CO_2 parameter, carried out simulating an “on” and “off” scenario.

5.2. Indicator and Assessment Methods

The assessment of the objectives and evaluation of the proposed methodology will be based on indicators common to all the ICT Emission test sites.

5.2.1. Indicators

Indicators are used for estimating the performance or impacts of a transport telematics applications, and thus for measuring how far the objectives will be achieved by the application.

Two basic requirements have to be considered when defining indicators: they must be able to reflect clearly the related performance or impact and must be capable of reliable assessment using the experimental tools and measurement methods chosen.

In case of a cross-site or cross-project collaboration, it is necessary to define a set of common indicators and to determine those indicators in a comparable way at different sites to enable a cross-site comparison or a generalisation of the results provided by the individual projects/sites.

Indicators are either directly measured or derived from measurements. When simulation is used instead of measurement, indicators will usually be outputs of the simulation.[3]

5.2.2. Reference cases

The outcomes of the ICT emission methodology will be compared against real situation measured in the test fields in order to show ICT measures are well simulated.

5.2.3. Success Criteria

Success criteria define the expectations about the behaviour of the methodology. The success or failure of evaluation results is tested against these criteria.

5.2.4. Methods of Indicator Measurement

Indicator calculation is made on the base of simulations results; in some cases simulations results have to be compared with data collected via measurement on field. Collection of data on real environment needs to be carried out respecting statistical approach rules.

5.3. ICT Emission Indicators

5.3.1. Selection criteria

The definition of indicators has to be based on main parameters dealt inside the ICT emission methodology. Since the methodology uses traffic and emission models, these have been analysed in order to identify their leading parameters. The evaluation methodology introduced in next paragraphs, also requires comparison against real world measurements, thus indicators need to be based on parameters "easily" measurable on field.

Among all traffic parameters provided by micro and macro models, the following have been chosen as most relevant:

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[3] D2.3.1 Guidebook for Assessment of Transport Telematics Applications, CONVERGE Project TR 1101.

- **Travel time / average speed**: main indicators of traffic state; common to both levels of simulation (macro and micro);
- **Number of stops**: main parameter provided by micro simulators providing the level of interruption of traffic.
- **Percentage of stop time and percentage of constant speed**: representative parameters depicting the behaviour of traffic flow; they affect vehicle emissions and are provided by micro simulators.

Among emission parameters provided by simulators, the most relevant are:

- **CO_2 Emission**: indicator of vehicle emission and main target of the ICT emission methodology.

- **Fuel consumption**: relevant indicator measurable or achievable by micro and macro simulation; it allows also the estimation of the CO_2 emissions (if not available).

5.3.2. COMMON INDICATORS

Nr	Indicator	Micro	Macro
1	**Capability to simulate an ICT measure**		
1.1	travel time / average speed	X	X
1.2	number of stops	X	
1.3	percentage of stop time	X	
1.4	percentage of constant speed	X	
2	**Capabilities to model vehicle emissions**		
2.1	emission	X	X
2.2	fuel consumption	X	X
3	**Capability to estimate an ICT measure effects on traffic parameters**		
3.1	travel time / average speed	X	X
3.2	number of stops	X	
3.3	percentage of stop time	X	
3.4	percentage of constant speed	X	
4	**Capability to test if an ICT measure has positive impacts on CO_2 emissions**		
4.1	emission	X	X

Nr	Indicator	Micro	Macro
4.2	fuel consumption	X	X
5	**Capability to estimate potential reductions in CO_2 emissions**		
5.1	emission	X	X
5.2	fuel consumption	X	X

Table 10: Indicators and level of simulation

5.3.2.1. Capability to simulate an ICT measure

The ICT Emission methodology is founded on the capabilities to simulate any ICT measures using commercial macro and micro traffic simulators.

Evaluating if an ICT measure can be simulated, requires the comparison of simulation results with a "reference case" such as real measurements done in the area simulated. The main idea is to set up the reference case using real traffic data parameters measured with ICT measure in "on" and "off" scenarios.

The comparison will be made over the following traffic parameters:

- travel time;
- number of stops;
- percentage of stop time;
- percentage of constant speed.

The simulation will cover a real geographical area, where some paths will be selected, each one with a start point, end point, direction and length. Traffic parameters will be calculated starting from simulation results or from measurement on these selected paths. The measurements on field will allow the calculation of statistical confidence interval for each parameters on each path.

5.3.2.1.1. Travel time

The travel time is calculated as time spent by a vehicle to cover a path from start point to end point.

When more vehicles are used, the travel time will be the average of travel time calculated for each vehicle.

The indicator 1.1 “Travel Time” compares travel time of any relevant path simulated by models with its correspondent measured travel time.

The success criterion is satisfied when travel time produced by simulation lies inside confidence interval calculated using real traffic measurements.

Objective: **Number:** **Indicator:**	Capability to simulate an ICT measure 1.1 **Travel Time**
Definition	Travel time needed to run along a path
Relevance	Assessment of simulation accuracy
Methods	Comparison with reference case
Reference case	Measured real traffic parameters
Operational Issues	Scenario ICT Measure on and off
Success Criterion	Respect of confidence interval

Table 11: Capability to simulate an ICT measure - travel time

In some cases could be more suitable use the average speed instead of travel time. The success criterion is satisfied when average speed produced by simulation lies inside confidence interval calculated using real traffic measurements.

5.3.2.1.2. Number of stops

The number of stops is the average of the count of vehicle stops of all vehicles considered. A stop is added to the tally every time a vehicle's speed drops below 3 km/h. A stopped vehicle speed must reach 14.4 Km/h again before it can generate any additional stops. That way vehicles moving up in a queue do not generate multiple stops.

The indicator 1.2 “Number of stop” compares average number of stops on any relevant path simulated by models with average number of stops coming from real measurements.

The success criterion is satisfied when number of stops produced by simulation is inside confidence interval calculated using real traffic measurements.

Objective: **Number:** **Indicator:**	Capability to simulate an ICT measure 1.2 **Number of stops**
Definition	Number of time speed decreases below a threshold (3 km/h).
Relevance	Assessment of simulation accuracy
Methods	Comparison with reference case
Reference case	Measured real traffic parameters
Operational Issues	Scenario ICT Measure on and off
Success Criterion	Respect of confidence interval

Table 12: Capability to simulate an ICT measure - number of stops

5.3.2.1.3. Percentage of stop time

The percentage of stop time is the ratio between the sum of time a vehicle spent with a speed between 3 km/h (trigger for starting to count) and 14.4 km/h, and the journey (path) total travel time.

When more vehicles are used, the percentage of stop time will be the average of the percentages calculated for each vehicle.

The indicator 1.3 "percentage of stop time" compares the percentage of stop time on any relevant path simulated by models with measured percentage of stop time.

The success criterion is satisfied when percentage of stop time produced by simulation is inside confidence interval calculated using real traffic measurements.

Objective: **Number:** **Indicator:**	Capability to simulate an ICT measure 1.3 **Percentage of stop time**
Definition	Time spent with a speed below a threshold (3 km/h) divided by the total travel time on a path
Relevance	Assessment of simulation accuracy

Methods	Comparison with reference case
Reference case	Measured Real traffic parameters
Operational Issues	Scenario ICT Measure on and off
Success Criterion	Respect of confidence interval

Table 13: Capability to simulate an ICT measure - percentage of stop time

5.3.2.1.4. Percentage of constant speed

The percentage of constant speed is calculated as time spent by a vehicle at a constant speed divided by the total travel time on a path.

Constant speed means that speed is not increasing or decreasing but remain consistent over time (zero acceleration).

When more vehicles are used, the percentage of constant will be the average of the percentages calculated for each vehicle.

The indicator 1.4 “percentage of constant speed” compares the percentage of constant speed on any relevant path simulated by models with percentage of constant speed measured.

The success criterion is satisfied when percentage of constant speed produced by simulation is inside confidence interval calculated using real traffic measurements.

Objective: **Number:** **Indicator:**	Capability to simulate an ICT measure 1.4 **Percentage of constant speed**
Definition	Time spent at constant speed divided by the total travel time on a path
Relevance	Assessment of simulation accuracy
Methods	Comparison with reference case
Reference case	Measured real traffic parameters
Operational Issues	Scenario ICT Measure on and off
Success Criterion	Respect of confidence interval

Table 14: Capability to simulate an ICT measure - percentage of constant speed

5.3.2.2. Capability to model vehicle emission

The ICT emission methodology is also based on the capabilities to model vehicle emission using a simulator able to simulate different kind of vehicles.

In order to evaluate vehicle emission simulator it is necessary to compare simulation results with a “reference case” such as real measurements.

The reference case will be set up measuring and collecting CO_2 emission and fuel consumption of actual vehicles measured on real world condition or on chassis dynamometers.

The comparison will be made over the following traffic parameters:

- CO_2 emission
- Fuel consumption.

5.3.2.2.1. CO_2 Emission

The simulation will be based on driving cycles generated by real world on board measurement or chassis dynamometers trials.

CO_2 emission is defined as number of CO_2 grams over km.

The indicator 2.1 “CO_2 emission” compares CO_2 emission simulated by models with measured one.

The success criterion is satisfied when CO_2 emission produced by simulation is inside confidence interval calculated using real measurements.

Objective: **Number:** **Indicator:**	Capability to model vehicle emission 2.1 **CO_2 emission**
Definition	CO_2 emission
Relevance	Assessment of simulation accuracy
Methods	Comparison with reference case

Reference case	Measured Real parameters
Operational Issues	Collection of real driving profile and CO_2 emissions
Success Criterion	Respect of confidence interval

Table 15: Capability to model vehicle emission - CO_2 emission

5.3.2.2.2. Fuel consumption

The simulation will be based on driving cycles generated by real world on board measurement or chassis dynamometers trials.

Fuel Consumption is defined as number of fuel litres over km.

The indicator 2.2 “Fuel consumption” compares fuel consumption simulated by models with measured one.

The success criterion is satisfied when fuel consumption produced by simulation is inside confidence interval calculated using real measurements.

Objective: **Number:** **Indicator:**	Capability to model vehicle emission 2.2 **Fuel consumption**
Definition	Fuel consumption
Relevance	Assessment of simulation accuracy
Methods	Comparison with reference case
Reference case	Measured Real parameters
Operational Issues	Collection of real driving profile and fuel consumption
Success Criterion	Respect of confidence interval

Table 16: Capability to model vehicle emission - fuel consumption

5.3.2.3. Capability to estimate ICT measure effects on traffic parameters

This assessment objective is based on the assumption it is possible to simulate an ICT emission via a traffic simulator. The purpose is to evaluate how much an ICT measure impacts on traffic parameters such as:

- travel time;
- number of stops;
- percentage of stop time;
- percentage of constant speed.

The simulation will cover a real geographical area, where it will be needed to select some paths each one with a start point, end point and direction. The evaluation will be made comparing simulation results in "on" and "off" scenarios.

Comparisons will be made using the following formula:

I = [(Pof – Pon)/Pof]*100

I: Indicator percentage of variation

Pof: Parameter with system off

Pon: Parameter with system on

The formula has been conceived in order to express a percentage estimating the variation.

5.3.2.3.1. Travel time

Objective: **Number:** **Indicator:**	Capability to estimate ICT measure effects on traffic parameters 3.1 **Travel Time**
Definition	Percentage of Travel Time variation I = [(TTof – TTon)/TTof]*100
Relevance	Assessment of ICT Measure impact on traffic parameters
Methods	Comparison in scenario system on and off
Reference case	Travel Time with system off
Operational Issues	Scenario ICT Measure on and off
Success Criterion	**Positive value**

Table 17: Capability to estimate ICT measure effects - travel time

5.3.2.3.2. Number of Stops

Objective: **Number:** **Indicator:**	Capability to estimate ICT measure effects on traffic parameters 3.2 **Number of stops**
Definition	Percentage of N° of stops variation I = [(NSof – NSon)/pof]*100
Relevance	Assessment of ICT Measure impact on traffic parameters
Methods	Comparison in scenario system on and off
Reference case	N° of stops with system off
Operational Issues	Scenario ICT Measure on and off
Success Criterion	**Positive value**

Table 18: Capability to estimate ICT measure effects - number of stops

5.3.2.3.3. Percentage of Stop Time

Objective: **Number:** **Indicator:**	Capability to estimate ICT measure effects on traffic parameters 3.3 **Percentage of stop time**
Definition	Percentage of percentage of stops time variation I = [(PSTof – PSTon)/PSTof]*100
Relevance	Assessment of ICT Measure impact on traffic parameters
Methods	Comparison in scenario system on and off
Reference case	Percentage of stop time with system off
Operational Issues	Scenario ICT Measure on and off
Success Criterion	**Positive value**

Table 19: Capability to estimate ICT measure effects - percentage of stop time

5.3.2.3.4. Percentage of constant speed

Objective:	Capability to estimate ICT measure effects on traffic parameters

Number: Indicator:	3.3 **Percentage of constant speed**
Definition	Percentage of percentage of constant speed variation I = [(PCSof – PCSon)/PCSof]*100
Relevance	Assessment of ICT Measure impact on traffic parameters
Methods	Comparison in scenario system on and off
Reference case	Percentage of constant speed with system off
Operational Issues	Scenario ICT Measure on and off
Success Criterion	**Negative value**

Table 20: Capability to estimate ICT measure effects - percentage of constant speed

5.3.2.4. Capability to estimate potential reductions in CO_2 emissions

This assessment objective overloads and covers also the objective “Capability to test if an ICT measure has positive impacts on CO_2 emissions”.

The evaluation is based on the assumption that Traffic and Emission models well simulate ICT impacts. The capability to estimate potential CO_2 emission reductions will be evaluated running simulations of ICT measure in scenarios on and off and comparing results.

The comparison will be made over:

- fuel consumption;
- CO_2 emission.

Both comparisons will be made using the following formula:

I = [(Pof – Pon)/Pof]*100

I: Indicator of percentage of reduction (CO_2 emission or fuel consumption)

Pof: Parameter (CO_2 emission or fuel consumption) with system off

Pon: Parameter (CO_2 emission or fuel consumption) with system on

The formula has been conceived in order to express a **positive** percentage estimating the emission or fuel consumption reduction. If the result of formula application is a negative percentage or zero, the ICT measure simulated has no impacts in reducing emissions and consumption.

5.3.2.4.1. CO_2 Emission

Objective: **Number:** **Indicator:**	Capability to estimate potential reductions in CO_2 emissions 2.1 & 3.1 **Percentage of CO_2 reduction**
Definition	Percentage of CO_2 reduction I = [($CO_2$of – CO_2on)/ $CO_2$of]*100
Relevance	Assessment of ICT Measure impact on CO_2 emission
Methods	Comparison in scenario system on and off
Reference case	Estimated emission with system off
Operational Issues	Scenario ICT Measure on and off
Success Criterion	**Positive value**

Table 21: Capability to estimate potential reductions in CO_2 emissions

5.3.2.4.2. Fuel consumption

Objective: **Number:** **Indicator:**	Capability to estimate potential reductions in fuel consumption 2.2 & 3.2 **Percentage of fuel consumption reduction**
Definition	Percentage of fuel consumption reduction I = [(FCof – FCon)/FCof]*100
Relevance	Assessment of ICT Measure impact on fuel consumption
Methods	Comparison in scenario system on and off
Reference case	Estimated fuel consumption with system off
Operational Issues	Scenario ICT Measure on and off
Success Criterion	**Positive value**

Table 22: Capability to estimate potential reductions in fuel consumption

5.3.3. ICT Measures Indicators

In the following table are summarized for each categories and measures, the indicators affected. The purpose is to suggest which indicators consider dealing with ICT measures.

Classification	Name	Indicator
Navigation and Travel Information	On-Board navigation Systems	travel time
		fuel consumption
		emission
	Dynamic on-trip routing	travel time
		fuel consumption
		emission
	Green enhanced navigation system	travel time
		fuel consumption
		emission
	Green enhanced navigation system with real time data	travel time
		fuel consumption
		emission
	Intelligent Parking	travel time
		fuel consumption
		emission
	Web based pre-trip information system	travel time
		fuel consumption
		emission
Traffic Managem ent and Control	Isolated controlled intersections	travel time
		emission
		% idling time

	Plan based control	travel time
		emission
		% idling time
		% constant speed
		number of stops (at km)
	Traffic adaptive Urban Traffic Control - UTC	travel time
		emission
		% idling time
		% constant speed
		number of stops (at km)
	Traffic adaptive Urban Traffic Control + V2I	travel time
		emission
		fuel consumption
		% idling time
		% constant speed
		number of stops (at km)
	Ramp Metering	emission
		fuel consumption
		travel time
		% constant speed
	Dynamic lane	emission
		fuel consumption
		travel time
		% constant speed
	Speed Control (point-to-point)	travel time
		emission
		fuel consumption
		% constant speed
		number of stops (at km)
	Dynamic Speed Limits	travel time
		fuel consumption
		% constant speed
		emission

		number of stops
Demand & Access Management	Infrastructure-use pricing	travel time
		emission
		traffic flow
	Carbon-credit schemes	travel time
		emission
		traffic flow
	Restricted traffic zones	travel time/average speed
		emission
		traffic flow
	Pay-as-you-drive strategy	travel time
		Emission
		traffic flow
Driver behaviour change and eco driving	Promotion of an energy-efficient style of driving	fuels consumption
		Emission
		travel time
		% constant speed
	Gear Shift Indicator	fuel consumption
		Emission
	Start & Stop system	fuel consumption
		Emission
	Tyre pressure Monitoring	fuel consumption
		Emission
ADAS	Cruise Control	fuel consumption
		Emission
		% constant speed
	Navigation based Cruise Control	fuel consumption
		Emission
		travel time
		% constant speed
	Adaptive cruise Control (ACC)	fuel consumption
		Emission

		% constant speed
	ACC+STOP&GO	fuel consumption
		Emission
		% constant speed
	Cooperative Cruise Control	fuel consumption
		Emission
		% constant speed
Others	Road geometry	travel time
		fuel consumption
		Emission

Table 23: ICT Measures indicators

5.4. EVALUATION PLANNING

The ICT Emission methodology will be evaluated using the indicators as defined in chapter 5. The consortium decided to take at least one ITC measure for each ICT category.

The following table summarize ICT measures that will be simulated:

Nr.	ICT Measures		Madrid	Rome	Turin
1	**DRIVER BEHAVIOUR CHANGE AND ECO DRIVING**				
1.1	Promotion of an energy-efficient style of driving		x		x
1.2	Start & Stop		x	x	x
2	**NAVIGATION AND TRAVEL INFORMATION**				
2.1	Dynamic Green enhanced navigation system		x		x
3	**TRAFFIC MANAGEMENT AND CONTROL**				
3.1	Traffic adaptive Urban Traffic Control - UTC		x	x	x
3.2	Ramp Metering				
3.3	Dynamic lane				
3.4	Dynamic Speed Limits		x		
4	**DEMAND AND ACCESS MANAGEMENT**				
4.1	Restricted traffic zones				
5	**ADVANCED DRIVER ASSISTANCE SYSTEMS (ADAS)**				
5.1	Cruise Control		x		x
5.2	Navigation based Cruise Control				
5.3	Adaptive cruise Control		x		x
5.4	ACC+STOP&GO		x		x

Table 24: Summary of ICT measures simulated

6 The Turin case: an example

The following paragraphs show how to apply the evaluation methodology to a real case: the Urban Traffic Control in Turin. This example covers both Level 1 (communication with public authorities, press and public) and level 2 (technical implementation).

Please note results/impacts provided in the following paragraphs are not coming from real simulations but have been used just to complete the example.

6.1. LEVEL 1

Level 1 introduces to public authorities, press and general public the ITS measure adopted in Turin (UTC), the ICT methodology and the potential results.

6.1.1. USER AND THEIR NEEDS

The reference scenario consists in introducing an UTC system in a new area of the city.

Chapter 2 (Users and their needs) identified the following potential users:

1) Local authorities such as:
    a. Traffic and transport department
    b. Environment department
    c. Health department
    d. Urban planning department
2) Decision makers such as:
    a. Urban development
    b. Traffic and transport
    c. Environment
    d. Health

These users need to answer at least to the following questions:

1) Which are the impacts of an UTC system on traffic?

2) Which are the impacts of this system on CO_2 emission?

6.1.2. ITS MEASURE – URBAN TRAFFIC CONTROL

UCT is an infrastructure based system able to measure (traffic monitoring) the level of traffic on a road network enabling then a management or control of traffic in order to optimize the use of the available road capacity.

The Turin system is a Traffic Adaptive Urban Traffic Control able to control several traffic light intersections collecting traffic measurements through their on road sensors and coordinate their green and red phases in order to optimize road capacity and reduce time wasted at each intersections.

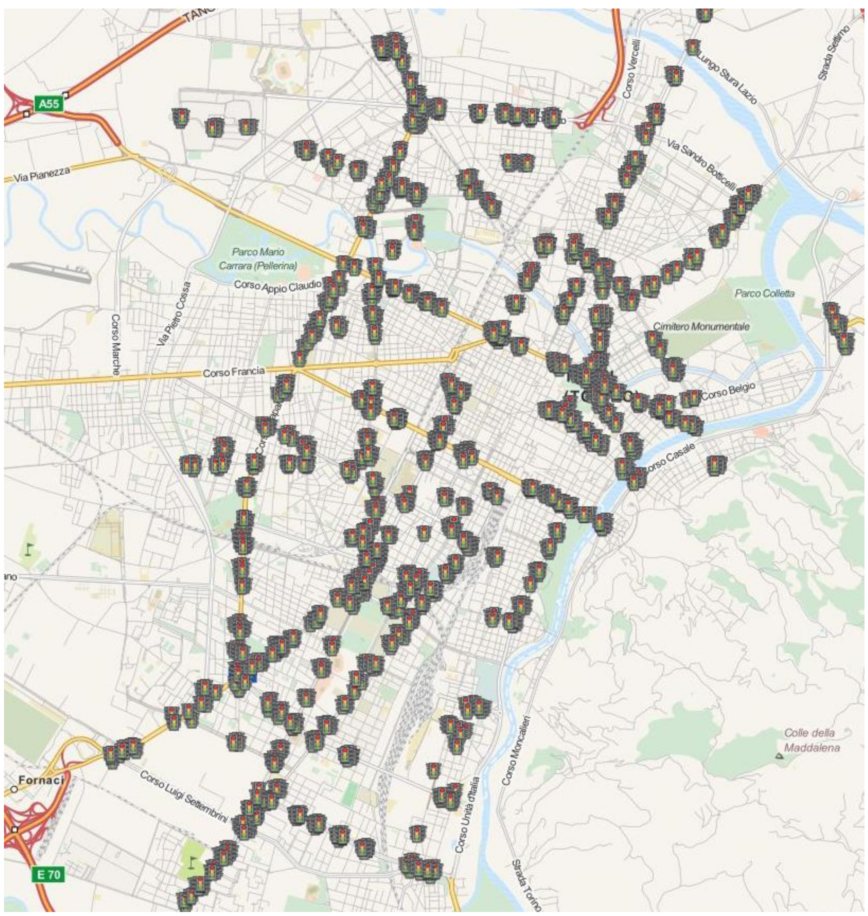

Figure 11: UTC intersections

This system impacts the following traffic parameters :

a. travel time / average speed

b. number of stops

c. percentage of stop time

d. percentage of constant speed

The optimization of road capacity and reductions of time spent waiting for the green phase produces benefits also for :

e. Fuel consumption

f. CO_2 emissions.

6.1.3. METHODOLOGY

The main idea behind ICT Emission project is to use commercial traffic simulation tools and vehicle emission models to assess impacts of ICT measure on energy consumption and CO_2 emission as described in chapter 4 and illustrated in the following figure.

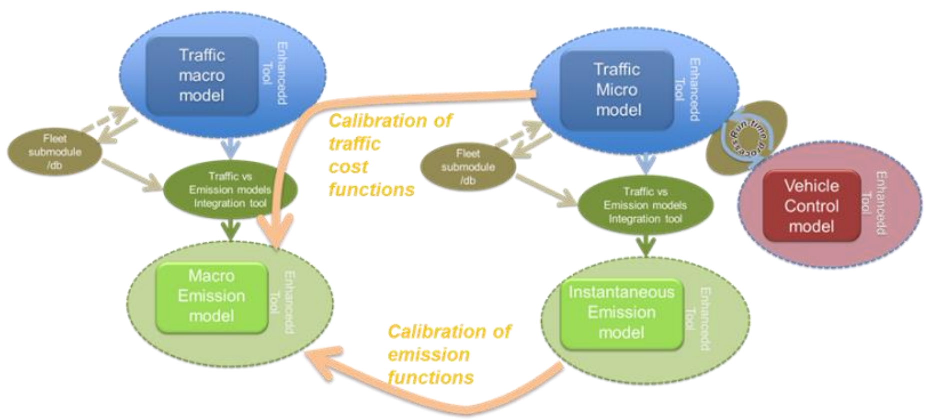

Figure 12: Complete model architecture for CO_2 assessment

In this example the ICT measure is an advanced Traffic Adaptive Urban Traffic Control.

6.1.4. Results of evaluation

Level 1 finishes providing the results of the evaluation of the impact of the Traffic Adaptive Urban Traffic Control with respect to emissions:

Fuel consumption reduction	3%
CO_2 emissions reduction	4%

In the Turin case also the impact on traffic parameters are significant and have to be presented:

Travel Time reductions	10%
Number of Stop reductions	3%
Percentage of Stop Time reductions	3%
Percentage of Constant Speed increment	5%

6.2. Level 2

Level 2 provides technical details about indicators and their calculation.

6.2.1. Capability to simulate the ICT measure

Evaluating if a Traffic Adaptive Urban Traffic Control can be simulated, requires the comparison of traffic simulation results with a “reference case” such as real measurements done in the area simulated.

The comparison will be made on the following traffic parameters:

a. travel time / average speed

b. number of stops

c. percentage of stop time

d. percentage of constant speed

6.2.1.1. Definition of reference cases

The idea is to set up the reference case using real traffic data parameters measured with UTC in "on" and "off" scenarios.

Figure 13: Intersections in the segment to be micro simulated

The simulation covers a real geographical area where some paths have to be selected, each one with a start point, end point, direction and length. Traffic parameters (if not already available from previous measurements) will be measured on these paths thought a on field measurement campaign.

The measurements on field will allow the calculation of statistical confidence interval for each parameters on each path.

6.2.1.2. Definition and calibration of the traffic models

The traffic models (Micro and Macro) representing the area covered by simulation, have to be defined and calibrated. Data coming from on field measurements are fundamental in the calibration phase.

A model can be defined “calibrated” when traffic parameters resulting from simulations are inside the confidence intervals of the corresponding measured parameters, for both scenarios (system on and off).

6.2.1.3. Success criteria

The evaluation has a positive result if the outcomes of the calibrated models fall inside the confidence intervals obtained by on field measurements.

6.2.2. Capability to Model Vehicle emissions

The evaluation will be based on the comparison between model vehicle emission simulation results and “reference cases” coming from real measurements.

The comparison will be made on the following emission parameters:

e. Fuel consumption

f. CO_2 emissions.

6.2.2.1. Definition of reference cases

The idea is to set up the reference case using real “emission” parameters measured with UTC in “on” and “off” scenarios.

The simulation covers a real geographical area where some paths have to be selected, each one with a start point, end point, direction and length. Emission parameters (if not already available from previous measurements) will be measured on these paths through a on field measurement campaign. These measurements require the use of dedicated devices connected to the vehicle can bus in order to collect engine and gear parameters (gear position, acceleration, speed, instantaneous fuel consumption etc.)

The measurements on field will allow the calculation of statistical confidence interval for each parameters on each path.

6.2.2.2. Definition and calibration of the emission models

The emission model have to be calibrated. Data coming from on field measurements are fundamental in the calibration phase.

A model can be defined "calibrated" when emission parameters resulting from simulations are inside the confidence intervals of the corresponding measured parameters, for both scenarios (system on and off).

6.2.2.3. Success criteria

The evaluation has a positive result if the outcomes of the calibrated models fall inside the confidence intervals obtained by on field measurements.

6.2.3. Capability to estimate ICT measure effects on traffic parameters

Starting from the assumption it is possible to simulate a Traffic Adaptive Urban Traffic Control via a traffic simulator, the evaluation will be done comparing simulation results in "on" and "off" scenario.

The simulation will cover a new real geographical area, where new paths each one with a start point, end point and direction will be selected.

6.2.3.1. Definition of a new area

The new real geographical area has to be identified together with its main paths; the sequence of intersections with all their topological characteristics and traffic conditions have to be collected.

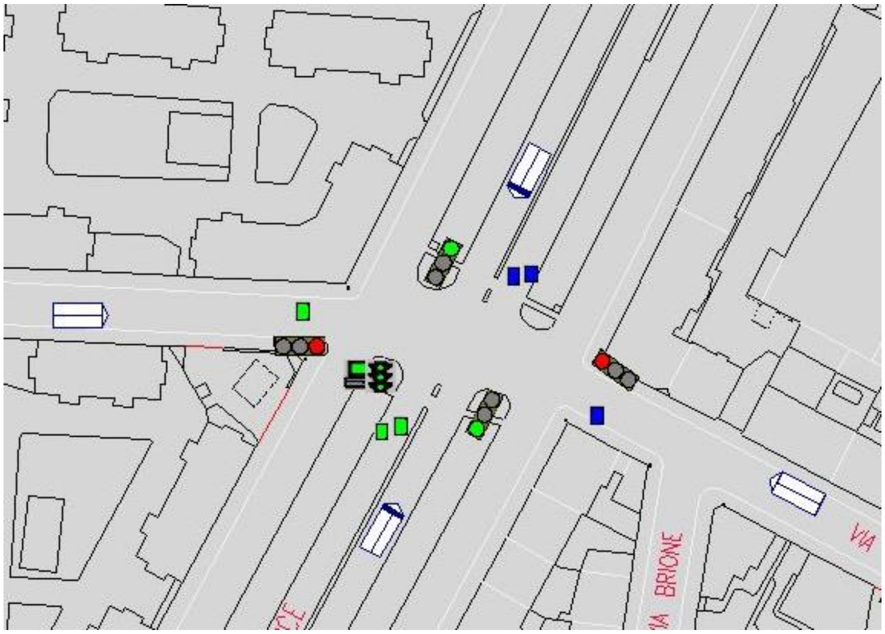

Figure 14: Example of a new Intersection to be micro simulated

6.2.3.2. Adjustment of the traffic models on the area

The new area has to be modeled inside the traffic simulation tools (Micro & Macro).

6.2.3.3. Traffic Simulation in scenario ON & OFF

Both Traffic models (micro - Aimsun - and macro - MTModel -) have to be used to carry out the simulation in scenario off (the Traffic Adaptive Urban Traffic Control not active) and scenario on and the traffic parameters coming out have to be stored.

6.2.3.4. Effects on traffic indicators

The effects of the ICT measure will be calculated on:

a. travel time / average speed

b. number of stops

c. percentage of stop time

d. percentage of constant speed

using the following formula:

I = [(Pof – Pon)/Pof]*100

where:

I: Indicator percentage of variation

Pof: Parameter with system off

Pon: Parameter with system on

The formula has been conceived in order to express a percentage estimating the variation.

6.2.3.5. Success criteria

The evaluation has a positive result (Traffic Adaptive Urban Traffic Control has a positive effects) if the indicators are:

- positive for Travel Time;
- positive for Number of Stop;
- positive for Percentage of Stop Time;
- negative for Percentage of Constant Speed.

6.2.4. CAPABILITY TO ESTIMATE POTENTIAL REDUCTIONS IN CO_2 EMISSIONS

Starting from the assumption that Traffic and Emission models well simulate Traffic Adaptive Urban Traffic Control, the capability to estimate potential CO_2 emission reductions will be evaluated running simulations in scenarios “on” and “off” and comparing results.

6.2.4.1. Emissions Simulation in scenario ON & OFF

The outcomes of the traffic simulation in the scenario on and off, will be used to feed the vehicle emissions model and the emissions have to be calculated and stored (divided by scenario).

6.2.4.2. Effects on Emission indicators

The effects will be calculated on:

e. Fuel consumption

f. CO_2 emissions.

using the following formula:

I = [(Pof – Pon)/Pof]*100

where:

I: Indicator percentage of variation

Pof: Parameter with system off

Pon: Parameter with system on

The formula has been conceived in order to express a percentage estimating the variation.

6.2.4.3. Success criteria

The evaluation has a positive result (Traffic Adaptive Urban Traffic Control has a positive effects) if the indicators are:

- positive for Fuel Consumption;
- positive for CO_2 emissions.

7 Conclusion

The Evaluation Plan tackles the challenge of proving the soundness of the ICT Methodology in targeting the impact on CO_2 emission of ICT measures.

The **evaluation methodology** introduced in this document, evaluates the **ICT methodology** against assessment objectives defined keeping in mind final users and their needs.

Assessment objectives can be summarized as follow:

- Capability to simulate an ICT measure;
- Capabilities to model vehicle emissions;
- Capability to estimate ICT measure effects on traffic parameters;
- Capability of test if an ICT measure has positive impacts on CO_2 emissions;
- Capability of estimate potential reductions in CO_2 emissions.

The **ICT methodology** combines traffic models (Micro & Macro) with emission models and it is characterized by several degrees of freedom:

- different ICT measures;
- different areas and contest of applications;
- different typologies of vehicles;
- different test sites (Turin, Madrid, Rome).

The **evaluation methodology** has been based on the use of "**Common Indicators**" to overcome the complexity raising from the listed degrees of freedom and provide an easy way to compare results coming out from different scenarios (ICT measure, test site, vehicle etc.).

The definition of the indicators has been driven by the analysis of main parameters characterizing and out coming from all traffic and emission models used:

- Travel time;
- Average speed;
- Number of stops;
- Percentage of stop time;
- percentage of constant speed;
- CO_2 Emission;
- Fuel consumption.

Indicators have been defined for each of the assessment objectives:

Nr	Indicator
1	**Capability to simulate an ICT measure**
1.1	travel time / average speed
1.2	number of stops
1.3	percentage of stop time
1.4	percentage of constant speed
2	**Capabilities to model vehicle emissions**
2.1	Emission
2.2	fuel consumption
3	**Capability to estimate an ICT measure effects on traffic parameters**
3.1	travel time / average speed
3.2	number of stops
3.3	percentage of stop time
3.4	percentage of constant speed
4	**Capability to test if an ICT measure has positive impacts on CO_2 emissions**
4.1	Emission
4.2	fuel consumption
5	**Capability to estimate potential reductions in CO_2 emissions**
5.1	Emission
5.2	fuel consumption

Table 25: List of Indicators

Indicators definition is completed by a table summarizing for each ITC categories and measures, which indicators are affected and are to be taken in account in the evaluation process.

This evaluation plan has been aimed at providing all the elements required to evaluate and finalize the outcomes of the project paving the way to the material evaluation activities.

8 Reference List

1. D2.3.1 Guidebook for Assessment of Transport Telematics Applications, CONVERGE Project TR 1101.
2. D3.1 Final Evaluation Plan, HEAVEN Project IST-1999-11244.