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Intelligent transport systems — Extracting trip data using nomadic and mobile devices for estimating CO_2 emissions —
Part 1:
Fuel consumption determination for fleet management

Systèmes de transport intelligents — Extraction des données de voyage via des dispositifs nomades et mobiles pour l'estimation des émissions de CO_2 —

Partie 1: Détermination de la consommation de carburant pour la gestion de la flotte

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 204, *Intelligent transport systems*.

A list of all parts in the ISO 23795 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document has been established to define the monitoring of energy consumption based on measured speed profiles from a vehicle in motion compared to a virtual vehicle driving with defined speed reference cycles.

The service uses in-vehicle nomadic and mobile devices and a client server architecture where the dynamic speed profile per second is evaluated with fixed vehicle configuration parameters inside the server. With the near real-time communication between the nomadic device (ND) and the server, the results of the calculation can also be made visible to the driver during the trip for eco-drive purposes.

The application allows NDs to become a measurement tool for quantifying the energy contributions and inertia forces of a moving vehicle in units of [%] relative to the virtual vehicle moving along the reference cycles.

This document can be used by fleet operators, logistic service providers, public transport operators and eco-drive trainers to develop applications which allow the measurement (in units of [%]) of the energy consumption in litres of gasoline or diesel equivalent (in joules or kWh), relative to the energy consumption of a given standard vehicle.

The methodology also optimizes carbon emission calculations using standard energy consumption without being calibrated to the real trip behaviour of a moving vehicle. This solution has been successfully implemented in the public-private partnership research and development (R&D) projects listed in Table 1:

Table 1 — List of public-private partnership R&D projects

Name	Full name	Duration
LCMM	Low Carbon Mobility Management co-funded by the: Federal Ministry for Economic Cooperation and Development https://energypedia.info/wiki/Emission_Data_Monitoring_Technology	2010 - 2014
AEOLIX	Architecture for European Logistics Information eXchange https://aeolix.eu/	09/2016 – 08/2019
CO-GISTICS	Deploying Cooperative Logistics https://cogistics.eu/	01/2014 – 05/2016
ESA	European-wide mobility, safety and efficiency management for logistics enterprises https://business.esa.int/projects/eu-wide-mobility-safety-efficiency-management-logistics	12/2013 – 01/2017

Intelligent transport systems — Extracting trip data using nomadic and mobile devices for estimating $C0_2$ emissions —

Part 1: Fuel consumption determination for fleet management

1 Scope

This document specifies a method for the determination of fuel consumption and resulting CO_2 emissions to enable fleet managers to reduce fuel costs and greenhouse gas (GHG) emissions in a sustainable manner. The fuel consumption determination is achieved by extracting trip data and speed profiles from the global navigation satellite system (GNSS) receiver of a nomadic device (ND), by sending it via mobile communication to a database server and by calculating the deviation of the mechanical energy contributions of:

a) aerodynamics,

b) rolling friction,

c) acceleration/braking,

d) slope resistance and

e) standstill,

relative to a given reference driving cycle in [%]. As the mechanical energy consumption of the reference cycle is known by measurement with a set of static vehicle configuration parameters, the methodology enables drivers, fleet managers or logistics service providers to calculate and analyse fuel consumption and CO_2 emissions per trip by simply collecting trip data with a GNSS receiver included in an ND inside a moving vehicle. In addition to the on-trip and post-trip monitoring of energy consumption (fuel, CO_2), the solution also provides information about eco-friendly driving behaviour and road conditions for better *ex-ante* and *ex-post* trip planning. Therefore, the solution also allows floating cars to evaluate the impact of specific traffic management actions taken by public authorities with the objective of achieving GHG reductions within a given road network.

The ND is not aware of the characteristics of the vehicle. The connection between dynamic data collected by the ND and the static vehicle configuration parameters is out of scope of this document. This connection is implementation-dependent for a software or application using the described methodology which includes static vehicle parameters and dynamic speed profiles per second from the ND.

Considerations of privacy and data protection of the data collected by a ND are not within the scope of this document, which only describes the methodology based on such data. However, software and application developers using the methodology need to carefully consider those issues. Nowadays, most countries and companies are required to be compliant with strict and transparent local regulations on privacy and to have the corresponding approval boards and certification regulations in force before bringing new products to the market.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
nomadic device
device that provides communications connectivity via equipment such as cellular telephones, mobile wireless broadband (WIMAX, HC-SDMA, etc.), WiFi, etc. and includes short range links, such as Bluetooth, Zigbee

Note 1 to entry: Nomadic devices do not necessarily implement ITS-specified security, e.g., hardware security module.

[SOURCE: ISO 13111-1:2017, 3.1.14 — modified. Definition shortened and Note 1 to entry added.]

3.2
privacy
choice made by the vehicle owner to grant information access for a special tool or user, or if the data should be used in the vehicle/off-board systems or not

Note 1 to entry: The privacy/authorization information is kept as master information off-board and synchronized to the on-board V-ITS-S.

[SOURCE: ISO 13185-3:2018, 3.4]

4 Abbreviated terms

Abbreviated term	Definition
API	acceleration performance index
EPI	energy performance index
EUDC	extra-urban driving cycle
GHG	greenhouse gas
GNSS	global navigation satellite system
GPS	global positioning system
HC-SDMA	high capacity - spatial division multiple access
HDT	heavy duty truck
HDV	heavy duty vehicle
IoT	internet of things
ITS	intelligent transport system
ITS-S	ITS-station
KPI	key performance indicator
LCMM	low carbon mobility management
LCV	light commercial vehicle
LPH	litre per 100 km
ND	nomadic device
R&D	research and development
STS	standstill
UDC	urban driving cycle

Abbreviated term	Definition
V-ITS-S	vehicular and personal ITS station
vLPH	virtual litre per 100 km based on the [%] deviation of real and reference speed profiles
WiFi	wireless ethernet (technology based on IEEE 802.11 standards)
WiMAX	worldwide interoperability for microwave access
WLTP	worldwide harmonized light vehicles procedure

5 Method for fuel consumption determination for fleet management

5.1 Introduction

To implement the method for fuel consumption determination for fleet management as specified in the present document, the descriptions in the subsequent subclauses shall be respected. The informative Annex A presents a concept for the implementation of the method.

5.2 Conventions of applied Newtonian physics

This document is based on the conventions of applied Newtonian physics in the context of the energy and fuel consumption equation as described in detail in Reference [6].

Formula (1) shows the distance consumption of fuel, Φ, in grams per metre (g/m) for vehicles either in motion with speed, v, at $v > 0$ or standing still with $v = 0$, which can easily be converted to litres per 100 km considering that 1 litre of diesel weighs between 820 and 845 grams and 1 litre of petrol around 750 g:

$$\Phi = \Phi_{\mathrm{v}} + \Phi_{\mathrm{id}} \tag{1}$$

where

Φ_{v} is fuel consumption in motion with speed $v \geq \varepsilon$ and $\varepsilon \approx 1$ in metres per second (m/s);

Φ_{id} is idling fuel consumption with speed ranges defined by $\varepsilon > v \geq 0$.

The calculation of Formula (1) includes Formulae (2) - (7) for inertial forces F_{A}, F_{B}, F_{C}, F_{D}, F_{E} (see 5.3), defined as follows:

$$\Phi_{\mathrm{v}} = \eta b_{\mathrm{e}} \frac{\int_0^T (F_{\mathrm{A}} + F_{\mathrm{B}} + F_{\mathrm{C}} + F_{\mathrm{D}} + F_{\mathrm{E}}) v \Delta t}{\int_0^{T'} v \Delta t} \tag{2}$$

$$F_{\mathrm{A}} = m * \frac{\Delta v}{\Delta t}, \Delta v > 0 \tag{3}$$

$$F_{\mathrm{B}} = \beta m * \frac{\Delta v}{\Delta t}, \Delta v < 0 \tag{4}$$

$$F_{\mathrm{C}} = \frac{\rho}{2} * A' * c_{\mathrm{W}} v^2 \tag{5}$$

$$F_{\mathrm{D}} = mg\mu \tag{6}$$

$$F_E = mg * \sin(\alpha) \quad (7)$$

where symbols are as follows:

η is the numerical value of the engine efficiency, expressed in percent (%);

b_e is the numerical value of fuel value, expressed in grams per kilowatt hour (g/kWh);

T is the numerical value of the driving time, expressed in seconds (s);

T' is the numerical value of the driving time to reach the reference distance, usually 100 kilometres, expressed in seconds (s);

v is the numerical value of the speed, expressed in metres per second (m/s);

Δt is the numerical of the time interval per second applied for the integral in Formula (1), expressed in seconds (s);

Δv is the numerical values of changing speed of the vehicle from one second to the next defining positive and negative acceleration according to Newtonian Physics, expressed in metres per second (m/s);

β is the numerical value of the propulsion, expressed with no units;

where the vehicle constants are as follows:

m is the numerical value of the total weight of the vehicle, expressed in kilogram (kg);

A' is the numerical value of the cross-sectional area, expressed in metres squared (m^2);

c_w is the numerical value of the drag coefficient, expressed without units;

where the constants describing road conditions are as follows:

α is the numerical value of the slope angle, expressed in degree (°);

μ is the numerical value of the friction coefficient, expressed without units;

where the physical constants are as follows:

ρ is the numerical value of air density, expressed in kilograms per metre to the power of three (kg/m^3);

g is the numerical value of acceleration of gravity, expressed in metres per second squared (m/s^2).

The proposed method is based on the innovation that GNSS receivers detect speed profiles per second and on the assumption that all constants used in Formula (1) have the same numerical values for the vehicle in motion and the virtual vehicle. This addresses also idle creep, where any overestimation of the true zero velocity fuel consumption is inconsequential to the practical zero velocity fuel consumption, meaning that any constant error introduced into the variable equation by idle creep can be reasonably mitigated by the comparison to the virtual vehicle model. Due to small fluctuations of GNSS speed signals, zero-values of speed were defined in Formula (1) in the numerical range of 0 to 1 of speed values expressed in metres per second (m/s).

On the other hand, the proposed method includes the following pre-conditions when analysing trips of vehicles in motion by detecting speed profiles with the GNSS receiver of an ND:

— All vehicle configuration constants used in Formula (1), particularly weight, tyre pressure, cross-sectional area and drag coefficient, are time-independent in driving cycle and real-trip data;

— all constants describing road surface conditions are time-independent and, therefore, shall be identical with regards to cycle and real-trip data;

— all constants describing physical constants, especially air density, are time-independent and therefore shall be identical with regards to cycle and real-trip data;

— fuel consumption when idling, introduced in Formula (1) as Φ_{id}, is defined in units of litres per seconds (l/s). Calculation is triggered by the GNSS receiver whenever speed values are smaller than a given threshold, usually 1 m/s. By comparing the standstill time of the real trip to the one of the worldwide harmonized light vehicles procedure (WLTP) cycle, a percentage deviation results which can be used for expressing the influence of standstill. Usually, established driving cycles such as WLTP neglect the influence of slope resistance and downhill forces, inertial forces which impact fuel consumption in mountainous road networks. Therefore, slope work in Formula (1) cannot be measured in percentage relative to a given driving cycle.

The application of these pre-conditions leads to the following conventions for fleet managers using the described method:

— the above constants shall be identical in driving cycle and real-trip data; otherwise, the fuel determination and percentage of energy deviation measured per trip by the nomadic device become invalid;

— any usage of the methodology shall rely on the correct start and stop definition of a trip, i.e. the method becomes invalid when a detected speed profile per trip includes mileage of different vehicles, but vehicle configurations of only one vehicle;

— when changing load and vehicle weight in a trip (e.g. in logistics operation), trip data has to be adjusted with the corresponding start and stop functions or an average load, such as the ones used for sustainability reports, and GHG emissions shall be applied.

5.3 Explanation

As stated in Formula (1) and according to the laws of Newtonian physics, the energy consumption of any vehicle travelling in space and time is separated by a part for motion ($v > 0$) and a second part for standstill ($v = 0$). According to Newton, the need for energy then results from inertial forces opposing the motion of the vehicle including the energy demand for accelerating the vehicle [Formula (3)] or energy losses caused by braking [Formula (4)] as well as aerodynamic [Formula (5)] and rolling friction resistance [Formula (6)]. Additionally, there is energy needed to drive uphill as well as there can be energy gained and/or lost while driving downhill [Formula (7)], which is caused by slope resistance and slope down forces.

By integrating all mentioned forces along a given trip distance, an energy value in joule results which has to be transferred into fuel with the unit of litre or electric power with the unit of kWh. The parameter in the energy equation is given by the fuel value b_e.

Finally, this value has to be multiplied by the engine efficiency, η, depending on the different types of engines, e.g. combustion, biofuel or electric. Usually, the fuel consumption is referred to the given distance of 100 km, resulting in the well-known units of litres per hundred kilometre or kilowatt-hours per hundred kilometres.

5.4 Relevance of energy equation for nomadic devices

As found in several field trials since 2010 (see References [4], [8] and [11]) the parameters in the energy equation can be separated into a dynamic function of speed and a static function of fixed vehicle configuration parameters combined with parameters describing the road characteristics as well as with physical parameters.

Under the assumption that all parameters of the static function are constant system configuration values, the dynamic speed profile per second becomes the dominant influence factor for analysing energy demand and fuel consumption which are directly linked to the carbon emissions per trip. On the other hand, the speed profile per second is detected by any GNSS satellite receiver of a nomadic device and is therefore available for fuel and emission monitoring. Additionally, the satellite receiver examines the geographical location, exact time, height and direction in order to evaluate trip data *ex-post*, e.g. on a digital map.

To minimize the errors in calculating energy consumption and carbon emissions resulting from the assumption of static parameters, it was found in several field trials that the best quality results are achieved when comparing the inertial forces from Formulae (2) - (7) to speed reference cycles, e.g. driving constant speed, ECE or WLTP.

5.5 Example of the presented methodology

To give a simple example on how to use real on-trip speed profiles relative to the reference cycles,[8] consider a vehicle in motion driving 90 km/h constantly without acceleration, slope resistance or standstill. For a plain road network with slope α = 0 and constant speed with no acceleration events, this can be summarized as shown in Formula (8):

$$\frac{E_{\mathrm{M},i}}{E_{\mathrm{M},o}} = \frac{\left(F_{\mathrm{D},i} + F_{\mathrm{C},i}\right) * v_i * \Delta t / \int \Delta x}{\left(F_{\mathrm{D},o} + F_{\mathrm{C},o}\right) * v_o * \Delta t / \int \Delta x'} \quad (8)$$

where

$E_{\mathrm{M},i}$ is the energy demand of the vehicle *i* in motion, expressed in joules (J);

$E_{\mathrm{M},o}$ is the energy demand of the virtual reference vehicle *o*, expressed in joules (J);

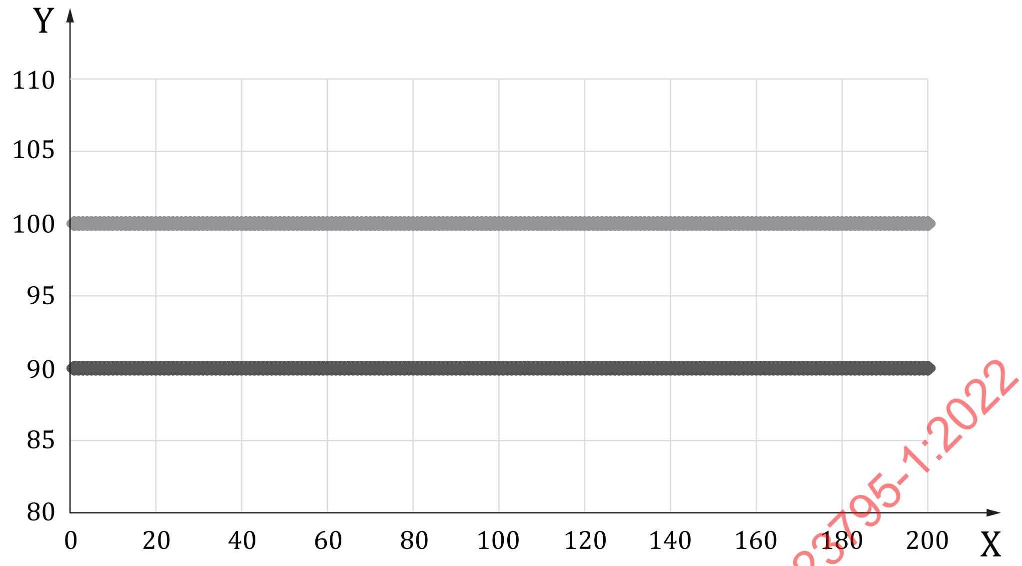
F_D is the inertial force of rolling friction acting on the vehicle in motion with index *i* and *o* according to those of E_M, expressed in units of Newton (N);

F_C is the inertial force of aerodynamic acting on the vehicle in motion with index *i* and *o* according to those of E_M, expressed in units of Newton (N);

Δx is the distance travelled by the vehicle in motion, expressed in units of metres (m);

$\Delta x'$ is the distance travelled by the virtual reference vehicle, expressed in units of metres (m).

All other symbols and definitions are used according to those of Formula (2). To show the usefulness for fleet operators and drivers with regards to analysing fuel and CO_2 an illustration is given for the very simple case of comparing a virtual vehicle driving constant speed of 90 km/h with a real vehicle driving constantly at 100 km/h, with both vehicles integrated according the Formula (8) in a given time frame of 200 seconds; see Figure 1.



Key

X time (s)

Y speed (km/h)

Figure 1 — Constant driving cycle 90 km/h compared to real speed 100 km/h (y-axis) versus the time window of 200 s (x-axis)

The force for the rolling resistance, simplifying it in Formula (1) into one term for the entire vehicle, is defined as in Formula (9):

$$F_D = mg \cdot \mu \tag{9}$$

with mass, m, in (kg), gravity constant, g, equal to 9,81 m/s^2 and μ as a dimensionless rolling coefficient which is usually expressed in the numerical value 0,015 for private passenger cars. For a private car with weight 1 305 kg, this gives a rolling friction force of 192 N. For the real speed profile, this does not change if the mass does not change and is assumed to be constant.

Additionally, the definition for the aerodynamic resistance is given using Formula (10):

$$F_C = c_w A' \cdot \frac{\rho}{2} \left(\frac{v}{3,6} \right)^2 \tag{10}$$

where all definitions follow those given in Formula (5).

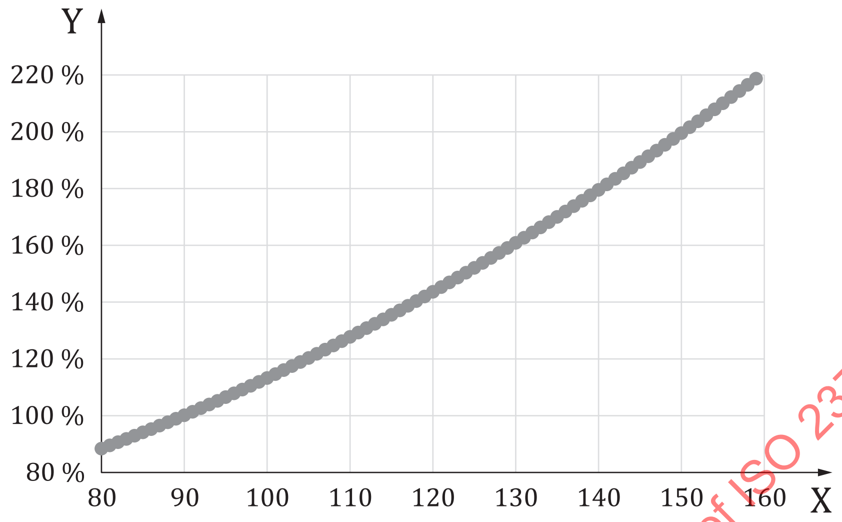
For a normal, middle-sized passenger car with cross-section A=2,48 m^2, c_w=0,26 and ρ=1,204 kg/m^3, this results in a total force of 243 N while driving at 90 km/h and 300 N when driving at 100 km/h.

Assuming the very simple reference cycle of driving constant speed of 90 km/h for 200 s, the proposed measurement methodology shall be described by inserting the above vehicle parameter into Formula (8). For constant speed, Formula (8) reduces to a percentage relation of forces; see Formula (11)

$$\frac{E_{M,i}(100)}{E_{M,o}(90)} = \frac{(192+300)}{(192+243)} = 113 \tag{11}$$

where the final value is expressed in percentage (%).

Formula (11) shows that the given private passenger car driving at 100 km/h needs 13 % more acting force on the axis than the same car driving at 90 km/h. If the fuel consumption for the reference cycle is known, in the present case of 90 km/h, then Formulae (8) to (12) shall be considered as an indirect measurement tool analysing relative fuel consumption and CO_2 emissions. Results are shown in Figure 2, where it is observable that driving with speed ranging between 80 km/h and 90 km/h decreases energy demand, while driving with speed ranging between 90 km/h and 160 km/h increases demand, with double energy when driving at 150 km/h.



Key

X speed, km/h

Y energy, % rel. 90 km/h

Figure 2 — Energy and fuel demand increase in percentage relative to the energy demand driving at 90 km/h with percentage increase (y-axis) versus driving speed (x-axis)

It is noted that percentage values relative to the reference cycle are indicative and not absolute, as speed and engine behaviour are mathematically not coupled in a linear way but by complex thermodynamics of fuel combustion and engine efficiency; see Formula (1). Nevertheless, "easy-to-understand" indicators help drivers to better understand energy demand linked to their speed selection while driving, as calculations are based on the percentage of quantified energy demand for real and virtual speed profiles. This gives a direct feed-back by applied Newtonian physics and is brand- and engine-independent, thus making the ND a complementary sensor system for the purpose of analysing energy demand.

The benefit of having the suggested energy demand information in percentage can play a similar role to that of energy labels, nowadays very common for electric light bulbs and household devices showing different colour codes linked to their comparative energy demand.

As drivers are used to evaluating fuel consumption by the unit (litres per hundred kilometres), in Anglo-American literature often stated as the abbreviated unit LPH, this percentage-deviation shall be translated into the unit vLPH (virtual litres per hundred kilometres) by the following procedure according to Formula (1):

a) Multiply the sum of inertia forces in N with the distance travelled per second, giving the energy demand per second in Nm or J;

b) Sum up all energies in the given time window of the reference cycle and divide by the total distance travelled during the speed profile, giving results in J/m;

c) Multiply J/m with 1 000 × 100 to give J/100 km;

d) Divide the result by $3{,}6 \times 10^6$ to find values in units of (kWh/100 km);

e) Divide the result by fuel value, b_e, and engine efficiency, η, to achieve virtual l/100 km (vLPH).

With regards to the accuracy of the proposed methodology, any measurement of percentage deviation relative to a given reference cycle cannot be more precise than the precision of the reference cycle itself. As all vehicle parameters are set to constant, errors occur by nature of the measurement technology in rolling coefficient and tyre pressure, aerodynamics and even mass, not to mention thermodynamics of the engine. Speed reference cycles (e.g. the WLTP cycle), take place under laboratory conditions and not on the road while driving. This means that all changes of parameters such as tyre pressure, mass, weather conditions (e.g. wind) and others have influence with regards to real fuel consumption.

Nevertheless, as automobile consumers worldwide use values for fuel and CO_2 as one criterion for their vehicle and engine choice consumption, vehicle registration authorities feel obliged to give indications of fuel and CO_2 consumption for these consumers based on standardized laboratory speed cycles, independently of the complexity linked to the energy equation with all their parameters. Evaluating real speed profiles by NDs relative to reference cycles has the same purpose: find out the percentage of speed and energy deviations relative to reference profiles and show strategies for fleet operators and drivers to reduce fuel consumption and CO_2 emissions.

So far in this document, a simplified calculation has been presented, which does not yet consider the influence of acceleration, standstill or slope within the real on-trip or the virtual reference cycle. This can be found in Annex B. Nevertheless, the basic principles already show how the proposed methodology can be used as tool to quantify energy demand in road transport by the applied principles of Newtonian physics in combination with given reference cycles and ND sensor systems.

Further details of calculating energy behaviour for strategic monitoring of fleets and how to save their fuel and CO_2 demand by using the proposed methodology are elaborated in Annex B. Additional and useful literature as well as results from pilot projects and academic studies can be found in the Bibliography, in the published results of field trials in China in Reference [4].

Annex A
(informative)

Concept for implementation

A.1 System architecture

To obtain information about the energy behaviour per trip, a low-cost solution called Low Carbon Mobility Management (LCMM) cloud platform architecture has been developed and applied in a number of pan-European logistics projects. This solution considers the economic constraints felt by most logistics companies and their difficulties in investing in the introduction of new technologies. A plug-&-play solution is adopted, where GPS data provided by the HDVs is sent to a database, elaborated, analysed, mapped and then given back in a simplified version to drivers and dispatchers. A schematic architectural representation of the platform is presented in Figure A.1 and further details can be found in Reference [4] in the Bibliography.

The process goes as follows: primary GPS data about vehicles derives from a mobile phone installed in the truck. Such data, which includes time, latitude, longitude, speed and altitude, are transmitted every fifteen seconds to the server platform. Since the average duration of a mobile phone with GPS turned on is four hours, which is a short period in comparison to the average daily tour of a truck, the mobile phone is equipped with an external battery that extends the duration of the battery to the duration of the entire trip. With this system, the driver needs to turn the device on or off only once a day and can use the smart phone as a telephone or mobile internet device during the day without losing any information.

Before the beginning of each trip, all users need to register their vehicle configuration according to a predefined database and register some user information including the average payload of the specific trip. Data is transmitted to the LCMM platform, which includes four main technical components.

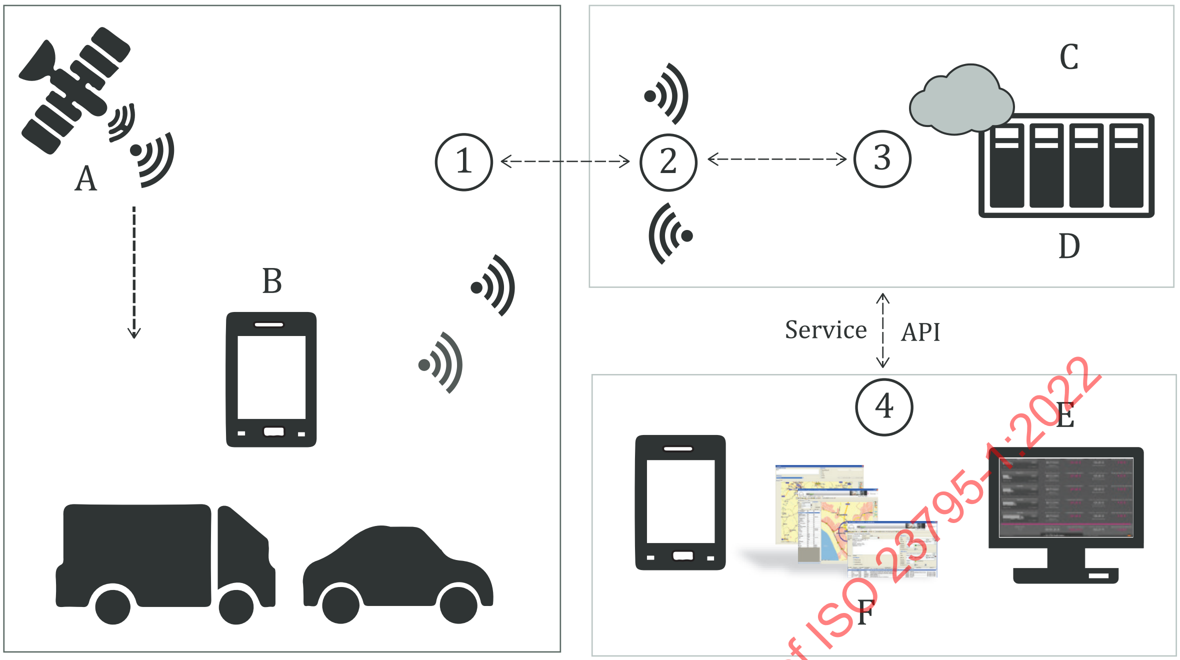
1) A nomadic device with GNSS satellite receiver, e.g. GPS.

2) The radio data transmission to connect device and cloud server.

3) An Internet of Things (IoT) or ICT back-end platform to receive trip data and manage the device.

4) A web-interface to give fleet-operator or others access to the trip data.

The collected GPS data is analysed and evaluated within the database server by any programming language: in the piloted projects, PHP was used. Inside the server, the percentage deviation relative to reference cycle, nowadays WLTP, is calculated and used as a basis for determining fuel consumption and CO_2 emissions.



Key

A GPS
B smartphone
C cloud server
D IoT platform
E fleet operator
F client application
1 mobile terminal device with app
2 telecom network connectivity
3 cloud server/device and data management
4 visualization tools and dashboard

SOURCE: CAVALLARO, F., MAINO, F., & MORELLI, V. (2013)[8], WILLENBROCK R., TISCHLER J.[11];reproduced with the permission of the authors

Figure A.1 — LCMM cloud platform architecture

A.2 LCMM — Front-end

On left side of the system architecture in Figure A.1, a mobile phone is shown which is installed inside the vehicle, using standard in-vehicle cradles, common also for smart phone based in-vehicle navigation. After starting the LCMM APP software application on the mobile side, the exemplary design of the main menu is illustrated in Figure A.2.

SOURCE: CAVALLARO, F., MAINO, F., & MORELLI, V. (2013)[8], WILLENBROCK R., TISCHLER J.[11], reproduced with the permission of the authors

Figure A.2 — LCMM exemplary Android APP design

Once the application has been started, trip recording is running, and satellite data are sent to the server in the sample frequency of 1 Hz in compressed data format. The data are stored and extracted in the mySQL database for online monitoring and reporting in the back-end side, after giving access to authorized users by an IT administrator.

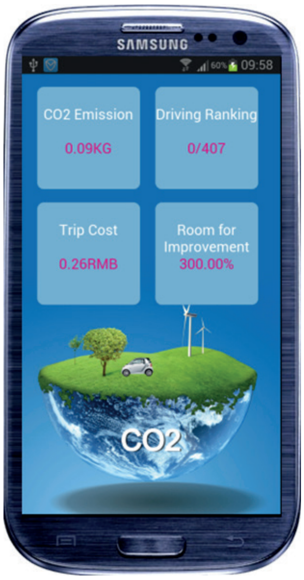
In Figure A.3, an example of three screens visible for the driver inside the vehicle is presented. The energy panel (Figure A.3, left) shows increased energy demand of 58 % relative to the reference cycles. The colour helps drivers to be aware of their eco-drive behaviour in the time window given by the reference cycle. Compared to this, (Figure A.3), middle, shows a relative increase of 36 %, which has colour code yellow-orange with regards to the reference cycle in terms of fuel consumption and CO_2 emissions. Finally, Figure A.3, right, shows a trip with improved driving performance and energy demand reduction of -10 % relative to reference cycle values.

SOURCE: CAVALLARO, F., MAINO, F., & MORELLI, V. (2013)[8], WILLENBROCK R., TISCHLER J.[11], reproduced with the permission of the authors

Figure A.3 — LCMM cloud platform in use, examples of Red-Green-Yellow encoded feedback for drivers on-trip with trip-related evaluation of travel time, distance and energy performance

On-trip visualization for drivers is limited by safety concerns and usually involves nothing more than a short glance at the colour coding to acquire some feedback on driving eco-mode or not. The positive learning effect for drivers is rather linked to remembering the principles of eco-mode driving by using inertia forces and smart braking or choosing the right speed on motorways according to traffic flow and trip planning. The ex-post evaluation then clarifies details of positive or negative impact on energy demand linked to certain driving manoeuvres.

Whenever trip recording needs to be stopped, drivers press a stop button to terminate trip recording. Before shutting down the LCMM APP, drivers are informed about some general evaluation results of the recorded trip. These include CO_2 emissions, ranking inside the fleet of users, trip costs or savings, as well as indications for improvements in percentage, for example. Figure A.4 shows the LCMM front-end APP design in an exemplary manner, as used in the 2013 Jiangsu field trial[7] after trip recording has finished. Note that the presented numbers in Figure A.4 do not match with real trip data, but only present dummy test data.



SOURCE: CAVALLARO, F., MAINO, F., & MORELLI, V. (2013)[8], WILLENBROCK R., TISCHLER J.[11], reproduced with the permission of the authors

Figure A.4 — LCMM exemplary Android APP design; informative panel after trip recording has been stopped

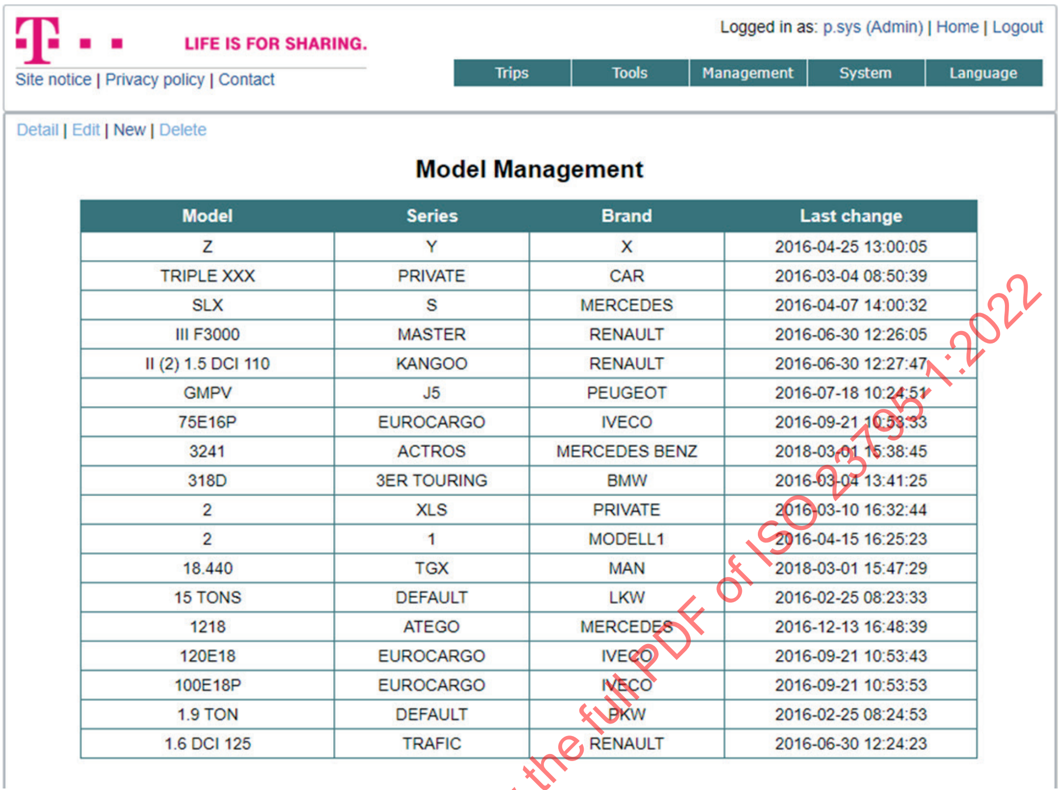
In the 2013 Jiangsu field trial, based on the consumption registered by the mobile phone, the fuel cost function and the performance of the driver was determined, both in aggregate and disaggregate forms. They were visualized thanks to specific tools, such as summary sheets about driving performance of the single vehicles, their speed curves and an emission profile map. Compared to on-board unit platform solutions, many new features were introduced based on the physics of driving calculations, usually not easily accessible by the use of in-vehicle on-board units for freight transport operators, such as time lost, grade work, normalized braking and acceleration index. During the field trial execution, ND and Android APP software gave high flexibility for adding or shutting down service features and functions of the LCMM APP, which were requested by the fleet operator for information exchange with their drivers on the front-end.

In Clause A.3, the LCMM back-end solution is described. This back-end solution includes the modules indicated in Figure A.1 (System Architecture). It was not only used to test the effectiveness of eco-drive training in the Chinese province of Jiangsu, but also to execute several R&D field trials in Europe (see Table 1 in the Introduction).

The aim of all field trials with a different number of commercial users was to understand whether the real-time component provides reliable information, which would help to launch ND solutions that can be considered consistent with the traditional macro-modelling approaches adopted to evaluate the CO_2 efficiency of vehicular fleets. As previously mentioned, this would not only contribute to an *ex-post* evaluation of the performances but could also grant a prompt modification of the driving style to reduce fuel consumptions and CO_2 emissions. In this way, it is possible to understand the real potentialities granted by field trials, giving at the same time a practical solution to improve their effectiveness.

A.3 LCMM — Back-end

Before discussing the online evaluation and reporting function of LCMM, Figure A.5 gives an overview of the vehicle model management where the different fixed parameters necessary for the energy demand calculation according to Formulae (1) to (8). Different models with their vehicle characteristics in cross section, rolling friction, empty weight, etc. were included and could be changed at any time, e.g. in case engine efficiency turned out to be somehow different in real driving mode operation compared to cycle values. After a specific vehicle is registered in the LCMM database it can be selected by drivers and used for their trip evaluation.



Model	Series	Brand	Last change
Z	Y	X	2016-04-25 13:00:05
TRIPLE XXX	PRIVATE	CAR	2016-03-04 08:50:39
SLX	S	MERCEDES	2016-04-07 14:00:32
III F3000	MASTER	RENAULT	2016-06-30 12:26:05
II (2) 1.5 DCI 110	KANGOO	RENAULT	2016-06-30 12:27:47
GMPV	J5	PEUGEOT	2016-07-18 10:24:51
75E16P	EUROCARGO	IVECO	2016-09-21 10:53:33
3241	ACTROS	MERCEDES BENZ	2018-03-01 15:38:45
318D	3ER TOURING	BMW	2016-03-04 13:41:25
2	XLS	PRIVATE	2016-03-10 16:32:44
2	1	MODELL1	2016-04-15 16:25:23
18.440	TGX	MAN	2018-03-01 15:47:29
15 TONS	DEFAULT	LKW	2016-02-25 08:23:33
1218	ATEGO	MERCEDES	2016-12-13 16:48:39
120E18	EUROCARGO	IVECO	2016-09-21 10:53:43
100E18P	EUROCARGO	IVECO	2016-09-21 10:53:53
1.9 TON	DEFAULT	PKW	2016-02-25 08:24:53
1.6 DCI 125	TRAFIC	RENAULT	2016-06-30 12:24:23

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Figure A.5 — LCMM back-end vehicle configuration module

The LCMM back-end offers several possibilities for online-monitoring and reporting functions. Feedback on driving performances is provided back to freight transport operators through the website platform (for post-trip evaluations and tour planning of the fleet manager), or through the front-end Android application (for real-time evaluations) mentioned in A.2. The website platform provides detailed information about the time of the trip listed as well as the duration of trip, distance travelled, average speed, energy behaviour in percentage relative to reference cycle from during the field trial the European Driving Cycle (Urban UDC and Extra-Urban EUDC).

An example of the appearance of the website evaluation of recorded trips for fleet operators can be found in Figure A.6 showing an LCMM recorded trip with a private passenger car in Sweden. At the top of Figure A.6, the trip ID, vehicle model, date and time are listed together with some basic energy evaluations, i.e. the normalized energy performance index (EPI) in units of cl/t×km, which was found to be effective when comparing vehicle and load influence during the fleet operation in logistics.

Figure A.6 also illustrates the energy colour coding used within the different pilot projects designed to monitor fuel and CO_2 demand along a given trip of a vehicle in motion. Green was chosen to indicate the same demand as that of the reference cycle or better, yellow for demand increase between 100 % and 150 %, whereas red represents fuel and CO_2 increase above 150 %. The introduction of traffic light colour coding allows logistics fleet operators and drivers to better understand causes and effects of certain driving manoeuvres including effects of traffic congestion, road segments suffering of reduced capacity due to construction work, etc. By exporting trip data and energy analysis to ex-post data files in ".csv", ".pdf" or ".kml" format, drivers and logistics service providers can monitor details for pre-trip tour planning considering energy demand and individual driving behaviour.

NOTE ".kml" is the data format which can be used for Google Earth digital map presentations.

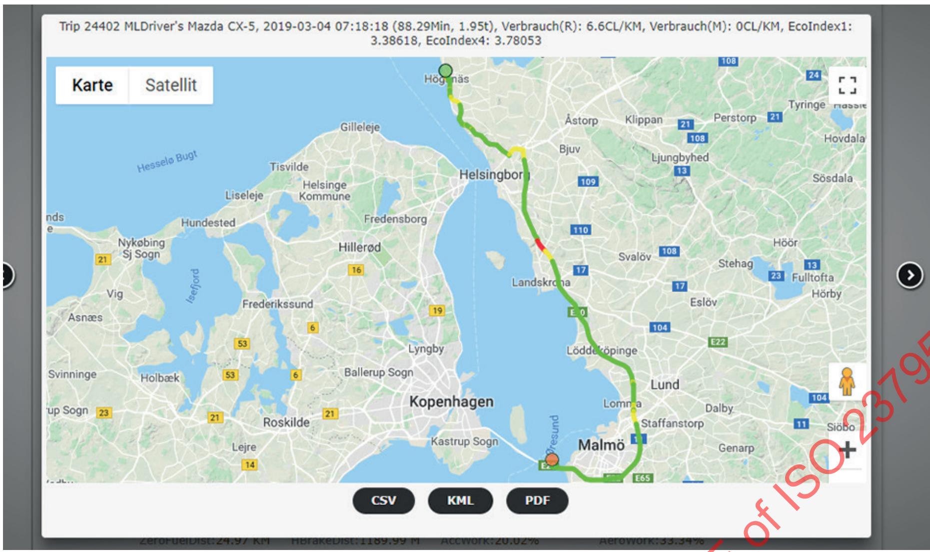

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Figure A.6 — LCMM cloud platform in use, recorded private passenger trip in Sweden and digital map presentation

Figure A.7 shows the same trip from Sweden in the speed (km/h) over time (s) cartesian presentation, including stop time and urban/extra-urban segments of the recorded trip, whereas Figure A.8 gives an indication of the same trip including height information.

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Figure A.7 — LCMM cloud platform in use, recorded private passenger trip speed profile (y-axis) over trip time recorded (x-axis)

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Figure A.8 — LCMM cloud platform in use, recorded private passenger trip Height profile (y-axis) over trip time recorded (x-axis)

Once a fleet has recorded several trips for a given set of vehicles, evaluations and reports with regard to distance, time of the day and date, energy performance and energy contributions in percentage and others can be given for strategic savings in fuel and CO_2 consumption. Additionally, the function for top-down criteria with regard to performance is helpful for deciding training or incentive measures according to the energy performance in fuel savings.

In Figure A.9, this is shown in an exemplary manner for three selected trips sorted by the selection criteria “time”. Additional selection criteria are “Distance”, “AvgFuel” (based on [vLPH]), “Speed”, “Ranking”, “Duration”, “TimeLost”, “EcoIndex1” (Energy Performance Index, EPI), “EcoIndex4” (Acceleration Performance Index, API) and “BrakeIndex”.

In the field trials mentioned in the Introduction, different measures to link the recorded and sorted trips to strategic fuel and CO_2 saving were applied. Whereas in the Jiangsu field trial in China[7] two months of baseline trip recording by APP usage of 25 commercial vehicles was executed followed by a second phase including a professional eco-drive training and LCMM top-down ranking and trip data evaluation for the payment of incentives, other fleet operators just used the data to find out weaknesses of their tour planning and used the LCMM data for re-scheduling their daily logistics operation.

As eco-drive is a rather new area of investigation and service deployment, a need was identified for measurement tools that allow quantifying psychological driving behaviour and speed choices including the sensitive effect of acceleration and braking. The chosen methodology to link the trip recording to average fuel and CO_2 consumption from driving cycles was found useful as automobile customers and drivers are used to fuel consumption indications based on reference cycles, published in the vehicle registration documents by the authorities already.

Thus, percentage deviation of energy demand relative to cycle values and units of vLPH (virtual litre/100 km) can offer an APP service provider standardized quantifiers for eco-drive and fuel/CO_2-oriented solutions and ND service design.

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Figure A.9 — LCMM cloud platform in use, recorded trip and top-down ranking methodology to derive strategic management measures for fleet operators and logistics service provider

A.4 LCMM – Results from selected reference projects

Figure A.10 shows the energy demand of the VIP shuttle services operated during 2010 EXPO[7] in Shanghai close to area of entry gates to the Pavilions. The shuttle vehicles were BMW limousines and the NDs were HTC smartphones equipped with GPS satellite receivers. As can be seen, fuel and CO_2 demand were presented on Google Earth digital maps in ".kml" and made available via a website to all EXPO organizing entities via authorized access to the LCMM web-service implemented in a Shanghai data centre.

For the eco-drive field trial execution in Jiangsu from 2013 until 2014, the same technology was used with LCMM Android APP on Samsung smartphones equipped with GPS receivers in a fleet of 25 commercial vehicles. After eco-drive training for this fleet, in Jiangsu fuel and CO_2 savings in the range of 5 % for LCV and 8,8 % for HDV was found. It was found and published in Reference [4] that the LCMM APP helped to better determine the CO_2 baseline related to the logistics activities of an enterprise. Reference [4] also described how to train drivers to operate vehicle manoeuvres towards eco-drive and fuel/CO_2 reduction.

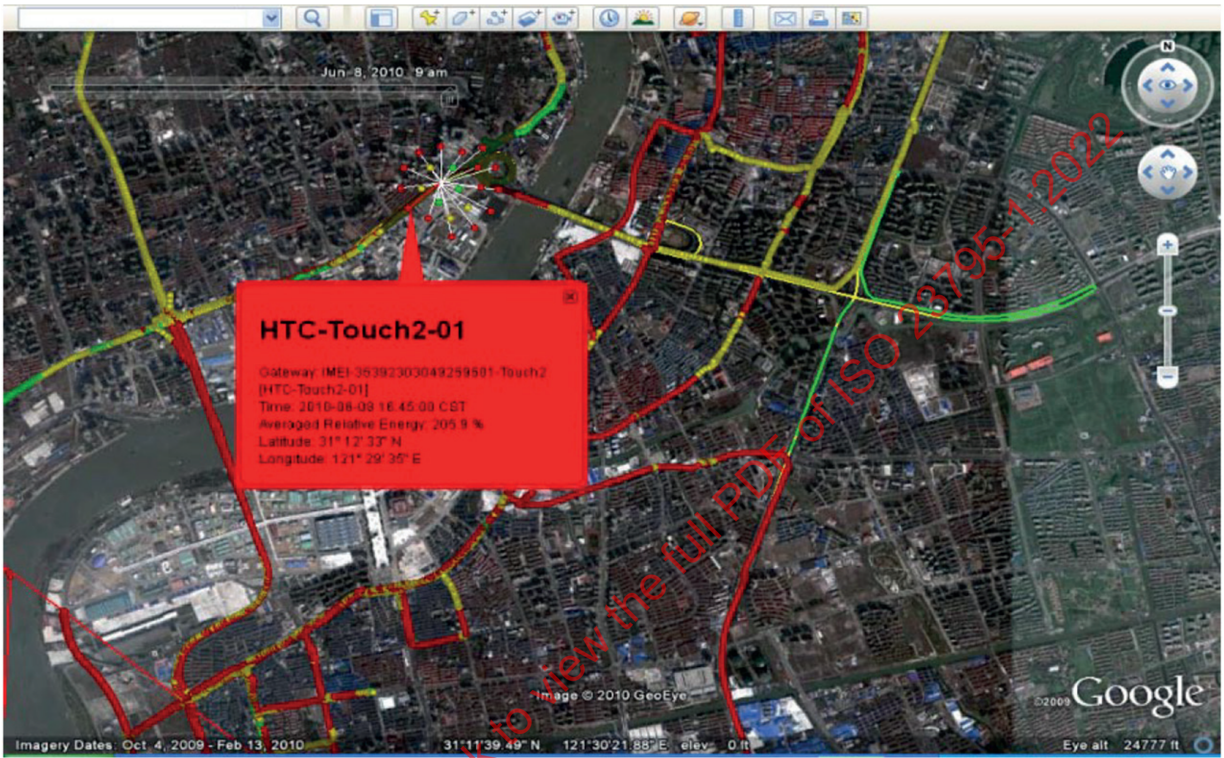

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Figure A.10 — Graphical interface of the LCMM back-end as used during Shanghai EXPO 2010

Annex B
(informative)

Application of the method in a use case study — Examples and results

B.1 Detailed description of monitoring fuel and CO_2 of a Volkswagen Golf VII driving in urban road conditions

B.1.1 Step 1 Server side: Calculate reference cycle of virtual vehicle

a) Assign physical constants: g = 9,81 m/s², ρ = 1,204 kg/m³

b) Assign vehicle configuration: e.g. Volkswagen Golf VII

m = 1 305 kg

A = 2,57 m²

μ = 0,015

c_w = 0,31

c) Assign speed reference trip: e.g. WLTP low

d) Calculate:

$$V_0 = \left(\sum_{i=1}^{N} v_{i0} \right) \frac{1}{N}, v_0 > 0$$

If: $v_{i+1} > v_i$

$$a_0 = \sum_{i=1}^{N} (v_{i+1} - v_i) \frac{1}{N}$$

If: $v_{i+1} < v_i$

$$b_0 = \sum_{i=1}^{N} (v_{i+1} - v_i) \frac{1}{N}$$

If: $v_i = 0$

$$S_0 = \sum_{i=1}^{N} i [$$

where

V is the average speed calculated as sum of single speed v_i per second divided by events, N;

S is standstill;

$_0$ is an index to represent energy values used to measure percentage of deviation relative to the reference cycle;

a is the positive acceleration value;

b is the negative acceleration value.

B.1.2 Step 2 Server side: Find real speed of moving vehicle

a) Assumption: Vehicle has on-board ND with satellite receiver and will send out to the server the “speed, time and location” collected per second.

b) Then: Speed real trip profile is assigned in the server as:

V (1s – Ns)

c) Calculate:

$$V=\left(\sum_{i=1}^{N} v_i\right) * \frac{1}{N}, v_i > 0$$

KPI of Aerodynamic Resistance (in %)

$$\frac{V^2}{V_0^2}$$

$$\text{If } V = 0\text{: } S = \sum_{i=1}^{N} i \tag{B.1}$$

KPI of Standstill (in %)

$$\frac{S}{S_0}$$

Same methodology is applied to:

KPI of Acceleration (in %)

$$\frac{a}{a_0}$$

KPI of Braking (in %)

$$\frac{b}{b_0}$$

As acceleration and braking behaviour are the KPIs for any eco-drive mode of driving, a second parameter is recommended to compare not only the average per cycle but also the number of seconds per trip relative to the reference cycle where acceleration or braking events take place.

This is written in Formulae (B.2) and (B.3):

KPI of positive acceleration, a: Count if ($a > 0$)

— Compare $$\frac{\sum_{i=1}^{N} i(a > 0)}{\sum_{i=1}^{N} i(a_0 > 0)} \text{ in \%} \tag{B.2}$$

KPI of negative acceleration, b: Count if ($b < 0$)

— Compare $$\frac{\sum_{i=1}^{N} i(b > 0)}{\sum_{i=1}^{N} i(b_0 > 0)} \text{ in \%} \tag{B.3}$$

B.1.3 Summary

Step 1 of the calculation compares the average speed of a virtual vehicle moving with reference speed v_0 relative to the real average speed v. Additionally, it compares based on Newton’s energy equations:

— Aerodynamic in %

— Standstill in %

— Acceleration in %

— Braking in %

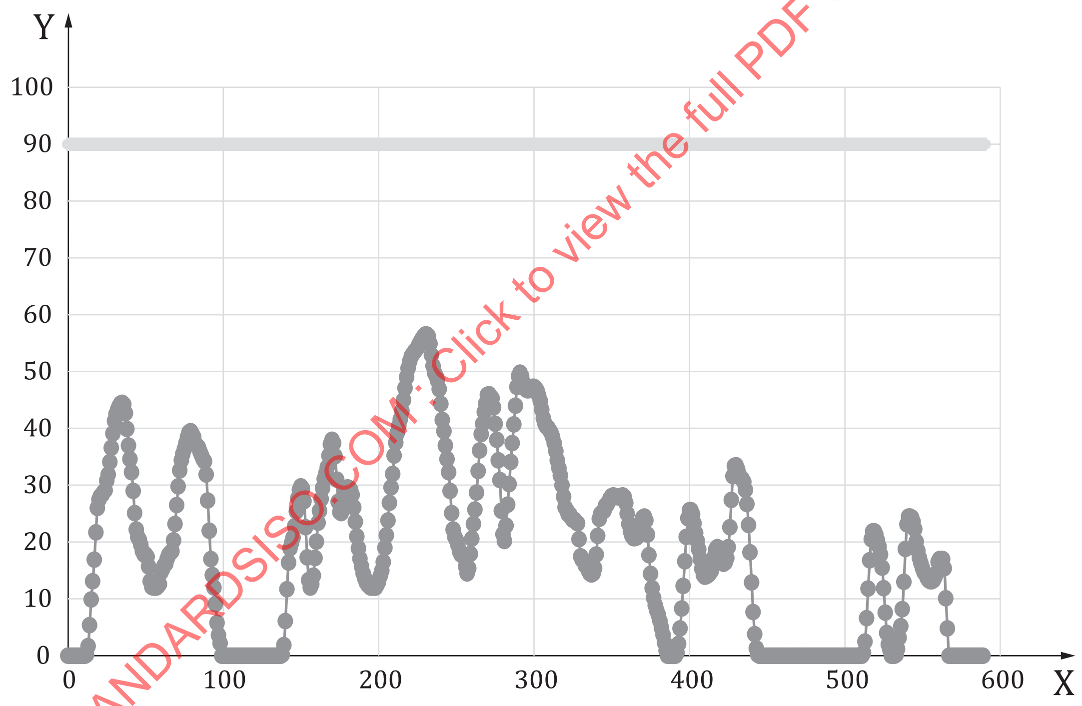
All KPIs can be coded relative to any given reference cycle according to the following scheme:

Green	KPI	0 < KPI in % ≤ 100 %
Yellow	KPI	100 % < KPI in % ≤ 150 %
Red	KPI	150 % ≤ KPI in % ≤ 300 %

The threshold given was found to be reasonable based on several field trials in Europe and China to make eco-drive behaviour measurable and comparable for different vehicle types, “driving-styles” and road characteristics. Additionally, it gives drivers and fleet managers an overview of problems found and can be presented easily on a digital map for post-trip, on-trip and pre-trip planning purposes.

B.2 Consumption calculation and the relation to the WLTP reference cycle

In this clause, an example for using the suggested methodology based on the WLTP driving cycle, speed mode LOW, reflecting urban driving conditions, is elaborated to give a description of the implemented calculations. Some details concerning the use of GNSS speed profiles from NDs compared to the WLTP reference cycles are shown in Figure B.1.



Key

X time (s)

Y speed (km/h)

Figure B.1 — Speed profile of WLTP, speed mode LOW

The bottom line shows the WLTP reference cycle for the speed mode LOW, which typically occurs in urban driving conditions. This WLTP cycle has a duration of 590 seconds and an average speed of 18,9 km/h. The distance travelled by a virtual vehicle driving with the WLTP speed profile characterized LOW adds up to 3,1 km including a standstill time of 150 s.

For calculating fuel and CO_2, the dynamic speed profile is used, which is a function in time, with the following vehicle configuration table, which is assumed to be constant in time (Table B.1). In this table it can be seen what kind of vehicle configuration values are required to be collected before starting to calculate the energy demand in a specific reference cycle. The WLTP initially followed reference cycles which were different in Europe, US and Asia, misleading consumers with regards to their fuel costs and their CO_2 emissions. Fortunately, a new driving cycle harmonized measurement worldwide and expanded the WLTP reference speed cycles to a wide range of LCVs.

With the vehicle configuration table, a straightforward calculation of fuel consumption and CO_2 emissions can be executed. This is shown in Table B.2 in an exemplary manner for the first 20 seconds of the WLTP LOW cycle. Using the vehicle configurations introduced in Table B.1, it can be seen that the reference cycle is in idling mode for the first 12 seconds with assumed fuel consumption of 1/3 600 litres per second resulting from the published consumption of 1 litre per hour. Seconds 13 to 20 give evidence of an acceleration phase and have acting inertial forces such as stated in Formulae (6), (5) and (3) indicated in Table B.2 as rolling (Roll), aerodynamic (AERO) and acceleration (ACC) resistance according to Newtonian physics. Consequently, all forces have measurement units of Newton (N). The column work (W) then results by simply multiplying the sum of these three forces by the distance travelled in metres, as shown in the "Distance" column, leading to Nm measured in Joule (J).

Table B.1 — Time-independent vehicle configuration parameters for private passenger cars (e.g. Volkswagen Golf VII)

Vehicle characteristics (Volkswagen Golf VII)	Value	Unit
Mass	1 305	kg
μ	0,015	—
c_w	0,31	—
Area	2,57	m^2
Engine efficiency	0,25	—
Idling fuel consumption	1	l/h
Density	740	g/l
Specific energy	9,92	kWh/litre
CO_2 emission	2,4	g/l
Air density	1,204	kg/m^3
Gravitational constant	9,81	m/s^2

Table B.2 — Applying Formulae (1), (2), (3), (4), (5), (6) and (7) to the first 20 seconds of WLTP LOW and the configuration parameters of Table B.1

Time s	Speed m/s	Distance m	Roll N	AERO N	ACC N	W > 0; "No *Perpetuum Mobile*" J	STS l/s
1	0,00	0,00	0	0	—	—	2,78E-04
2	0,00	0,00	0	0	0	0	2,78E-04
...							
12	0,00	0,00	0	0	0	0	2,78E-04
13	0,06	0,06	192	0	73	15	0,00E+00
14	0,47	0,47	192	0	544	348	0,00E+00
15	1,50	1,50	192	1	1 341	2 302	0,00E+00
16	2,75	2,75	192	4	1 631	5 024	0,00E+00
17	3,64	3,64	192	6	1 160	4 943	0,00E+00
18	4,69	4,69	192	11	1 378	7 418	0,00E+00
19	6,03	6,03	192	17	1 740	11 751	0,00E+00
20	7,22	7,22	192	25	1 559	12 825	0,00E+00

When continuing the procedure for all 590 seconds of the WLTP LOW cycle, a total value of 42,6 MJ per 100 km results which equals 11,8 kWh per 100 km. By dividing this with the specific energy density listed in Table B.1 and considering that with an engine efficiency of 25 % the energy demand is 4 times higher, this leads to a fuel consumption of 4,8 litres per 100 km. Finally, the idling engine operation of assumed 150 seconds standstill needs to be added, which gives a final fuel consumption of 6,1 litres per 100 km, exactly what can be found in reference literature for the model presented in this document.[12]

For comparing the stated WLTP LOW and the vehicle parameter of a Volkswagen Golf VII given in Table B.1, Table B.3 shows the values for constantly driving at 90 km/h.

Table B.3 — Applying Formulae (1), (2), (3), (4), (5), (6) and (7) to the first 10 seconds of driving at a constant speed of 90 km/h using the configuration parameters of Table B.1

Time s	Speed m/s	Distance m	Roll N	AERO N	ACC N	W > 0; "No *Perpetuum Mobile*" J	STS l/s
1	25,00	25,00	192	300	—	—	0,00E+00
2	25,00	25,00	192	300	0	12 301	0,00E+00
...							
9	25,00	25,00	192	300	0	12 301	0,00E+00
10	25,00	25,00	192	300	0	12 301	0,00E+00

Summing this up over a timeframe of 590 seconds leads to an energy demand of 49 MJ per 100 km or 5,5 litres per 100 km when calculating as described earlier for the WLTP LOW speed profile. With this result it becomes possible to follow the procedure derived in B.1 and to derive comparable key performance indicators to better understand the quality of specific trip, including driving behaviour, road characteristics or traffic conditions.

Before doing so, special attention should be given to Table B.2 and B.3 columns W > 0 “No *Perpetuum Mobile*” listed in J. According to the well-known law of energy conservation in technical mechanics, it is not possible for more energy than available in a closed system to be recovered, as energy can only be transformed and not increased. Thereby, it is impossible in mechanics to have “*Perpetuum Mobile*” engines creating a higher output of energy than possible by a given energy input. Additionally, the 2nd law of thermodynamics postulates that friction and other operational losses occur while running an engine, which also causes more losses when driving a car than could be regained, for example, by driving downhill or braking in eco-mode. The usefulness and application of these basic principles from mechanics and thermodynamics are shown in Table B.4.

Compared to Table B.2 and Table B.3, Table B.4 includes another column that is introduced to show the value of resisting inertial forces summed in case of negative number results. Such negative work (W < 0) would lead to gaining more energy than available inside the closed system, thus contradicting the Laws of Thermodynamics and the Law of Energy Conservation. To comply with the Laws of Physics, the work analyzed for fuel consumption is zero or greater than zero, meaning that all negative values are automatically set to zero when negative.

When applying this procedure to the WLTP LOW speed profile, negative work of (-)15,9 MJ per 100 km is set to zero caused by braking events above threshold. On the other hand, the vehicle operation approaches minimum energy consumption and CO_2 emission whenever braking takes place in a smooth and eco-friendly way, known as sailing at idle, making benefit of the car driving with the overrun fuel cut-off and not needing any more fuel. Formulae (2) to (7) enable drivers and fleet operators to quantify this eco-mode and to compare driving behaviour, road characteristics and the influence of traffic conditions by pattern recognition.

