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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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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:

$$\Phi = \Phi_{\mathrm{v}} + \Phi_{\mathrm{id}} \quad (1)$$

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:

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

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

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

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

$$F_{\mathrm{D}} = m g \mu \quad (6)$$

$$F_E = mg * \sin(\alpha) \tag{7}$$

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.

