Behavioural and Societal Sciences
Van Mourik Broekmanweg 6
2628 XE Delft
P.O. Box 49
2600 AA Delft
The Netherlands

www.tno.nl

T +31 88 866 30 00
F +31 88 866 30 10
infodesk@tno.nl

TNO report

TNO 2013 R10297

Fuel consumption meter requirements for light-duty vehicles – Final report

Date	16 April 2013
Author(s)	Sam van Goethem (TNO) Coen Obdeijn (TNO) Arjan Stuiver (TNO) Maarten Dam (TNO) Robin Vermeulen (TNO) Savas Geivanidis (LAT) Zissis Samaras (LAT) Dimitris Tsokolis (LAT) Pavlos Fragkiadoulakis (LAT)
Copy no	TNO-060-DTM-2013-00997
Number of pages	64 (incl. appendices)
Number of appendices	4
Sponsor	European Commission - DG Enterprise and Industry Performed under FRAMEWORK CONTRACT ENTR/F1/2009/030.1, Lot no. 4: "Eco-Innovation Techniques in the field of the Automotive Industry", Specific contract SI2.629009
Project name	Development of a complete test procedure for Fuel Consumption Meters in LD vehicles, which can be integrated into implementing legislation
Project number	033.22988

Summary

This report deals with the development of requirements for fuel consumption meters as a measure for the reduction of CO_2 emissions of light-duty vehicles. The work is done for the European Commission, DG Enterprise and Industry for specific contract SI2.629009, “Development of a complete test procedure for fuel consumption meters in light-duty vehicles”, implementing Framework Service Contract ENTR/F1/2009/030.1.

Fuel consumption meters (FCM) in light-duty vehicles are a cost-effective measure for reducing CO_2 emissions (see also TNO report MON-RPT-2010-03084). To implement this measure, the Commission is currently preparing a co-decision Regulation, which would mandate FCM’s for all light-duty vehicles. To do so, requirements for the demanded quality and the functionality of an FCM should be developed before establishing a type-approval procedure in which the requirements could be checked. The aim of the work therefore was to define the functional and technical requirements for FCM’s. This was done by means of a literature review, by running a test programme in which FCM’s are evaluated and by consulting the stakeholders for their experience with FCM’s.

A minimum set of functional and technical requirements has been developed (for a complete list, see appendix A). With these requirements, a driver has access to a tool with a minimum set of functionalities that has proven to be supportive for eco-driving. A more extended set of tools would limit the freedom of design for manufacturers and is therefore avoided as much as possible.
The investigation has shown that a certain level of accuracy is needed for an FCM to be supportive for eco-driving. It was concluded that the trip average fuel consumption should be displayed accurately to make the effect of a change in driving style on fuel consumption visible to the driver. The instantaneous fuel consumption, however, does not need to be displayed very accurately but rather be responsive to certain changes in driving events.

For current FCM’s an accuracy of about ±4% is achievable, when the vehicle is tested on a chassis dynamometer in a conventional emission laboratory. This in-lab accuracy will result in an achieved accuracy of about ±8 to 9% under real-world conditions.
Exploratory chassis dynamometer tests have shown that a physical test procedure on a chassis dynamometer is feasible for checking the accuracy of the trip average fuel consumption as displayed by an FCM. However, it needs to be investigated how the instantaneous fuel consumption can be checked. Here, the test procedure would benefit from the inclusion of the online fuel consumption as broadcasted by the vehicles OBD/CAN interface.

It is recommended to further develop the procedure for testing the FCM, based on experience gained in this investigation and in close cooperation with the stakeholders. Trial tests need to be performed to evaluate and improve the test procedure. Therefore it is recommended to follow up this study as planned by a program for the development of a physical test procedure (based on further chassis dynamometer testing). This test procedure is needed to validate the developed requirements for FCM’s in light-duty vehicles.

Contents

1 Introduction

1.1 Background

Fuel consumption meters (FCM) in light-duty (LD) vehicles are a cost-effective measure for reducing CO_2 emissions (see also TNO report MON-RPT-2010-03084). An FCM:

– supports Eco-driving.
– supports the use of other in-car devices, like the gear shift indicator.
– provides the driver with the actual fuel consumption (FC) of his car.

To implement this measure, the European Commission is currently preparing a co-decision Regulation, which would mandate FCM's for all LD vehicles. To do so, basic legal requirements for a FCM should be developed before establishing a type approval procedure.

The European Commission needs to develop technical requirements and a type approval procedure for FCM. Therefore, the European Commission put out a service request under the Framework Service Contract No ENTR/F1/2009/030.1 . This work of the service request is focussing on the development of:

- technical and functional requirements and;
- a complete physical test procedure (for chassis dynamometer testing) to assess the developed requirements for Fuel Consumption Meters in LD vehicles.

The work is split in four work packages:

- Work package 100: Definition of FCM requirements
- Work package 200: FCM Type approval test procedure development
- Work package 300: Validation and finalisation of the FCM test procedure
- Work package 400: Technical annex to the regulation

This report is the result of work package 100. The outcome of this report will be followed up by work package 200 where a type approval test procedure is developed. Work package 200 will then be followed up by work package 300 where the type approval test procedure will be validated. The final result of work package 400 will be the regulatory technical text, fully describing the technical and functional requirements and the test procedure for FCM, which can be annexed to implementing legislation.

1.2 Aim and approach

The aim of work package 100 is to define the requirements for FCM in light-duty vehicles by a literature review of the currently available experiences with in-car devices and running a test programme in which FCM's are evaluated.

The work gives an overview of FCM requirements that cover:

- Functional requirements (display, presentation, visualization, etc.)
- Technical requirements (reliability, accuracy)

The requirements must be:

- supportive for fuel consumption improvement by the driver (Eco-driving),
- practically applicable,
- based on acceptance by drivers,
- technically feasible,
- verifiable in a physical type approval procedure and,
- not decreasing the safety.

Based on the requirements above choices are made on which of the functional and technical requirements actually can be applied to a FCM and can fulfil the needs mentioned above. The choices made are founded by literature, input from the stakeholders and fuel consumption tests performed on a chassis dynamometer.

With regard to the functional requirements, human-machine interaction specialists within TNO are consulted to verify at which level an average driver can use fuel consumption information to improve FC optimally. A kick-off meeting with the stakeholders was organised to take the stakeholders along in the project. Apart from the stakeholders, specialists from the industry and independent authorities were consulted to verify amongst others, the current state of technology and technically feasible accuracies of FCM and their experience with FCM by means of questionnaires. Furthermore, the experts on Eco-driving were consulted and the possible requirements for the FCM were discussed in a workshop. Finally, when all information from the stakeholders was gathered, an overview of the obtained requirements was presented in a meeting with technical experts of the stakeholders to align the requirements with their views and experiences. The requirements as a result of the before mentioned efforts are documented in this report.

Electric, CNG, LPG, flexi-fuel, and dual-fuel vehicles etc. are not in the scope of this investigation. However the requirements should apply to all of them as well. For vehicles running on various fuels and gaseous fuels, an accurate determination of the fuel consumption on-board becomes more difficult and therefore these vehicles may need to be further investigated.

1.3 Structure of the report

In chapter 2 the responses from the questionnaires are summarised. This gives a better understanding on FCMs from the stakeholders point of view. Human machine interaction aspects in general and specifically for a FCM are discussed in chapter 3. The outcome of the work of the HMI specialists, the definition of functional requirements for FCMs, is presented at the end of chapter 3. The technical requirements as resulting from the technical elaborations are reported in chapter 4. The conclusions and recommendations are given in chapter 5.

2 Stakeholder questionnaire

A questionnaire was made to collect information from the stakeholders. The questions were related to the:

- current market penetration of FCM systems
- FCM in relation to economic driving
- FCM specifications
- technical boundaries
- human machine interaction
- functionality and working principles of a FCM

The questionnaire was made available to the stakeholders through the European CIRCABC site on October 26th 2012. Two responses were sent in; one from ACEA[1] and one from JAMA[2]. The questionnaire is to be found in Appendix C. The questionnaire results are summarized hereafter. Excluded from this summary are the responses on the human machine interaction and working principles of FCM which will be discussed in chapter 3.

FCM market penetration in 2012
The percentage of total vehicle production sold in the EU that are equipped with FCM as a standard feature is according to JAMA 97%. According to ACEA this could be different per vehicle brand, ranging between 40 and 100%. The FCM is offered as an option on less than 1% of total vehicle production sold according to JAMA. Distribution of FCM systems also depends on the vehicle segments. For higher segments ACEA indicate a range of 90 to 100% fitment and lower segments a range between 60 to 80% fitment. Both ACEA and JAMA indicate that some models in vehicle segments like Mini, SUV, Trucks and other do not have a FCM. Both organisations mention that there are no technical boundaries to equip every vehicle with an FCM, provided that there is enough lead time to implement them.

Display FCM
Common ways to display fuel consumption to the driver is instantaneous and trip average, both expressed in [l/100km] and [km/l]. The displayed unit [l/100km] or [km/l] could however be dependent on country specific preferences. Idle fuel consumption [l/hour] is not displayed according to JAMA, whereas ACEA indicate that some vehicles switch automatically to [l/hour] when driving below a certain speed or at stand still. Vehicle lifetime fuel consumption in [litre] is not yet displayed. Other ways to display fuel consumption are [miles/gallon], [kg/km] for CNG or LPG vehicles. Representation of fuel consumption is sometimes pictorial or displayed as histograms where also data from the past is presented.

Determination of FC
To derive the fuel consumption on a display, existing signals from the engine and vehicle are used. Most used is the commanded injection quantity [litre] and running distance [km]. Some other signals that can be used are look-up tables based on engine specific conditions, engine load indications, intake airflow, manifold

[1] ACEA is the European Automobile Manufacturers' Association
[2] JAMA is the Japan Automobile Manufacturers Association

pressure, lambda sensor signal. Note that running distance is derived from wheel rotation counting in combination with an assumed tyre circumference.

Accuracy of a FCM
Both JAMA and ACEA indicate that based on a comparison of fuel consumption test and evaluation methods an accuracy of plus and minus 10% is possible. It is indicated that the mentioned accuracy is still dependant on fuel density dispersions available in the market and operating environment of each individual user. Manufacturers validate the FCM accuracy using various test cycles on a test bench and on-road driving. No information was provided on data that demonstrated those accuracies.

According to ACEA and JAMA particular parameters that have an influence on the accuracy are the fuel injectors, fuel pressure, battery voltage, asynchronous fuel injection, fuel temperature, fuel density, fuel vapour volume, percentage of bioethanol, tyre differences (circumference, air pressure, wear), vehicle mass, total distance travelled, odometer requirement to run-ahead (1%), fuel flow measurement, canister purge, DPF regeneration, display resolution, vehicle speed sensor. How much each of the parameters is influencing the accuracy was not indicated.

The internal fuel consumption calculations take place at a frequency of 10 [Hz] and are displayed at slower refresh rates to the driver. FCM data like trip average is most likely to be stored in the instrument cluster or random-access memory of the engine control unit and is not specifically protected against manipulation.

It is indicated that the fuel consumption calculations are independent of the fuel used e.g. diesel, gasoline, etc. Technically any vehicle can be supplied with a FCM, provided there are no specific or lead-time requirements that need to be met. Unsure is which accuracy can be met for LPG, CNG, dual fuel and flexi fuel vehicles. Besides accuracy, such fuel consumption is likely to be displayed differently like e.g. in [kg/100km] or [kg/hour] together with the ‘normal’ fuel consumption in [l/100km].

3 Functional FCM requirements

This chapter describes the functionalities and the recommended draft requirements of the fuel consumption meter. For this description the following paragraph structure is setup:

- fuel consumption meter definition: What is defined by a 'FCM'?
- current fuel consumption meters: Which functionalities do current FCMs already have?
- effects of fuel consumption meters on eco-driving: What effect can a FCM have on eco-driving?
- functionalities of a fuel consumption meter: Which functionalities are needed to support eco-driving? Are there also other functionalities a FCM can serve?
- functional requirements fuel consumption meter: Which requirements are needed to ensure the FCMs functional operation?

Throughout this chapter, commonly used units to display fuel consumption are used as examples. The examples are not meant to limit the units to express fuel consumption. In general all internationally accepted units are allowed to express fuel consumption e.g. mile per gallon (mpg), km/l, l/100km, km/l, l/h, etc.

3.1 Fuel Consumption Meter definition

The fuel consumption meter is defined as:
"An in-car display that displays fuel and or energy consumption information to the driver about the cars' instantaneous and average fuel consumption."

A more in-depth description for the functionalities can be found in paragraph 3.5.
The FCM serves different purposes:

- The instantaneous fuel consumption display mainly serves as a tool which can be supportive for eco-driving;
- The average fuel consumption display mainly serves as a tool which can be supportive for eco-driving and create awareness among drivers about the vehicles' fuel consumption;
- Other functionalities like the life-time fuel consumption. This information can create awareness of the vehicles' fuel consumption among the driver, possible buyers and policy makers.

Functional requirements are formulated to serve these purposes, taking into account safety aspects of the HMI display. Additional requirements with regard to safety are formulated, in case these requirements could not be related directly to the FCM functionalities.

3.2 Current fuel consumption meters

Several types of fuel consumption meters are on the market. This section provides an overview of the different aspects of the fuel consumption meters. The information is based on the description of the fuel consumption meters by ACEA and JAMA in response of the questionnaire as mentioned in chapter 2.

FCM design Aspects	**Features of FCM appearing in current passenger cars**
Design	
Types of displays	Numeric text with units, numeric text with units and icon, classic analogue meter with pointer, vertical bar with pointer, two vertical bars with pointers for average and instantaneous.
Location of the display	Meter, combination meter, multi-function display, navigation system, instrument cluster, centre display, optionally head-up display.
Analog/digital	The information is all based on digital information. Some displays are digital (numeric), some displays are analogue (meters, bars).
Size of display and digits	Sizes between existing FCM differ substantially, depending on space available for the instrument cluster and other displays. Ranging from 2” to 7” with digits ranging from 3-12 mm.
Colour	Single colour and multi-colour on black background.
Amount of information displayed	Although some displays simultaneously show information about different aspects, industry has indicated they prefer displaying one type (average, instantaneous) at a time.
Icons	Gas station, Jerry can
User interaction	
Availability of FC information	FC is with some but not with all systems visible from key-on. Often when FC was selected as display option at key-off it will be visible at key-on. The majority of vehicles are equipped with a toggle system (button operation is required), with which FC may be accessed.
Functional aspects	
Refresh rate	Average FC : From 1sec to 120 sec Instantaneous FC: From 0.1sec to 2sec Note: refresh rate and interval are related aspects, e.g. a high refresh rate with a long interval may still result in stable slow changing information.
Type of information displayed	l/100km (seconds) km/l (seconds) l/100km (trip average) km/l (trip average) Same as above but in miles and gallons Distance to empty tank (km)

Source of information	Mainly commanded injection quantity, but also vehicle speed, running distance, maps, load, intake airflow, lambda sensor information.
Idle information	Some FC systems switch to litres per hour if speed is very low (< 5km/h). JAMA indicates that the emergence of idling start/stop systems will render idle information useless in coming years.
Accuracy	Plus or minus 10%, although it depends on test methods, market fuel density and operating environment.

3.3 Effects of fuel consumption meters on eco-driving

De Goede, Hogema, Vermeulen and Bleuanus (2010) compared several studies which examined the effect of fuel consumption meters on the fuel consumption. Short-term effects were estimated at a CO_2 and fuel consumption reduction in the range of 1.5% to 5% . An important factor in the level of the effect is the system knowledge and motivation to reduce fuel consumption, because a fuel consumption meter does not provide any advice. The studies to which was referred, were mostly tests in which the drivers were motivated to reduce fuel consumption.

Furthermore, the study reports that the FCM could give feedback about the use of in-car instruments, in particular the gear-shift indicator was investigated, and as such an FCM could result in an additional improvement of the fuel consumption.

FCM can create awareness about fuel consumption, but it raises the question whether drivers know how to use the information and are willing to improve their driving style to drive more fuel efficient.

This is also one of the reasons that there are several initiatives for the development of eco-coaching applications. Currently, there are initiatives which use the fuel consumption information and use it in a more educative way. Eco-coaching is subject of several European Projects, such as ECOWILL, eCoMove and EcoDriver. One of the main objectives of ECOWILL is to integrate eco-driving in driving school curricula and driving tests. Education of drivers is seen as an important means to reduce a vehicles fuel consumption. The displayed information on FCM's can help the eco-driving educated drivers to improve their driving style more because it gives feedback of the driving style just put in practice. This requires that vehicles are equipped with a FCM and that there is a minimum set of functionalities and information made available to the driver. This functionality and information should be harmonized, such that drivers can use the instrument with ease and interpret the information with minimum distraction from driving in traffic. Harmonized information and functionality ensures that learning time and interpretation time are minimal.

Within the European projects eCoMove and EcoDriver, HMI's are developed which give insight to the driver on which driving aspects he/she can improve and advice for improvement is given. For real-time feedback the instantaneous fuel consumption plays a role, while average fuel consumption plays for instance a role in comparing eco-driving scores to make the driver aware of his/her improvement.

3.4 Functionalities of a fuel consumption meter

Real-time feedback is considered most useful to improve the driving style of a driver. Current FCM’s provide information about the instantaneous fuel consumption as ‘real-time feedback’. The outcomes of an evaluation by Manser et al. (2010) is that horizontal bars and/or simple representations (e.g. pictures) were most usable. Their participants preferred representative or symbolic forms of fuel economy in formation, rather than text representation. This outcome suggests that drivers mainly use the relative changes in the fuel economy state, instead of the absolute changes. This raises the question of whether a very high accuracy is needed for instantaneous fuel consumption, to make FCM a valuable tool for eco-driving. This accuracy question is the subject of chapter 4.

Average fuel economy is also supportive for eco-driving by creating awareness about the drivers’ driving style and the fuel economy of a car. It can give the driver an insight in potential savings, in case the driver changes his/her driving style to a more fuel efficient driving style. The accuracy plays therefore a more important role for the average fuel consumption, because here the absolute value of the fuel consumption is important. The desired and already achievable level of accuracy is the subject of chapter 4.

From a consultation of driver training experts within the project ECOWILL it turned out that if drivers are trained to drive economical, they learn how to make use of fuel consumption meter and in particular the displayed average fuel consumption. During driving, the driver can actually see the fuel consumption decreasing if he or she is applying eco-driving techniques consistently.

Average fuel consumption could also be indirectly supportive for eco-driving, because it can make the driver aware of the consumed fuel over a trip, which he/she can relate back to the vehicles fuel consumption label. The vehicles’ fuel consumption label value is serving as a reference to indicate that the driver did better or worse than this number.

Other functionalities

Other functionalities the FCM can have are for instance lifetime fuel consumption in litres, average lifetime fuel consumption in litres/100km, non-resettable average fuel consumption over a variety of time (e.g. week, month, year). The non-resettable week/month/year fuel consumption information is supportive for eco-driving by having the same effect as the resettable average fuel consumption. Only difference is that the time length over which the fuel consumption is averaged is fixed, where the trip average can be reset manually by the driver. Without resetting the trip average, the averaged value comprises the fuel consumption since the last reset. The total lifetime fuel consumption is more vehicle, driver and trip related. Its value could serve statistical purposes to evaluate the real-world fuel consumption of a vehicle but also a fleet of vehicles. A consumer may also use this number to value a vehicle when it is compared to values from the same vehicle type. The functionalities a FCM can serve besides instantaneous and average fuel consumption are discussed further in the next paragraph.

3.5 Functional requirements of fuel consumption meters

In the previous paragraphs the FCM and its functionalities as a supportive tool for eco-driving are explained. To ensure that the functionalities of a FCM are covered in case they are mandated into current legislation for LD vehicles, requirements are needed. The document of Kroon (Appendix B), describing the requirements of a fuel consumption meter, is used as a starting point for this study. Three different types of sources are used to verify the requirements described by Kroon:

- Commission Recommendation (26/V/2008): A recommendation on guidelines on safe and efficient in-vehicle information and communication systems;
- Evaluation studies of fuel economy interfaces;
- Questionnaire answers of JAMA & ACEA;

These three sources are used to discuss recommendations about the current requirements as suggested by Kroon. This is schematically depicted in Figure 1.

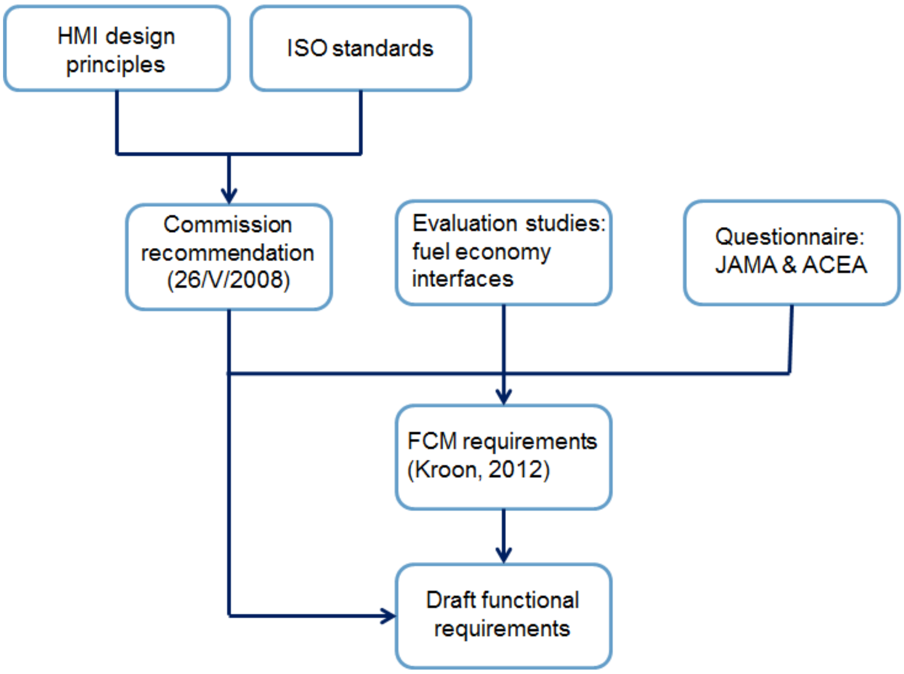

Figure 1: Used sources to derive draft functional requirements for a FCM

The functional requirements of Kroon are rearranged using the structure of the design principles presented in the Commission recommendation on safe and efficient in-vehicle information and communication systems (2008). Functional requirements which are suggested by the recommendation, but not part of Kroon's requirement, are added.

For every draft functional requirement, the requirement is:

- Compared to the European guidelines and discussed whether they are in line with the requirements.
- Checked whether it serves the desired functionality of the FCM, as specified in paragraph 3.4
- Discussed using the comments of JAMA and ACEA on the requirements.

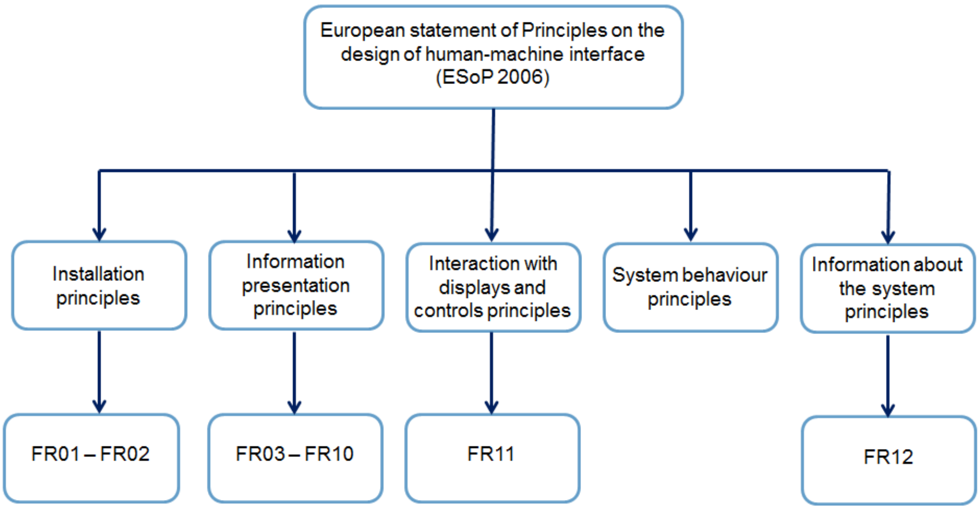

Figure 2: Overview of functional requirements

3.5.1.1 *Installation principles*

The HMI should be close to the line of sight and not block the line of sight, according to an existing standard about the installation principles of HMI [ISO 4513 (2003): *Road Vehicle – Visibility, method for establishment of eyellipses for driver's eye location*.]

<u>FR01</u>
Three requirements of Kroon are related to the location of the fuel consumption meter. These requirements are not in line with European guidelines on HMI installation principles. The requirements of Kroon specifically address possible locations of the FCM. The requirement based on the European guidelines on HMI installation principles would not specify the location this specifically, because it limits the options of possible locations in future developments. This is also one of the remarks of ACEA in the stakeholder reaction. In case three possible locations are mentioned in the requirements, then it limits possible future development such as an FCM in a heads-up display.

Therefore it is recommended to formulate the functional requirement with regards to the location of the FCM as formulated in FR01.

FR01	The driver must be able to read the information displayed about fuel consumption from a regular seating position. The information displayed must be displayed close to the line of sight.

<u>FR02</u>
Another installation principle describes the need of the display to avoid glare and reflection. This is based on the existing standard:

- ISO 15008 (2003): Road vehicles – ergonomic aspects of transport information and control systems – specification and compliance procedures for in-vehicle visual presentation.

This is currently not in the described functional requirements of Kroon and it is recommended to add this requirement to the functional requirements. As stated by ACEA in the stakeholder reaction this is already the case in current FCM design.

FR02	The fuel consumption display should be designed to avoid glare and reflections.

3.5.1.2 *Information presentation principles*

According to the information presentation principles, the in-car HMI should:

- be assimilated with a few glances by the driver;
- use (inter)nationally agreed standards;
- provide accurate information in a timely manner;
- give information with a higher safety relevance a higher priority;
- not mask audible warnings by system generated sounds.

Several ISO standards are available which specify these functional requirements in technical requirements:

- ISO 15007-1 (2002): Road vehicles – Measurement of driver visual behaviour with respect to transport information and control systems – Part 1: Definitions and parameters.
- ISO TS 15007-2 (2001): Road vehicles – Measurement of driver visual behaviour with respect to transport information and control systems – Part 2: Equipment and procedures.
- ISO 15008 (2003): Road vehicles – ergonomic aspects of transport information and control systems – specification and compliance procedures for in-vehicle visual presentation.
- ISO FDIS 16673: Road vehicles – ergonomic aspects of transport information and control systems - Occlusion method to assess visual distraction.
- ISO 15006 (2004) - Road vehicles - Traffic Information and Control Systems (TICS) - Auditory presentation of information
- ISO 2575 (2004) - Road vehicles - Symbols for controls, indicators and tell-tales
- ISO 7000 (2004) - Graphical symbols for use on equipment — Index and synopsis

<u>FR03</u>

Kroon describes the need for a permanent display of fuel consumption. Current instrument clusters of cars however display multiple tell-tales and indicators already active via legislation on the same display, as ACEA states in their reaction to the requirements. Reserving a separate display space only for FCM will lead to extra effort and costs for the industry. From the drivers point of view, not every driver is interested in FC information and without the possibility to switch this display off it can become irritating. Therefore it is not recommended to have fuel consumption permanently displayed, but that the driver has the possibility to switch to the desired FC indicator on the instrument cluster.

One aspect of the requirement, which is recommended to add is about the overruling in case of emergencies. This is in line with two information presentation principles (Commission recommendation (26/V/2008)):

- Information with higher safety relevance should be given higher priority.

This is formulated in FR03.

FR03	The vehicle must be equipped with an on-board device, which can display the fuel consumption described in FR04 on the drivers request. The fuel consumption display may be overruled in case of: • (road) safety emergencies; • risk of running out of fuel; • technical failures related to OBD

<u>FR04</u>
From the FCM definition in paragraph 3.1 three different sorts of functionalities were given:

- Instantaneous fuel consumption
- Average fuel consumption
- Other functions like life time fuel consumption

The functionality serves different purposes from eco-supporting to creating consumer awareness. To get a better understanding about these functionalities and how they should function, they will be the subject of the discussion hereafter.

Instantaneous fuel consumption
Instantaneous fuel consumption is the displayed instantaneous fuel consumption in l/100km while the car is moving and the fuel consumption in l/hour when the car is idling. ACEA and JAMA state that engine start-stop systems are widely utilised in current production vehicles and that the l/hour requirement is therefore an out-dated technical boundary. It is however recommended to add the idling (l/hour) requirement, because start and stop systems can also be turned off or not used by drivers.

Instantaneous fuel consumption is mainly supportive for eco-driving, because it provides real-time feedback on the fuel consumption. This information is valuable for the driver at:

- Constant speed: The driver is made aware that driving at a lower and constant speed in a higher gear has a positive effect on the fuel consumption. Furthermore, the driver is made aware of the effect vehicle speed hason the fuel consumption (e.g. driving 120 km/h instead of 130 km/h). This fuel consumption effect is directly visible to the driver by adapting his set point speed. Driving the same speed at a higher gear (e.g. advised by the GSI) will result in a FC difference the driver could take notice of. The FCM should however be capable of indicating the FC difference between driving at the same speed and different gear or driving at low speeds where the savings are marginal.
- Coasting: The driver is made aware that the car does not consume fuel when coasting, as a result of the fuel cut-off. This could lead to drivers coasting more, because it has a positive effect on the fuel consumption. At a glance the driver can notice a fuel cut-off when his FCM displays that no fuel is consumed during coasting.
- Accelerating: The driver is made aware that gear shifting at a lower engine speed during the acceleration has a positive effect on the fuel consumption.

This fuel consumption benefit would probably be hard to recognise from the FCM reading. Moving horizontal bars and/or simple representations (e.g. pictures) were found most usable rather than solely a numerical representation. There is no common standard for these pictorial representations. Setting requirements will limit the freedom of design for manufacturers and is therefore not recommended. From a HMI perspective a rapidly changing number is difficult to follow when only a few glances of attention can be spent to the FCM display. Therefore a high accuracy demand is not recommended during acceleration. The lowest refresh rates indicated by ACEA and JAMA will therefore be sufficient.

- Idling: The driver is made aware of the fuel consumption while idling or can see what the effect of activating/deactivating the stop and start system is. Idling information is displayed in litre/hour and therefore requests the FCM to switch from litre/100km to litre/hour to display the instantaneous fuel consumption during standstill. If the stop-start system is activated and the engine is automatically turned off, the FCM displays zero or '-' fuel consumption. When driving off after a standstill, the FCM display switches back to display litre/100km. Kroon defined that the display should switch to litre/hour below 5km/h. ACEA commented that this speed limit is too low because at that low speeds and during stop and go traffic the FCM value is 'blinking'. This 'blinking' would cause an increase of driver distraction and/or annoyance according to ACEA. In the stakeholder meeting a speed of 30km/h was mentioned under which fuel consumption information is not displayed to avoid distraction by 'blinking' . The 'blinking' distraction could also be solved by decreasing the refresh rate (delay) of the fuel consumption value at low speeds as opposed in the previous point.
- Complying the GSI advice: The driver is made aware of the benefit which can be gained when complying with the GSI advice. The GSI will advise the driver to change gear early during acceleration and advise to shift to a higher gear when driving at constant speed. Note that the fuel saving benefit under real-life conditions is hard to be recognised by the driver, especially during acceleration when the fuel consumption value is changing rapidly. More likely that during constant speeds the fuel saving benefit of driving in the gear that is advised by the GSI will be noticeable. This is only possible if the FCM can provide an accurate value with an resolution that is able to indicate the differences.

The accuracy suggested by the stakeholders in chapter 2 (plus or minus 10%) may be too high to even indicate the fuel saving results from an eco-driving style. The instantaneous fuel consumption information should be able to indicate the absolute steps (e.g. resolution steps of 0.1 l/100km) close to what the actual increase of fuel consumption is in order to be supportive for eco-driving.

Average fuel consumption

The average fuel consumption, also called 'trip average', comprises the fuel consumption averaged since the last manual reset. This functionality is also supportive for eco-driving and can mainly improve the awareness of drivers of their fuel consumption and the effect of their driving style. Depending on acceptance and motivation drivers may use the average fuel consumption information as a tool to improve their fuel consumption. Also, with the trip average fuel consumption a comparison between the vehicles fuel consumption label and the drivers actual fuel

consumption value can be made. The fuel consumption differences could then be related to a combination of driving style, mission profile (e.g. city driving, high way driving) and environmental conditions (road surface, road slopes, rain etc.).
For a driver it is hard to make a clear distinction of which factors are responsible for the average fuel consumption and how much his driving behaviour influenced this number. The driver is however shown a realistic value of the fuel that is actually consumed. If the driver consequently applies for instance the 'golden rules of Eco-driving' from the European ECOWILL project (e.g. anticipate traffic flow, maintain a steady speed at low RPM, check tyre pressure frequently etc.) on repetitive routes (e.g. commuting), drivers are able to identify the effects they have on fuel consumption.

If the driver is aware of and can rely on his FCM value, it motivates him to get the trip average fuel consumption value closer to or even below the fuel consumption label value. If the driver notices that he can actually influence his fuel consumption value depicted by the FCM and approach or be better that the label value it is increasing awareness about his or her influence when driving.

The future EU fuel consumption test (WLTP) will result in a fixed driving cycle which will deliver a fixed fuel consumption value, specifically for the given drive cycle or drive cycle parts. A driving style or a usage pattern differing from what is implicitly present in the test cycle (WLTC) may of course lead to values clearly different from the test cycle fuel consumption. Having an accurate trip average or life time average fuel consumption could then be of benefit in several ways.

When the fuel consumption is accurate and reliable, a driver can relate the average FC to the vehicles' fuel consumption label and notice and learn that his behaviour leads to either a similar or a different fuel consumption, depending on his driving style and usage pattern. When large deviations are observed a driver might become motivated to look for ways to improve fuel consumption.

The label fuel consumption, stemming from a driving cycle can be marketed as 'standard test result', allowing a comparison of the fuel consumption of vehicles in a sales brochure, whereas an accurate FCM could indicate the real fuel consumption depending on driving style and usage pattern of the given driver. An accurate fuel consumption value makes clear to drivers that their fuel consumption may actually differ from the label and that they can improve fuel consumption.

From a human behavioural aspect drivers might only be motivated when they know that they can rely on the fuel consumption value presented by their FCM. In other words when a saving of 5 to15% (ECOWILL factsheet, 2010) can be achieved by applying eco-driving consequently over a period of time, the average fuel consumption must be accurate and precise enough to measure differences that are much smaller. As a rule of thumb the precision of the measurement system should be at least one-third of the lowest achievable fuel consumption reduction to be able to indicate the acquired savings (e.g. approximate 1.7% for 5% and 5% for 15%).

Other functionalities
The FCM could also have other functionalities such as the total lifetime fuel consumption and a non-resettable fixed time related fuel consumption.

Lifetime fuel consumption
The total lifetime fuel consumption comprises the fuel used over the total mileage of the vehicle. Lifetime fuel consumption is a requirement in Kroon, 2012 and is not part of current FCMs. It is not known how the consumers would use this information. Together with the mileage counter, customers may use the information to value the state of a used vehicle. For this functionality it is important that the information has a certain proven reliability and accuracy.

Total lifetime fuel consumption can serve a statistical purpose of fuel used over the total mileage to get a better understanding of the real life fuel consumption over the time the vehicle is driven. When this information is collected during periodic inspections it could serve as a tool to monitor the overall and fleet specific fuel consumption. The total lifetime fuel consumption information could be displayed in litres or represented in an average fuel consumption in litre/100km.

It should be noted that the total lifetime fuel consumption is depending on driver behaviour (e.g. aggressive, relaxed), the environmental conditions (e.g. fuel, temperature, air density, road surface roughness etc.) and the specific mission profile (e.g. highway, city). Each vehicle owner and the environment it is driven in has therefore an influence on the lifetime fuel consumption.

ACEA states that the justification for total lifetime consumption is unclear and that it is not likely that total lifetime fuel consumption changes driver behaviour. Furthermore they indicate that there are no provisions yet to already provide a total lifetime fuel consumption.

Period related fuel consumption
A non-resettable fuel consumption value over a certain period of time (for instance a week/month/year) could be a additionally functionality of a FCM. This functionality is currently a point of discussion in the United States to get a better overview of what the fuel consumption of vehicles is in practice.

Lifetime fuel consumption could provide statistical information for other purposes, like monitoring FC for fleet management, driving style bonus systems, trend analyses, emission modelling and CO_2 control and taxation.

It is recommended to investigate how the total life time fuel consumption could be of use for consumers or policy makers, before implementing it as a final requirement.

Refresh rate
Current FCM systems have varying refresh rates of the values displayed (source: questionnaire answers JAMA and ACEA). This refresh rate should not be confused with the screen refresh rate of a display. There is no proof found in evaluation studies which suggest a certain refresh rate for either support of fuel efficient driving or an increase in usability.

It is recommended to keep a range in the requirements with regard to this aspect, because there is no proven ‘optimum’ value for the refresh rates. A low refresh rate could however influence the displayed accuracy of the fuel consumption meter when the real value is constantly changing. This is the case during stop and go traffic.

The refresh values are formulated in FR04a and FR04b and are based on the current refresh values as suggested by JAMA and ACEA and take into account the remark form JAMA to exclude a minimum refresh rate as this could restrict future development flexibilities. Note that an increase of refresh may only be needed if the fuel consumption value will deviate too much from the actual fuel consumption that is calculated at a higher frequency than it is refreshed on the FCM. According to chapter 2, the instantaneous fuel consumption is calculated at 10Hz.

Unwanted manipulation
It is recommended to add FR04c to the requirements to avoid unwanted manipulation of the total lifetime fuel consumption. If consumers will use the lifetime fuel consumption as a reference to value a car, manipulation of this value (with or without mileage counter manipulation) could lead to unjustified value manipulation of used cars, which is misleading to consumers.

FR04	Visible upon request of the driver the fuel consumptions display can switch between: • 'instantaneous fuel consumption' in litres/100km and automatically switching to litres/hour during idling and standstill • 'average fuel consumption' in litres/100km • 'lifetime total fuel consumption' in litres/100km
FR04a	The instantaneous fuel consumption figure [l/100km] or [l/h] presented must be refreshed as frequently as needed but not exceeding 2 sec, showing the average over the refreshed period. During idling at standstill or nearly standstill (not exceeding 5 km/h) and in case a start and stop system is absent or turned off by the driver, the instantaneous fuel consumption display automatically switches to [l/h].
FR04b	The trip average fuel consumption in litres/100km comprises the fuel consumption over the distance driven since the last manual reset with a refresh rate of maximum 10 seconds.
FR04c	The lifetime total fuel consumption in litres/100km is available upon request of the driver, this value cannot be reset and is secured in the same way the total vehicle mileage is secured.

<u>FR05</u>
Kroon describes the need for at least a numerical form for depicting the fuel consumption. The outcomes of an evaluation by Manser et al. (2010) is that horizontal bars and/or simple representations (e.g. pictures) were most usable. Their participants preferred representative or symbolic forms of fuel economy in formation, rather than text representation. Manser et al. (2010) suggested that text representation can however improve comprehension, in case it is added to a representative component feature. This means that drivers are better able to determine the absolute value of fuel consumption. This can be useful to serve as a tool for eco-driving in case of constant speed driving, idling, fuel cut offs and driving at lower speeds.

It is stated by ACEA and JAMA that manufacturers should have the freedom to add other forms of representation for instantaneous fuel consumption.

Therefore FR05 is formulated stating the need for minimal a numerical form, leaving the option open to add graphical or symbolic forms for fuel consumption display.

FR05	The instantaneous, average and lifetime fuel consumption display is depicting fuel consumption in a numerical form and optional presented together with graphical or symbolic forms.

<u>FR06</u>
Kroon describes the resolution of the fuel consumption information provided by the FCM. It is recommended to remain the functional requirement in its current form. In case the measurement units of fuel consumption are in a lower resolution than 0.1, the indication is too rough to be informative and is of less use to be supportive for fuel consumption improvement by the driver. Secondly the accuracy of the FCM, as specified in later on in TR01 also demands a resolution formulated in FR06.
JAMA responded that the proposed resolution of 0.1 for litres/100km can be accepted. They indicated to not have a requirement on the maximum amount of digits for lifetime fuel consumption in litres as limits the freedom of design.

FR06	The on-board computer must display fuel consumption in [litre/100km] and idling fuel consumption [litre/hour] with a resolution of 0.1 and total lifetime fuel consumption [litre] with a resolution of 1, with enough digits to display the total amount of fuel consumed

<u>FR07</u>
According to Jamson and Marat (2005) an increased visual complexity of in-vehicle displays produces unsafe driving behaviour. One of the HMI design principles which deals with the complexity of in-vehicle displays is formulated in one of the information presentation principles (Commission recommendation (26/V/2008)):
"Visually displayed information presented at any one time by the system should be designed in such a way that the driver is able to assimilate the relevant information with a few glances which are brief enough not to adversely affect driving."

To ensure the understandability of the information displayed, it is recommended to have textual or symbolic additions for the displayed unit and time period as is formulated in FR07. Both ACEA and JAMA indicated that small display spaces limit the large textual representations. The proposal from ACEA to allow international agreed abbreviations (e.g. litres/100km, litres/hour, l/100km etc.) is therefore also recommended to be allowed.

FR07	Textual or symbolic addition of the displayed unit and time period (average trip, instantaneous, lifetime) or their internationally agreed abbreviations is required.

FR08
In case symbols are used it is recommended to use internationally agreed standards, which is also an information presentation principle (Commission recommendation (26/V/2008):
"Internationally and/or nationally agreed standards relating to legibility, audibility, icons, symbols, words, acronyms and/or abbreviations should be used."

FR08	Internationally agreed standards relating to legibility, audibility, icons, symbols, words, acronyms and/or abbreviations should be used on FCM's.

As stated by ACEA in their stakeholder reaction to the requirements, there is currently no symbol included for FCM in ISO2575. In case this recommended requirement is put into practice we agree with the recommendation to a mandate to ISO (i.e. ISO 13/TC 22/WG 5) to develop appropriate symbol(s).

FR09
Another information presentation principle (Commission recommendation (26/V/2008) deals with the visual presentation (font sizes, luminance contrast and colour use). It is recommended to add a functional requirement in line with this principle, as formulated in FR09. Both ACEA and JAMA did not have any comments on this requirement.

FR09	The visual presentation of information (font sizes, luminance contrast and colour use) should be in line with: *ISO 15008 (2003): Road vehicles – ergonomic aspects of transport information and control systems – specification and compliance procedures for in-vehicle visual presentation.*

3.5.1.3 *Interactions with displays / controls*

According to the European HMI design guidelines, with regards to interaction with displays and control, the system should:
- allow the driver to have one hand at the steering wheel;
- not require long and uninterruptible sequences of manual-visual interface;
- not require time-critical responses;
- be able to operate without adverse impact on the primary driving controls;
- allow the driver to control the loudness auditory information;
- give response which is timely and clearly perceptible.
- Be capable of being switched from providing non-safety-related dynamic visual information to a mode where that information is not provided to the driver.

FR10
The HMI design guidelines with regards to interaction with displays and control describe multiple aspects which are mainly applicable to more complex in-vehicle systems.
The interaction with current FCM's is quite simple and therefore it is recommended to include just FR10 for the FCM with regards to the interaction with displays and control. Both ACEA and JAMA did not have any comments on this requirement.

FR10	Interaction with the FCM should allow the driver to have at least one hand at the steering wheel.

3.5.1.4 System behaviour principles

The system behaviour principles describe principles for more advanced HMI’s and are not specifically applicable to FCM’s Therefore no requirements related to system behaviour principles are formulated.

3.5.1.5 Principles on information about the system

The European HMI design principles on information about the system are more applicable for more advanced HMI. It is however recommended to add one functional requirement with regards to information about the system. This entails that a consumer should be provided with information on how to operate the FCM interface and what the symbols and abbreviations represent. To enhance eco-driving it is recommended that the manufacturer also describes how the driver could make the most benefit of noticing the fuel savings e.g. the effect of complying the GSI advice, driving constant speed in a higher gear etc. However this educational information is also widely spread through many other channels e.g. internet, driving schools etc.

FR11	The FCM should have adequate instructions in a manual for the driver covering use. This includes the description of the interaction with the FCM and an explanation on the used symbols and abbreviations.

4 Technical FCM requirements

In chapter 3 the functionalities and corresponding requirements were discussed based on stakeholder input from ACEA, JAMA, literature and expert opinions. The discussion brought forward that accuracy and precision of the FCM play a role on how the fuel consumption information can be used by the consumer. The FCM can be used to enhance eco-driving and make the driver aware of the actual fuel that is consumed.

As no requirements exist on accuracy and precision for a FCM, technical requirements are developed with the purpose to be able to eventually evaluate a FCM in a chassis dynamometer test procedure. Developing a test procedure is out of scope of this report. Technical requirements of a FCM were studied from a theoretical and practical point of view (paragraph 4.1 to 4.3). In the last part of this chapter, paragraph 4.4, the study results are discussed. Based on the results technical requirements are drafted.

To get a better understanding of which accuracy and precision is feasible, the following evaluations have been performed:

- <u>Theoretical evaluation</u> of the possible inaccuracies when determining the fuel consumption. The parameters that influence the achievable accuracy of the FCM will be discussed based on both a chassis dynamometer test and under real-world conditions. In a chassis dynamometer test, parameters that influence the accuracy and precision of an FCM are controlled or can be kept constant (e.g. room temperature, type of fuel, tyres used). It is thus expected that a higher level of accuracy and precision can be achieved in chassis dynamometer test in comparison with real-world conditions.
- <u>Real-world data</u> of FCM: Fuel consumption data was gathered by TNO. This data includes FCM readings. The data was used to evaluate the difference between measured and displayed averaged trip fuel consumption.
- <u>Chassis dynamometer measurements</u>: During the project three vehicles equipped with a FCM were evaluated on their instantaneous and trip average fuel consumption. For recording the instantaneous fuel consumption a special visual recording tool was used. These measurements gave insight on the FCM performance of the tested vehicles over the applicable driving cycles. With the tests, experience is gained with validating an FCM in a chassis dynamometer test procedure.

Based on the evaluation results and discussion, technical requirements will be drafted that are: feasible, needed for a FCM to be supportive for eco-driving and at the same time are providing the consumer with accurate information.

4.1 Theoretical evaluation

Several parameters influence the accuracy at which a FCM can calculate the actual fuel consumption. How these parameters influence the calculation is essential to define the level of accuracy that is feasible for a FCM. How the FCM is calculating the fuel consumption in theory is explained and discussed in this paragraph.

The displayed FC on the FCMs display is based on calculations that are made by the vehicles engine control unit (ECU). This calculation uses different input parameters available in the vehicle like the amount of fuel that is injected and the travelled distance. In a physical test procedure this calculated and displayed FC shall be checked. Both the calculation in the vehicle and the test procedure have variances that determine together which level of accuracy and precision could be set for the FCM.

Hereafter, a description is given of how fuel consumption is commonly calculated and which parameters have an influence on the accuracy in a chassis dynamometer test

Fuel consumption calculation
To display fuel consumption information, some signals are needed. For average and instantaneous fuel consumption two signals are needed:
1. An estimate of the actual injected fuel in litres per hour and
2. An estimate of the vehicle speed in kilometres per hour.

If these two signals are divided, the fuel consumption in litres per 100 kilometres can be obtained from:

$$\frac{\text{fuel consumption [l/h]}}{\text{vehicle speed [km/h]}} * 100[\text{km}/100\text{km}] = \text{fuel consumption [l/100km]}$$

Note that:
- Every per cent deviation of a parameter that is used to derive fuel consumption [l/hour] or vehicle speed [km/h], results in the same deviation of fuel consumption in [l/100km].
- The average FC is derived by the integration of the instantaneous FC over time and its accuracy and reliability thus relies on the quality of the instantaneous determination of the FC.

The next sections explain in more detail how the vehicle speed and the injected fuel quantity are commonly determined and how much the corresponding expected deviations from these parameters are.

4.1.1 Determination of the vehicle speed
The determination of the vehicle speed is done in two steps. First a sensor measures the speed of a wheel in rotations per minute (rpm). Consequently, this rotational speed signal is converted to speed in kilometres per hour. This vehicle speed may not be confused with the speed indicated by the speedometer in the dashboard. The speedometer is by law restricted to indicate a speed that is not higher than the actual speed. This means that there are two vehicle speed signals available. A more accurate speed and a displayed vehicle speed.

When it is known how much rotations a wheel has made, the travelled distance can easily be calculated using the dynamic tyre diameter. However the dynamic tyre diameter changes depending on the situation, a static circumference is assumed by a ECU to calculate vehicle speed. The dynamic tyre diameter differs from the normal static diameter in the sense that the tyre under loaded conditions is pressed and as such the wheel makes more rotations than a perfectly round tyre. Also a small amount of tyre slip under dynamic conditions may influence the dynamic diameter. An estimate of the circumference of a tyre can be derived from the following formulas.

$$\text{dynamic tyre circumference [m]} = \pi * \text{dynamic tyre diameter [m]}$$

$$\begin{aligned}\text{vehicle speed [km/h]} &= \text{dynamic tyre circumference [m]} * \text{wheel speed [rpm]} * 0.06 \\ &= \pi * \text{dynamic tyre diameter [m]} * \text{wheel speed [rpm]} * 0.06\end{aligned}$$

The factor 0.06 is used to convert m/min to km/h. The vehicle speed accuracy is also directly dependent on the accuracy of the wheel speed sensor. But also an uncorrected change in wheel diameter, like tyre dimension variations, influences the vehicle speed calculation.

4.1.1.1 The influence of tyre dimension variation

A vehicle model is often offered with an option to choose from different tyre/rim combinations. Across the combinations, tyre dimensions and eventually the circumference will differ from the assumed circumference to calculate vehicle speed. In an eventual test procedure however, tyre and rim dimensions are fixed for the vehicle being tested.

In practise, several factors can influence tyre diameter and therefore the circumference over time, for example:

- Wear: during lifetime a tyre gets worn, the tread depth decreases and as a result a tyres circumference decreases. In a chassis dynamometer test the tyres are tested within a prescribed tread depth range. For the proposed WLTP the allowed tread depth is fixed within a certain range.
- Multiple tyre dimensions: the manufacturer prescribes the tyre dimensions that may be fitted on the vehicle. Across tyres there are differences of circumference expected in the real-world. For a chassis dynamometer test the tyre dimensions are known.
- Tyre air pressure: assuming that the tyre is set to the prescribed air pressure this hardly affects tyre circumference.

Wear

The circumference from the actual tyres the car is equipped with can deviate from an assumed value when the tyre is worn. In the currently being developed WLTP is prescribed that tyres worn to a maximum of 80% of their original tread depth shall be used for a chassis dynamometer test. With a fixed assumed circumference, defined based on the tyre fitted, the actual circumference can deviate from the tyres being used ranging from 100 and 80% of tread depth. How tyre wear influences in the end the tyre circumference is best explained with two examples. Note that theoretical dimensions are used rather than dynamic dimensions which makes it less complex but comes down to the same principle.

Chassis dynamometer

Assuming a tyre with size 195/55/16 has a tyre circumference of 195.1 cm. The new tyre has a tread depth of 9mm. The lower tolerance of tread depth of 80% (WLTP limit) corresponds to a tread depth of 7.2mm. This means that when the tyre in the example is worn to the limit and tested, its circumference has decreased to

193.9cm, which is about 0.6% of the total circumference. When setting the assumed circumference at the middle (90% of tread depth) this results in a possible deviation of ±0.3% from the actual circumference.

Real-world
Assuming a tyre with size 195/55/16 has a tyre circumference of 195.1 cm. Assume the new tyre has a tread depth of 9mm. The legal minimum for safety is a tyre tread depth of 1.6mm. This means that when the tyre in the example is worn to its legal lower limit of tread depth, its circumference has decreased to 190.4 cm. This is about 2.5% of the total circumference. When setting the assumed circumference at the middle (50% of tread depth) this results in an possible deviation of ±1.25% from the actual circumference.

Multiple tyre dimensions
Besides tyre wear the tyre dimension also influences the circumference; a vehicle can namely be equipped with several different tyre/rim combinations. In Figure 3 an example is given of tyre circumferences of a range of new and worn tyre dimensions available on one vehicle model.

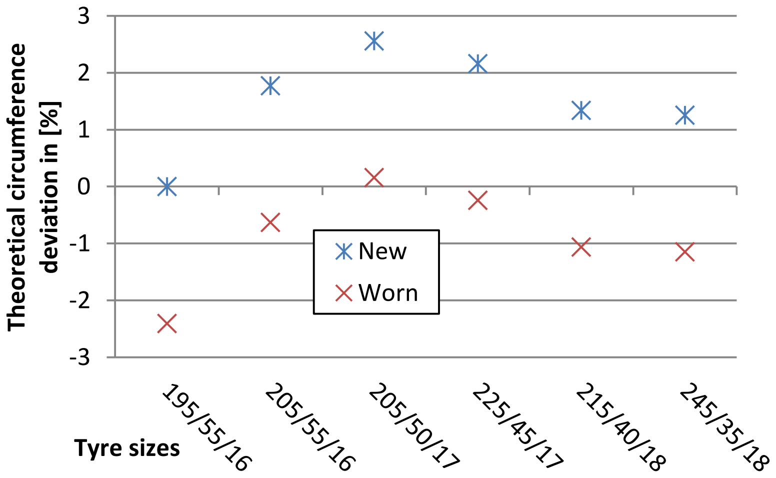

Figure 3: Tyre circumferences of new and worn tyre dimensions available on one vehicle model

Assuming the 195/55/16 as baseline the calculated vehicle speed could differ within the range of ±2.5% from the actual speed when the vehicle is fitted with one of the prescribed tyre sizes. If the vehicle speed calculation is however corrected for the tyre size (e.g. when a tyre is exchanged in a workshop) deviation could theoretically decrease to ±1.25% when the assumed tyre circumference is set in the middle of the tyre wear range.

4.1.1.2 *Wheel speed sensor accuracy*
A wheel speed sensor is mounted near the driveline of a vehicle and delivers electronic pulses generated by the sensor. The electronic pulses are generated by a toothed wheel that is attached to a rotating shaft. Every pulse that is measured represents a rotational movement of the shaft. The time between two or more pulses is registered and converted into angular speed. Although these measurements are quite accurate, there are some computation problems that could influence the measurement like:
- Sampling time effects
- Quantization effects

- Non-ideal teeth

Datasheets of different brands mention accuracies between 0.02% and 0.7%. There is no difference in accuracy expected between the chassis dynamometer and real-world situation.

4.1.2 Obtaining consumed fuel

The fuel injected by the injectors determines the fuel consumption over time. The fuel system, fuel properties and the environmental conditions determine how accurately the amount of injected fuel in litres can be calculated. In the questionnaire it is indicated by the stakeholders that the ‘injected fuel’ signal is the main parameter for calculating fuel consumption together with vehicle speed), which was explained in the previous paragraphs.

Inside the Engine Control Unit (ECU) it is determined how much fuel is going to be injected. Engine torque demand, actual operating conditions, possible corrections and limitations and possible fuel cut-off demands are taken into account when calculating the desired fuel quantity to be injected. Fuel parameters like fuel pressure, fuel temperature and fuel density, but also battery voltage, influence the difference between the calculated ‘to be injected’ fuel quantity. Often an ECU can correct for most of these parameters by the use of correction factors. After fuel is injected, the ECU is able to determine how much fuel was actually injected, via sensors like e.g. the lambda sensor or the cylinder pressure sensor, and is able to use this information to adapt the injected quantity. This so-called close loop control is needed to accurately control the mixture of fuel and air so that the combustion is optimal and the after treatment is working most efficiently. Exact figures on how accurate the determination of the actual injected fuel quantity is were not found in literature.

Aftermarket FCM

There are companies who claim that they can provide a retrofit FCM which displays the fuel consumption with an accuracy of 1%. The companies indicate that the required information is obtained via the CAN-bus communication by using signals that are ‘indicators’ for the injected fuel quantity. Actual fuel consumption data is used to calibrate this type of instruments. Such a high level of claimed accuracy can hardly be achieved, using for instance the current method of measuring fuel consumption on a chassis dynamometer, nor can it be derived from statistics from refuelling and mileage data.

ACEA indicated that if all tolerances of the total signal chain (e.g. signal measurement, signal transmission, signal processing, signal computing, averaging effects) will be summed up, the total inaccuracy could end up to ±20% of deviation in fuel consumption under real driving conditions. Deviation of FC derived from the vehicles FCM in a test procedure is according to ACEA caused by canister purge, fuel injector ageing (±1%), fuel density at fuel injector, diesel injection quantity (4%), trip computer resolution, CAN-bus signal (2%). ACEA’s view is that an overall accuracy requirement of less than ±10% or 1 l/100km (whichever is less) is not feasible and can only be a laboratory performance target.

JAMA suggests an achievable accuracy of ±10%, based on a comparison of fuel consumption test methods. They also indicate that it is difficult to reach a higher level of accuracy to quantify real-world accuracy as it is highly dependent on the operating environment of each user. Parameters that have an influence according to JAMA (not exclusive) are the injectors, fuel pressure, battery voltage, asynchronous fuel injection, fuel temperature, ambient temperature, fuel density, fuel vapour volume, percentage of bioethanol, tyre differences (circumference, tyre pressure, wear), vehicle mass, total distance travelled.

The indicated achievable accuracies of a FCM found, show a great diversity (± 1% from aftermarket FCM systems, and ±10% from stakeholders). An accuracy of ±1% under real-world conditions, which uses fuel consumption information from the vehicle itself, is not in line with what the vehicle manufacturers state being represented by ACEA and JAMA.

Obtaining fuel consumption from OBD (On-board Diagnostics)
Alessandrini et. al. (2010) provided a method to calculate fuel consumption via signals like air mass flow, lambda (air-fuel ratio), engine load and engine rpm via OBD. They evaluated their method on several vehicles over different drive cycles including NEDC and ARTEMIS and found that their method derives the fuel consumption with an accuracy of ±4% (including diesel and gasoline). To acquire this level of accuracy, each particular vehicle needed extra chassis dynamometer tests to obtain specific characteristics of the vehicles. The method could also be used by manufacturers, but they indicated that calculation based on counting injections and injected fuel quantity is used most often (chapter 2). Assuming the manufacturers could calculate the fuel consumption more accurately it is assumed that an accuracy of less than 4% can be achieved.

The approach of Alessandrini et al. (2010) showed that although no information about the vehicles' fuel consumption was broadcasted on the vehicles' OBD port, it is possible to estimate the fuel consumption based on information from OBD that is available. It was mentioned that several vehicles provide fuel consumption data on the OBD port but as publically broadcasting this information on the OBD port is not mandatory. Not every vehicle has this data available. In the current OBD II standard, SAE J1979, there is a provision for instantaneous fuel consumption in l/hour but manufacturers are not required to provide this information. Some manufacturers provide the information, others not. If fuel consumption information can be provided by every vehicle manufacturer, this kind of data can be of use in a test procedure. One could also think of mandating fuel consumption information (e.g. instantaneous, average, lifetime) in current OBD protocols to allow an easier validation of the fuel consumption assuming this value corresponds to the displayed fuel consumption value on the FCM.

Achievable theoretical accuracy
In this paragraph the most relevant individual causes of inaccuracy in the determination of the fuel consumption were discussed. All individual inaccuracies summed up determine the total achievable accuracy. Summing up all inaccuracies is a method to evaluate the minimal achievable accuracy of the fuel consumption determination. In practice, however, it is less likely that causes of inaccuracies occur at the same time and in the same direction (plus or minus). In the case of the determination of the fuel consumption an overview of the results from the evaluations in this paragraph is given in Table 1. Note that for injected fuel quantity

accuracy under real-world conditions, the 10% total accuracy of stakeholders is corrected for tyre dimension variation and wheel speed sensor errors.

Table 1: Overview of accuracies concerning fuel consumption calculation based on the theoretical evaluation.

Methods	**Chassis dynamometer situation**	**Real-world situation**
Tyre dimension variation	Max. ±0.3%	Max. ±2.5%
Wheel speed sensor	±0.02-0.7%	±0.02-0.7%
Injected fuel quantity	Max. ±4%, Alessandrini (2010)	±6.8% (stakeholders: 10% - 2.5% - 0.7%)
Total FCM accuracy	**Max.± 5%**	**±10%**

As the deviation of the individual factors does not always point in the same direction, accuracy of the FCM could be even better in practice. A suggestion to reduce the deviation in the real-world situation further is to take tyre dimension variation into account by changing the assumed tyre circumference that corresponds to the actual fitted tyre. This will increase the accuracy of real-world situations by 1.25%.

4.2 Practical experiences with FCM

In the previous paragraph a theoretical evaluation of fuel consumption measurement was made, based on the available literature and stakeholder response (Questionnaire and a stakeholder workshop). Based on the information found, indications of a theoretically achievable accuracy of a fuel consumption measurement were given. Still missing is an evaluation of the already achievable accuracies of existing FCMs to see how they perform in practice (this paragraph) and in a chassis dynamometer test (next paragraph). To get a better understanding on the accuracy level of a FCM under real-world conditions, this data was gathered during the project. Based on the theoretical and practical experiences, conclusions on which level of accuracy is already feasible and needed can then be made. The evaluation of this data will be subject of this paragraph.

4.2.1 FCM performance under real-world conditions

Refuelling data (litres and mileage) and trip average fuel consumption displayed by the FCM of two diesel passenger cars (Euro 2 and 3) was gathered by TNO. The vehicles covered more than 2 years of driving mainly in the Netherlands by the same person. The cars have covered approximate 164,000 kilometres of distance in the period between 2008 and 2012. To widen the scope of vehicles, data of two more vehicles (Euro 3 and 4), including gasoline and diesel, was gathered over a period of several months in 2013.

The data of each vehicle was analysed and is referred to as vehicle 1 to 4. Vehicles 1 and 2 have 141 and 83 recordings over a period of approximate 2.5 and 2 years. Vehicles 3 and 4 have 5 recordings. The results of the measurements are depicted in Table 2. Note that there is always a deviation expected when refilling the vehicle at the gas station. The error however decreases when more refuelling is recorded.

Table 2: Results from refuelling data and trip average FCM data of 4 vehicles

Tank data vs Trip average FCM	**Vehicle 1 diesel**	**Vehicle 2 diesel**	**Vehicle 3 diesel**	**Vehicle 4 gasoline**
Samples (n=)	141	83	5	5
Mean	-3%	-8.5%	-10%	-3%
Average deviation (from mean)	±2.4%	±1.8%	-	-
Absolute minimum	-12.2%	-13.6%	-11%	-4%
Absolute maximum	11.7%	2.7%	-7%	-1%

Accuracy
The accuracy of a measurement system is the degree of closeness of measurements of a quantity to that quantity's actual (true) value. In this case the FCM is the measurement system which measures the quantity fuel consumption. On average the FCM on all vehicles doesn't always indicate an accurate fuel consumption value. Remarkable is that all four vehicles have a negative mean deviation and there seems to be a certain systematic error present. On average an overly positive fuel consumption value is presented which is not reflecting the actual fuel consumption.
There is a spread in the observed accuracy of the 4 vehicles and some show a better accuracy then others (Vehicle 1 and 4, -3%, and vehicle 3, -10%). The best result (-3%) of vehicle 4 indicate that it is possible for a FCM to indicate a fuel consumption value that is close to what is actually consumed.

It is unsure what has caused the systematic offset. The offset could be caused by assumptions that are made in the ECU calculating the consumed fuel. This could for instance be factors like fuel density, differences in tyre circumference (assumed circumference), aged injectors, because if these values are assumed to be fixed, a consistent error arises. It is less likely that factors like fuel pressure, battery voltage, asynchronous fuel injection, fuel temperature, fuel vapour volume, tyre differences (air pressure and wear), have a direct effect on the mean values because the measurements took place over multiple years under many different real-world conditions and seasons. Expected is that the last mentioned factors do effect the repeatability (precision) of the FCM.

It is remarkable that the offset is only found in one direction. With this offset the driver has the perception that the fuel consumption is lower than it actually is.

Comparable measurement method and findings
Reed, P. (2011) reported his findings of comparable measurements to determine the accuracy of a FCM. In a test with seven different modern vehicle types, approximately 2500km were covered. The article: *'Your Fuel Economy Gauge is Fibbing'* is reporting that the tested FCMs on average are displaying an overly optimistic fuel consumption value. They found one FCM that indicated a 19% too optimistic value. On average the FCM reading showed a systematic error of -5.5%.

Precision
Precision of a measurement system, also called reproducibility or repeatability, is the degree to which repeated measurements under unchanged conditions show the same result. With the measurements conducted under real-world conditions, over several years, a lot of factors may have influenced the measurements of the FCM. All factors mentioned as influencing factors by stakeholders in chapter 2 could not be monitored, controlled or kept constant. For the measurements the conditions are taken ‘as is’. If a FCM is already showing a high precision under uncontrolled conditions, the FCM is ‘robust’ for the conditions it was tested in. Looking at the precision of the FCMs under the ‘as is’ conditions, vehicle 1 and 2 show an average deviation of ± 1.8% and ± 2.4%. When looking at the distribution of the data points, almost 90% of all data points stay within a deviation of about 4 to 5% from the mean (see Figure 4). However the individual trip average FCM readings can be substantially higher occasionally when looking at the absolute maximum and minimum values (-13.6% and 11.7%).

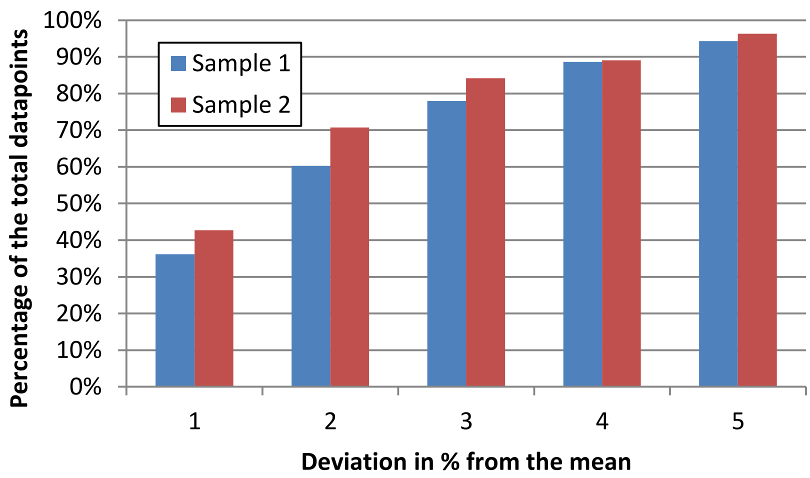

Figure 4: Cumulative frequency distribution of individual ’measurements’ on two vehicles; Deviation of the fuel consumption displayed compared to the tank data.

It can be concluded that the best performing FCM was able to show an accuracy of -3% with a precision of 4 to 5% in 90% of all measurements under real-world conditions.
If the systematic error could be corrected, all the tested FCM’s could have shown a better accuracy. Not all vehicles show the same systematic error. What the exact cause of the systematic error is could not be determined based on the data.

Chassis dynamometer accuracy and precision
It is expected that in a chassis dynamometer test procedure an even better level of accuracy and precision is possible because most influencing environmental conditions and vehicle parameters are controlled or fixed (e.g. temperature, fuel, driving pattern, assumed tyre circumference). As tyre wear increases over time it is expected that also the accuracy is effected by this over time. From the theoretical analysis in paragraph 4.1.1.1 we know that tyre circumference deviations can drop from a maximum ±2.5% to ±0.3%, which is a reduction of approximate 2%.

4.3 Chassis dynamometer tests

4.3.1 Target of testing

The aim of the testing activity was to investigate the accuracy of FCM systems already available in the market as well as to assess the ability of existing in-laboratory test procedures to serve the verifiability of the FCM requirements during a physical test procedure.
For this reason it was planned to evaluate up to three FCM systems on the chassis dynamometer over legislative as well as more transient driving cycles. The vehicles should be equipped with different FCMs.

4.3.2 Test setup and instrumentation

A standard CVS / chassis dynamometer setup was used for the tests (Figure 5).

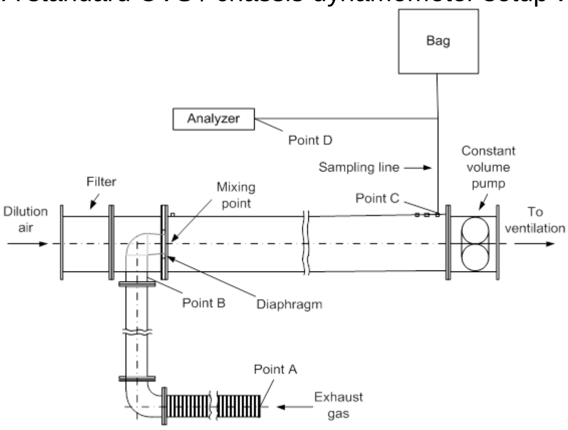

Figure 5: CVS setup and exhaust gas sampling used for the tests

The tests and CO_2, fuel consumption calculations were performed according to regulations UN/ECE R83 and UN/ECE R101.
Different methods of fuel consumption recording were used as follows (headings correspond to nomenclature also used in results presentation):

4.3.2.1 Lab. FC CVS bag (laboratory reference equipment)

For the determination of the total fuel consumption over each driving cycle, bag sampling of exhaust gas was used similarly to the standard EU type-approval procedure. CO, CO_2, HC were analysed and fuel consumption was calculated using the legislative carbon balance based calculation.

4.3.2.2 Lab. FC instantaneous (laboratory reference equipment)

In order to get an estimation of the instantaneous fuel consumption and also verify the accuracy of the procedure, modal analysis of the instantaneous concentrations at diluted exhaust gas was also performed. The calculation of the instantaneous fuel consumption was performed using the same methodology as for the bag sampling (paragraph 4.3.2.) adapted as follows.
According to UN/ECE R83, the mass emissions of gaseous pollutants are calculated as follows:

$$M_i = \frac{V_{mix} \cdot Q_i \cdot k_h \cdot C_i \cdot 10^{-6}}{d} \qquad (1)$$

Where:

M_i = mass emission of the pollutant i in grams per kilometre,

V_{mix} = volume of the diluted exhaust gas expressed in litres per test and corrected to standard conditions (273.2 K and 101.33 kPa),
Q_i = density of the pollutant i in grams per litre at normal temperature and pressure (273.2 K and 101.33 kPa),
K_h = humidity correction factor used for the calculation of the mass emissions of oxides of nitrogen. There is no humidity correction for HC and CO,
C_i = concentration of the pollutant i in the diluted exhaust gas expressed in ppm and corrected by the amount of the pollutant i contained in the dilution air,
D = distance corresponding to the operating cycle in kilometres.

The concentration of pollutant i in the diluted exhaust corrected by the amount of the pollutant in the dilution air is calculated as follows:

$$C_i = C_e - C_d \cdot \left(1 - \frac{1}{DF}\right) \qquad (2)$$

Where:
C_i = concentration of the pollutant i in the diluted exhaust gas, expressed in ppm and corrected by the amount of i contained in the dilution air,
C_e = measured concentration of pollutant i in the diluted exhaust gas, expressed in ppm,
C_d = concentration of pollutant i in the air used for dilution, expressed in ppm,
DF = dilution factor.

In the case of instantaneous fuel consumption calculation C_e was the instantaneous concentration of pollutant i as measured in the diluted exhaust gas in real time during the test. Since ambient concentration C_d can be considered stable during the test, the integral ambient bag concentration was used in the calculations. The DF was also calculated using the instantaneous pollutant concentrations instead of the integrated cycle values.
The total pollutant mass in [g/km] for the cycle for each pollutant was calculated as the sum of the instantaneous values of equation (1). These values for CO, CO_2, HC were then used for the calculation of fuel consumption according to the UN/ECE R101 equations.

4.3.2.3 FCM average, FCM instantaneous (vehicle on-board FCM system)

Finally, in order to record the indication of the FCM system of the tested vehicles a camera was installed at the FCM screen of the vehicle acquiring video in real time. The indications of this video were then post processed using an OCR system developed specifically of vehicle indication processing covering both numerical indications as well as graphic indications (e.g. bar charts). The outcome of this processing was two sets of values, a value of the FCM system averaging module over the driving cycle (trip average was reset before each cycle) as well as a second-by-second trace of the instantaneous FCM indication.

4.3.3 *Test cycles and protocol*

The vehicle was driven on a chassis dynamometer following different driving cycles including both the legislative NEDC with its sub cycles UDC and EUDC sampled separately as well as the Artemis driving cycles (Figure 6). In addition a set of steady speed tests was also performed.

The test protocol followed for each repetition was as follows:

- NEDC (type-approval)
- NEDC (hot start)
- Artemis Urban (highly transient)
- Artemis Road (gear shifting at higher rpm)
- Steady speed: 50, 80, 100 km/h

The above protocol also covered the current type-approval cycle as an option for parallel FCM type-approval, the more transient Artemis driving cycles covering wider areas of the engine map as well as steady state operation to assess the basic FCM accuracy independently of accuracy of the real time FC determination.

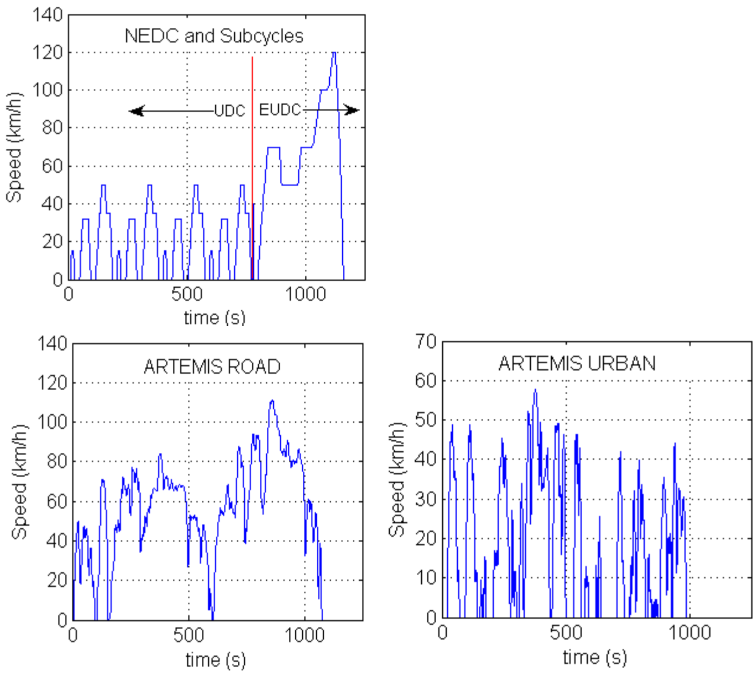

Figure 6: Driving cycles

4.3.4 *Vehicle technologies tested*

Three FCM equipped test vehicles were chosen in order to assess the FCM of one modern diesel and one modern gasoline vehicle FCM as well as the accuracy of the FCM system of an older vehicle. The test vehicles were randomly chosen based on availability and sufficient market share. The sample size was limited by measurement resources. The technologies and the characteristics of the vehicles used for the tests are summarized in Table 3.

Table 3: Vehicle technologies tested

Vehicle segment	**Fuel**	**Engine capacity [cc]**	**Model year**	**Emission standard**	**Target: Assess the accuracy of the FCM of a**	**Fuel saving system evaluated**
'Lower medium'	diesel	1600	2012	Euro 5	modern diesel vehicle	Start & stop
'Lower medium'	gasoline	1400	2012	Euro 5	modern gasoline vehicle	Gear shift indicator
'Lower medium'	gasoline	1800	2002	Euro 3	old vehicle (gasoline)	-

In order to assess the ability of the FCM systems to distinguish the difference between different driving behaviours and fuel saving options at least in laboratory conditions, it was decided to evaluate test cars equipped with a system able to affect the driving behaviour of the test driver in a repeatable way during the test. For this reason the diesel car was chosen to be equipped with a start & stop system. When this system was activated the vehicle engine was stopped when speed dropped to 0 km/h. The gasoline car was equipped with a gear shift indicator advising the driver with a gear shifting that can reduce fuel consumption. The vehicles were tested both with these systems deactivated (normal type-approval test) as well as activated.

4.3.5 *Results of testing*

The results of testing are presented in Figure 7 to Figure 14:

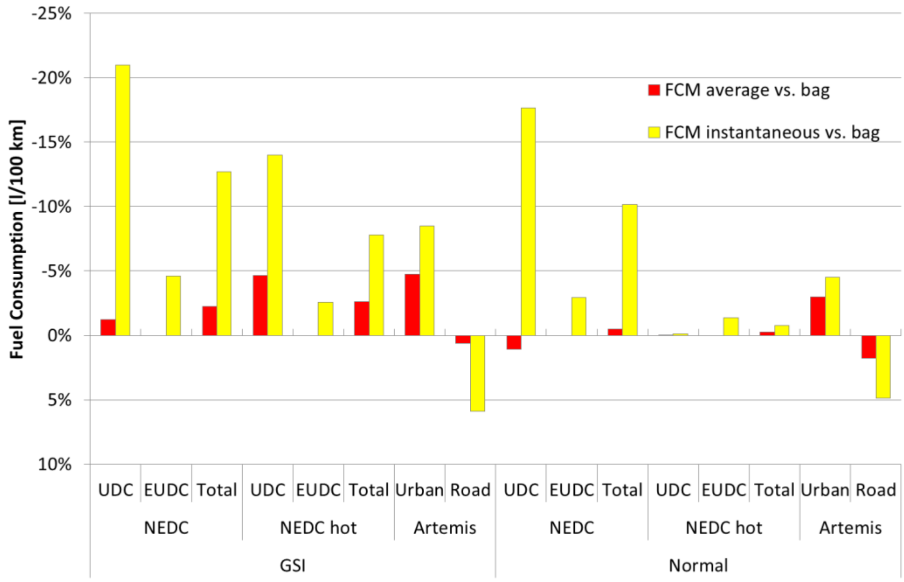

Figure 7: Gasoline, Euro 5: FC_{FCM} vs. FC_{bag} [% difference]

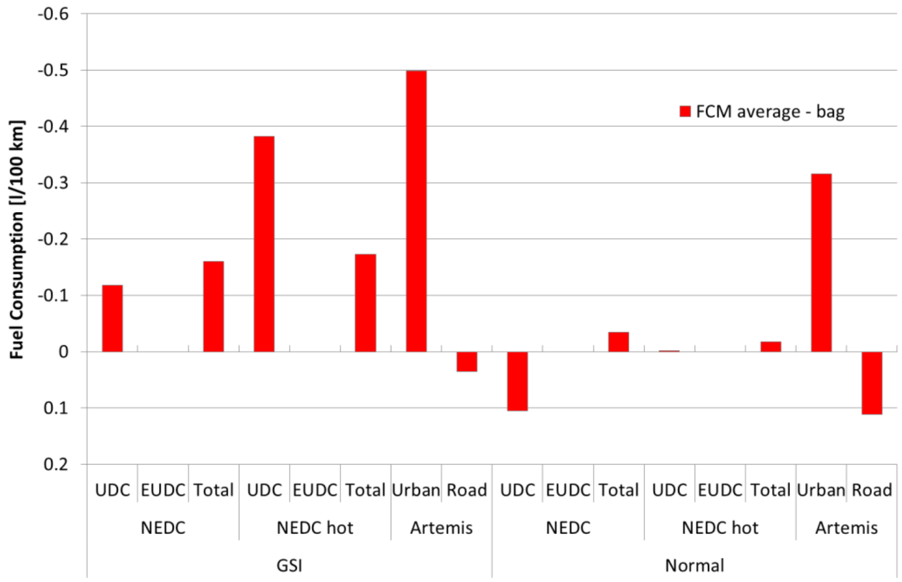

Figure 8: Gasoline, Euro 5: FC_{FCM} vs. FC_{bag} [l/100 km]

For the gasoline Euro 5 vehicle it has to be noted that the instantaneous FCM deviates more in cycles with long vehicle stops due to the fact that FC unit definition (l/100 km) does not cover parts of the driving cycles when vehicle speed = 0 km/h.

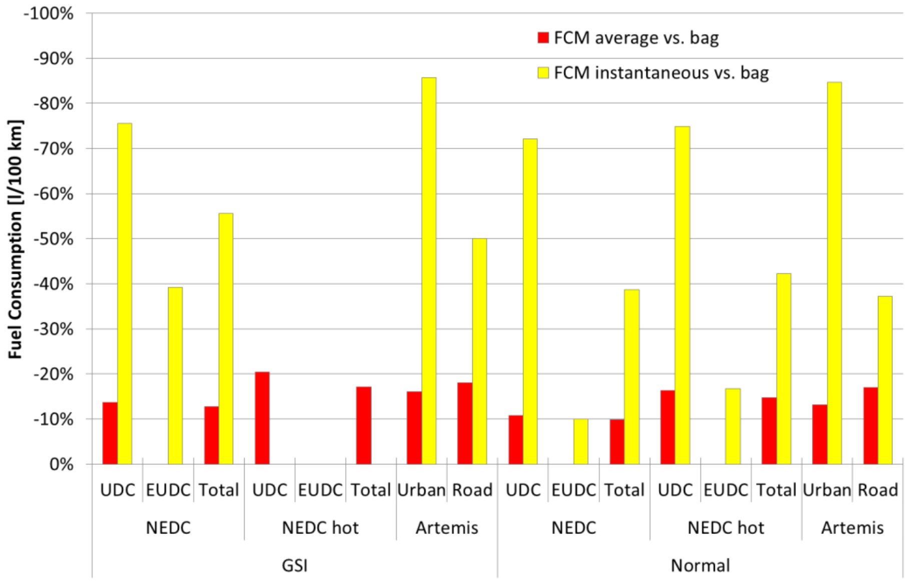

Figure 9 Diesel, Euro 5: FC_{FCM} vs. FC_{bag} [% difference]

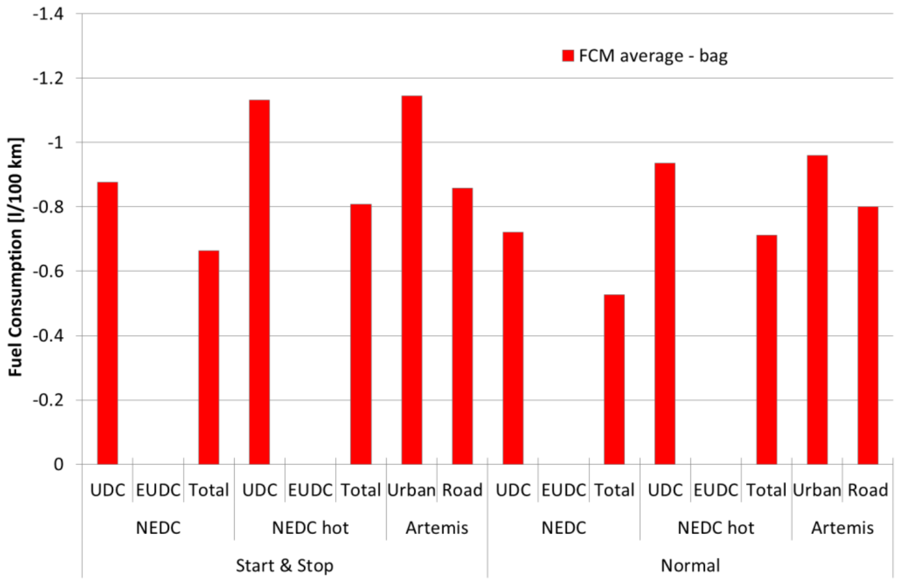

Figure 10: Diesel, Euro 5: FC_{FCM} vs. FC_{bag} [l/100 km]

For the diesel Euro 5 vehicle, the FCM measured lower FC compared to laboratory methods. It has to be noted that the FCM instantaneous calculation deviation is high due to an on-screen warning signal covering FC information for certain periods of testing thus no FC was taken into account during these periods.

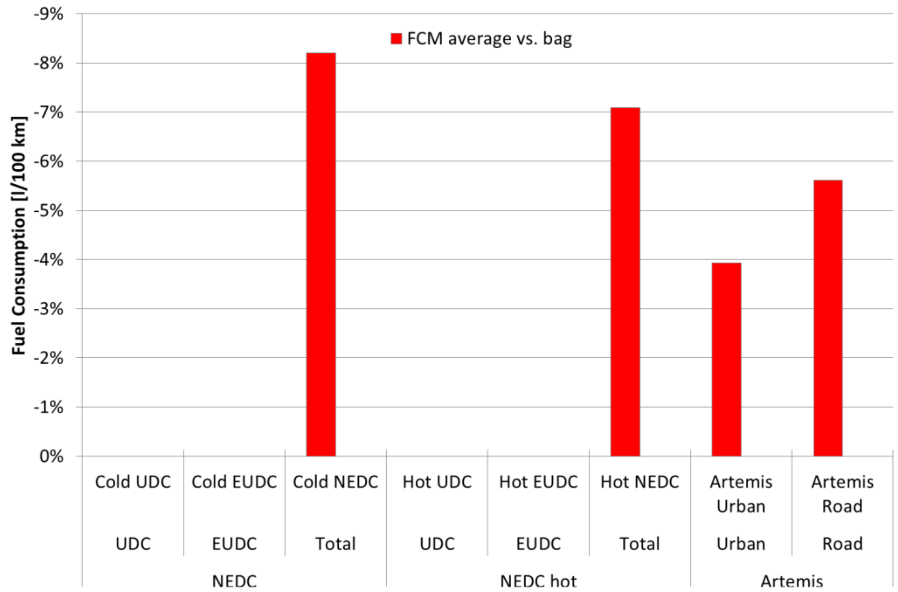

Figure 11: Gasoline, Euro 3: FC_{FCM} vs. FC_{bag} [%]

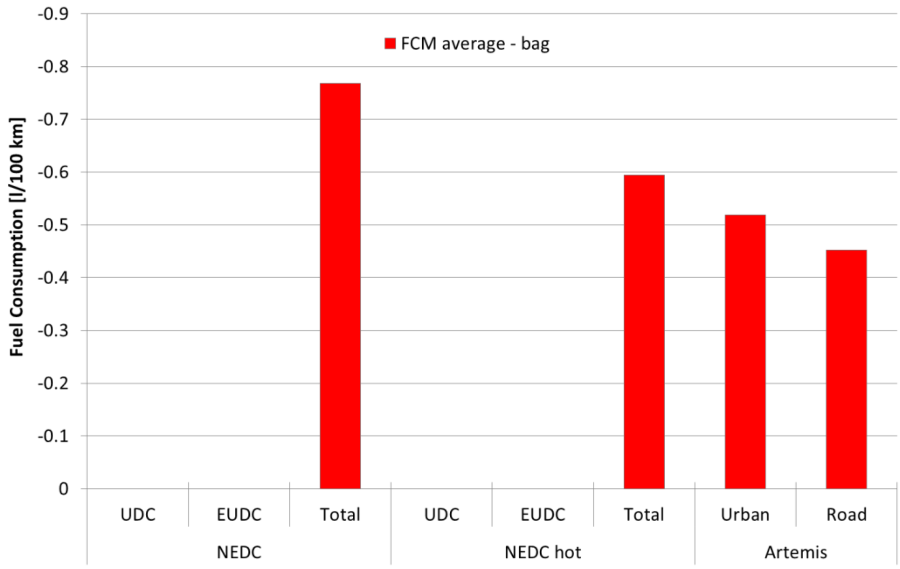

Figure 12: Gasoline, Euro 3: FC_{FCM} vs. FC_{bag} [l/100 km]

Regarding the gasoline Euro 3 vehicle similar results were obtained by all measurement methods leading to low deviations.

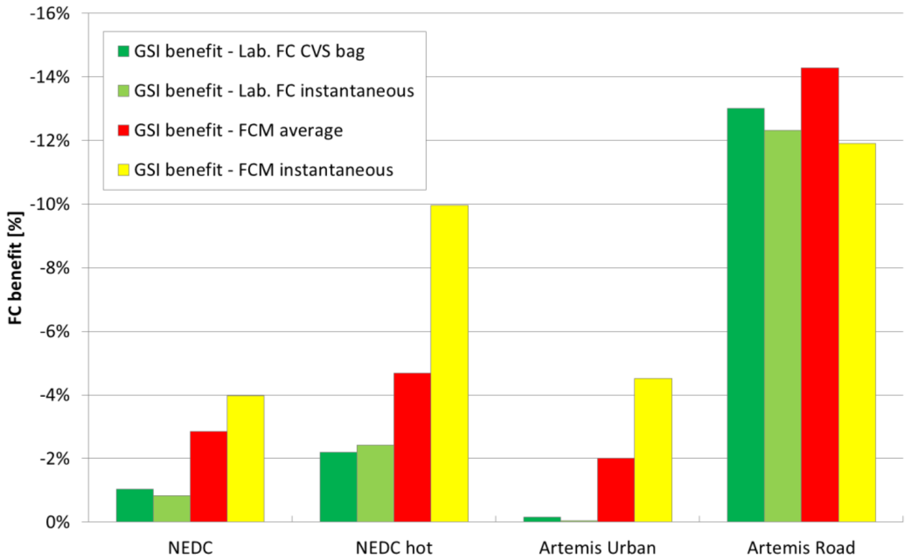

Figure 13: Gasoline, Euro 5: FC benefit due to GSI [%]

In the Euro 5 gasoline vehicle laboratory tests, the FCM calculated higher FC benefit since the absolute FC calculated by the FCM is lower. As already mentioned instantaneous FCM deviates more in cycles with long vehicle stops due to the fact that FC unit definition (l/100 km) does not cover parts of the driving cycles when vehicle speed = 0 km/h.

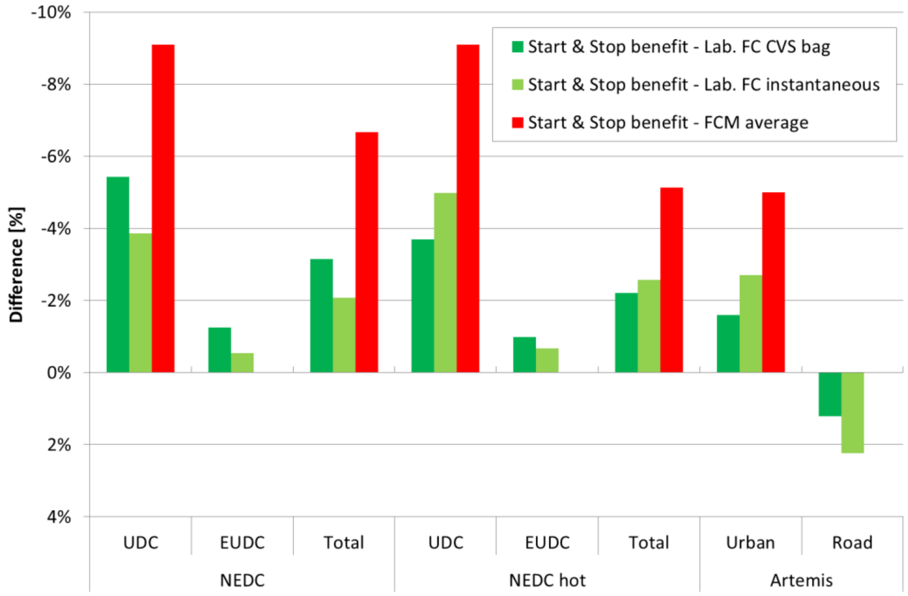

Figure 14: Diesel, Euro 5: FC benefit due to Start&Stop [%]

As seen in the results of the start & stop system of the diesel Euro 5 vehicle FC benefit is calculated, as expected, only at cycles with vehicle stops. Artemis Road shows FC increase with start & stop due to the very short pause duration. Due to these short pauses the fuel benefit due to engine stop is outmatched by the fuel penalty due to engine start. It can be said that the FCM overstates in general the FC benefit of the start & stop system.

Based on the results of the FCM systems testing presented in Figure 7 to Figure 14, the tested FCM systems demonstrated the following accuracies:

- Gasoline vehicle: 1% to -5% (-4% to -8% on older vehicle)
- Diesel vehicle: -10% to -18%

The instantaneous FCM measurement leads to lower FC calculation due to the fact that FC is not defined at vehicle stops (due to being expressed on a per km basis), therefore these periods of operation are not taken into account in the calculation of the total FC. Another reason for missing data were warning messages appearing during chassis dynamometer testing that were covering the FCM screen and data.

4.4 Discussion

In this chapter the achievable accuracy and precision of the FCM was evaluated before drafting technical requirements. Based on the evaluation results and discussion, technical requirements will be drafted that are feasible and needed for a FCM to be supportive for eco-driving and at the same time are providing the consumer with accurate information. The technical requirements are concerning the accuracy of a FCM that can be evaluated in a test procedure.

Comparison of the results

The different results in this chapter show that in the theoretical evaluation the estimated accuracy of the FCM is much higher than what was measured in the real-world situation. An overview of the determined and measured accuracies of an FCM is given in Table 4.

Table 4: Overview of the determined accuracy of a FCM on a chassis dynamometer and under real-world conditions.

Evaluations	**Chassis dynamometer situation**	**Real-world situation**
Theoretical (paragraph 4.1)	Max. 5%	10%
Real-world measurements (paragraph 4.2)	-	Systematic error -3% and precision 4 to 5%
Chassis dynamometer tests (paragraph 4.3)	1 to -5%	-
Supportive for eco-driving (paragraph 3.5)	-	As accurate as possible, relative change need precision of at least 1.7% to indicate 5% saving

The results deviate between the different evaluations and situations. A FCM will be evaluated on a chassis dynamometer and therefore a feasible accuracy range is determined for this situation.

Accuracy range

One vehicle has shown an accuracy range of +1 to -5%. This suggests that the FCM was capable to be within an accuracy range of about plus and minus 3%.The ‘worst’ performing FCM showed an accuracy range of -10 to -18%. Suggesting an accuracy range of plus and minus 18% would then not reflect the achievable accuracy of a FCM, because a systematic error prevents the FCM to be more accurate. When correcting the systematic error the FCMcould show a deviation of ±4% from the mean. To a certain extent, the theoretical and real-world evaluations (paragraph 4.1 and 4.2) show that a systematic error could not be completely prevented and should be taken into account. By setting an accuracy range the margin for large systematic errors will be limited. The range should be sufficient to cover possible systematic errors that can occur and should take into account the precision of the FCM system.

Systematic error
Suggestions of parameters that could cause a systematic error were given in paragraph 4.2. Main parameters are tyre wear and wheel speed sensor accuracy. In a chassis dynamometer situation these parameters are causing a total error of plus and minus 1% (0.7% for the sensor and 0.3% for allowable tyre wear).

In the real-world situation this would be 3.2% (0.7% for the sensor and 1.25% for tyre wear and 1.25% for tyre dimension variation) and could be even 2% in case the assumed tyre circumference is adjusted according to the tyre dimension that is fitted (0.7% for the sensor and 1.25% for tyre wear). Beside the systematic error, also the precision at which a FCM could derive the fuel consumption value determines an achievable accuracy range.

Precision
From the theoretical evaluation in paragraph 4.1 the accuracy and precision at which the fuel injection quantity could be derived in the real-world situation is about 7% (6.8%). This number was derived based on the 10% achievable accuracy indicated by stakeholders. For the chassis dynamometer situation, the fuel injection quantity was assumed to be maximum 4% accurate, because with indirect signals Alessandrini et al. (2010) was able to be that accurate. It is assumed that a manufacturer is able to be more accurate by having direct signals available that are related to the fuel consumption, such as quantity per injection and amount of injections. This would indicate that there is a minimal drop of 2.8% in fuel injection quantity determination between the real-world and chassis dynamometer situation. When this drop is applied to the precision that was shown in the real-world measurements (precision 5% in 90% of all data points) this comes down to about 2.2% (5 minus2.8%).

Achievable accuracy range
The systematic error and precision determine together the achievable range of accuracy of the FCM. In case of the chassis dynamometer situation this sums up to an achievable range of plus and minus 3.2% (systematic error of 1% and precision of 2.2%). When rounding this number, this comes down to an achievable accuracy range of plus and minus 4%. When a FCM is achieving such level of accuracy in a chassis dynamometer test, in the realworld a maximum range of approximate 8 to 9% of accuracy is expected.

Relevance for eco-supportive driving
As indicated in chapter 3, there is not a direct need to have high accuracy for the instantaneous FC to be supportive for eco-driving. The feedback on instantaneous FC should rather be able to distinguish FC results by driving at constant speed, idling, coasting, GSI shift strategy and accelerating. However, there is no reason to not displaying the most accurate fuel consumption value to the driver as the results show that current FCMs could already provide more accurate information.
During driving drivers could be distracted by rapidly changing numbers. Avoiding distraction caused by the changing number is of more importance (because of safety) than displaying the most accurate number. Research showed that in these dynamic driving patterns simple visual representations work best which was left open to manufacturers in FR05. During constant driving patterns (e.g. constant

speed, idling) the instantaneous fuel consumption information should be available to the driver and should be close to the actually consumed fuel.

Considering the different possible functionalities of the FCM (e.g. displaying instantaneous, average fuel consumption or other) the following should be taken into account before requirements for the accuracy are proposed:

- Instantaneous fuel consumption: As indicated in chapter 3 the absolute value (accuracy) is of less importance than the educative support from showing the relative fuel consumption effect (precision) of different driving conditions (e.g. constant speed in a higher gear, activating stop-start, coasting etc.) to the driver. The relative change, however, should be accurate enough to indicate the changes in fuel consumption due to applying eco-driving techniques. The resolution of a FCM should however be high enough to indicate the difference (e.g. 0.1 l/100km instead of 0.5l/100km). To indicate possible fuel saving in an order of 5% (which is indicated as the lower band of applying eco-driving techniques) the precision of the system should be at least 1.7%. Based on the results it was indicated that the tested FCMs theoretically can have a precision of about 4 to 5% under real-world conditions. The environmental conditions in the real-world measurements could not be controlled and are taken ‘as is’. This suggests that the precision of a FCM could be much higher than the conservative 2.2% in a chassis dynamometer test situation, where all influencing parameters are constant. As the precision of the FCMs wasn’t specifically evaluated in the chassis dynamometer tests, this theoretical precision should be investigated further. Based on the conservative theoretical precision of 2.2% in a chassis dynamometer test it is recommended that possible ways to increase the precision should be investigated. Furthermore, the measurement systems in the test procedure need to be sufficient to measure such level of precision and accuracy.
- Average fuel consumption: This figure should be presented as accurate, precise and reliable as possible. The driver can only rely on this figure, if it is assured that it has a certain proven accuracy. When the driver wants to apply eco-driving techniques he can rely on the fuel consumption values of the FCM within the given range of performance. Eco driving experts indicate that especially the effects of eco-driving techniques applied on repetitive commuting routes should be indicated accurately by the FCM, because the driver can see the effect of his driving technique. When taking into account the accuracy a range of +4% and -4% this is already feasible.
- With a known reliability, accuracy and precision a driver can compare the label value of his vehicle with the actual fuel consumed under real-world conditions. This difference could serve as a motivation to apply eco-driving techniques. Other functionalities of displaying fuel consumption information: The non-resettable average week/month/lifetime and total lifetime fuel consumption are functionalities that could serve multiple purposes. These could be statistical purposes like monitoring FC per vehicle or fleet management, driving style bonus systems, trend analyses, emission modelling and CO_2 control and taxation. Given the feasible accuracy of the FCM, these functionalities could be derived with at least the same accuracy.

Kroon, 2012, formulated a technical requirement for a FCM on accuracy (1% and/or 0.1 [l/100km]). This requirement was not shown to be feasible based on the results.

Based on the evaluation results and discussion, the following technical requirements are drafted : feasible, needed for a FCM to be supportive for eco-driving and at the same time providing the consumer with as accurate as possible information.

TR01a	The instantaneous and idling fuel consumption data displayed shall not deviate from the real fuel consumption by more than 4 [%] during constant speed driving and idling. A constant speed is considered when a speed set point is maintained over a period of 2 seconds. *The unit could also be [miles/gallon or mpg], [kg/100km], [litre], [km/l], [Wh/km] etc. and accuracy stays 4[%].

TR01b	The trip average fuel consumption data displayed shall not deviate from the real fuel consumption by more than 4 [%] *The unit could also be [miles/gallon or mpg], [kg/100km], [litre], [km/l], [Wh/km] etc. and accuracy stays 4[%].

Other FCM functionalities

Throughout this study other functionalities, than strictly being directly contributing to eco-supportive driving, were identified as for example lifetime fuel consumption. The accuracy for these functionalities could be within 4% which is held achievable for a FCM. To get more value for customer awareness the higher the accuracy the better. It is therefore recommended to further investigate what extra effort would be needed to increase the accuracy. To leave room for other functionalities TR01c is drafted.

TR01c	Other fuel consumption data displayed e.g. week/month/lifetime average, total lifetime, shall not deviate from the real fuel consumption more than 4[%]. *The units may vary e.g. [litres], [litre/100km], [km/litre], the maximum deviation stays 4[%].

In theory, options are available which could improve the accuracy of the FCM. For instance drivers could be given the possibility to adjust the offset of their FCM themselves. The accuracy could also be improved in a technical way; the FC which is calculated by the ECU could be compared to the refuelling volume or tank fuel level by using a fuel level sensor. The calculated FC can be corrected if there is a (consistent) deviation due to a systematic error. In theory even the speedometer could be checked and corrected if a GPS system is present on-board.

Until now, there are no examples found of a FCM which leaves the possibility to drivers to adjust their systematic error. This could however result in complications for the lifetime fuel consumption, which should not be manipulated. In addition to preventing manipulation the manufacturers could however limit the rate of adjustment within the boundaries given by a maximum deviation range or just disable the option to adjust for life-time fuel consumption.

Asses FC information in a test procedure

To assess how much the displayed FC deviates from the measured FC, the fuel consumption value displayed on the FCM should be stored in order to compare the results with the fuel consumption measurement method from the lab. In this project a visual recognition technique was used. The visual recognition showed some implications in which data could not be recorded. As the OBD II SAE J1979 protocol already has a data broadcast provision, this option should be considered. Furthermore aftermarket FCM suppliers already claim to make use of the vehicles' CAN-bus communication system to determine the fuel consumption. This would mean that manufacturers could also have the ability to make such information available. In this case, probably the CAN-communication details should be made available for the Type Approval Authorities (TAA) to make sure this information can be stored. Based on an evaluation of the FCM accuracy the following technical requirement TR02a for visual recognition and TR02b for OBD/CAN data logging is drafted.

TR02a	The fuel consumption data e.g. average, instantaneous, idle, or other specified shall be available on the FC display on request of the driver under all conditions when the vehicle is driving and idling.

TR02b	The fuel consumption data e.g. average, instantaneous, idle, or other specified shall be available on the physical OBD port* under all conditions when the vehicle is driving and idling. *Implementing/adjusting it in OBD protocol could be considered. The FC signals, which represent the displayed FC functionalities, should however be available for Type Approval Authorities (TAA)

5 Conclusions and recommendations

The EC's goal to make the FCM mandatory for passenger cars makes that a FCM needs to be defined in terms of functionality and technical performance. This study aims at the development of functional and technical requirements of a FCM.

In this study research on technical and functional requirements for fuel consumption meters is performed by means of a literature review into the currently available experiences with in-car devices, real-world experience, chassis dynamometer tests and a questionnaire to the stakeholders. The results were discussed with the stakeholders.

This effort resulted in a strengthened motivation to implement FCM in light-duty vehicles, supported by both technical and functional requirements which support eco-driving. The requirements could be assessed in a test procedure to be developed with the goal to derive a test procedure which can be annexed to implementing legislation.

5.1 Conclusions

This study has resulted in a list of functional requirements which are feasible and which fulfil the general criteria: the FCM needs to be supportive for fuel consumption improvement by the driver, practically applicable, based on acceptance by drivers, technically feasible, verifiable in a physical type approval procedure, not decreasing the safety and give accurate and reliable information to the consumer about the actual FC of his vehicle. The complete list of draft requirements can be found in appendix A.

Draft requirements
The draft requirements are meant to ensure a proper harmonised functional FCM. This FCM should be seen as a standardised tool to support eco-driving. The requirements do not limit the freedom of design as they are based as much as possible on already existing FCM capabilities and as such the vehicles already comply to the majority of requirements. Furthermore, the requirements are not limiting the manufacturers in displaying their own ways of displaying fuel consumption, which would only be complimentary or add more value to be supportive for eco-driving. The requirements ensure that FCM functionalities, that have been identified to be supportive for eco-driving, are assured. These functionalities are instantaneous fuel consumption and average fuel consumption. In addition, also other possible functionalities of a FCM were discussed.

Instantaneous fuel consumption
Instantaneous and idling FC is directly contributing to eco-driving by teaching the driver what the fuel consumption consequence of his driving behaviour is during several real-time driving conditions. This FC information is only effective if the FCM is able to provide information that is able to indicate the relative fuel consumption benefit and give an indication of the absolute fuel consumption value. Providing highly reliable and absolutely accurate instantaneous FC information to the driver is of lower importance than the teaching aspect is. An already feasible accuracy of ±4% should however be suitable. This requirement does not apply to situations

where the speed in not stabilised as rapidly changing figures can be distracting to the driver. Graphical and symbolic forms of instantaneous fuel consumption information show better understandability during dynamic driving. The manufacturer is free to add such forms of information together with the numerical form. The instantaneous and idling functionalities are covered by the draft requirements and can be checked either by visual inspection or by a yet to define test procedure.

Average fuel consumption
The trip average FC directly supports eco-driving by creating awareness to a driver and by giving him feedback on how well he applied eco-driving over a given trip. The trip average fuel consumption is reset by the driver and reflects the driver's efforts of applying eco-driving techniques. The average fuel consumption value should be presented as accurately as possible. An already feasible accuracy of ±4% should however be suitable.

Additional functionalities
Other additional functionalities of displaying fuel consumption information are non-resettable average week/month/lifetime and total lifetime fuel consumption. These functionalities could serve multiple purposes. Whereas the weekly and monthly fuel consumption have a comparable effect as the average fuel consumption, the yearly and lifetime could serve statistical purposes. This could be purposes like monitoring FC for a single vehicle or fleet, driving style bonus systems, trend analyses, emission modelling and CO_2 control and taxation. It was not investigated in detail how consumers or fleet owners use this information. Given the feasible accuracy of the FCM, these functionalities could be derived with at least the same accuracy. An already feasible accuracy of ±4% should however be suitable.

Test procedure
A test procedure to evaluate the functional and technical requirements of current FCM systems is explored. The procedure is based on a chassis dynamometer test where the FC is measured using the carbon balance method. A visual recognition system is used to read the FCM display and compare the obtained values with the measured FC. The visual recognition method to record instantaneous FC showed to be sensitive for vehicles that show messages overruling the display and for instances when there is no signal indicated, e.g. occurring at low speeds. It was concluded that recording of the OBD/CAN signals could be an option besides visually reading the signals from the display provided that manufacturers can provide this information. This capability should be further investigated before choosing between vision recognition techniques and OBD/CAN.

5.2 Recommendations

The following recommendations are based on the work in WP 100 as discussed in this report and are meant to give direction to the work to be performed for *Work package 200: FCM Type approval test procedure development*. Based on the conclusions that were made, recommendations are given for the requirements and test procedure.

Functional requirements
Most functional requirements could be assessed via inspection (e.g. a check on functionality or a check on the availability of operating instructions). Based on the reactions given by stakeholders, there is still some confusion or misunderstanding on the requirements (e.g. average seating position, average driver length, operating instructions, malfunctioning). This leads to the following questions that should be addressed in the development of a test procedure:

1. Which misunderstandings could occur? (both from a stakeholder and a type approval authority point of view)
2. Which provisions can be taken in the test procedure description to tackle a misunderstanding of the procedure?

Technical requirements
The technical requirements are about validating the accuracy of a FCM. The performed chassis dynamometer evaluation and practical experiences gave insight on how a FCM performs. The preliminary accuracy requirement as it was defined in this study (±4%) is based on the evaluations that are conducted and may still need to be adjusted based on the test procedure to be developed. In a follow-up programme focus is needed on the development of a test procedure for the FCM. For the development of the test procedure, the following issues are recommended to be addressed:

1. For the development of a test procedure for FCM it is the most efficient to build upon existing procedures. Therefore, it is recommended to investigate what existing test procedures or elements of test procedures are suitable to be used for testing FCM. Are there any other developments in other EU working groups the FCM procedure could benefit from?
2. Which (additional) test equipment is needed for the assessment on particular visual recognition, OBD/CAN logging and accuracy?
3. Could all FCM indications (instantaneous, trip average, idle, lifetime, other) be assessed in one test? Or is a sequence of tests required?
4. What external factors are of influence on the results and how can they be controlled in the test procedure?
5. How should alternative fuels like dual-fuel, flexi-fuel, CNG/LPG, electric be treated?
6. How should the information transfer from OBD/CAN of the vehicle to the measurement equipment of a type approval authority be arranged and how should the data be evaluated?

6 Literature

Braimaister, L.G., (2002). Mobiele computers in personenauto's en mogelijke effecten op de
Verkeersveiligheid. SWOV, Leidschendam

Dillon, A., Morris, M. G. (1996.) User acceptance of new information technology: theories and models. http://dlist.sir.arizona.edu/1261/

Doan, K. (2012.) NHTSA aims to create federal safety guidelines for in-car technology. Retrieved at 19th of October from http://vr-zone.com/articles/nhtsa-aims-to-create-federal-safety-guidelines-for-in-car-technology/16227.html

Govaerts, L., Verlaak, J., ECO-DRIVING in a company fleet, Final Report Belgian Pilot,
VITO, January 2003

Goede, de M. Hogema, J. Vermeulen, R. Bleuanus, S. (2010). Effects of a gearshift indicator and a fuel economy meter on fuel consumption

Horrey, W.J. & Wickens, C.D. (2006). Examining the impact of cell phone conversations on driving using a meta-analytic techniques. In: Human Factors, vol. 48, nr. 1, p. 196-205.

Jamson, A. H., & Merat, N. (2005). Surrogate in-vehicle information systems and driver behavior: Effects of visual and cognitive load in simulated rural driving. *Transportation Research Part F*: *Traffic Psychology and Behavior*, *8*(2), 79-96.

Meschtscherjakov, A., Wilfinger, D., Scherndl T., Tscheligi, M. (2009). Acceptance of Future Persuasive In-Car Interfaces Towards a More Economic Driving Behaviour. University of Salzburg

Manser, M.P., Rakauskas, M., Graving, J., Jenness, J.W. (2010). Fuel Economy Driver Interfaces: Develop Interface Recommendations (Report on Task 3). DTNH22-08-D-00115

National Highway Traffic Safety Administration. (2012.) Visual-Manual NHTSA Driver Distraction Guidelines for In-Vehicle Electronic Devices.

Reding, V. (2008). Commission recommendation of 26/V/2008 on safe and efficient in-vehicle information and communication systems. Brussels.
Update of the European Statement of Principles on Human-Machine Interface

Theeuwes, J. (2008). *Visuele afleiding in het verkeer*. Vrije Universiteit, Amsterdam.

Alessandrini, A., Filipi, F., Ortenzi, F.. Consumption calculation of vehicles using OBD data. Retrieved December 2012 from
http://www.epa.gov/ttnchie1/conference/ei20/

Reed, P. (2011) Your Fuel Economy Gauge Is Fibbing. Retrieved at 29th of March 2013 from http://www.edmunds.com/fuel-economy/your-fuel-economy-gauge-is-fibbing.html

7 Signature

Delft, 16 April 2013

Sam van Goethem	Nina Waldhauer
Author – Project Leader	Framework Contract manager

A Draft FCM requirements

Technical requirements

An overview is presented with the recommendations for the current technical requirements in Table 5.

Table 5: FCM technical requirements

TR01a	The instantaneous and idling fuel consumption data displayed shall not deviate from the real fuel consumption by more than 4 [%] during constant speed driving and idling. A constant speed is considered when a speed set point is maintained over a period of 2 seconds. *The unit could also be [miles/gallon or mpg], [kg/100km], [litre], [km/l], [Wh/km] etc. and accuracy stays 4[%].
TR01b	The trip average fuel consumption data displayed shall not deviate from the real fuel consumption by more than 4 [%] *The unit could also be [miles/gallon or mpg], [kg/100km], [litre], [km/l], [Wh/km] etc. and accuracy stays 4[%].
TR01c	Other fuel consumption data displayed e.g. week/month/lifetime average, total lifetime, shall not deviate from the real fuel consumption more than 4[%]. *The units may vary e.g. [litres], [litre/100km], [km/litre], the maximum deviation stays 4[%].
TR02a	The fuel consumption data e.g. average, instantaneous, idle, or other specified shall be available on the FC display on request of the driver under all conditions when the vehicle is driving and idling.
TR02b	The fuel consumption data e.g. average, instantaneous, idle, or other specified shall be available on the physical OBD port* under all conditions when the vehicle is driving and idling. *Implementing/adjusting it in OBD protocol could be considered. The FC signals, which represent the displayed FC functionalities, should however be available for Type Approval Authorities (TAA)

Functional requirements

In Table 6 an overview is presented with the recommendations for the current functional requirements.

Table 6: FCM functional requirements

FR01	The driver must be able to read the information displayed about fuel consumption from a regular seating position. The information displayed must be displayed close to the line of sight.
FR02	The fuel consumption display should be designed to avoid glare and reflections.
FR03	The vehicle must be equipped with an on-board device, which can display the fuel consumption described in FR04 on the drivers request. The fuel consumption display may be overruled in case of: • (road) safety emergencies; • risk of running out of fuel; • technical failures related to EOBD
FR04	Visible upon request of the driver the fuel consumptions display can switch between: • ‘instantaneous fuel consumption’ in litres/100km and automatically switching to litres/hour during idling and standstill • ‘average fuel consumption’ in litres/100km • ‘lifetime total fuel consumption’ in litres/100km
FR04a	The instantaneous fuel consumption figure [l/100km] or [l/h] presented must be refreshed as frequently as needed but not exceeding 2 sec, showing the average over the refreshed period. During idling at standstill or nearly standstill (not exceeding 5 km/h) and in case a start and stop system is absent or turned off by the driver, the instantaneous fuel consumption display automatically switches to [l/h].
FR04b	The trip average fuel consumption in litres/100km comprises the fuel consumption over the distance driven since the last manual reset with a refresh rate of maximum 10 seconds.
FR04c	The lifetime total fuel consumption in litres/100km is available upon request of the driver, this value cannot be reset and is secured in the same way the total vehicle mileage is secured.
FR05	The instantaneous, average and lifetime fuel consumption display is depicting fuel consumption in a numerical form and optional presented together with graphical or symbolic forms.
FR06	The on-board computer must display fuel consumption in [litre/100km] and idling fuel consumption [litre/hour] with a resolution of 0.1 and total lifetime fuel consumption [litre] with a resolution of 1, with enough digits to display the total amount of fuel consumed

FR07	Textual or symbolic addition of the displayed unit and time period (average trip, instantaneous, lifetime) or their internationally agreed abbreviations is required.
FR08	Internationally agreed standards relating to legibility, audibility, icons, symbols, words, acronyms and/or abbreviations should be used on FCM's.
FR09	The visual presentation of information (font sizes, luminance contrast and colour use) should be in line with: *ISO 15008 (2003): Road vehicles – ergonomic aspects of transport information and control systems – specification and compliance procedures for in-vehicle visual presentation.*
FR10	Interaction with the FCM should allow the driver to have at least one hand at the steering wheel.
FR11	The FCM should have adequate instructions in a manual for the driver covering use. This includes the description of the interaction with the FCM and an explanation on the used symbols and abbreviations.

B Dutch FCM draft requirements, Kroon

Minimum requirements for on-board computers/ fuel economy meters

Display
The on-board computer/fuel economy meter must be equipped with a display presenting fuel consumption data in analogue or digital form.

Data presentation
The on-board computer/fuel consumption meter must provide at least the following data:

1. Instantaneous fuel consumption: l/100 km;
2. Average fuel consumption: l/100 km;
3. Fuel consumption when idling: l/hour.
4. Lifetime total fuel consumption: l.

Ad 1: Instantaneous fuel consumption must be presented immediately after the vehicle starts moving.
Ad 2: Average fuel consumption must comprise the fuel used over the distance covered since the last ‘reset’ action.
Ad 3: Fuel consumption while idling must always be presented when the engine is idling.
Ad 4: Lifetime fuel consumption is displayed at the driver's request (pushing a button) either for a certain period or until deactivation by the driver. The lifetime fuel consumption cannot be reset (same level of security to be applied as for the mileage counter).

The three sorts of data presentation aforementioned may only be temporarily overruled by other sorts of data to be displayed in case of:
= (Road) safety emergencies;
= Risk of running out of fuel;
= Technical failures.

Location of the display
The display for the on-board computer/fuel consumption meter must be positioned at one of the following locations:

1. In the instrument panel of the vehicle’s dashboard;
2. In the central console;
3. In the central part of the dashboard.

Any location chosen for the display shall be above knee level of an average driver’s length.
The average driver’s length shall be derived from the regular driver’s size as actually applied by the car manufacturers.

Ad 1: When a revolution counter is present in the instrument panel, the display must be located in or immediately next to the revolution counter. When no revolution counter is present, the display must be located in or immediately next to the speedometer.

Visualisation of the display
- The driver must be able to read the information displayed about instantaneous or average fuel consumption or fuel consumption when idling easily from a regular seating position during all (meteorological) conditions.
- The instantaneous fuel consumption figure presented must vary as frequently as needed to present real values to the driver but not more frequently than every two seconds and not less frequently than every five seconds, whenever the fuel use varies during driving.

Operating the on-board computer/fuel consumption meter
The driver must be able to operate the on-board computer/fuel consumption meter easily from any regular driver's position.
Reliability of the data displayed

- The fuel consumption data displayed shall not deviate from the real fuel consumption more than 0.1 l/100 km or 0.1 l/hour.
- The presentation of the instantaneous fuel consumption may be retarded but not later than three seconds after the real fuel consumption.

C Design principles HMI

Human Machine Interface aspects for in-car systems

An intuitive design of Human Machine Interfaces (HMI's) can improve the usability and acceptance among users. Usability and acceptance tests are often carried out to evaluate the intuitiveness of HMI's. A high degree of usability and acceptance can minimize negative effects on the traffic safety (Manser et al., 2010). The European Commission has written a recommendation on safe and efficient in-vehicle information and communication systems (Reding, 2008). These guidelines take the aspects of usability, acceptance and traffic safety into account. This chapter therefore describes the aspects usability, acceptance and traffic safety applied to in-vehicle HMI's and the European guidelines. The guidelines are a starting point for the definition of functional requirements formulated in chapter 3.

Usability

The international standard ISO 9241-11 defines the principle usability as:
"The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use."

The definition is broad, because it is defined at a product level. Manser, Rakauskas, Graving and Jenness (2010) specified the definition for in-vehicle HMI's. In their study three different aspects of usability were investigated to evaluate the usability of in-vehicle fuel economy HMI's:

- Understand ability: the extent to which drivers understand the information displayed on a HMI in a short time period.
- Comprehensibility: the extent to which drivers could accurately comprehend changes in the fuel economy state.
- Usefulness: the extent to which the drivers thought the HMI was usable. This is expressed in terms of participant's ratings of usefulness and satisfaction.

The evaluation on these aspects was carried out among 16 participants. Images of fuel economy HMI's were shown to the participants, which had to answer questions to determine to which extent they understood the information displayed and state changes. These outcomes were used to determine whether drivers found different Fuel Economy Driver Interface Concepts (FEDIC) usable and valuable for improving fuel economy.
Horizontal bars or symbolic forms of fuel economy information (such as bars and iconic images) scored high on usability among participants compared to text displays. The bars or symbolic information should however be visually simple. For instance multiple bins representing continually-updating five minute intervals spanning the last hour were considered too visually complex. These designs were scored high by the participants on the statement "I think this component is difficult to figure out.".
According to Manser et al. (2010), text representations should still remain a viable consideration for FEDIC design, because a display featuring representative information could easily include text to further improve comprehension.

Acceptance
Several definitions of acceptance can be found. Dillon and Morris (1996) defined acceptance with regard to information technology systems as:
"The demonstrable willingness within a user group to employ information technology for the tasks it is designed to support."

Meschtscherjakov, Wilfinger, Scherndl and Tscheligi (2009) evaluated five different in-car *persuasive interfaces*. These interfaces should persuade drivers to drive in a more economical way. The interfaces were evaluated on acceptance by three aspects:

1. the behavioural intention to use,
2. the perceived usefulness and
3. the perceived ease of use.

The Eco Speedo-meter (based on Honda's Ambient Meter) was rated the highest on user acceptance. This system provides the driver with non-compulsory visual advices. Participants stated that they felt disturbed by other systems which provide the user with tactile and/or auditory feedback. Auditory feedback was often compared to the 'nagging' of a passenger in their car (Meschtscherjakov et al., 2009). The auditive feedback was in all cases corrective or punitive, the effect of positive or complimenting auditive feedback was not evaluated and is also less studied in general.

Safety
The effect of in-vehicle telematics applications on the traffic safety is a much discussed topic. A quantified effect of these applications on accidents is not available. There is however an indication, based on empirical research, that 1.3% of all accidents could be directly related to the manual operation of for instance the car radio, air-conditioning or mobile phone (Braimaister, 2002). More recently, a study carried out by the NHTSA (2012) showed that in 2010 5% of the accidents caused by distraction were 'distraction-related crashes involving an electronic device'.

According to Jamson and Marat (2005) an increased visual complexity of in-vehicle displays produces unsafe driving behaviour such as slower driving reaction time to objects on the road, decreased minimum time-to-contact and a greater frequency of steering corrections. The driving simulator study of Manser et al. (2010) showed that participants made more glances away from the road when FEDIC displays were present, which indicates that there are potential safety implications due to FEDIC use.

A general rule of the thumb is that drivers should not be distracted by in-vehicle applications for more than 2 seconds. According to Theeuwes (2008) the visual distraction of an in-car application should not last longer than 1.6 seconds. Horrey and Wickens (2007) carried out a driving simulation experiment, which showed that 80% of the driving simulator accidents could be accounted to a visual distraction of more than 1.6 seconds.

Design principles of in-vehicle systems
Guidelines have been developed to maximize the usability, acceptance and to minimize negative effects on the traffic safety. Currently, there are European guidelines about the design of in-vehicle systems (Reding, 2008), which the

automobile manufactures already use. The National Highway Traffic Safety Administration (NHTSA) has also set national distracted-driving guidelines for automobile manufacturers (Doan, 2012).

The European guidelines and NHTSA draft guidelines use five overall design principles:

1. The system supports the driver and does not give rise to potentially hazardous behaviour by the driver or other road users.
2. The allocation of driver attention while interacting with system displays and controls remains compatible with the attention demand of the driving situation.
3. The system does not distract or visually entertain the driver.
4. The system does not present information to the driver which results in potentially hazardous behaviour by the driver or other road users.
5. Interfaces and interface with systems intended to be used in combination by the driver while the vehicle is in motion are consistent and compatible.

The design principles are further specified in 28 specific principles (shown in Appendix B) in five categories. The five categories of principles are shortly summarized below.

1. Installation principles: The in-car system should
   - not block the view of road scene or vehicle controls;
   - but should be located close to the line of sight;
   - Be designed to avoid glare and reflections.
2. Information presentation principles: The information presented on the system should:
   - be assimilated with a few glances by the driver;
   - use (inter)nationally agreed standards;
   - provide accurate information in a timely manner;
   - give information with a higher safety relevance a higher priority;
   - not mask audible warnings by system generated sounds.

3. Interactions with displays / controls: The system should:
   - allow the driver to have one hand at the steering wheel;
   - not require long and uninterruptible sequences of manual-visual interface;
   - not require time-critical responses;
   - be able to operate without adverse impact on the primary driving controls;
   - allow the driver to control the loudness auditory information;
   - give response which is timely and clearly perceptible;
   - be capable of being switched from providing non-safety-related dynamic visual information should be capable to a mode where that information is not provided to the driver.

4. System behaviour principles: The system should:
   - automatically disable any visual information not related to driving, when the car is in motion;
   - not adversely interfere with displays or controls required for the primary driving task and road safety;
   - disable functions not intended to use by the driver while driving or, as less preferred option, clear warnings against the unintended use should be provided;

- present information about the current status and any malfunction within the system that is likely to have an impact on safety.

5. Principles on information about the system: The system should have:
   - adequate instructions;
   - instructions which are correct and simple;
   - instructions in languages or forms designed to be understood by the intended group of drivers;
   - instructions which state which functions are intended for use by the driver;
   - product information designed to accurately convey the system functionality;
   - product information which clarify if special skills are required to use the system as intended by the manufacturer or if the product is unsuitable for particular users.
   -

Installation Principles

Principle 1.1: The system should be located and fitted in accordance with relevant regulations, standards, and the vehicle and component manufacturers' instructions for installing the systems in vehicles.

Principle 1.2: No part of the system should obstruct the driver's field of the road scene.

Principle 1.3: The system should not obstruct any vehicle controls and displays required for the driving task.

Principle 1.4: Visual should be positioned as close as practicable to the driver's normal line of sight.

Principle 1.5: Visual displays should be designed and installed to avoid glare and reflections.

Information Presentation Principles

Principle 2.1: Visually displayed information presented at any one time by the system should be designed in such a way that the driver is able to assimilate the relevant information with a few glances which are brief enough not to adversely affect driving.

Principle 2.2: Internationally and/or nationally agreed standards relating to legibility, audibility, icons, symbols, words, acronyms and/or abbreviations should be used.

Principle 2.3: Information relevant to the driving task should be accurate and provided in a timely manner.

Principle 2.4: Information with higher safety relevance should be given higher priority.

Principle 2.5: System-generated sounds, with sound levels that cannot be controlled by the driver, should not mask audible warnings from within the vehicle or the outside.

Principles on Interactions with Displays/Controls
Principle 3.1: The driver should always be able to keep at least one hand on the steering wheel while interacting with the system.

Principle 3.2: The system should not require long and uninterruptible sequences of manual-visual interface. If the sequence is short, it may be uninterruptible.

Principle 3.3: The driver should be able to resume an interrupted sequence of interface with the system at the point of interruption or at another logical point.

Principle 3.4: The driver should be able to control the pace of interface with the system. In particular the system should not require the driver to make time-critical responses when providing input to the system.

Principle 3.5: System controls should be designed in such a way that they can be operated without adverse impact on the primary driving controls.

Principle 3.6: The driver should have control of the loudness of auditory information where there is likelihood of distraction.

Principle 3.7: The system's response (e.g. feedback, confirmation) following driver input should be timely and clearly perceptible.

Principle 3.8: Systems providing non-safety-related dynamic visual information should be capable of being switched to a mode where that information is not provided to the driver.

System Behaviour Principles
Principle 4.1: While the vehicle is in motion, visual information not related to driving that is likely to distract the driver significantly should be automatically disabled, or presented in such a way that the driver cannot see it.

Principle 4.2: The behaviour of the system should not adversely interfere with displays or controls required for the primary driving task and for road safety.

Principle 4.3: System functions not intended to be used by the driver while driving should be made impossible to interact with while the vehicle is in motion, or, as a less preferred option, clear warnings should be provided against the unintended use.

Principle 4.4: Information should be presented to the driver about current status and any malfunction within the system that is likely to have an impact on safety.

Principles on Information about the System
Principle 5.1: The system should have adequate instructions for the driver covering use and relevant aspects of installation and maintenance.

Principle 5.2: System instructions should be correct and simple.

Principle 5.3: System instructions should be in languages or forms designed to be understood by the intended group of drivers.

Principle 5.4: The instructions should clearly state which functions of the system are intended to be used by the driver while driving and those which are not.

Principle 5.5: Product information should be designed to accurately convey the system functionality.

Principle 5.6: Product information should make it clear if special skills are required to use the system as intended by the manufacturer or if the product is unsuitable for particular users.

D FCM stakeholder questionnaire

HUMAN MACHINE INTERACTION QUESTIONS

1. What are the key aspects of the current HMI design process for in-vehicle technology?
2. What principles are used when designing in-vehicle systems.
   a. HMI principles?
   b. Guidelines? (e.g. the Commission Recommendation of 26/V/2008 on safe and efficient in-vehicle information and communication systems: Update of the European Statement of Principles on Human-Machine Interface)
3. Can you give us an overview of the systems that already exist in your current vehicles? We would like to now:

Segments	'Mini' Vehicle:….. Example: Smart fortwo, Fiat Panda, Citroën C1	'Small' Vehicle:….. Example: VW Polo, Mini Cooper, Fiat Punto	'Lower medium' Vehicle:….. Example: VW Golf, Audi A3, Volvo C30, Alfa Romeo 147	'Medium' Vehicle:….. Example: BMW 3-series, Mercedes-Benz C-Class, Audi A4, VW Passat
Where is the display located in the car				
Is it analog or digital				
Sizes (of the display, of the digits on the display etc.)				
Is the FC information directly available after starting the vehicle or are there more actions needed (pressing a button e.g.)?				
What is the refresh rate of the FCM values? (instantaneous and average FC)				
Other				

4. Have you performed research into influencing drivers to driver more economically? What were your conclusions?
   a. Did you use information about fuel consumption in this research?
5. Have you performed research on safety related aspects (like driver work load, distraction) concerning in vehicle information systems? What were your conclusions?
   a. Did you include FC information in this research?
6. Have you performed research on how to provide in an most efficient manner necessary information to the driver? What were your conclusions?
   a. Did you include FC information in this research?
7. What functional requirements are desirable and should be included into future legislation?
8. Which existing literature, data or experiences can you share with TNO?

FUEL CONSUMPTION METER QUESTIONS

1. How many percent of the total vehicle production sold in the EU are supplied with:
    a. FCM as a standard feature?
    b. FCM as an option?
2. How does this distribution (percent of total vehicle production sold in the EU with standard FCM or option) look like for the different vehicle segments? (mini, small, lower medium, medium, upper medium, luxury, sport, van, suv/off road, others)
3. Can you give us an overview of the differences between systems that are available among different vehicle segments?

	'Mini' Vehicle: Example: Smart fortwo, Fiat Panda, Citroën C1	'Small' Vehicle: Example: VW Polo, Mini Cooper, Fiat Punto	'Lower medium' Vehicle: Example: VW Golf, Audi A3, Volvo C30, Alfa Romeo 147	'Medium' Vehicle Example: BMW 3-series, Mercedes-Benz C-Class, Audi A4, VW Passat
What is displayed to the driver (FCM and other types of feedback):	*yes/no, comment*	*yes/no, comment*	*yes/no, comment*	*yes/no, comment*
l/100km (actual, on seconds basis)				
km/l (actual on seconds basis)				
l/100km (trip average)				
km/l (trip average)				
l/h (idle fuel consumption)				
liters (trip consumptions)				
liters (total over lifetime)				
other				
Which data do current FCMs use for the estimation of fuel consumption?	*yes/no, comment*	*yes/no, comment*	*yes/no, comment*	*yes/no, comment*
Maps (based on e.g. engine speed,				
load, throttle position etc.)				
Commanded injection quantity				
Intake air flow, manifold pressure				
Lambda sensor signal				
Vehicle speed				
Other				

4. What is the accuracy of the currently used FCMs for the measuring the instantaneous/average fuel consumption (l/100km, km/l, l/h)?
5. How do you test and validate these FCM values?
6. Do you have data which demonstrates these accuracies?

7. Which parameters may have an influence on this accuracy?
8. How much influence has each of those parameters on the total accuracy?
9. What is the frequency of the fuel consumption measurement(s)?
10. What accuracy of fuel consumption measurements (l/100km, km/l, l/h) do you consider feasible?
11. Is there a difference in calculation for different fuels? *(please describe the differences per fuel)* Gasoline? Diesel? Other?
12. Are these calculations available for TNO? (yes/no)

OTHER

1. Are there vehicle types/engine types which cannot be supplied with a FCM? If not, why?
2. Is there in that case still a provision in the calculation module (like engine electronic computational unit) that determines/calculates fuel consumption related signals
3. How and where is the data concerning the fuel consumption averages and total fuel consumption stored?
4. Is this information protected against manipulation?
5. Is it possible to provide Fuel Consumption Meter information in current production models via OBD/CAN bus?
6. During the project, up to three measurements with a vehicle on a chassis dynamometer are foreseen. Are you willing to provide FCM information on OBD/CAN bus during the project (PID, dbc files etc.)?