Directives for new-generation Fuel Economy Devices

Project Modern Drive Devices

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Summary

In the Netherlands, Novem (the Netherlands Agency for Energy and the Environment) has gained a lot of experience and results in the area of fuel saving in-vehicle devices. In the last decade field experiments have been carried out with econometers, on-board computers, cruise controls and speed and revolution limiters. Some of these feedback devices, however, have become more or less obsolete.

Therefore, the University of Twente developed a new fuel-efficiency support tool: if actual driving behaviour deviates from an optimal fuel-efficient behaviour, detailed advice is presented to the driver on how to change driving behaviour in order to minimise fuel consumption. A recently carried out field experiment, co-financed by Novem, with the new fuel-efficiency support tool revealed that car drivers were able to reduce fuel consumption by 11% on average due to the support tool (Van der Voort, 2001).

Recently, in the Netherlands, there seems to be a growing demand for reliable feedback and registration devices. Many driving schools, for example, want to be able to make a good trip analysis on driving style and fuel consumption. The demand is likely to grow further in the near future because of the promoting activities of The New Driving Force programme (Het Nieuwe Rijden). As part of the programme amongst others all Dutch driving instructors and examiners will be trained in practising the driving style of TNDF and also in teaching it to their pupils.

This has urged parties in the Netherlands and in Germany to take the first step in developing new-generation 'plug-and-play' devices, so called Modern Drive Devices (MDD). MDD stands for a concept of a fuel economy device that consists of the following features:

- It is a plug-and-play system, which implies that it can be installed in the existing fleet rather easily;
- It can register several variables like fuel consumption, CO_2-emission, aspects of the driving style and distance travelled;
- The performance values of these variables can be presented on a PDA display (e.g. Palm display) in the vehicle;
- The PDA can be taken out to edit or analyse the data in more detail afterwards on a PC by means of a specially designed software package.

At the request of Novem, the Centre for Transport Studies of the University of Twente in the Netherlands has conducted a study on the MDD-concept.

The objective of this study was initially threefold:

1. Elaborate and assess the MDD-concept;
2. Test MDD-prototypes with respect to technical functionality and performance and accordance with specifications;
3. Assess the MDD-prototypes with respect to user-friendliness and overall performance during a large-scale field trial.

In order to achieve the objective, interviews with several distinguished user groups (i.e. driving instructors, private car drivers and fleet owners) have been held to elaborate and assess the MDD-concept. After this specification phase, three MDD-prototypes were manufactured, according to the specifications formulated, and tested in two testing vehicles. Because of several (severe) shortcomings revealed during this testing phase, it was not advisable to perform the large-scale field trial with the momentarily available MDD-version. Instead, the specification and test results of the MDD-concept were generalised in order to formulate directives for new-generation fuel economy devices. The directives distinguish

between in-vehicle devices with and without data storage capacity. In addition, directives for new-generation fuel economy software packages are being given.

Regarding the directives formulated it should be noted that the directives do not give detailed technical solutions, extensive development strategies or ready-to use algorithms and thresholds. The directives formulated do not form blueprints for successful development and market introduction. The directives do, however, provide important preconditions that have to be met in order to develop an adequate fuel economy device.

1 Introduction

In the Netherlands, Novem (the Netherlands Agency for Energy and the Environment) has gained a lot of experience and results in the area of fuel saving in-vehicle devices. In the last decade field experiments have been carried out with econometers, on-board computers, cruise controls and speed and revolution limiters. Some of these feedback devices, however, have become more or less obsolete.

Therefore, the University of Twente developed a new fuel-efficiency support tool: if actual driving behaviour deviates from an optimal fuel-efficient behaviour, detailed advice is presented to the driver on how to change driving behaviour in order to minimise fuel consumption. A recently carried out field experiment, co-financed by Novem, with the new fuel-efficiency support tool revealed that car drivers were able to reduce fuel consumption by 11% on average due to the support tool (Van der Voort, 2001).

Recently in the Netherlands, there seems to be a growing demand for reliable feedback and registration devices. Many driving schools, for example, want to be able to make a good trip analysis on driving style and fuel consumption. The demand is likely to grow further in the near future because of the promoting activities of The New Driving Force programme (TNDF. Dutch: ‘Het Nieuwe Rijden’). As part of the programme amongst others all Dutch driving instructors and examiners will be trained in practising the driving style of TNDF and also in teaching it to their pupils.

This result has urged parties in the Netherlands and in Germany to take the first step in developing new-generation ‘plug-and-play’ devices, so called Modern Drive Devices (MDD). The problem with existing equipment for retrofit purposes is that it is either obsolete, has limited or no possibilities of registration and is mostly only suitable for petrol-vehicles. Furthermore, fitting in this equipment in vehicles costs a lot of time and money. The MDD-concept is based on the principles of easy-to-use and easy-to-fit in (at low costs) in current fleet of vehicles. And moreover, the MDD-concept will be suitable for petrol-, L.P.G.- and diesel-vehicles. The MDD-concept provides drivers and fleet owners with feedback on driving behaviour and therefore stimulates an energy-efficient driving style.

At the request of Novem, the Centre for Transport Studies of the University of Twente in the Netherlands conducted a study on the MDD-concept. The study consisted of three stages addressing the following objectives:

1. Elaborate and assess the MDD-concept;
2. Test MDD-prototypes with respect to technical functionality and performance and accordance with specifications;
3. Assess the MDD-prototypes with respect to user-friendliness and overall performance during a large-scale field trial.

In order to elaborate and assess the MDD-concept, interviews and panel discussions with driving instructors, private car drivers and fleet owners have been held. As a result of these interviews specifications for the MDD were formulated. To test the MDD, three prototypes of the MDD, in accordance with the specifications formulated, were fitted into two vehicles in order to assess the technical functionality and performance. Because of several (severe) shortcomings revealed during the testing phase, it was not advisable to perform the large-scale field trial with the momentarily available MDD-version. Instead, the specification and test results of the MDD-concept were generalised in order to formulate directives for new-generation fuel economy devices.

In chapter 2 the method used in the study is explained. In this chapter the MDD-concept is clarified as well. Chapter 3 contains the approach and results of the elaboration and assessment part of this study. The approach and outcome of testing the MDD-prototypes and the advisability of performing a large field trial is described in Chapter 4. The directives for the development of a fuel economy device based on the outcome of the specification and testing phases can be found in Chapter 5. Chapter 6 contains general conclusions.

2 Method

In order to achieve the objective of this study on the MDD-concept the following method was used. To elaborate and assess the MDD-concept, interviews and panel discussions with driving instructors, private car drivers and fleet owners have been held with respect to their preferences. To test the technical functionality and performance, three prototypes of the MDD-concept were developed in accordance with the specifications. Two identical vehicles were equipped with the prototypes, and were put through severe tests. The outcome of the interviews, panel discussions and the testing are used to formulate general directives for fuel economy devices.

MDD stands for a concept of a fuel economy device that consists of the following features:

- It is a plug-and-play system, which implies that it can be installed in the existing fleet rather easily;
- It can register several variables like fuel consumption, CO_2-emission, aspects of the driving style and distance travelled;
- The performance values of these variables can be presented on a PDA display (e.g. Palm display) in the vehicle;
- The PDA can be taken out to edit or analyse the data afterwards on a PC in more detail by means of a specially designed software package.

Figure 1 illustrates the MDD-concept.

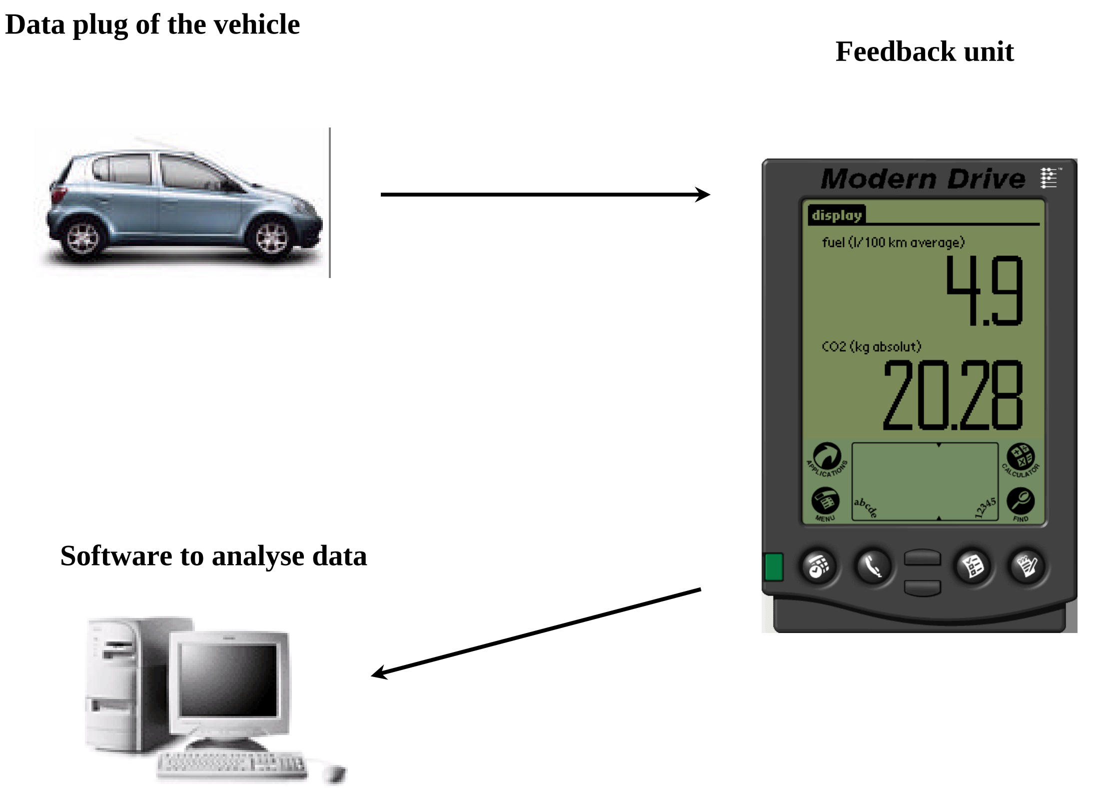

Figure 1. MDD-concept

3 Specification phase

3.1 Approach

The specification phase was conducted in order to investigate the preferences of several user groups with respect to the feedback unit and the software package of the MDD-concept. Representatives of the following distinguished user groups have been interviewed (number of representatives is in parenthesis):

- Instructors of advanced driver training courses (5);
- Instructors of driving school curricula (17);
- Private car drivers (31);
- Fleet owners (12):
  - Business car drivers (3);
  - Service companies (3);
  - Courier companies (3);
  - Lease companies (3).

A literature study was performed to make an inventory of existing fuel economy devices and directives with respect to user interfaces for in-vehicle systems and software packages (Van der Voort et al., 2002). To a large extent, the questionnaire for the interviews has been formulated on the basis of this literature study. Respondents were asked for their appreciation of the MDD-concept in terms of usefulness and appeal. Furthermore, the completion of the MDD-concept was investigated. For example by asking what sort of information is wanted on the display and in the software package, what units of information are desired and which presentation forms could be used best on the display (e.g. digital numbers) and in the software package (e.g. tables and graphs).

The Traffic Safety Centre Rozendom (VVCR) supported this part of the survey by recruiting and selecting the representatives of the user groups and arranging the appointments for the interviews. Private car drivers were recruited from advanced driver training courses. The interviews with private car drivers and a part of the instructors of driving school curricula were conducted as panel discussions. The discussions took place consistent with the questions that were asked during the face-to-face interviews with representatives of the other user groups.

3.2 Results

On the basis of the interviews with representatives of the user groups, specifications for the MDD-concept and the accompanying software package were formulated (see also Van der Voort et al., 2002). In general, the user groups find the MDD-concept to some extent useful and appealing. This goes especially for instructors and fleet owners of courier companies. The MDD-concept is appreciated less by private car drivers and fleet owners of other types of companies. Figure 2 shows the appreciation of the concept with respect to usefulness and appeal. The appreciation was deducted from a questionnaire as a rating on –2 to 2 rating scales. Usefulness was determined by asking representatives their opinion on 5 items (useful-useless, good-bad, effective-superfluous, assisting-worthless and raising alertness-sleep inducing) according to the procedure by Van der Laan et al (1997). Appeal was determined by averaging the ratings with respect to four items (pleasant-unpleasant, nice-annoying, likeable-irritating and desirable-undesirable).

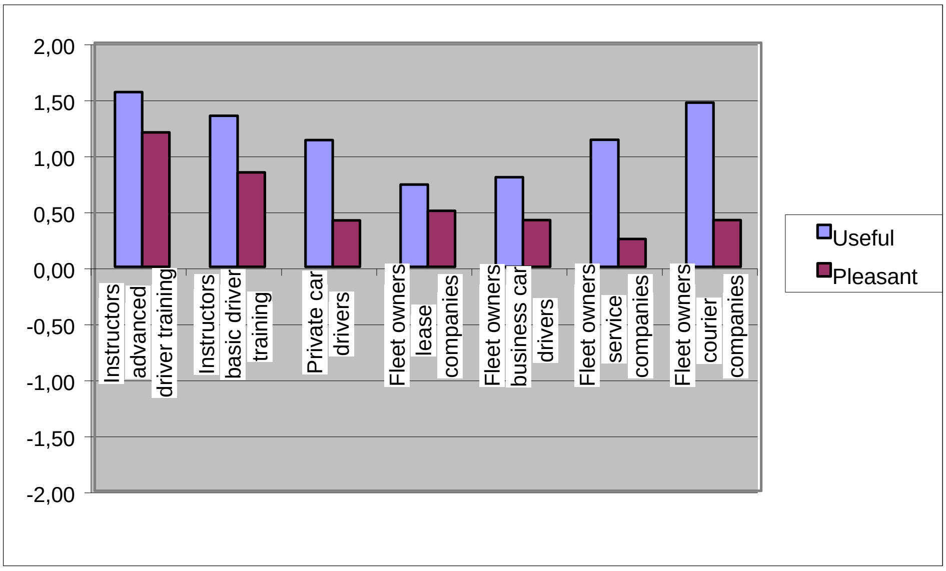

Figure 2. Appreciation of the MDD-concept

Specifications for the MDD-concept

Specifications were formulated for each user group separately at first. After that, the specifications were matched in order to trace the extent of similarity in the preferences of different user groups concerning the MDD-concept and the software package. In consideration of costs, the production of a fuel economy device that meets the preferences of several user groups is preferable to the production of specific devices for each of the distinguished user groups.

It appears that not all user groups have similar preferences regarding the information displayed by the MDD-concept. Each group wants information about fuel consumption and basic characteristics of the driving style. However, driving instructors prefer more detailed aspects of driving style to be presented on the display. Instructors of advanced driver training courses and private car users are interested in CO_2-emission and distance travelled as well. However, it should be noted that the specification for the latter user group could be biased, since all private car drivers were recruited from advanced driver training courses and are therefore more likely to have an interest in the effects of their driving style.

Based on the preferences of the distinguished user groups, three different types of the MDD-concept have been formulated. It should be noted that if other user groups are assumed, other types of the MDD-concept could possibly be identified. Specifications for the MDD-concept based on the distinguished user groups are listed below.

The general specifications that apply to the MDD-concept are:

- Fuel economy devices like the MDD-concept should be suitable for vehicles that run on petrol, L.P.G. (liquid gas) or diesel;
- All information should be presented in 1 decimal;
- Driving instructors prefer a swivelling, lighted and for both the trainee and the instructor visible device that, for example, can be fixed to the windscreen;
- The other user groups prefer a device with multiple functions (e.g. combined with route navigation) that can be integrated in the dashboard;
- Possibility to switch between different kinds of information should be present;
- Possibility to turn off the interface should be present;
- Data recording should continue if the motor breaks down accidentally (especially for driving school curricula);
- Recorded data should be saved and stored after ending a trip (i.e. turning off the engine);

- Considering standard in-vehicle systems, there is no wish for duplicate information. An exception is information about speed, because users expect that the value given by the MDD-concept is more accurate than the value given by the speedometer. If no revolution counter is present in the vehicle, driving instructors and private car drivers indicate that this information should be displayed by the MDD-concept.

Table I shows the specifications of each of the three types of the MDD-concept formulated. Type I represents the MDD-concept according to the preferences of fleet owners of business car drivers, service companies and courier companies. Type II represents the MDD-concept according to the preferences of instructors of advanced driver training, private car drivers and fleet owners of lease companies. Finally, Type III represents the MDD-concept according to preferences of instructors of driving school curricula.

Table I: Specifications of the three types of MDD-concept

Specifications	Type I	Type II	Type III
Information about:			
• **Fuel consumption**			
o L/100 km	?	?	?
o Km/l	?	?	?
o L		?	
• **Driving style**			
o Speed		?	?
o Revolutions		?	?
o Acceleration			?
o # too fast accelerations	?	?	?
o # too hard decelerations	?	?	?
o # long idling periods	?	?	?
• **CO_2 emission**			
o g/km		?	
• **Distance travelled**			
o Km		?	?
Presentation of information:			
• **Values**			
o Analogue			
o Digital	?	?	?
• **Timing**			
o Current/total values during driving of:			
▪ Fuel consumption	?	?	?
▪ Driving style	?	?	?
▪ CO_2 emission		?	
▪ Distance		?	
o Average/total values after driving of:			
▪ Fuel consumption	?	?	?
▪ Driving style	? (speed)	? (speed)	?
▪ CO_2 emission			
▪ Distance	?	?	?

Specifications for the software package

With respect to specifications of a software package that can be used to analyse data generated by the MDD-concept afterwards on a PC, different types can be distinguished as well. Preferences among the user groups differ from each other regarding (units of) sorts of information wanted and the time scale presented in the software package. Most fleet owners prefer information about fuel consumption and driving style only, while driving instructors and private car drivers want information about CO_2-emission and distance as well. Compared with private car drivers, driving instructors indicate that the software package should present more detailed aspects of the driving style. With respect to the time scale, driving instructors are merely interested in trip values, whereas the other user groups additionally demand for aggregated values over longer time scales (e.g. week, month) depending on personal preferences.

Based on the preferences of these user groups in particular, three different types of the software package can be formulated. Again it should be noted that if other user groups are assumed, other types of the software package could possibly be identified. In general, the following specifications apply to the software packages:

- Data generated by the MDD-concept can be analysed by means of Excel;
- All information should be presented in 1 decimal;
- Possibility to display more than one kind of information in a graph should be present;
- Most user groups give preference to automatically loading of information to PC (radiographic instead of using a Palm). Some respondents indicated that they only wish for a software package if the data is loaded automatically to their PC;
- Possibility to make comparisons between trips, persons and vehicles should be present.

Table II shows the three different types of software packages that have been formulated. Type I represents the software package according to preferences of private car drivers and fleet owners of service companies. Type II represents the software package according to preferences of fleet owners of lease companies, business car drivers and courier companies. The software package according to instructors of advanced driver training courses and driving school curricula is represented by Type III.

3.3 Conclusions

Driving instructors and fleet owners of courier companies value the MDD-concept most. It is appreciated less by private car drivers and fleet owners of other types of companies. It appears that not all user groups have similar preferences for the information presented on the MDD-display and in the accompanying software package. Considering the costs involved, it is preferable to produce fuel economy devices that meet the preferences of more than one user group. With respect to the preferences of the user groups distinguished in this qualitative survey, three types of the MDD-concept as well as three types of the software package are identified. Generally, these types differ from each other regarding kind of information, units of information and time scale (e.g. trip values, aggregated values on a week or month) presented.

Table II: Specifications of the three types of software packages

Specifications	Type I	Type II	Type III
Information about:			
• **Fuel consumption**			
o L/100 km	?	?	?
o Km/l	?	?	?
o Effective saving[1]		?	?
• **Driving style**			
o Speed	?	?	?
o Time driven in gear X			?
o Acceleration	?		?
o # too fast accelerations	?	?	?
o # too hard decelerations	?	?	?
o # long idling periods		?	?
• **CO_2 emission**			
o g/km		?	?
• **Distance travelled**			
o Km		?	?
Presentation of information:			
• **Form**			
o Digital (e.g. table)	?	?	?
o Diagram			
• Possibility to display fuel consumption in a graph (course of time)		?	
• Possibility to display time driven in gear X in a pie chart			?
• **Time scale**			
o Trip values	?	?	?
o Aggregated on longer scales (e.g. week, month)	?	?	
• Possibility to display average/total values of trips or other time scales in 1 graph (course of time)	?	?	?
• Possibility to make comparisons between self-indicated time scales	?	?	

[1] Effective saving represents the reduction in fuel consumption as a percentage of the total amount of fuel that *could have been* saved.

4 Testing phase

4.1 Approach

The testing phase was conducted in order to test three MDD-prototypes, developed by Modern Drive Technology, with respect to their technical functionality and performance and correspondence with the specifications formulated during the testing phase. The test results are presented over two testing periods, which were conducted during different development stages of the MDD-prototypes.

Two Opel Astras were used as test vehicles. A Palm hand held computer was used as vehicle-user interface. The vehicles were tested in several driving situations, amongst others cruising, accelerating, idling, driving backwards and driving in a state of fuel supply closing. During the testing periods, the technical performance of the MDD-prototypes was judged with respect to:

- Accuracy and reliability of the measurements and displayed values;
- Correspondence with the specifications formulated during the specification phase.

Besides testing the in-vehicle part of the MDD, the accompanying software package for analysing data on a PC afterwards was tested with respect to:

- Correctness of the analysis and display of data;
- Correspondence with specifications formulated during the specification phase.

4.2 Results

The in-vehicle MDD-prototypes satisfy nearly all specifications formulated during the specification phase. However, the testing phase revealed problems with respect to the technical performance. These problems are summarized into four categories: universal implementation in vehicles, hardware, data measuring and software.

Universal implementation

During the installation of the MDD in the test vehicles problems with respect to universal implementation were revealed. Reading out the CAN-bus, the MDD main data source, interpreting the different signals of the CAN-bus, installing additional hardware to measure variables not measured by the CAN-bus etc., revealed to give more problems than expected, which made installing the MDD difficult.

In an ideal situation all measurements can be obtained by reading out the CAN-bus. However, as became obvious during testing, CAN-bus systems of some vehicles cannot provide all necessary data and additional systems are needed to provide the MDD with data. As a result, the MDD should be provided with additional hardware to be able to handle data provided by systems other than the CAN-bus. The developed MDD-prototype is equipped with all the necessary hardware (irrespective of the need for additional hardware); the hardware of the developed MDD-prototype is therefore suitable for every vehicle (universal).

However, the software included in the in-vehicle MDD will not be universal. Each vehicle has a different CAN-bus “protocol structure” and this structure must be implemented in the MDD in order to read out and interpret the data. In addition, each vehicle has different CAN-bus “identifiers”, etc. This problem does not only occur when looking at different vehicle brands or types (i.e. gasoline, diesel or L.P.G.). Even vehicles from the same brand and type, but with different year/location of manufacturing are not always equipped with resembling CAN-bus protocols. Therefore the MDD will need to be adapted for each vehicle in order to function correctly. Although it is expected that the MDD will work accordingly in any vehicle, this cannot be guaranteed based on the testing that is performed in this project.

Hardware

This category contains findings with respect to the used in-vehicle hardware (Palm). The findings relate to shortcomings of the Palm selected, limitations in power supply and data storage capacity:

- The vehicle-user interface of the MDD, the Palm hand-held computer, was fixated to the windscreen by means of a standard Palm windscreen fixation accessory. This turned out to be a *defective fixation*; the Palm set was trembling during driving.
- The *limited size of the Palm display* causes readability problems with respect to the small text clarifying the measurement values;
- Shortcomings of the Palm with respect to *illumination* of the interface cause inability to read the display in dark situations;
- *Undistinguishable start and stop buttons* for data storage complicate operating the Palm;
- Comprehensive data measurement and laborious data compression imply that the user of the MDD will be frequently confronted with the *limitations of the Palm storage capacity*. The Palm's memory capacity was 8 MB, which corresponds with roughly 16 hours of driving. This means that MDD users are obliged to (dependent on vehicle use) transfer stored data from the Palm to a PC frequently;
- The power for the tested vehicle user interface (Palm) is supplied by 2 not in-vehicle rechargeable batteries, which provide the Palm with energy for approximately 12 to 16 hours of driving, which is corresponding with the data storage capacity;

Data measuring

With respect to data measuring, tests with the MDD-prototypes revealed that:

- Defining thresholds and algorithms correctly and accurately is essential, because quality of processing and displaying measurements is strongly dependent on the correctness and accuracy of used thresholds and algorithms. Problems with respect to the inaccurate measuring and displaying of amongst others the number of too fast accelerations, the number of too hard decelerations and the number of gear changings, were directly caused by *use of incorrect and inaccurate thresholds and algorithms* (i.e. too low/high);
- The different measurement and display frequencies used in the MDD cause *problems regarding the aggregation of data*. The MDD's measurement frequencies (250 ms) differ from the display frequencies (500 ms) and storage frequencies (1000 ms). This means that four measured values are aggregated into two displayed values and one stored value. As a result, measured data, displayed data and stored data are not corresponding;
- The automatic *stop of data measurement failed*. Data sets show that although the engine was shut off, data recording still continued and affected averages of amongst others speed. This emphasizes the importance of clear-cut rules for automatic start and stop of data recording. For instance, improper engine halt of 10 seconds or less should not cause data recording to stop.

Software

Testing the prototypes of the software package, used to analyse data generated by the MDD on a PC afterwards, revealed that the software packages display values in accordance with the values displayed by the in-vehicle Palm computer. The recorded data are also analysed correctly by all three software packages. However:

- The prototypes of the software packages *deviate from the specifications* formulated with respect to:
  - Presentation of information as digital numbers (in a table): only partial present;
  - Presentation of information in 1 decimal: not the case;
  - Aggregated values on longer time scales (e.g. week, month): not present;

    - Possibility to display the average or total values of trips or other time scales in 1 graph (course of time): not present;
    - Possibility to make comparisons between time scales longer than a trip: not present.
- The software packages are *not in all respects user-friendly*. For example, it is not immediately clear how to display recorded data in a table or graph; it is not possible to load more than 10 trips in the software packages and no ‘Help’ function nor a manual do exist. In addition, users have to edit the ‘ini’-file themselves in order to set language.

4.3 Advisability of an evaluation phase

Depending on the outcome of the testing phase a third (evaluation) phase will be added consisting of a large field trial during which the MDD will be assessed with respect to its user-friendliness and overall performance. However, the testing phase revealed that the MDD-prototypes of both the in-vehicle part as well as the software packages still contained several (severe) shortcomings. These shortcomings are of such nature that they can not easily and rapidly be solved and are very likely to affect the assessment with respect to user-friendliness and overall performance. Therefore, it is not advisable to perform a large-scale field trial with the momentarily available MDD-version.

5 Specification directives for fuel economy devices

The outcome of the specification of the MDD-concept and the testing of the MDD-prototypes is generalised in order to come to directives for (the development of) fuel economy devices.
A distinction is being made between directives for an in-vehicle device and directives for data storage and software packages.

The distinction is being made because data evaluation after driving consequently implies the possibility of data storage during driving. Therefore, the objectives of the device have to be kept in mind during development, i.e. are data storage possibilities desired or not? Points of interest are the possibilities to use a software package and the amount of data that has to be stored, which is proportional to driving time.

5.1 Directives for in-vehicle devices

The directives for in-vehicle devices are summarized into 4 categories: system, ergonomics, information and presentation related directives.

System related

- Liability and warranty problems may reveal when a device breaks into existing in-vehicle systems, like the CAN-bus network protocol structure. Possible (negative) interference of the system with existing (important) in-vehicle systems should be prevented at all time. Existing in-vehicle systems like the CAN-bus network protocol should therefore be as less as possible tampered with.
- The fuel economy device should be fitted in in such a way that it is universal or easily adaptable. A fuel economy device should be universal to overcome problems with respect to:
    - Different vehicle brands and types;
    - Different fuels (petrol, L.P.G., diesel);
    - Different types of engines and motor management systems (a.o. hybrid, turbo-charged, GDI-direct injection, variable valve timing).
- The in-vehicle device should have the possibility to be integrated with other functionalities, in order to prevent a jumble of in-vehicle systems in a vehicle (e.g. route navigation systems, kilometre registration for commercial drivers, GSM-applications). The possibility to provide or extend the device with additional functions is likely to increase market potential.
- The in-vehicle device should have adequate power supply capacity in order to record data during a longer time period. Systems that make use of the internal power supply of the vehicle or systems that can be recharged during driving are preferred;
- The in-vehicle device should have adequate data storage capacity as well in order to record data during a longer time period.

Ergonomics related

- The display of the fuel economy device should meet the following general demands:
    - Good visibility (non-reflecting display with readable text and numbers);
    - Illuminated display (when necessary);
    - Possibility to turn off.

- The display should not block the (co-)driver's sight. Besides, the position of the display should meet the following demands per user group:

User group	Demands
Driving instructors	Not integrated in the dashboard of the vehicle, but a loose, trembling-free and swivelling (and therefore visible for both driver (student) and instructor) installation (e.g. fixed to the windscreen)
Fleet owners & Private car drivers	Integrated in the dashboard of the vehicle

- Resetting the fuel economy device should not be too easy. This prevents the driver from accidentally deleting/resetting trip data;
- Language should be adaptable to the driver's language or otherwise to the driver's preference;
- Comprehensible and mutual distinguishable buttons/pictograms, preferably marked with colours, are required to start and stop data recording;
- Measured data, displayed data and stored data should correspond in all cases. The refresh frequency of displayed data should in addition be limited; display frequencies should not exceed values of two per second. Measurement, display and/or storage frequencies can cause aggregation problems when they differ from each other (see section 4.2).

Information related

- Dependent on the preferences of the user groups, the fuel economy device should present information about:
    - Fuel consumption;
    - CO_2-emission;
    - Driving style;
    - Distance travelled;
    - Costs.
- Preferred units of these kinds of information are:

Information	Units
Fuel consumption	l/100 km km/l (1 : …) l/h l (cumulative fuel consumption)
CO_2-emission	g/km
Driving style	speed in km/h revolutions (rpm) acceleration (+/-) in m/s^2 # too fast accelerations # too hard decelerations # long idling periods
Distance travelled	Km km until 'empty'
Costs	e.g. fuel costs/km

- The use and value of thresholds is dependent on many variables. However, the table below contains some general directives.

Information	Threshold	Algorithm points of interest
Too fast accelerations	> +2 m/s^2	• Check sensitivity of measurements when accelerating from low speeds (< 5 m/s) • Construct algorithms which can distinguish long continuous accelerations from (many) short accelerations
Too hard decelerations	< -3 m/s^2	• Check sensitivity of measurements when decelerating at low speeds (< 5m/s) • Construct algorithms that can distinguish long decelerations instead of measuring (too many) short decelerations
Automatic data recording stop	engine shut down > 10 sec	
Long idling periods	> 30 sec	Note: >30 sec irrespective of the fact that the vehicle has (already) driven

Presentation related

- The fuel economy device should not give information that is already provided by other in-vehicle systems with the exception of speed. Most user groups expect that the device compared to the traditional speedometer could display speed more accurately. However, when duplicate information other than speed is displayed, correspondence with data provided by other systems is necessary;
- Drivers should be given the opportunity to switch between different kinds of information;
- With respect to possible ways of presenting feedback, visual presentation is preferred to auditory;
- Digital displays (text and numbers) are preferred to analogue presentation of data;
- All information has to be presented in 1 decimal;
- The fuel economy device should preferably present interpretations of values, or even better support drivers by giving directed advice.
- Besides comments on driving style, the driver should also be provided with positive feedback;
- After driving, averages and totals of information should be available on the display of the fuel economy device. The driver should be able to define the desired computation period; in other words, it should be possible to calculate averages over every desirable driving period;
- During driving, measured data has to be displayed continuously, providing the driver with current values;
- Recommendations for relevant units on the display are:

	Speed = 0	Speed > 0
Throttle position = 0 %	… l/h 0 km/l	0 l/100km --- km/l (or 1 : ---) or fixed value e.g. 99 km/l
Throttle position > 0 %	… l/h 0 km/l	… l/100 km … km/l (or 1 : …)

N.B. Throttle position =0% means no pressure is placed on the gas pedal.

5.2 Directives for data storage and software packages

Providing direct feedback during driving is only the basic feature of a fuel economy device. By storing data generated by the fuel economy device, it is in addition possible to analyse driving behaviour by means of a specially designed software package amongst others to provide feedback over a longer period. Directives for these kinds of applications of fuel economy devices are given below.

Data storage

- The fuel economy device should have enough data storage capacity. The preferred data storage capacity is dependent on the amount of data and the quality of data compression. When data storage capacity is (too) small, users are forced to (dependent on vehicle use) transfer stored data to the PC frequently or delete stored data frequently;
- The fuel economy device should have enough power supply capacity. The power supply capacity depends on one hand on the comprehensiveness of data measurement and on the other hand on the use of the fuel economy device. From a practical point of view, it is advised against to use power supplies that have to be renewed frequently. Systems that make use of the internal power supply of the vehicle or systems that can be recharged during driving are preferred;
- Data transfer from the fuel economy device to the PC should be fast, not sensitive to disturbances and not time consuming. Therefore, preference is given to automatically loading of information (e.g. radio graphically instead of using a PDA or chip card system).

Software package

After driving, the software package can be used to analyse data generated by the fuel economy device. In general, the software package should be user-friendly, robust and include a manual. Directives with respect to ergonomics, information and presentation are listed below.

Ergonomics related

- Language should be adaptable to the user’s language or otherwise to the user’s preference;
- Windows look-and-feel applications are recommended in order to optimise the clarity and comprehensibility of the software package;
- Prevent user actions outside the software package, for example working with configuration files (*.ini);
- It should be possible to analyse data generated by the fuel economy device also by means of spreadsheet or database programmes (e.g. Microsoft Excel).

Information related

- Dependent on the preferences of the user groups, the software package should present information about:
    - Fuel consumption;
    - CO_2-emission;
    - Driving style;

- Distance travelled;
- Costs.

- Preferred units of these kinds of information are:

Information	Units
Fuel consumption	l/100 km km/l (1 : …) effective saving[2] L
CO_2-emission	g/km
Driving style	speed in km/h acceleration (+/-) in m/s^2 # too fast accelerations # too hard decelerations # long idling periods time driven in gear X
Distance travelled	Km
Costs	e.g. fuel costs/km

- The software package should provide information that reflects trip values and aggregated values on longer time scales (e.g. week, month);
- The provided information can be person or vehicle related;
- The software package should give advice or positive feedback, for example by giving an interpretation of tables and graphs.
- It should be possible to make comparisons between trips, persons, vehicles and self-indicated time scales;
- The software package should be able to handle a large number of data files and to make comparisons between them

Presentation related

- All information should be presented in 1 decimal;
- The software package has to present information as digital numbers in tables;
- Next to tables, the following presentation forms are desired:
    - Bar charts: for displaying average/total values of amongst others trips (course of time);
    - Line charts: for displaying for example information about fuel consumption (course of time);
    - Pie charts: for displaying for example the time driven in gear X.
- It should be possible to display more than one kind of information in a graph;
- The software package should provide a legend with each graph;
- It should be possible to present all information about one kind of information (e.g. fuel consumption or driving style) simultaneously on one screen.

[2] Effective saving represents the reduction in fuel consumption as a percentage of the total amount of fuel that *could have been* saved.

6 General conclusions

The Centre for Transport Studies of the University of Twente has conducted a study on the MDD-concept. MDD stands for a concept of a fuel economy device that can register fuel consumption, CO_2-emission, aspects of driving style and distance travelled, and presents the values on a PDA display (e.g. Palm display). In addition, a specially designed software package can be used to analyse the data generated by the MDD on a PC afterwards. The MDD-concept is based on a plug-and-play principle, which implies that it can be installed in the existing fleet rather easily.

The objective of this study was initially threefold:
1. Elaborate and assess the MDD-concept;
2. Test MDD-prototypes with respect to technical functionality and performance and accordance with specifications;
3. Assess the MDD-prototypes with respect to user-friendliness and overall performance during a large-scale field trial.

The elaboration and assessment of the MDD-concept revealed that respondents of several distinguished user groups acknowledge the value of fuel economy devices and consider the accompanying software package a helpful tool, especially for fleet owners. Driving instructors and fleet owners of courier companies value the MDD-concept most. It appears that not all user groups have similar preferences for the information to be presented on the MDD-display and in the accompanying software package. Considering the costs involved, it is preferable to produce fuel economy devices – like the MDD-concept and the software package – that meet the requirements of more than one user group. With respect to the preferences of the distinguished user groups, three types of the MDD-concept as well as of the software package were identified. Generally, these types differ from each other regarding the kind of information, units of information and time scale (e.g. trip values, aggregated values on a week or month) presented.

The testing of the MDD-prototypes revealed that the MDD-prototypes satisfy nearly all specifications formulated during the specification phase. However, with respect to technical functionality and performance, some problems revealed themselves. These problems can be summarized in four categories:
- Universal implementation: The MDD can not be installed easily in all vehicles;
- Hardware: The MDD-prototypes showed shortcomings with respect to power supply, data storage capacity and fixation of the MDD in the vehicle;
- Data measuring: Measuring thresholds, algorithms and aggregation rules are not optimised and lack accuracy;
- Software: The prototypes of the software packages deviate from several specifications formulated and are not in all respects user-friendly.

Based on the outcome of the testing, it was concluded that it was not advisable to perform a large-scale field trial to assess the user-friendliness and overall performance of MDD with the momentarily available MDD-version.

Therefore, results of the elaboration and testing of the MDD have been generalised in order to come to directives for new-generation fuel economy devices. The directives distinguish between in-vehicle devices with and without data storage capacity. The distinction is due to the fact that data evaluation after driving consequently implies the possibility of data storage during driving. Therefore, the objectives of the device have to be kept in mind during development, i.e. are data storage possibilities desired or not? Points of interest are the possibilities to use a software package and the amount of data that has to be stored, which is proportional to driving time.

The general directives for in-vehicle devices are summarised into four categories, which are of equal importance for the development of a fuel economy device. The categories are related to:

- The system, e.g. the fuel economy device should be universal to overcome problems with respect to among others things different vehicle brands and types;
- Ergonomics, e.g. the display of the fuel economy device should be good visible, illuminated (when necessary) and not blocking (co-)driver's sight;
- Information, e.g. the fuel economy device should present information about fuel consumption, CO_2-emission, driving style, distance travelled and costs (dependent on the preferences of the user groups);
- Presentation, e.g. the driver should be given the opportunity to switch between different kinds of information.

In addition general directives for data storage and accompanying software packages are formulated. With respect to data storage, the fuel economy device should – for example – have enough data storage capacity in order to record data during a longer time period.

The directives for software packages can be divided into three categories, related to:

- Ergonomics, e.g. it should be possible to analyse data generated by the fuel economy device also by means of spreadsheet or database programmes (e.g. Microsoft Excel);
- Information, e.g. the software package should provide information that reflects trip values and aggregated values on longer time scales (e.g. week, month);
- Presentation; e.g. all information should be presented in 1 decimal.

Regarding the directives formulated it should be noted that the directives do not give detailed technical solutions, extensive development strategies or ready-to use algorithms and thresholds. The directives formulated do not form blueprints for successful development and market introduction. The directives do, however, provide important preconditions that have to be met in order to develop an adequate fuel economy device.

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