FESTA Support Action
Field operational test support Action

D2.1 – A Comprehensive Framework of Performance Indicators and their Interaction

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(see Author List on next page)

Consortium:
This deliverable consists of several documents. They are described in the following table:

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<td>FESTA D2_1_PI_Matrix_Final.xls</td>
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**Author List**

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<thead>
<tr>
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<th>Members</th>
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</thead>
<tbody>
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<td>Juha Luoma</td>
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<td></td>
<td>Harri Peltola</td>
</tr>
<tr>
<td></td>
<td>Pirkko Rämä</td>
</tr>
</tbody>
</table>
What is the precision requirement for this measure? Guidelines?

Field Operational Test

What is the resolution requirement for this measure? Guidelines?

Criticality of measuring, logging, Performance Indicator, e. g. very fast startup-time, very high frequency or resolution, etc.

Required

Comments on the indicator References of studies that used the PI. e. g. frequency of use, well validated through studies, construct validity …

- End shunts

P04 Minimum speed Mix speed recorded over certain distance/time, but can be treated as continuous measure if calculated as rolling average - End shunts

P07 Spot speed measured speed in a certain spot (defined location) m/s (kph or mph) objective quantitative speed sensor and position speed profile

P11 maximum acceleration peak level of rate of change of vehicle deceleration associated with either appropriate response to extreme event or as consequence of delayed response (e.g. inattention) speed sensor

P12 maximum jerk peak level of rate of change of acceleration

P13 maximum peak level of rate of change of acceleration

P14 number of times brake force > suitable speed associated with illegal behaviour (speeding) N/A

P15 Mean time headway (THW)

P16 number of times speed limit was exceeded m/s or m (%) (count) objective quantitative speed sensor

P17 Standard deviation of time headway (THW)

P18 Standard deviation of the local THW minima. s objective quantitative

P19 Standard deviation of the local THW minima. s objective quantitative

P20 speed sensor

P21 speed sensor and position sensor

P22 speed sensor and position sensor

P23 speed sensor and position sensor

P24 street edge detection

P25 street edge detection

P26 speed sensor

P27 speed sensor

P28 speed sensor

P29 speed sensor
<table>
<thead>
<tr>
<th>Page</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The time-to-collision (TTC) performance indicator is used to determine the PI per distance, time duration, type of road etc.</td>
</tr>
<tr>
<td>1</td>
<td>The TTC samples are measured at a fixed time interval.</td>
</tr>
<tr>
<td>1</td>
<td>The proportion of TTC local minima less than 1s reflects the traffic density.</td>
</tr>
<tr>
<td>1</td>
<td>The probability of following the lead car is determined by the duration and amplitude of safety-critical TTC values.</td>
</tr>
<tr>
<td>1</td>
<td>The TLC is defined as the time to reach the lane marking.</td>
</tr>
<tr>
<td>1</td>
<td>The proportion of time-to-line-crossing (TLC) values is measured in situations where two vehicles pass each other.</td>
</tr>
<tr>
<td>1</td>
<td>The number of lane changes made per hour or per kilometre is measured.</td>
</tr>
<tr>
<td>1</td>
<td>The proportion of time-to-line-crossing (TLC) values is measured in situations where two vehicles pass each other.</td>
</tr>
<tr>
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</tr>
<tr>
<td>1</td>
<td>The proportion of time-to-line-crossing (TLC) values is measured in situations where two vehicles pass each other.</td>
</tr>
</tbody>
</table>

**Notes:**
- **TTC:** Time-to-collision
- **PI:** Performance Indicator
- **THW:** Time Headway
- **TLC:** Time to Line Crossing
- **PET:** Post Encroachment Time
- **LOS:** Lane Orientation Status
- **GPS:** Global Positioning System
- **PET:** Post Encroachment Time
- **LOS:** Lane Orientation Status
- **GPS:** Global Positioning System
# Measures

<table>
<thead>
<tr>
<th>Measure group</th>
<th>Measure name (KEY)</th>
<th>Description</th>
<th>Comments</th>
<th>Generalisability</th>
<th>Unit</th>
<th>Other limitations</th>
<th>Special needs</th>
<th>Storage requirement</th>
<th>Comment storage requirement</th>
<th>Potential problems regarding privacy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed group</td>
<td>Speed_CAN</td>
<td>Vehicle speed obtained from the CAN bus</td>
<td>Need speed profile of the vehicle</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed group</td>
<td>Speed_GPS</td>
<td>Vehicle speed obtained from a GPS-based sensor</td>
<td>In tunnels the GPS signal is usually lost, and no speed reading is possible. When starting the sensors a time up to 5 minutes may be necessary to acquire precise GPS data.</td>
<td>m/s</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed group</td>
<td>Speed_WheelDist</td>
<td>A pulse sensor on a free rolling wheel</td>
<td>In order to get better accuracy in $V$ and $dV/dT$ compared to using ABS</td>
<td>m/s</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acceleration group</td>
<td>Acc_Long</td>
<td>Measurement of vehicle longitudinal translational acceleration using analogue or digital accelerometer(s); Most easy and cheap applications are digital, higher bandwidth problem to isolate vehicle acceleration from gravity</td>
<td>5 m/s²</td>
<td>None significant, but output needs to be noise filtered</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>May arise if max speed exceeds speed limit</td>
<td></td>
</tr>
<tr>
<td>Acceleration group</td>
<td>Acc_Lat</td>
<td>Measurement of vehicle lateral translational acceleration using analogue or digital accelerometer(s); Most easy and cheap applications are digital, typically lower bandwidth problem to isolate vehicle acceleration from gravity</td>
<td>5 m/s²</td>
<td>None significant, but output needs to be noise filtered</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>May arise if max speed exceeds speed limit</td>
<td></td>
</tr>
<tr>
<td>Acceleration group</td>
<td>Acc_Vertical</td>
<td>Acceleration of the vehicle in $z$-direction (vertical): for detection of road bumps location etc.</td>
<td>m/s²</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Braking group</td>
<td>Brake_Force</td>
<td>Force with which the brake pedal is pressed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Braking group</td>
<td>Accelerator_Operation</td>
<td>Distance how far the accelerator is pressed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Braking group</td>
<td>KickDown_Activation</td>
<td>Kick down function activation in vehicles with automatic transmission</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Units

- **Speed_CAN:**Vehicle speed obtained from the CAN bus
- **Speed_GPS:**Vehicle speed obtained from a GPS-based sensor
- **Speed_WheelDist:**A pulse sensor on a free rolling wheel
- **Acc_Long:**Measurement of vehicle longitudinal translational acceleration using analogue or digital accelerometer(s)
- **Acc_Lat:**Measurement of vehicle lateral translational acceleration using analogue or digital accelerometer(s)
- **Acc_Vertical:**Acceleration of the vehicle in $z$-direction (vertical): for detection of road bumps location etc.
- **Brake_Force:**Force with which the brake pedal is pressed
- **Accelerator_Operation:**Distance how far the accelerator is pressed
- **KickDown_Activation:**Kick down function activation in vehicles with automatic transmission

### Notes

- **Comments:** The general class of measures, such as Speed, Position, Acceleration etc.
- **Description:** The name of the measure. It also works as key for this table, therefore no duplicates can occur.
- **Additional comments to the measure:** Description of this measure. Additional comments to the measure. This measure is not applicable to the Vehicle
- **Generalisability:** Standard unit that applies to the measure. Use preferably SI units.
- **Unit:** General limitations of the measure, which can be important to consider in FOT. Nature of the limitation can be technical, ethical, legislative, etc.
- **Other limitations:** Important needs to be considered for the measure. They can be technical, practical, legislative, etc.
- **Special needs:** Space requirement to store the data with the typical frequency.
- **Storage requirement:** Comment on the data format for the memory requirement (for example binary or ASCII format).
- **Comment storage requirement:** Explanation of how this sensing system contributes to the privacy issues for FOTs.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Unit</th>
<th>Sensitivity</th>
<th>Processing Requirement</th>
<th>Filter Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clutch_Operation</td>
<td>Distance how far the clutch pedal is pressed</td>
<td>m</td>
<td>None significant, but must be filtered</td>
<td>Signal processing</td>
<td>User definable</td>
</tr>
<tr>
<td>Gear_Selected</td>
<td>Active gear, either selected by the driver or by the automatic transmission system</td>
<td></td>
<td>None significant, but output needs to be filtered</td>
<td>Signal processing</td>
<td>User definable</td>
</tr>
<tr>
<td>Direction_Indicator</td>
<td>Activity of direction indicators (left or right turn indicated)</td>
<td></td>
<td>None significant, but output needs to be filtered</td>
<td>Signal processing</td>
<td>User definable</td>
</tr>
<tr>
<td>Jerk</td>
<td>Post-processed rate of change of acceleration</td>
<td>m/s&lt;sup&gt;3&lt;/sup&gt;</td>
<td>None significant, but output needs to be filtered</td>
<td>Signal processing</td>
<td>User definable</td>
</tr>
<tr>
<td>Lateral position</td>
<td>Lateral position of the vehicle to the center line</td>
<td>m</td>
<td>Small, some bytes per second</td>
<td>User definable</td>
<td>None significant</td>
</tr>
<tr>
<td>Steering wheel position</td>
<td>Steering wheel position obtained from the CAN bus</td>
<td>°</td>
<td>User definable</td>
<td>None significant</td>
<td>None significant</td>
</tr>
<tr>
<td>GPS position</td>
<td>Longitudinal vehicle position</td>
<td></td>
<td>Position profile needed for each trip</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GPS_Latitude</td>
<td>Latitude vehicle position</td>
<td></td>
<td>Position profile needed for each trip</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time_DistanceOtherVehicles</td>
<td>Time distance to the vehicle ahead in the own lane, adjacent lane and oncoming lanes</td>
<td>seconds</td>
<td>Information on traffic in oncoming lanes is important for systems that give overtaking or passing assistance on single carriageway roads. Distance to vehicles in the own lane is often critical information and distance to vehicles in adjacent lanes is highly desirable.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Space_DistanceLeadVehicle</td>
<td>Space distance to the vehicle ahead in the own lane</td>
<td>metres</td>
<td>Information on traffic in oncoming lanes is important for systems that give overtaking or passing assistance on single carriageway roads. Distance to vehicles in the own lane is often critical information and distance to vehicles in adjacent lanes is highly desirable.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Space_DistanceOtherVehicles</td>
<td>Space distance between FOT vehicle and the vehicle behind in the own lane and vehicles in adjacent and oncoming lanes</td>
<td>metres</td>
<td>Information on traffic in oncoming lanes is important for systems that give overtaking or passing assistance on single carriageway roads. Distance to vehicles in the own lane is often critical information and distance to vehicles in adjacent lanes is highly desirable.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Space_DistanceOtherVehicles</td>
<td>Space distance between vehicles that are not part of the FOT</td>
<td>metres</td>
<td>Information on traffic in oncoming lanes is important for systems that give overtaking or passing assistance on single carriageway roads. Distance to vehicles in the own lane is often critical information and distance to vehicles in adjacent lanes is highly desirable.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Pre-processed (derived from sensor, other pre-processed)

<table>
<thead>
<tr>
<th>Countermeasures for ensuring privacy</th>
<th>Signal processing based data dropout</th>
<th>Synchronisation</th>
<th>Pre-processing methodology</th>
<th>Equation for pre-processing</th>
</tr>
</thead>
<tbody>
<tr>
<td>How can the data be handled/processed to minimize the privacy intrusion</td>
<td>Typical conditions at which the measure drops data directly related to the signal processing</td>
<td>How is the data synchronized with the other measure if it is an aggregation of more than one measure?</td>
<td>Methodology for signal processing. Short description on how the data is pre-processed to achieve the wanted results.</td>
<td>How the pre-processing is made. Pre-processing should be relatively simple operations. There is a need to have cross-references to other KEY_measures. All KEY_measures used must be defined to be used.</td>
</tr>
<tr>
<td></td>
<td>Data is synchronized with the CAN bus synch timer when stored in files (one column is the CAN synch).</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sensor noise reduction Low pass filter cut-off frequency ~ 5Hz (noise reduction).</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sensor noise reduction, standard signal processing technique.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**
- Failure of system
- Failure of system synch via common data logger
- Sensor noise reduction
- Low pass filter cut-off frequency ~ 5Hz (noise reduction)
- Sensor noise reduction, standard signal processing technique.
<table>
<thead>
<tr>
<th>Purpose</th>
<th>Methodology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failure of system synchronisation via common data logger</td>
<td>Sensor noise reduction, low pass filter cut-off frequency ~ 25Hz (noise reduction) based on Acc_Long, standard signal processing technique.</td>
</tr>
<tr>
<td>Discarding data x kilometres around the start/stop point of the vehicle is one option.</td>
<td></td>
</tr>
<tr>
<td>Pre-processing limitations</td>
<td>Sensor source</td>
</tr>
<tr>
<td>---------------------------</td>
<td>---------------</td>
</tr>
<tr>
<td>Reference to the specific sensor this measure is based on</td>
<td>Source data on which the data is based. This can be of importance for the limitations and requirements of the indicator</td>
</tr>
</tbody>
</table>

**Raw (from sensor)**

**S00**

In tunnels the GPS signal is usually lost, and no speed reading is possible. When starting the sensors a time up to 5 minutes may be necessary to acquire precise GPS data.

**S01**

GPS satellite position (trigonometric calculation on phase difference between L1 and L2 signal and C/A + P-code) with data from at least 3 satellites.

Data is synchronized with the CAN bus synch timer when stored in files (one column is the CAN synch).

GPS sensor is installed in vehicle (where metal roofing does not weaken signal). Data is send via USB or RS232 to computer, where the NMEA data is logged for offline evaluation.

**S02, S01**

**S03, S08**

Sensor output corresponds to acceleration being experienced (typically piezoelectric - containing microscopic crystal structures that get stressed by accelerative forces, causing small voltages to be generated. System requires regular calibration. $mV$ converted to $g$.

Sensor failure Sensitivity of sensor critical to accuracy of recorded data. Consideration of natural frequency of sensor mounting required.

No Dependent on quality of sensor. Typically between 100-500Hz

Dependent on quality and type of system

**Processed signals suffer from attenuation**

**S03, S05**

Sensor output corresponds to acceleration being experienced (typically piezoelectric - containing microscopic crystal structures that get stressed by accelerative forces, causing small voltages to be generated. System requires regular calibration. $mV$ converted to $g$. Synchronization via common external data logger using CAN bus timer.

Sensor failure Sensitivity of sensor critical to accuracy of recorded data. Consideration of natural frequency of sensor mounting required.

No Dependent on quality of sensor. Typically between 100-500Hz

Dependent on quality and type of system

**Processed signals suffer from attenuation**

**S03, S07**

Sensor output corresponds to acceleration being experienced (typically piezoelectric - containing microscopic crystal structures that get stressed by accelerative forces, causing small voltages to be generated. System requires regular calibration. $mV$ converted to $g$. Synchronization via common external data logger using CAN bus timer.

Sensor failure Sensitivity of sensor critical to accuracy of recorded data. Consideration of natural frequency of sensor mounting required.

No Dependent on quality of sensor. Typically between 100-500Hz

Dependent on quality and type of system

**Processed signals suffer from attenuation**

**S03, S09**

Sensor output corresponds to acceleration being experienced (typically piezoelectric - containing microscopic crystal structures that get stressed by accelerative forces, causing small voltages to be generated. System requires regular calibration. $mV$ converted to $g$. Synchronization via common external data logger using CAN bus timer.

Sensor failure Sensitivity of sensor critical to accuracy of recorded data. Consideration of natural frequency of sensor mounting required.

No Dependent on quality of sensor. Typically between 100-500Hz

Dependent on quality and type of system

**S07**

**S10, S00**

**S00**
Processed signals suffer from attenuation

| 503 | as 503 | mV converted to g and processed to g/s | Synchronisation via common external data logger using CAN bus timer | Sensor failure | As 503 | No | Order of magnitude worse than accelerometer | Order of magnitude worse than accelerometer |

Synchronisation via common external data logger using CAN bus timer

Sensor failure

No

Order of magnitude worse than accelerometer

NO

A camera captures the environment and out of this information software calculates in the background the lateral position to the center line?

pictures

converted and processed to m

Data is synchronized with the CAN bus synch timer when stored in files (one column is the CAN synch).

NO

Data storing with the CAN bus time

YES
### Specification Range

<table>
<thead>
<tr>
<th>Resolution</th>
<th>Resolution Comment</th>
<th>Precision/Accuracy</th>
<th>Precision/Accuracy Comment</th>
<th>Storage Needs</th>
<th>Frequency</th>
<th>Resolution</th>
<th>Precision/Accuracy</th>
<th>Storage Needs</th>
</tr>
</thead>
</table>

- **What resolution range is available for this sensor?**
  - Explanation in text about issues with resolution for this sensor.

- **What precision/accuracy is available for this sensor?**
  - Explanation in text about issues with precision/accuracy for this sensor.

- **How much data (kb/mb) is required per hour recording?**
  - Explanation in text what frequency is required and why.
  - Estimated position error when full sky coverage and good satellite position: ??-??m.

- **What is the maximum output typically?**
  - Typical accelerometer sensitivity 1000mV/g.
  - Typical dynamic range ±5g.
  - Between -10 % - 1% proportional to sensor noise.
  - ~2Mbyte per hour.
  - Current standards more than acceptable.
  - Current sensor standard acceptable.

- **Current standards more than acceptable.**

- **Scale 1-5 of how important good precision/accuracy is for Performance Indicators.**

- **Current standards more than acceptable.**

Note that the specifications will give the general specifications of this measure from the specific sensor type, as well as a typical values for reference state-of-the-art FOTs.
<table>
<thead>
<tr>
<th>Order of magnitude worse than accelerometer</th>
<th>Order of magnitude worse than accelerometer</th>
<th>Order of magnitude worse than accelerometer</th>
<th>~2Mbyte per hour</th>
<th>Current standards more than acceptable</th>
<th>Current standards more than acceptable</th>
<th>3</th>
<th>Current sensor standard acceptable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated position error when poor visibility on the street</td>
<td>Current standards more than acceptable</td>
<td>Current standards more than acceptable</td>
<td>3</td>
<td>Current sensor standard acceptable</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full steering range (typical -780° to +780°), typical resolution 0.1°</td>
<td>Typical dynamic range +/- 2.5°</td>
<td>Current standards more than acceptable</td>
<td>Current standards more than acceptable</td>
<td>3</td>
<td>Current sensor standard acceptable</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sensor group</td>
<td>Sensor class</td>
<td>Sensor type</td>
<td>Sensor Key</td>
<td>Description</td>
<td>Technology used</td>
<td>Typical hardware interface</td>
<td>Secondary hardware interface</td>
</tr>
<tr>
<td>-------------</td>
<td>--------------</td>
<td>-------------</td>
<td>------------</td>
<td>-------------</td>
<td>-----------------</td>
<td>---------------------------</td>
<td>---------------------------</td>
</tr>
<tr>
<td>Grouping of sensors to indicate what the main type of information these sensors measure</td>
<td>Sensor class</td>
<td>The specific type of sensor.</td>
<td>Description of the sensor.</td>
<td>What is the underlying technology used for this sensor?</td>
<td>The typical source of the data.</td>
<td>Alternative source of data if usual source is not used.</td>
<td>Typically, what communication protocol is the raw data source using?</td>
</tr>
<tr>
<td>Vehicle</td>
<td>Vehicle bus</td>
<td>CAN (or LIN/MOST/FlexRay)</td>
<td>S00</td>
<td>The vehicle bus is considered a sensor with many possible outputs. For each FOT, the capabilities of the intended vehicle must be investigated.</td>
<td>Several different built-in sources.</td>
<td>Available vehicle bus</td>
<td>The particular protocol version for the bus. Details may be proprietary and not available.</td>
</tr>
<tr>
<td>Positioning system</td>
<td>GPS</td>
<td>GPS</td>
<td>S01</td>
<td>&quot;Standard&quot; consumer global satellite positioning system.</td>
<td>GPS</td>
<td>Internal</td>
<td>CAN or USB</td>
</tr>
<tr>
<td>Positioning system</td>
<td>DGPS</td>
<td>DGPS</td>
<td>S02</td>
<td>Enhanced GPS, using reference stations on the ground, improving accuracy.</td>
<td>GPS, radio, DGPS service</td>
<td>Internal</td>
<td>RS232</td>
</tr>
<tr>
<td>Positioning system</td>
<td>Inertial Navigation System (INS)</td>
<td>Inertial Navigation System (INS)</td>
<td>S03</td>
<td>Acceleration and gyro based system often used in combination with GPS to &quot;fill in the blanks&quot; at GPS dropouts.</td>
<td>Usually accelerometers and gyro.</td>
<td>Device CAN</td>
<td>RS232</td>
</tr>
<tr>
<td>Vehicle dynamics</td>
<td>Yaw rate</td>
<td>Yaw rate</td>
<td>S04</td>
<td>Angular rate sensor</td>
<td>Vehicle bus</td>
<td>Analog</td>
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</tr>
<tr>
<td>Vehicle dynamics</td>
<td>Pitch rate</td>
<td>Pitch rate</td>
<td>S05</td>
<td>Angular rate sensor</td>
<td>Analog</td>
<td></td>
<td></td>
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<tr>
<td>Vehicle dynamics</td>
<td>Roll rate</td>
<td>Roll rate</td>
<td>S06</td>
<td>Angular rate sensor</td>
<td>Vehicle bus</td>
<td>Analog</td>
<td></td>
</tr>
<tr>
<td>Vehicle dynamics</td>
<td>Lateral acceleration</td>
<td>Lateral acceleration</td>
<td>S07</td>
<td>Accelerometer</td>
<td>Vehicle bus</td>
<td></td>
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<tr>
<td>Vehicle dynamics</td>
<td>Longitudinal acceleration</td>
<td>Longitudinal acceleration</td>
<td>S08</td>
<td>Accelerometer</td>
<td>Vehicle bus</td>
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<tr>
<td>Vehicle dynamics</td>
<td>Vertical acceleration</td>
<td>Vertical acceleration</td>
<td>S09</td>
<td>Sensor on free running wheel for increased accuracy.</td>
<td>Pulse sensor/counter</td>
<td>Analog</td>
<td></td>
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<tr>
<td>Driver/vehicle interaction control</td>
<td>Speed sensor</td>
<td>Speed sensor</td>
<td>S75</td>
<td>Sensor on free running wheel for increased accuracy.</td>
<td>Pulse sensor/counter</td>
<td>Analog</td>
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<tr>
<td>Driver/vehicle interaction control</td>
<td>Throttle pedal position</td>
<td>Throttle pedal position</td>
<td>S10</td>
<td>Vehicle bus</td>
<td>Analog</td>
<td></td>
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<tr>
<td>Driver/vehicle interaction control</td>
<td>Clutch pedal position</td>
<td>Clutch pedal position</td>
<td>S11</td>
<td>Vehicle bus</td>
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<tr>
<td>Driver/vehicle interaction control</td>
<td>Brake pedal position</td>
<td>Brake pedal position</td>
<td>S12</td>
<td>Vehicle bus</td>
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<tr>
<td>Driver/vehicle interaction control</td>
<td>Brake force</td>
<td>Brake force</td>
<td>S38</td>
<td></td>
<td>Analog</td>
<td></td>
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<tr>
<td>Driver/vehicle interaction control</td>
<td>Windscreen wipers position</td>
<td>Windscreen wipers position</td>
<td>S69</td>
<td></td>
<td>Analog</td>
<td></td>
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<tr>
<td>Driver/vehicle interaction control</td>
<td>Turn indicator status</td>
<td>Turn indicator status</td>
<td>S92</td>
<td></td>
<td>Analog</td>
<td></td>
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<tr>
<td>Driver/vehicle interaction control</td>
<td>Steering wheel angle</td>
<td>Steering wheel angle</td>
<td>S13</td>
<td>Vehicle bus</td>
<td></td>
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<tr>
<td>Driver/vehicle interaction control</td>
<td>Forward looking video</td>
<td>Forward looking video</td>
<td>S14</td>
<td>Low Light - High Res B&amp;W/colour video camera</td>
<td>CCD(CMOS)</td>
<td>Analog=&gt;digitizer (grabber card)</td>
<td>Digital: Ethernet, USB, Firewire (depending on grabber)</td>
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<tr>
<td>Driver/vehicle interaction control</td>
<td>Rearward looking video</td>
<td>Rearward looking video</td>
<td>S15</td>
<td>Low Light - High Res B&amp;W video camera</td>
<td>CCD(CMOS)</td>
<td>Analog=&gt;digitizer (grabber card)</td>
<td>Digital: Ethernet, USB, Firewire (depending on grabber)</td>
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<tr>
<td>Environment Video</td>
<td>Side looking video - left S16</td>
<td>Low Light - High Res B&amp;W video camera</td>
<td>CCD/(CMOS)</td>
<td>Analog=&gt;digitizer (grabber card)</td>
<td>Digital: Ethernet, USB, Firewire</td>
<td>(depending on grabber)</td>
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<tr>
<td>Side looking video - right S17</td>
<td>Low Light - High Res B&amp;W video camera</td>
<td>CCD/(CMOS)</td>
<td>Analog=&gt;digitizer (grabber card)</td>
<td>Digital: Ethernet, USB, Firewire</td>
<td>(depending on grabber)</td>
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<tr>
<td>RADAR/LIDAR</td>
<td>Forward looking RADAR S18</td>
<td>Multi target radar</td>
<td>24 GHz AAC radar</td>
<td>Device CAN</td>
<td>RS232</td>
<td>Yes</td>
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<tr>
<td>Side looking RADAR - left S19</td>
<td>Multi target radar</td>
<td>24 GHz AAC radar</td>
<td>Device CAN</td>
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<td>Side looking RADAR - right S20</td>
<td>Multi target radar</td>
<td>24 GHz AAC radar</td>
<td>Device CAN</td>
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<td>Rearward looking RADAR S21</td>
<td>Multi target radar</td>
<td>24 GHz AAC radar</td>
<td>Device CAN</td>
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<td>Forward looking LIDAR - scanning S35</td>
<td>Laser scanner</td>
<td>Laser class 1</td>
<td>Device CAN</td>
<td>Ethernet</td>
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<tr>
<td>Machine vision</td>
<td>Lane tracker S22</td>
<td>System to recognise road lanes and warn for lane drift, LDW</td>
<td>Forward-looking video camera</td>
<td>Vehicle bus</td>
<td>Device CAN</td>
<td></td>
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<tr>
<td>Blind spot-side S23</td>
<td>Detection of objects in blind spot</td>
<td>Cameras/radar, process</td>
<td>Device CAN</td>
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<td>Blind spot-front S24</td>
<td>Detection of objects in blind spot</td>
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<tr>
<td>Sign detection S25</td>
<td>Automatic detection of road signs</td>
<td>Cameras, processing</td>
<td></td>
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<td>Pedestrian detection S26</td>
<td>Automatic pedestrian detection</td>
<td></td>
<td>Device CAN</td>
<td>Ethernet, Firewire</td>
<td></td>
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<tr>
<td>Situational (environment)</td>
<td>Ambient air temperature S72</td>
<td>Vehicle bus</td>
<td>Analog</td>
<td>(ADC if secondary interface)</td>
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<td>Air flow S90</td>
<td>Vehicle bus</td>
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<td>Air pressure S71</td>
<td>Vehicle bus</td>
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<td>Humidity S73</td>
<td>Vehicle bus</td>
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<tr>
<td>Clock S99</td>
<td>Date/time</td>
<td>Internal logger</td>
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<tr>
<td>Driver video</td>
<td>Face video S27</td>
<td>Video of driver’s face</td>
<td>CCD/CMOS camera with IR light</td>
<td>Analog=&gt;digitizer (grabber card)</td>
<td>Ethernet</td>
<td>(depending on grabber)</td>
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<tr>
<td>Interior view (from driver rear) S28</td>
<td>Interior view for further driver behaviour analysis</td>
<td>CCD/CMOS camera with IR light</td>
<td>Analog=&gt;digitizer (grabber card)</td>
<td>Ethernet</td>
<td>(depending on grabber)</td>
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<tr>
<td>Head/eye-tracker</td>
<td>Eye-Tracker S29</td>
<td>Video-based eye, gaze and eye-lid tracking</td>
<td>Video, image process</td>
<td>Internal</td>
<td>Ethernet, CAN, serial</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Head-Tracker S30</td>
<td>Head and gaze tracking system with post-processing</td>
<td>Video, image process</td>
<td>Device CAN</td>
<td>Ethernet, other vehicle buses</td>
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<tr>
<td>Driver demographics</td>
<td>Age S39</td>
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<td>Gender S40</td>
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<td>Self-reported data S41</td>
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<td>Rater based annotation S45</td>
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<td>Driver annotation S46</td>
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<tr>
<td>Closed questions</td>
<td>Driver background data S83</td>
<td>Pen and paper</td>
<td>Web</td>
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<tr>
<td>Vehicle background data S42</td>
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<tr>
<td>Qualitative data collection - rating</td>
<td>Structured closed answer questionnaire - rating S82</td>
<td>Example: Questionnaire measuring driver acceptance of new in vehicle technology</td>
<td>Pen and paper</td>
<td>Web</td>
<td>Yes - need for input in database</td>
<td></td>
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</tr>
<tr>
<td>Open question S84</td>
<td>Self generated and self reported questionnaire. Included in a battery of questions used in study?</td>
<td>Pen and paper</td>
<td>Web</td>
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<tr>
<td>Fully open question</td>
<td>Example: &quot;What is your opinion on ISA in cars?&quot; Fully open question to driver for feedback on acceptance/opinion of specific system (ISA).</td>
<td>Pen and paper</td>
<td>Web</td>
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<tr>
<td>Vehicle status</td>
<td>Fuel flow meter S47 Vehicle bus</td>
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<td>Fuel temperature S81 Vehicle bus (?) Analog</td>
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<td></td>
<td>HC S48</td>
<td>Analog</td>
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<td>CH4 S50</td>
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<td></td>
<td>NOx S51</td>
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<td>NO2 S53</td>
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<td>PM S54</td>
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<td>CO S55</td>
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<td></td>
<td>Electricity from the net S74 Vehicle bus Analog (ADC if secondary interface)</td>
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<td>Electricity from the net S74 Vehicle bus Analog (ADC if secondary interface)</td>
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<td></td>
<td>Lambda S79</td>
<td>Analog</td>
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<td>Engine pressure S78</td>
<td>Analog</td>
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<tr>
<td>External information</td>
<td>Databases</td>
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<td>Road information database S96 Off-line road information</td>
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<td>Map database S94 Off-line geographical info</td>
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<td>Real-time traffic information S95 Information on traffic situations (density, flow, etc.)</td>
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<td>Real-time weather information S97 Information on road conditions (ice, wet, etc.)</td>
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<td>Real-time road condition S93 Real-time feedback on speed limits, etc.</td>
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<td>Modelling</td>
<td>Simulation models</td>
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<td>Macro simulation model S91</td>
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<td>Micro simulation model S89</td>
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<tr>
<td>Sensor position</td>
<td>Mounting tolerance and sturdiness needs</td>
<td>Electromagnetic noise specification</td>
<td>General latency (real world event to time stamp)</td>
<td>Specification range</td>
<td>Typical specification of State-Of-The-Art FOT</td>
<td>Calibration needs</td>
<td>Sensing drift</td>
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<tr>
<td>Definition of typical sensor position and how important the position is.</td>
<td>Explanation on how important the mounting tolerances are.</td>
<td>In text, what is the sensing system's usual contribution to EMC noise?</td>
<td>Examples of latency (possibly with different interfaces).</td>
<td>What is the size range for this sensor?</td>
<td>What is the weight range for this sensor?</td>
<td>Typical cost or cost range for sensing system?</td>
<td>What is the weight range for this sensor?</td>
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<tr>
<td>Antenna needs to be placed so that satellite signals can be received. The receiver itself can be placed anywhere within the vehicle?</td>
<td>Timing of CAN signals is generally non-deterministic.</td>
<td>Individual signals must be evaluated.</td>
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<tr>
<td>As GPS but with addition that the Differential receiver should be positioned some distance away from known sources of electromagnetic noise.</td>
<td>Preferred to be in a relatively central vehicle location if to be used as part of vehicle dynamics modeling.</td>
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<td>Fixed in vehicle.</td>
<td>(as above)</td>
<td>(as above)</td>
<td>(as above)</td>
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<td>(as above)</td>
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<td>At wheel</td>
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<td>rear-view mirror</td>
<td>Grabber: 200-500 cm^3 35 x 40 x 50 100-200 g $90-$350 30 x 33 x 37 $350 Sensata ACM100 Need to calibrate logger for latency.</td>
<td>Sensata ACM100</td>
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<td>rear-view mirror</td>
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<tr>
<td>Component Details</td>
<td>Dimensions</td>
<td>Weight</td>
<td>Price</td>
<td>Manufacturer</td>
<td>Voltage</td>
<td>Current</td>
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<td>TVCCD-30 Monacor</td>
<td>35 x 35 x 30</td>
<td>46 g</td>
<td>$100</td>
<td></td>
<td>12 VDC, 110 mA</td>
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<tr>
<td>Behind car front centre panel</td>
<td>40-110 ms (cycle time)</td>
<td>105 x 94 x 34</td>
<td>~300 g</td>
<td>Smartmicro</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Behind car front left panel</td>
<td>40-110 ms (cycle time)</td>
<td>105 x 94 x 34</td>
<td>~300 g</td>
<td></td>
<td>9-35 VDC, 3.6 W (ECU&lt;900 mA)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Behind car front right panel</td>
<td>40-110 ms (cycle time)</td>
<td>105 x 94 x 34</td>
<td>~300 g</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Behind left/right car rear panel</td>
<td>40-110 ms (cycle time)</td>
<td>105 x 94 x 34</td>
<td>~300 g</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Front grill</td>
<td>85 x 128 x 83</td>
<td>800 g</td>
<td>EUR (2008) ibeo LUX</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Windshield, headliner, or rear-view mirror</td>
<td>233 x 183 x 85</td>
<td></td>
<td></td>
<td>Mobileye</td>
<td>12 V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Headliner or rear-view mirror</td>
<td>Grabber: ??? ms</td>
<td>50 x 35 x 35</td>
<td>~100 g</td>
<td>Marshall V1214</td>
<td>12 V, 110 mA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Driver on or in the dashboard</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before and/or after test</td>
<td>No</td>
<td></td>
<td></td>
<td>Reference to standards</td>
<td>Interviewer bias, Interviewer bias</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before and/or after test</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------------------</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>As close as possible before and in front of the fuel flow meter</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Environmental constraints</td>
<td>Sensor based data dropout</td>
<td>Typical sensor startup time</td>
<td>Time required</td>
<td>Training requirement for interviewer/observer</td>
<td>Crashworthiness</td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------------------------</td>
<td>---------------------------</td>
<td>-----------------------------</td>
<td>---------------</td>
<td>-----------------------------------------------</td>
<td>-----------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>How does weather and environmental factors affect the data quality?</td>
<td>Typical problems with data dropout?</td>
<td>Typically, time from power on until data is being logged properly?</td>
<td>For example, time for follow-up interviews.</td>
<td>For subjective measures.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Antenna needs free access to the sky and satellites. Bridges, trees or buildings decrease quality or completely cancel out function (see above)</td>
<td>If satellite coverage is missing.</td>
<td>As above, and covered area must have reference stations.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-40 – +85 deg C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
-40 +70 deg C
-55 deg C
-30 deg C
-40 deg C
-55 deg C
-30 deg C

In several languages
not validated in all
languages where
available

Subject refuses to answer single
cquestions or entire
questionnaire
X min

X min
| Drivers refuse to answer or answer a completely different question | X min | Maybe |
MATRIX STRUCTURE
The matrix is built up of three tables, which in a later stage can be utilised to create a relational database. The first table is "PerformanceIndicators". "Measures" is a second table, which contains measures used as input to the performance indicators. To obtain these measures a number of tools or sensors will be needed. The sensors at which the measures point can be found in the "Sensors" table. This has to be seen as a supplement to the document delivered as annex in the FESTA handbook. Each table contains a key-variable in the first column, which is used to identify the variable. A database will need this information to define relations and associations between the tables. Therefore it is important to make sure that the appropriate keys are entered when new performance indicators are listed. The key list must be complete, and the logical operators must be correct.

Example with the performance indicator "average speed":
The performance indicator "mean speed" is associated with three measures:
Speed_CAN OR Speed_GPS OR Speed_WheelUnitDistance.
Speed_CAN is the speed as obtained by the CAN bus, Speed_GPS is speed from a GPS sensor, for example. To collect these measures the sensors S01 (CAN bus speed) and/or S02 (GPS speed) can be used. S01 is simply the CAN bus output filtered for vehicle speed, and S02 is a specified GPS sensor.

A selection of situational variables can be found in the measures table. They provide information on the surrounding environment, weather, infrastructure, traffic, etc.

A few examples for events can also be found in the measures table. They are to be treated as suggestions; definitions and trigger values have to be decided upon within each FOT, depending on the hypotheses, geographical particularities and other issues.

User interface
The Excel database with several tables is not optimal in terms of usability, since a user has to navigate between different worksheets to collect the information in the example above. A simple user interface should be implemented where the user can for example select a number of performance indicators, and then get a list with the measures and sensors associated with them. There are several possibilities to design such a user interface. Certain modifications are still required before the information can be entered into a relational database or a similar tool.
This worksheet contains a description on how to use the PI matrix.

The matrix is two-dimensional and contains three tables:

- "Performance indicators" table: here all the performance indicators can be found.
  The associated measures (linked clear text name) are listed for each performance indicator.
- "Measures" table: in this table the measures are specified.
  The associated sensors are listed for each measure.
- "Sensors" table: here all the sensors are specified.

The tables are linked by keys, which uniquely identify each performance indicator, measure and sensor.
Each single performance indicator has one row in the PI matrix (first table), and descriptions in the columns.
Each single measure has one row in the measures matrix (second table), and descriptions in the columns.
If one measure can be read from more than one sensor, each of these instances is considered to be a different measure.
Each single sensor has one row in the sensors matrix (third table), and descriptions in the columns.

Performance indicators belong to one or several of the four main groups:
SAFETY, ENVIRONMENTAL ISSUES, EFFICIENCY, and ACCEPTABILITY.

For more detailed information and descriptions please refer to "How to use the FESTA PI Matrix".
How to Use the PI Matrix
FESTA WP2.1

2008-05-12

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1 The FESTA PI Matrix

The FESTA PI Matrix is a document containing Performance Indicators that can be used to assess safety, efficiency, environmental and acceptance aspects in a Field Operational Test (FOT). The list was compiled by a number of experts who used their own experience and the literature as basis.

The list is meant to be used as a tool both during the planning phase and during the analysis phase of an FOT. It should also be of help for budget decisions, as it can aid the user in estimating sensor costs, for example, but also in estimating how intricate and time intensive certain analyses are.

The list is meant to be used by people with background knowledge in the field, it does not substitute a solid education in traffic research. Even though the list is quite comprehensive, it is by no means exhaustive, which means that existing and established Performance Indicators might not be included, even though some effort has been made to cover all aspects that nowadays can be measured in a reasonable way in an FOT. The list can be extended and new Performance Indicators can be added.

2 Contents of the Matrix

The FESTA matrix contains three main tables. One is called “Performance Indicators”, one is called “Measures”, and one is called “Sensors”. Here mainly the first two will be described.

2.1 Performance Indicators

The Performance Indicators table contains more than 150 PI which can be based on log data from the car, from external sensors or from questionnaires, interviews and the like. Many of the mentioned PI are established in the traffic research world and have been used in many studies, both in the field and in simulators, others are relatively new and directly related to FOTs. The PI in the table are not sorted, but loosely grouped according to categories like speed related, lateral position related, acceptance related, eye movement related, and so on. For each PI different variables are described, like whether the PI is objective or subjective, whether it is qualitative or quantitative, how it is computed and so on. Not all variables are meaningful for all PI. One very important variable, however, is the one named “required measures”. Here, the measures that are necessary to compute the PI are named. They are connected via the logical operators AND or OR, and parantheses can be used to indicate grouping or facultative inclusion. If not the measure name but a measure group is mentioned, it is written in squared brackets [xxx]. Table 1 provides a short syntax guide.

<table>
<thead>
<tr>
<th>EXAMPLE</th>
<th>DESCRIPTION</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed_CAN OR Speed_GPS OR Speed_WheelUnitDistance</td>
<td>Either one of the measures is enough, but it is possible to</td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Syntax guide for the “required measures” variable in the Performance Indicator tab of the FESTA PI Matrix.
How to Use the PI Matrix (Annex to D2.1)

| Collect all three of them. | (Speed_CAN OR Speed_GPS OR Speed_WheelUnitDistance) (AND SpeedLimit_ISA OR SpeedLimit_RoadDatabase OR SpeedLimit_SignRecognition) | At least one of the speed measures and one of the speed limit measures have to be collected. |
| (Speed_CAN OR Speed_GPS OR Speed_WheelUnitDistance) AND [event time or location] | At least one of the speed measures and the event trigger of interest have to be collected. | In this case it is not defined which event has to be measured, but instead of listing all possible events the generic [event] is used. Here either the time of the event, synched to the vehicle time, or the location of the event can be of interest. |
| (Speed_CAN OR Speed_GPS OR Speed_WheelUnitDistance) AND Traffic_Flow AND Traffic_Density (AND Video_ForwardView) | At least one of the speed measures and traffic flow and traffic density have to be collected. Video forward view is a meaningful optional, depending on the hypotheses. | |

All measures that are mentioned in the “required measures”-variable can be found in the Measures table, where they are described further (see below). The only group that is not included in the Measures table are the subjective measures like questionnaires, focus groups, interviews, etc. The reason is that they do not fit into the structure of the matrix very well. Therefore, a reference is made to either the name of a questionnaire or a rating scale, or to the qualitative method in general that would produce the PI in question.

2.2 Measures

The Measures table includes all measures except for almost all measures collected with qualitative methods. Five different measure types exist, and they are treated slightly differently. Here they are described briefly, a more detailed description with examples can be found in the FESTA Handbook Chapter 5.

Direct Measures are collected directly from either vehicle-internal or from external sensors. No preprocessing of the signal before logging is required. Direct Measures have different sub-groupings, which are entered into the “measure group” variable.

Derived Measures are pre-processed before logging, and they build on Direct Measures, other Derived Measures, Events or Self-Reported Measures.

Self-Reported Measures are not included in general, but only if they in combination with another Direct or Derived Measure are the basis for a PI.
How to Use the PI Matrix (Annex to D2.1)

Events are singularities based on a combination of Direct Measures and/or Derived Measures. Situational Variables have to be defined for them.

Situational Variables describe the setting of the trip. They are normally not necessary in order to compute PI, but they can be used for detailed comparisons.

Events and Situational Variables are listed as examples. Their number is unlimited, and the hypotheses in the current study decide both which are of interest and how they have to be defined in order to allow a meaningful analysis. It is out of scope for FESTA and not meaningful, either, to provide detailed definitions at this stage.

2.3 How to Use the Matrix
In most cases one or several research questions are the reason for why a study is conducted. These research questions can be translated to hypotheses, which in turn result in certain Performance Indicators, that have to be studied in order to be able to answer the hypotheses and research questions. For this type of scenario the matrix can be used in the following way:

It is assumed that the Performance Indicators are defined via hypotheses. Then the PIs are located in the PI table. The descriptions provide additional information about the PI, including for example whether collecting them entails ethical issues or not. The “required measures” variable tells the user which measures are necessary in order to be able to compute the PI. Due to budget and/or other limitations a certain way of measuring can be preferred over another. Comparisons between different ways of obtaining a certain measure can be made both in the measures table and in the sensors table. Once it is decided which measures are going to be obtained, it is also possible to cross-check, whether other PI can be obtained with the same already selected sensors, and whether they contribute any added value in order to answer the hypotheses.

The hypothesis steers the selection of Situational Variables, too. These variables are not pointed at from the PI table if they are not critical for a PI. Rather, if the hypothesis states that it is necessary to split the analysis into subgroups defined by Situational Variables, those have to be collected, too. Here, the user has to go into the Measures table directly and select the desired Situational Variables, respectively add own ones, in case that they are not present yet. Not only those variables marked as Situational Variables can be used as such, but any other kind of variable as well.

If the hypothesis is related to Events, the Events in question have to be described and defined. The matrix only provides a list with examples of Events, but those are not defined more than on a very rough level.

It can be of interest to investigate which other PI can be computed with the sensors available for a certain study. To this end, the names of the measures that can be obtained have to be searched for in the “required measures” column in the PI table of the matrix. All PI for which all measures are available can be computed with the currently available sensors.
Below an example of how to work with the matrix are provided.

<table>
<thead>
<tr>
<th>Research Question A:</th>
<th>A low friction warning system will increase traffic safety in rural areas.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypothesis A:</td>
<td>A low friction warning increases the mean headway on icy rural roads while the warning is given.</td>
</tr>
<tr>
<td>Hypothesis B:</td>
<td>Mean speed will be increased during periods when no low friction warning is given, but low friction due to ice is possible.</td>
</tr>
<tr>
<td>PI:</td>
<td>Mean time headway (THW), mean speed.</td>
</tr>
</tbody>
</table>

**Resulting Measures:**

- **Mean THW:** THW (which is a Derived Measure, combined of
  \((Speed\_CAN \text{ OR } Speed\_GPS \text{ OR } Speed\_WheelUnitDistance) \text{ AND } Space\_DistanceLeadVehicle\))
- **Mean Speed:** \(Speed\_CAN \text{ OR } Speed\_GPS \text{ OR } Speed\_WheelUnitDistance\)

**Decision on Sensor:** The user in this example has no access to the vehicle CAN bus. As icy roads will most often occur out in the open, and not in tunnels, it is decided to use \(Speed\_GPS\) for speed measurement. Signal loss in tunnels will not disturb data collection in relevant areas, and GPS receivers are comparatively cheap. For measurement of the \(Space\_DistanceLeadVehicle\) a radar is bought, mounted and time synchronised with the GPS receiver.

**Situational Variables:** The hypotheses are directed at rural areas, which means that it is necessary to keep track of where the vehicle is driven. The Situational Variable \(Road\_Type\), possibly in combination with \(LOS\) will provide this information. In order to obtain the data a GPS receiver in combination with access to a road database are necessary. The GPS sensor is already planned as speed logging device. If access to a road database is not feasible, a rough classification of road types can be made via Google Maps, for example.

Hypothesis A focuses on icy rural roads, therefore it is necessary to know whether the road is icy or not (related measure: \(Road\_Friction\)). As it is deemed of importance to know about road friction with some
certainty, and because CAN information is not available
to this user, it is decided to buy a friction sensor, and
also to install a camera to catch the Video_ForwardView
measure, where recording is triggered by a
thermometer, which was bought additionally.

| Further PI: | With the measures that were selected a number of
other PI can be computed without additional logging
costs. Those that appear relevant are noted, because
they might help refine the answer to the research
questions. In this example especially Speed Variance and
the Standard Deviation of the local time headway
minima were collected for the icy patches and for
corresponding dry road segments. |

### 2.4 Adding new PI and Measures

This tool is most useful if it is kept up to date. If new PI and new measures are developed, they
should be added to the document. The following steps have to be taken when a new PI is added:

- Check that it is not already there.
- Fill in the PI and complete the row.
- Fill in the required measures. Check carefully which of them already exist and type the exact
  name of the existing measures. If measures that are not in the table yet are required, fill in
  those, too, and give them unique names.
- Make sure that the logical operators are correct.
- If new measures are needed, fill in those in new rows in the measures table and complete
  the rows.
- Continue in a similar manner with the sensors.
This annex contains further background to groups of PI that can be found in the matrix provided in excel-format, which is the main Deliverable 2.1. Specifically the indicators that pertain on environmental issues and traffic efficiency issues are treated here. Background information on the other Performance Indicator groups like driver behaviour or system performance are sufficiently covered in the FESTA handbook and in the PI matrix. A chapter on driver characteristics, which are not taken up in the matrix, is included as last part of this annex.
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1 List of abbreviations

BS Boredom susceptibility
DBQ Driver Behaviour Questionnaire
DE Driving Internality
DI Driving Externality
Dis Disinhibition
ES Experience seeking
FC Fuel consumption
FESTA Field operational Test support Action
FFM Five Factor Model
FOT Field Operational Test
IQ Intelligence Coefficient
LOC Locus Of Control
PI Performance Indicator
TAM Technology Acceptance Model
T-LOC Traffic Locus Of Control
TS Traffic situations
Annex WP 2.1.3
Environmental Indicators
1 Possibilities to estimate performance indicators for road vehicle exhaust emissions

1.1 Overview
For evaluation of environmental aspects of FOTs there is need for exhaust emission Performance Indicators (PI).

An FOT is used in order to estimate effects of for example ICT-functions (Information and Communication Technologies). In many cases one cannot expect big effects of ICT functions on emissions. Still, small effects could represent big benefits compared to costs, which means that even small effects could be of interest. The evaluation of representative exhaust emission effects in an FOT could be a big problem. The reason for this is that exhaust emissions could be difficult to estimate with enough accuracy to prove possible small effects. There is one important exception, fuel consumption (FC) and carbon dioxide (CO$_2$) emissions. FC can be estimated without high costs and with good accuracy.

The best PI/measure for exhaust emissions would in principle be the exhaust emissions themselves. Exhaust emissions include many different substances. One then needs to decide what substances will be included. One proposal for such a gross list could be what is included in the ARTEMIS-program$^1$. This program includes what is needed in most EU-countries: hydro carbons (HC); carbon monoxide (CO); nitrogen oxides (NO$_x$); FC; particulates (PM); CO$_2$; Methane (CH$_4$); non methane hydro carbons (NMHC); lead (Pb); sulphur dioxide (SO$_2$); laughing gas (N$_2$O) and ammonia (NH$_3$).

CO$_2$, SO$_2$ and Pb have in common they can easily be estimated based on FC.

There are two alternatives for quantifying exhaust emissions: measured exhaust emissions or calculated. For measurements there are still two alternatives: on board or in laboratory. The laboratory alternative demands use of logged driving patterns.

Because of the high complexity and costs for measurements of exhaust emissions, in practice, calculated emissions in most cases is the only alternative within reason. If a FOT represents extensive field measurements, of course there will be a big problem selecting a representative part for exhaust emission laboratory measurements.$^2$

A range of conditions have to be measured in order to calculate exhaust emissions. If all these conditions are measured and there is a reliable emission model available exhaust


$^2$ A rough estimation of exhaust emission measurements in laboratory should be 5000-10000 Euro per vehicle and day. The investment costs for on board equipment could be 100 000 euro.
emissions could be estimated, at least on a macro level. One problem with the macro level is that what is special with an ICT could perhaps not be expressed on a macro level. Still, there are available models also on the micro level.

Weather conditions are of considerable importance for exhaust emissions. Measured exhaust emissions at standardized test procedures usually are adjusted to reference conditions. In the standardized test procedures methods for such adjustments are documented and should be possible to use for evaluation of an FOT.

An advantage with a model is that the standard deviation should be smaller compared to measurements and because of this an indication should be easier to detect, with the drawback that there always will be a risk that the calculated effect is not representative.

If exhaust emissions cannot be estimated in absolute values one needs other measures correlated to these effects as PI. Such measures, correlated to emissions, should represent independent variables in emission models. When absolute values for emissions cannot be estimated, the corresponding PI should be independent variables with high correlation to exhaust emissions. One problem with such independent variables is that a relative change in such a variable could be different to the change in exhaust emissions.

Models for exhaust emissions in general include three parts:

- Cold start emissions
- Hot engine emissions
- Evaporative emissions.

Evaporative emissions are special since they appear both for parked vehicles and from vehicles with a running engine. Hot engine emissions is the part which is most depending on the driving pattern.

The following formula is a rough description of an exhaust emission model:

\[ \sum (\text{Traffic activity}) \times (\text{Emission factor}) = \text{Total emissions} \]

Of course, traffic activity data has a high correlation to total emissions. Traffic activity data includes at least:

- Exposure
- Engine starts.

Exposure is of importance in two ways, both the total value and the distribution on traffic situations.
In most cases total exhaust emissions per substance will increase when mileage and engine starts increase but not for sure. If the emission factors would decrease in parallel total emissions could decrease. An ICT can influence both traffic activity and emission factors. This structure of an emission model is of interest for exhaust emission measurements as well. When performing emission measurements the structure above is in general used in some way.

There are different types of calculation models for exhaust emission estimation:

- Macro level models
- Micro level models including engine simulation.

In macro models (aggregated level) input data is in a simplified form, for example average speed, compared to micro models with complete driving patterns. One important question is if the special characteristics of an ICT can be described in the input to such a model. If not, the ICT cannot be evaluated. In the EU area probably COPERT is the most well known macro model besides ARTEMIS. The main difference between COPERT and ARTEMIS is that COPERT uses average speed as input and ARTEMIS uses the distribution of mileage on traffic situations (TS). A traffic situation includes: type of area; type of road; speed limit; level of service and road gradient. ARTEMIS also, as an alternative option; it can use average speed as input.

One simple method to estimate fuel consumption on an aggregated level with high accuracy is notes about fuel filled in the tank and odometer reading. One drawback is that there is no possibility for time or geographical resolution with exception for the time period between filling the tank.

Examples for micro scale models: PHEM; VETO ; VERSIT etc. The first two models are based on mechanistical principles and the third on statistical. At least in principle there is a

---


difference in resolution, the mechanistical based models can estimate emissions "meter by meter" and the statistical model down to 100 m.

Models on a micro level should in general be able to describe most ICT functions. This is not the case for more aggregated level models. In the Swedish ISA project a micro level exhaust emission model, VETO, was used\(^7\). Micro models are often used for emission factor estimation and macro models for total emission estimations.

One important question is the expected accuracy of different types of models.

Micro level models based on VTI opinion:

- Fuel consumption or energy use for all types of engines: can be estimated with good accuracy
- Diesel engines and other substances than fuel/CO\(_2\): HC and NOx can be estimated with acceptable accuracy
- Petrol engines and other substances than fuel/CO\(_2\): For petrol engines without catalytic converters the accuracy is acceptable in general. With catalytic converters there are not that many models available with at least acceptable accuracy. VERSIT+ could be such a model.

When absolute emission values are not used as measures, PI could be classified after the structure in emission models, for example traffic activity and type of emission factor.

The hot emission factors for one vehicle are functions of a set of independent variables such as:

- Vehicle speed (V)
- Acceleration (dV/dT, +/-)
- Engine speed (which together with vehicle speed gives gear position)
- Meteorological conditions
- Road conditions etc.

Of course all vehicle parameters are of big importance for emission factors:

- Vehicle mass including load
- Cross section area
- Air resistance coefficient
- Rolling resistance
- Emission concept
- Engine power
- Type of engine
- Type of transmission
- Vehicle age etc.

The mix of fossil fuels with renewable fuels could result in different fuel quality from tanking to tanking. The mix of petrol with ethanol also changes in a systematic way from month to month during a year. The FC and other emission factors are influenced by the fuel mix. If there are values on the mix at least FC (and CO\textsubscript{2}, SO\textsubscript{2} and Pb) should be possible to estimate. Other exhaust substances for mixed fuels could be more difficult to estimate with models. Since FC is depending on the fuel mix one needs to have full control of used fuel quality if FC is measured in a FOT. It is not enough to fill the tank just anywhere. For evaluation one needs to adjust measured FC and emissions to one reference fuel mix.

In order to estimate emission factors on a micro level a driving pattern for the engine is needed directly or indirectly. A driving pattern for the engine constitutes of:

- Engine speed
- Engine torque
- Time distribution.

An indirect description of the engine driving pattern constitutes of:

- Vehicle speed
- Gear position
- Traction force including the acceleration contribution.

There are also more simplified forms of driving patterns:

- A distribution matrix with speed and acceleration classes
- An average speed.

In order to estimate such a matrix there must be good accuracy for both V and dV/dT.

In order to estimate the drag force there is need for dV/dT with good accuracy. In Appendix A expressions for error estimation are described. In order to reduce the error in V and dV/dT there is need for filtering of the logged driving pattern, see Appendix A. The smaller true dV/dT value the bigger relative importance of an error in dV/dT. For example at constant speed the drag force could be 0,2 N/kg (vehicle). If the maximum accepted error would be 0,02 N/kg and logging frequency 10 Hz the accuracy of measured distance should be 0.00005 m. For 1 Hz the accuracy demand should be 0.005 m. The filtering method in the Appendix to this section should improve the situation.

One question is to what extent an observed PI should be possible to explain, that is what caused the observed value. This raises a special demand on data like traffic conditions, driver information etc. Such data will in most cases be registered by other means than sensors in the FOT vehicle. The demand for this purpose is the possibility to connect data from the FOT vehicle with other data registers and situational indicators. This is also necessary in order for global scaling of results. The proposal should be that PI always should be estimated per registered TS in order to make comparisons between with and without ICT meaningful.
When exhaust emissions are measured they need to be adjusted to one reference meteorological situation.

In order to make a cost/benefit analysis of an ICT one needs geographic information about the PI since the damage/costs caused by emissions is depending on the degree of human exposure to the emissions. This demand should be able to be fulfilled by combining in-vehicle registered indicators with other data registers based on GPS. If a PI is based on average speed there must be a connection of the estimated PI to local conditions like speed limit.

The conclusion about what to include as PI would then be: exhaust emissions or indicators with high correlation to exhaust emissions.

The drive train of motor vehicles is becoming more complex by time. Such a complex drive train is a hybrid system. In a hybrid system PI need to represent both engines in the system.

1.2 List of proposed potential PI
Measures for PI estimation can be of two types: fixed and varying. In order to estimate total emissions one needs both.

Motor vehicle static data:

- manufacturer
- model
- year of type approval
- year of manufacturing
- emission concept
- registration number
- gross vehicle weight
- empty vehicle weight
- cross section area
- air resistance coefficient
- propulsion system:
  - type
  - power, max
- gear box, type. Number of gear positions
- gear box ratios
- final gear box ratio
- position of propulsion system
- drive wheels: front; rear; all
- number of axles
- wheels per axle

Trailer static data:

- model
- year of manufacturing
- registration number
- gross vehicle weight
• empty vehicle weight
• cross section area
• air resistance coefficient in relation to motor vehicle
• number of axles
• number of wheels per axle

There could be need for describing effects from hybrid vehicles taking part in a FOT. Because of this there could be need to use sensor data from more than one engine.

Engine 1, combustion:

• Measured fuel consumption
• Temperature of measured fuel consumption
• Measured content of exhaust emissions per substance
• Injection times
• Engine speed
• Engine pressure
• Lambda
• Air flow
• Fuel temp
• O₂ content in fuel
• Water temp
• Oil temp
• Temp of catalytic converter
• Use of engine heater
• Exhaust emissions directly.

Engine 2, electric:

• Engine speed
• Use of electricity from generator
• Use of electricity from battery

Auxiliaries:

• Air cond: use/not use
• Other auxiliaries: use/not use
• Cooling fan: operating/ not operating

Tires:

• manufacturer, model and dimension
• rolling radius
• rolling resistance coefficient
• tire pressure: cold tires; hot tires
• odometer reading at tire exchange.
One problem with tires is the influence of air pressure and ambient temperature on rolling resistance. Even if the tire pressure is correctly used from the handbook there might be other disturbing factors out on the road. To some extent data on ambient temperature and air pressure can be used afterwards for correction of the drag force.  

Vehicle load weight:

- driver + passengers
- load besides driver and passengers
- trailer connected or not
- amount of fuel in the tank.

The difference in total drag force between full and empty tank in a car could be some percent.

Driving pattern:

- time based 10 Hz (for example)
- time: date; time of the day
- road distance (a GPS will probably not have accuracy enough)
- accelerometer (x; y; z)
- gyro
- distance to vehicle in front
- distance to vehicle behind

If $dV/dT$ is to be used for the PI the demand of accuracy on time and coordinate increases. If a driving pattern with a resolution of 10 Hz will be used the accuracy of coordinate and time must be in focus. The time resolution for 10 Hz should be $< 1/1000$ sec. If for example a sensor for coordinate is fixed to the wheel axle the oscillation of the vehicle sprung mass can cause problems. The problems with this oscillation can to some extent be solved by using a gyro. In Appendix 1 uncertainty in computed $dV/dT$ is described.

Distance to the vehicle in front and to the vehicle behind influence air resistance.

GPS:

- Time
- Coordinate.

A GPS can be used for connecting measured data in the vehicle with data on conditions of importance outside the vehicle. If average speed is used to form the PI GPS can be used but not for describing a complete driving pattern.

---

Road and traffic conditions based on GPS and time:

- gradient; horizontal curve; road width; speed limit; junction; roughness; macrotexture
- traffic signal picture
- road surface conditions (in Sweden by use of the winter model)
- traffic flow.

In Sweden, for example, most of this data is available in a national road database.

Meteorological conditions:

- Air pressure (measured with vehicle sensor)
- Air temp (measured with vehicle sensor)
- Humidity (measured with vehicle sensor)
- Wind speed and wind direction could be measured with vehicle sensor but in most cases from sensors not in the FOT-vehicle.
Appendix to Annex 2.1.3

Uncertainties in computed acceleration

Suppose a vehicle is equipped with a measurement device (e.g., a wheel pulse instrument or a GPS) that produces data for a number of points in form of position and time. We assume here for simplicity that the spacing between subsequent points is constant in time. Let \((t_i, s_i)\) denote the time and position when the vehicle passes the \(i\)th point.

A very common way to estimate the velocity and acceleration at the \(i\)th point is to compute the standard symmetric difference quotients:

\[
v_i = \frac{s_{i+1} - s_{i-1}}{2h} \quad \text{for the velocity}
\]
\[
a_i = \frac{s_{i+1} - 2s_i + s_{i-1}}{h^2} \quad \text{for the acceleration},
\]

where \(h\) is the constant time difference between subsequent points: \(h = t_{i+1} - t_i\).

An important property of these estimates is that any disturbance or random error in position or time tend to be amplified resulting in a typical “noisy” velocity or acceleration curve. This is particularly true for the acceleration, especially if \(h\) is small. Let as assume that we have errors in positions only and that they are bounded by, say, \(\varepsilon\), i.e., \(|\Delta s_i| \leq \varepsilon\) for all \(i\). It is easily verified that the correspondingly induced errors in estimated velocity and accelerations, \(\Delta v_i\) and \(\Delta a_i\), resp., will satisfy the following inequalities:

\[
|\Delta v_i| \leq \frac{\varepsilon}{h}
\]
\[
|\Delta a_i| \leq \frac{4\varepsilon}{h^2}
\]

Hence, on the right hand sides of the inequalities we have upper bounds for the sizes of the fluctuations in velocity and acceleration caused by the errors (fluctuations) in measured positions.

The fluctuations in velocity or acceleration can be reduced by filtering. One such filter that has been found very efficient for this purpose is to apply repeated averaging:

For \(j = 0, N-1\)
For \( i=j+1, M \)

\[
a^{j+1}_i = \left( a^j_i + a^{j-1}_i \right)/2,
\]

End

where \( N \) denotes the total number of iterations, \( a^0_i, i = 1, \ldots, M \) denotes the computed (by differentiation) acceleration values (= \( a_i \)), and \( a^N_i \) denotes the corresponding filtered accelerations to the \( N \):th degree. (To avoid displacements of the acceleration signal, the averaging can be appropriately applied alternately backwards and forwards, i.e. replacing index \( i-1 \) with \( i+1 \) in every second iteration.) In experiments, the typical high frequency fluctuations that arise in the acceleration have been very efficiently reduced by this filter without seriously distorting the true curve. However, rather large values for \( N \) may be needed (\( N \) in the order of 20 to 30 has been found appropriate in our application).

By induction this filter can easily be shown to be equivalent to using a moving average with (normalized) binomial coefficients as weight coefficients. This means that:

\[
a^N_i = \sum_{k=0}^{N} \frac{1}{2^N} \binom{N}{k} a_{i-k}
\]

The degree of the binomial coefficients equals the total number of iterations for the repeated averaging.

E.g., for \( N=20 \) the weight coefficients are as in Table 1:

<table>
<thead>
<tr>
<th>Term</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vikt</td>
<td>184756</td>
<td>167960</td>
<td>125970</td>
<td>77520</td>
<td>38760</td>
<td>15504</td>
<td>4845</td>
<td>1140</td>
<td>190</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>Procent</td>
<td>18%</td>
<td>16%</td>
<td>12%</td>
<td>7%</td>
<td>4%</td>
<td>1%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

Thus, approximately 75% of the weight is located within two points from the middle point (Term=0). This simple analysis verifies that the dissipation is small when \( N = 20 \), i.e., that the original "true" curve is not seriously distorted by applying the filter. For increasing values of filtering degrees this dissipation is growing, but only very slowly.
Annex WP2.1.4
Traffic Efficiency Indicators
The aim of FESTA Task 2.1.4 is to identify and describe indicators of traffic efficiency and to provide guidance on the collection of traffic efficiency related data in Field Operational Tests (FOTs).

The efficiency of a traffic system can be measured as, for example, traffic flow, speed and density in relation to the optimum levels of these properties given the traffic demand and the physical properties of the road network.

A combination of Field Operational Tests (FOTs) and traffic modelling is required to allow estimation of traffic efficiency impacts of the tested technologies. A schematic picture of the proposed methodology is shown in Figure 1.

![Figure 1 FESTA Traffic efficiency estimation based on FOT results](image)

Driver behaviour data are based on the data collected in the FOT. These driver behaviour data will, together with the system functionality\(^9\) of the tested technology, be used as input to traffic modelling in order to aggregate the individual driver/vehicle impact on traffic efficiency effects. This requires that both driver/vehicle data of equipped vehicles and properties of the traffic system that the vehicles have driven in are collected in the FOT. Properties of the traffic system will henceforth be referred to as situational data\(^{10}\).

\(^9\) System functionality refers to the way in which the tested FOT system works. Information on when and how the system operates can be used to create parameters for the models developed.

\(^{10}\) Situational data are not necessarily directly relevant Performance Indicators or Measures, but must also be measured or recorded as they provide key background information that complements the driver behaviour data and is sometimes needed to derive the driver behaviour data. Examples include light conditions, system status (e.g. on or off) and road type. A list can be found in Table 3.
The appropriate traffic modelling approach will differ depending on which type of driving tasks the considered technology supports. Michon’s (1985) hierarchical driving model can be applied to select a traffic modelling approach. To model systems that support tactical or operational driving tasks it is appropriate to apply a traffic microsimulation model. A microsimulation model considers individual vehicles in the traffic stream and models vehicle-vehicle interactions and vehicle-infrastructure interactions. To model systems that support strategic and some types of tactical driving tasks it is appropriate to apply a traffic simulation model. A mesoscopic model considers individual vehicles but models their movements and interactions with a lower level of detail than microscopic models.

It is advisable to study traffic efficiency for a series of scenarios with varying levels of traffic penetration of the tested systems. The systems should also be studied in representative traffic volumes. This is achieved straightforwardly by running the traffic simulation model with different inputs. The situational data will also contribute to the differences between the scenarios (both measured and modelled).

Outputs from the traffic models will be used to make comparisons of traffic efficiency for the studied scenarios. Example outputs of interest are traditional quality of service and traffic efficiency indicators such as speeds, travel times, and queue lengths.

In addition to modelling, the system functionality, driver behaviour data and situational data can also be examined quantitatively.

1.3 Driver behaviour data
As mentioned above, driver behaviour data will be used in order to write rules that define behavioural aspects in the Microsimulation models. This means that the Performance Indicators and Measures that comprise this driver behaviour data are an intermediate level of information required in order to assess traffic efficiency using a traffic model.

1.3.1 Performance Indicators and Measures
In order to assist the development of the accompanying matrix, driver behaviour data has been separated into Performance Indicators and Measures.

*Performance Indicators* are quantitative or qualitative measurements, expressed as a percentage, index, rate or other value, which is monitored at regular or irregular intervals and can be compared to one or more criteria.

A *Measure* can either be direct or pre-processed. A direct measure is logged directly from a sensor, while a pre-processed measure is a combination of different direct or other pre-processed measures. A measure does not have a ‘denominator’ which makes it comparable to other instances of the same measure or to external criteria.

So, for example, the Performance Indicator ‘Deviation from desired lane’ can be derived from:

- ‘Video_ForwardView’ AND
- ‘Position_Lat’
- ‘DriverIntention_Lane’.
To be able to derive many of the Performance Indicators needed for the traffic model, the equipped vehicle’s driving course of events has to be recorded. This includes position, speed and acceleration in both longitudinal and lateral directions.

### 1.3.2 Sensors

An additional information layer in the matrix, ‘Sensors’, indicates how the Measures will be collected. Technical information on Sensors will be provided by partners in WP2.2.

It is difficult to identify all possible Performance Indicators and Measures that are needed for estimating traffic efficiency for any type of FOT system. However, Tables 1 and 2 contain those identified as generally useful for this purpose. The relationship between Performance Indicators and Measures is not shown in Tables 1 and 2, but is shown in the accompanying matrix.

#### Table 1 – Driver Behaviour Data: Performance Indicators

<table>
<thead>
<tr>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency of performed left and right lane changes</td>
<td>number per kilometre and hour</td>
</tr>
<tr>
<td>Frequency of active overtaking</td>
<td>number per kilometre and hour</td>
</tr>
<tr>
<td>Frequency of passive overtaking</td>
<td>number per kilometre and hour</td>
</tr>
<tr>
<td>Deviation from desired lane</td>
<td></td>
</tr>
<tr>
<td>Frequency of route changes</td>
<td>number per kilometre and hour</td>
</tr>
<tr>
<td>Travel time uncertainty</td>
<td></td>
</tr>
<tr>
<td>Delay</td>
<td></td>
</tr>
<tr>
<td>Following/free state profile</td>
<td></td>
</tr>
</tbody>
</table>

#### Table 2 - Driver Behaviour Data: Measures

<table>
<thead>
<tr>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceleration profile</td>
</tr>
<tr>
<td>Position</td>
</tr>
<tr>
<td>Time headway</td>
</tr>
<tr>
<td>Space headway</td>
</tr>
<tr>
<td>Performance Indicators</td>
</tr>
<tr>
<td>------------------------</td>
</tr>
<tr>
<td>Distance to other surrounding vehicles</td>
</tr>
<tr>
<td>Speed profile</td>
</tr>
<tr>
<td>Intended speed</td>
</tr>
<tr>
<td>Desired lane</td>
</tr>
<tr>
<td>Mental workload</td>
</tr>
<tr>
<td>Intended route</td>
</tr>
<tr>
<td>Actual route</td>
</tr>
<tr>
<td>Travel time (including stop time)</td>
</tr>
<tr>
<td>Travel distance (mileage)</td>
</tr>
<tr>
<td>Waiting time at intersections</td>
</tr>
<tr>
<td>Traffic density</td>
</tr>
<tr>
<td>Traffic flow</td>
</tr>
<tr>
<td>System interaction and driving behaviour related responses to alarm/warning</td>
</tr>
<tr>
<td>Reaction time to alarm/warning</td>
</tr>
</tbody>
</table>

These Performance Indicators and Measures should be ascertained for the baseline case (unequipped vehicle) FOT and equipped vehicle FOT, so that comparisons can be made between the two.

1.4 Situational data

In addition to the driver behaviour data, a series of additional ‘situational data’ have been identified. These are not necessarily directly relevant Performance Indicators or Measures, but must also be measured or recorded as they provide key background information that complements the driver behaviour data and is sometimes needed to derive the driver behaviour data.

For the situational data of a static nature, field observations or linkage of position and road databases are required. For the situational data of a more dynamic nature, e.g. traffic and driving conditions, road link measurements with loop detectors, video detectors, or other types of sensors are required. The situational data needed for Task 2.1.4, such as road type, weather conditions and light conditions are shown in Table 3.
### Table 3 – Situational data

<table>
<thead>
<tr>
<th>Area of Interest</th>
<th>Situational Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>System status</td>
<td>• On or off (including at which points during the journey e. g. on for the first hour, then switched off at 15:32) • Selected settings</td>
</tr>
<tr>
<td>Time</td>
<td>• Daylight/dark conditions                                                                                                         • Peak/off-peak/interpeak</td>
</tr>
<tr>
<td>Road environment</td>
<td>• Road type                                                                             • Environment (Urban/interurban/rural)                                                                                                 • Number of lanes</td>
</tr>
<tr>
<td></td>
<td>• Width of lanes                                                                       • Base capacity and saturation flows                                                                                                           • Central barrier</td>
</tr>
<tr>
<td></td>
<td>• Sight distance                                                                        • Speed limit                                                                                                                                         • Current traffic management: road markings, signs, etc</td>
</tr>
<tr>
<td></td>
<td>• Bus stops or parked cars along the street                                             • Hard shoulder                                                                                                                                     • Intersections</td>
</tr>
<tr>
<td></td>
<td>• Intersection frequencies                                                             • Intersection types                                                                                                                                • (signals/roundabouts/yield/stop)                                                                      • Number of stops on route</td>
</tr>
<tr>
<td>Traffic conditions</td>
<td>• Density                                                                                                                                       • Flow                                                                                                                                                • Speed distribution, average speed and standard deviation</td>
</tr>
<tr>
<td></td>
<td>• Traffic composition                                                                  • Other (unrelated) incidents that may affect traffic flow                                                                                     • Weather conditions</td>
</tr>
<tr>
<td></td>
<td>• Road conditions</td>
</tr>
<tr>
<td>Driving conditions</td>
<td>• Weather conditions                                                                                                                           • Wind speed                                                                                                                                         • Friction</td>
</tr>
<tr>
<td></td>
<td>• Precipitation (i.e. snow or rain)                                                    • Snow/ice</td>
</tr>
</tbody>
</table>

### 1.5 Model requirements

As mentioned above the choice of traffic model and the requirements on the traffic model depend to a large extent on the studied system. However, it is possible to outline some general model requirements. The traffic model has to offer possibilities to deal with enough vehicles such that it represents a typical traffic flow associated with the use of the system and also to model:

- the observed driving behaviour changes due to the system;
• the functionality of the system, if the system affects the vehicle’s performance; and
• the proportion of equipped vehicles in the modelled traffic flow..

1.6 Definitions
Where quantified definitions relating to traffic efficiency are required, for example, a
standard definition of congestion, these should be taken from the Highway Capacity Manual
(Ackerman et al., 2000).

1.7 References
Research Assignment (IN4140) TNO and TU Delft.

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Barcelo, Dumont, Montero, Perarnau and Torday (2002). Safety indicators for
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Annex WP2.1.6
Driver Characteristics
1 Executive Summary

Drivers differ on a large variety of characteristics, which may all have an influence on how they drive and use different systems and services. These differences may be important to take into account when planning a FOT. Four categories of driver characteristics may be distinguished:

- Demographic characteristics: gender, age, country, educational level, income, socio-cultural background, life and living situation, etc.
- Driving experience, and driving situation and motivation: experience in years and in mileage, professional, tourist, with or without passengers and children etc.
- Personality traits and physical characteristics: sensation seeking, locus of control, cognitive skills, physical impairments or weaknesses etc.
- Attitudes and intentions: attitudes towards safety, environment, technology etc.

Studies often focus on characteristics of individual drivers. However, drivers are not alone on the road. There are other road users and there may be passengers in the car, who may influence the driver’s behaviour.

There are several different reasons for considering driver characteristics:

- To make sure that the sample of drivers is representative of the target population.
- To explain the outcomes of the FOT.
- To improve systems and services, taking into account differences between drivers.

Driver characteristics may play different roles in FOTs:

- Characteristics of drivers possessed before the FOT may play a role in how they behave in traffic during the FOT.
- Although some characteristics are stable, other ones may change when using a system or service in the FOT. Attitudes may change radically before and after using a system for a longer period of time.

In general it is useful in a FOT to gather as many characteristics of drivers as practically possible. Even if no specific impacts are expected of certain characteristics, some outcomes may be explained better with more knowledge about the participants. A minimum set of data such as age, gender, income group and educational level is easy to gather from participants.

Next information is needed about driving experience. Usually this is measured by means of self-reports. The amount of practice, i.e. the mileage of an individual driver can be collected by asking the subject for an estimation of his/her overall mileage since licensing or the current mileage per year. However, beware that these self-reports are not very reliable.

For further understanding of driver behaviour one may consider to use questionnaires on attitudes, driving behaviour and personality traits. A well-known questionnaire about (self-reported) driving behaviour is the Driver Behaviour Questionnaire (DBQ). Some widely used
personality tests are the Five Factor Model (FFM) test and the Traffic Locus of Control (T-LOC) test. Special attention may be given to the personality trait of sensation seeking, which is correlated with risky driving. The Sensation Seeking Scale (SSS) measures this trait. These questionnaires are available in many different languages, but they are not always standardized and cultural differences may play a role. Personality traits are very easy to measure, just by administering a short questionnaire. However, the concepts and interrelations of factors are very complex, and results should be treated with caution.

When evaluating the acceptance and use of new systems in the car, drivers’ acceptability of technology is important. Both social and practical aspects play a role. Technology acceptance has different dimensions, such as diffusion of technology in the drivers’ reference group, the intention of using the technology, and the context of use (both personal and interpersonal). Measuring acceptability can be realized via (existing) standardized questionnaires, in-depth interviews before and after “use” (driving), and focus groups.
2 Introduction

2.1 Driver characteristics in general

Drivers differ on a large variety of characteristics, which may all have an influence on how they drive and use different kinds of systems and services. These differences may be important to take into account when planning a FOT.

Four categories of driver characteristics may be distinguished:

- Demographic characteristics: gender, age, country, educational level, income, socio-cultural background, life and living situation, etc.
- Personality traits and physical characteristics: sensation seeking, locus of control, cognitive skills, physical impairments or weaknesses etc.
- Attitudes and intentions: attitudes towards speeding, safety, environment, technology etc.
- Driving experience, and driving situation and motivation: experience in years and in mileage, professional, tourist, with or without passengers and children etc.

These characteristics are not independent; some are even highly related and influence each other. Combinations of these different characteristics may influence driving behaviour quite differently. For example, an elderly driver with a sensation seeking personality may take much less risk when driving with his grandchildren than when he was young and driving alone.

Characteristics may be stable and unchangeable, such as gender, or more volatile, such as attitude. Some of the driver characteristics can be measured very easily, such as age, but others are more complex, such as personality traits. Even simple demographic characteristics are not always easy to use for classifying drivers into groups, for example drivers who lived in different countries.

In this document we focus on characteristics of individual drivers. However, drivers are not alone on the road. There are other road users and there may be passengers in the car, who may influence the driver’s behaviour. For example studies have shown that young male drivers behave differently depending on the presence of passengers and on whether those passengers are male or female. There are also other kinds of influence, such as the (perceived) opinion of important others, such as parents, and more general social influences. So there is an interaction between the characteristics of the individual driver and those of other people.

2.2 The role of driver characteristics in FOTs

There are several different reasons for considering driver characteristics:

- To make sure that the sample of drivers is representative of the target population. If, for example, the sample contains a high percentage of young male drivers because
they were recruited from a university, the outcomes of the FOT will have less value for the whole population.

- To explain the outcomes of the FOT. If, for example, the FOT reveals that an anti-collision system causes a shorter headway for the group of sensation seekers, the cause may be that they increase their risk level by this behaviour.
- To improve systems and services. If, for example, the FOT reveals that elderly drivers did not benefit from a system while younger drivers did, improvement of the system may be focussed especially on this group.

Driver characteristics may play different roles in FOTs:

- Characteristics of drivers possessed before the FOT may play a role in how they behave in traffic during the FOT. For example young male drivers tend to be more prone to speeding.
- Although some characteristics are stable, other ones may change when using a system or service in the FOT, for example nervous drivers may become confident drivers because they feel that the new systems improve their safety. Attitudes may change radically before and after using a system for a longer period of time.

In general it is useful in a FOT to gather as many characteristics of drivers as practically possible. Even if no specific impacts are expected of certain characteristics, some outcomes may be explained better with more knowledge about the participants. A minimum of data such as age, gender, income group and educational level are easy to gather from participants. Next questions are needed about factual driving behaviour, such as mileage per year and reasons for driving (commuting, professional driving etc), and area of living and driving. For further understanding one may consider to provide questionnaires about attitudes, driving behaviour and personality traits. If there is reason to believe that characteristics are not stable, and may change during the FOT, it is recommended to administer the same questionnaire before and after the FOT.

In this document we will further explain the background of these characteristics, explain why they may be of interest in a FOT and how they may be measured. We will focus on three main issues:

- Driver experience, in Chapter 3
- Personality traits, in Chapter 4
- Self-reported driver behaviour, in Chapter 5
- Attitudes on technology, in Chapter 6

3 Driving experience

3.1 Description
The role of the factor “driver experience” has been discussed in the literature in particular within the context of the explanation for the strikingly high crash risk of young novice drivers. However, there is clear evidence that driving experience has a significant impact on
individual crash risk even if effects of age are controlled. Generally speaking, there seems to be a dramatic decrease of crash risk during the first months after licensing independently of driver age even if the starting level decreases with increasing driver age (Maycock et al., 1991). The variable “driving experience” describes the amount of practice a driver has gathered while performing the task of driving a vehicle which can be considered as the acquisition of a complex skill. This process can be described according to the well-known “Power-Law-of-Practice” which simply assumes that a skill or the proficiency of task performance increases as a function of practice (Groeger, 2000). There is also evidence that the “Power-Law-of-Practice” fairly nice describes skill acquisition when performing in-vehicle tasks like destination entry into a navigation system (Jahn et al., 2003).

There might be several mechanisms by which experience might influence driver behaviour. A very important finding in the context of FOTs has been reported by Lansdown (2002). The results of his driving simulator experiment suggest that novice drivers spend more time for looking away from the road when performing in-vehicle tasks than experienced drivers. As a whole Lansdown (2002, p.660) concludes that experienced drivers are “less taxed by the driving activity” which leaves them more spare-capacity from vehicle control for in-vehicle tasks. However, recent research provided no convincing evidence for the assumption that these additional capacities leads to a strong correlation between driving experience and hazard perception (Sagberg & Bjornskau, 2006). Moreover, the tendency to overestimate one’s own skill seems to be equally strong among novice and expert drivers (Waylen et al., 2004).

3.2 Measurement

Usually the variable “Driving Experience” is measured by means of self-reports. The amount of practice, i.e. the mileage of an individual driver can be collected by asking the subject for an estimation of his/her overall mileage since licensing or the current mileage per year.

We are not aware about much systematic research on the issue which question provides the better answers. At least with respect to reliability Tränkle (1981) found that the re-test reliability of self-reports of yearly mileage in a sample of young drivers (Median = 22 years of age) was surprisingly low ($r=.80$) whereas reports on lifetime-mileage seemed to be more stable ($r=.97$). However, as the subjects sample of this study was composed solely by students we cannot infer that the relationships found are also valid for the overall driver population.

3.3 Conclusions and recommendations for FOT

Without any doubt there is a need to have information on subjects’ individual driving experience when planning an FOT. As this variable can only be measured by means of self-reports and subjective estimations seem to be not very reliable we recommend to collect information about both aspects of driving experience (lifetime and yearly) and combine if needed.
4 Personality traits

4.1 Description

Personality is a complex concept. It consists of many different traits which are not always stable and may change over a lifetime. Personality may also be considered as a construct, derived from scores on research instruments. Just as intelligence is often operationalised by IQ (Intelligence Coefficient), where people have a high or a low score on an IQ test, personality traits are often determined by scores on a personality test, for example neuroticism. When determining personality of drivers, for using different driver groups in FOTs, we should not treat personality traits as discreet types like gender (one is either male or female). We cannot, for example, say that someone is neurotic or extrovert or not. However, we may say that someone is more neurotic if he/she scores higher on a neuroticism test or we may construct experimental groups with drivers who have passed a certain threshold in a test.

Personality traits may directly influence driving behaviour. However, different personalities may also have different attitudes and intentions, which are the determining factor for certain behaviour. For example a person with a high score on a sensation seeking test may drive more risky, but he/she may also have a different attitude about traffic rules and therefore not respect the speed limit, or he/she may take more risks in being late for meetings and therefore feels obliged to speed to arrive in time.

Using personality tests is a good way of making sure how certain personality types are represented in the study sample. If the percentage of drivers who score high on a sensation seeking scale is elevated in comparison with the normal driver population, or if these drivers are over represented in a certain condition, it will be harder to explain outcomes related to dangerous driving and to attribute them only to system characteristics.

Research on drivers’ personality has especially been focused on the relation between personality and unsafe driving and accidents. Two personality traits in particular of interest in this area: sensation seeking and locus of control.

4.2 Sensation seeking

Sensation seeking (SS) “is a trait defined by the seeking of varied, novel, complex, and intense sensations and experiences and the willingness to take physical, social, legal, and financial risks for the sake of such experiences” (Zuckerman, 1994 p. 27). Zuckerman (1994) has written a book on a large number of issues related to sensation seeking in a wide range of domains, and discusses a large number of international studies being done in this area. Sensation seeking has been found to be higher in males than females, and it declines with age. There seems to be a positive relationship with the level of education and occupational status. A high sensation seeking score is positively related with a wide variety of risky behaviours, for example risky sexual activities, gambling and financial risk taking.

The relationship between sensation seeking and risky driving and its consequences (such as collisions and citations for traffic violations) has been widely documented. Examples of risky driving are drinking and driving, non-use of seat belts, speeding and following too closely.
Jonah (1997) gives a comprehensive overview of 40 studies. He reports that sensation seeking accounted for 10-15% of the variance in risky driving. Although this is a high number, it also shows that it is not the only variable that plays a role. Jonah et al (2001) report that sensation seeking drivers may adapt their behaviour when using new systems that reduce risky driving, such as ABS. They may change their behaviour in order to maintain the same level of risk, so they may, for example, drive faster.

4.3 Locus of control
Another well-known personality trait is the concept of Locus of Control (Rotter, 1966). Individuals with an internal locus of control (internals) tend to perceive events as a consequence of their own behaviour whereas individuals with an external locus of control (externals) tend to believe events are under the control of external factors or powers that cannot be influenced. Research has suggested therefore that externals are more likely to be involved in traffic accidents since they are less likely to take precautionary steps and engage in responsible driving. Internals may overestimate their skills and since they believe that accidents are a consequence of their own behaviour engage in risky behaviour, confident that they possess the skills to avoid an accident.

However, not all studies give conclusive evidence of the relationship between locus of control and risky driving and accident involvement.

4.4 Five Factor Model of Personality
While sensation seeking and locus of control are specific personality traits, one can also look at a wider range. The five factor model of personality (FFM: Digman, 1990; Goldberg, 1993; McCrae & Costa, 1997) may be regarded as the basic structure of personality, consisting of:

- Extraversion: marked by pronounced engagement with the external world, characterized by positive emotions and being social, active and dominant.
- Neuroticism: relates to a tendency to be anxious, pessimistic and worry about one’s health.
- Conscientiousness: relates to the way individuals control, regulate and direct their impulses and is generally characterised by a tendency to be organised and persistent in pursuing goals.
- Agreeableness: refers to individuals concern with cooperation and social harmony and can be measured in terms of trust, compliance and altruism.
- Openness: characterised by a receptivity to new ideas and experiences.

Studies have been performed that link the factors of this model to aberrant driving behaviours, especially on the extraversion and neuroticism factors. A higher involvement in accidents is related to extraversion. High levels of neuroticism have been negatively related to driving confidence and positively related to driving stress. High levels of conscientiousness, agreeableness and openness are negatively related to risky driving, driving errors and involvement in accidents. However, the results are sometimes contradictory and there are interactions between the factors.
4.5 Other personality models

There is an extensive research on personality and many different models and tools exist. By no means have we intended to provide a complete list.

4.6 Measurements

4.6.1 Sensation Seeking

The Sensation Seeking Scale (SSS) operationalises this dimension and the SSS Form V is the most widely used measure of sensation seeking. The scale comprises of four sub-scales:

- Thrill and adventure seeking (TAS);
- Experience seeking (ES);
- Boredom susceptibility (BS);
- Disinhibition (Dis).

These subscales have been found to relate differently to various risky behaviours (Zuckerman, 1994) but Thrill and Adventure Seeking appears to have the strongest relationship to risky driving.

The scale contains 40 items. Respondents have to choose between alternatives, stating which one describes them best. An example of an item is:

A. I like “wild” uninhibited parties
B. I prefer quiet parties with good conversation

Zuckermann (1994) lists translations of the SSS into different languages.

An alternative scales is the Arnett Inventory of Sensation Seeking (AISS; 1994) which provides a short 20 item questionnaire which asks respondents to rate how likely each describes them. The scale is composed of two dimensions; novelty and intensity. An example item:

“I would like to travel to places that are strange and far away.”

(1 = describes me very well, 2 = describes me somewhat, 3 = does not describe me very well, 4 = does not describe me at all)

4.6.2 Locus of control

Montag and Comrey (1987) developed a test for locus of control consisting of two scales, a Driving Internality (DI) scale and a Driving Externality (DE) scale, designed to measure these constructs with specific reference to driving. Özkan and Lajunen (2005) have developed a driving targeted multidimensional locus of control scale. There are four scales within their Traffic Locus of Control Scale (T-LOC):

- “Other Drivers” (causes of accidents attributed to other drivers);
- “Self” (causes of accidents attributed to oneself);
- “Vehicle and Environment” (causes of accidents attributed to external factors);
- “Fate” (causes of accidents attributed to fate or bad luck).
In the T-LOC, participants are given a list of 16 possible causes of accidents. They are asked to indicate on a five-point scale how possible it is that those 16 reasons had caused or would cause an accident when they think about their own driving style and conditions. An example item:

“Whether or not I get into car accident depends mostly on shortcomings in other drivers’ driving skills” scale (1=not at all possible and 5=highly possible)

4.6.3 Five Factor Model of Personality
For the five factor scale of personality an international pool of items is available (see http://www.ipip.ori.org/). The test consists of 10 items per factor. Subjects are given a statement and they have to indicate on a five points scale how accurate it describes them. An example item (for extraversion) is

“Am the life of the party” 1 very inaccurate – 5 very accurate

The tests for the Five Factor Model have also been translated in many languages; contacts are available on the International Personality Item Pool website: http://www.ipip.ori.org/.

4.7 Use of personality traits and driver behaviour in FOTs
An example of using personality tests is the Intelligent Cruise Control Field Operational Test of the University of Michigan for the US National Highway Traffic Safety Administration (Francher et al., 1998). They administered a personality test before the FOT and a driver style test before and after the FOT. This last test was constructed for this study. The tests were used to investigate the differences between participants and to see whether the driving style was changed by the use of the system.

4.8 Concerns
Different variations of tests discussed above are used in different studies. Sometimes fewer items are used in order to avoid giving drivers very long questionnaires to fill in. It is, however, questionable what happens to the reliability if only a few items are used.

All the tests discussed above are translated in many different languages. Questionnaires are not always translated literally, sometimes wording or even complete items have to be changed in order to be made more understandable for a certain group. It is often the researcher who takes care of a translation for a specific study. This means that for most countries there are no formalised or standardized tests.

Studies performed with subjects with different nationalities and cultural background found differences, sometimes in interaction with variable like gender and age. We may assume that are cultural differences in how people perceive, for example, risk and sensation, and thus value items in test.

Another problem with administering personality tests is that these kinds of concept become more and more known by the general public. For example at the BBC website you can fill in the SSS yourself http://www.bbc.co.uk/science/humanbody/mind/surveys/sensation/. In Australia, a shortened version of the SSS is given on the official site for the driver
qualification test, so that drivers can test themselves in order to see whether they fall into the risk category:


You can even do a driver personality test on-line:


If a large part of the population for a FOT is already familiar with a test, bias in completing it may occur.

In conclusion, personality traits are very easy to investigate, just by administering a short questionnaire. However, the concepts and interrelations of factors are very complex and even if there are strong correlations with dangerous driving, this relation is mainly statistical. We should not say things like that a certain driver is a sensation seeker and that that is the reason for speeding.

Given the mixed evidence especially regarding Locus of Control and the Five Personality Factors, their role in FOTs as a variable for driver characteristics should be treated with caution.
5  Self-reported driver behaviour

5.1  Description
Another way of looking at driver characteristics is look at their self-perceived and intended behaviour. There is a more direct link between intended and actual behaviour than between personality and behaviour. The theory of planned behaviour (Azjan, 1988) explains that human behaviour is guided by three kinds of considerations:

- Behavioural: beliefs about the likely outcomes of behaviour;
- Normative: beliefs about the normative expectations of others and motivation to comply with these expectations;
- Control: beliefs about the presence of factors that may facilitate or impede performance of the behaviour and the perceived power of these factors.

Together these beliefs lead to an intention to behave in a certain way. Of course the actual behaviour is also influenced by the actual control one has to execute the behaviour. For example, the intention to drive faster may be caused by the beliefs that it will bring you quicker at your destination (behavioural), that everyone speeds (normative) and that there are no dangerous bends in the road (control). If there is no speed limiting system in the car (actual control), a driver with this intention will probably speed. Asking drivers about their beliefs will thus predict, at least for some part, their behaviour.

Another way of distinguishing driver groups is to ask them directly about their behaviour. Of course one has to be aware that there is a clear distinction between asking a driver about past behaviour and measuring the behaviour directly with an objective method.

Drivers may be questioned about all different kinds of beliefs, intentions and behaviour. If we want to focus on risky behaviour a distinction may be made between (Reason et al., 1990):

- Errors: planned actions which fail to achieve their intended consequences, for example a misjudgement of distance to another car;
- Lapses: attention and memory failures, for example getting into the wrong lane when approaching a roundabout;
- Violations: deliberate deviations from safe and legal practices, for example running red traffic lights. Also aggressive acts fall under this category.

Again the determining factor is the intention, not the observable outcome of the behaviour. Driving too fast on a certain road may be caused by braking too late (error), forgetting the maximum speed for this road (lapse) and speeding (violation). Studies show that especially a high score on violations is positively related to accident involvement. A high frequency of lapses may be an indication for older drivers that they are not fit to drive.
5.2 Measures
The Driver Behaviour Questionnaire (DBQ) is widely used to measure driver behaviour (Reason et al. 1990). The questionnaire consists of items describing errors, lapses and violations. The subject has to indicate on a 6 point scale the frequency with which they committed each type of aberrant behaviour. There are different variations of this test, but the original test has 50 items. A 24 item test is also used often (Parker et al., 1995). An example item:

"Misjudge speed of oncoming vehicle" (0 = Never to 5 = nearly all the time)

For measuring beliefs and intentions one may also devise a dedicated questionnaire. A guideline from Azjen (2000) may be found on:

http://people.umass.edu/aizen/pdf/tpb.measurement.pdf. Especially for investigating the intentions and beliefs about a specific system for a FOT this may be a good option.

5.3 Other self-reported driver characteristics
There are also other self reported driver characteristics, such as driving style and driving competence. There are no standard methods for measuring this. Studies often construct their own method and test, sometimes based upon the tests described above.

5.4 Use of driver behaviour tests in FOTs
In the Road Departure Crash Warning System Field Operational Test of the University of Michigan for the US National Highway Traffic Safety Administration (LeBlanc, et al., 2006), the following tests were used in the pre-driving phase: DBQ, driver style, SSS, and locus of control to be used in analyses of driver acceptance. Four other measures were collected. They included the sensation seeking scale, the locus of control scale, a driving risk assessment questionnaire, and a driving dilemma scenarios questionnaire. These four measures were not directly used in any subsequent RDCW FOT analyses, but were administered to RDCW drivers to facilitate other research projects.

5.5 Concerns
The same concerns that were identified for the personality traits apply to tests of self-reported driver behaviour. Again there are many variations of the DBQ, both in terms of length, items and language.
6 Acceptability of Technology

6.1 What is Acceptability?
1. “Satisfactoriness by virtue of conforming to approved standards.” “Worthy of being accepted.”
2. “Adequate to satisfy a need, requirement, or standard; satisfactory"

Regarding the field of “technology acceptance”, the term acceptability indicates the degree of approval of a technology by the users, which can be measured by the frequency of use. According to Nielsen (Nielsen, 1993), the general acceptability of an interactive system depends on, whether a system can satisfy the needs and expectations of its users and potential stakeholders.

6.2 Social Acceptability and Practical Acceptability of Technology
Acceptability in the framework of introducing new technologies (cf. Innovation), relates to social and individual aspects as well, another distinction of different levels of acceptability can be operated, regarding “social acceptability” and “practical acceptability” (cf. Nielsen, 1993).

- “Social acceptability” can be defined as an “ex-ante” acceptability, which refers to the social representations and socio-cultural disposition prior to the use of a specific technology.
- “Practical acceptability” refers to acceptability in the framework of the real confrontation with a given technology and the individual decision to use this technology or not.
- Further, the aspects of perceived utility and usability, as well as the aptitude to use the technology should be integrated in this framework.

The distinction of “social acceptability” to “practical acceptability” operates of two levels, an upstream level, which considers the societal dimension of acceptability and a downstream level, on which the individual acceptability is considered. Both levels are in a kind of hierarchical relationship, meaning that the social acceptability is prior to the practical acceptability on the individual level.

Social Acceptability relates to the socio-cultural predispositions towards a technology, which is socially constructed on behalf of social representations. In the framework of a constructivist approach (cf. Engel, Krishnakumar et. al., 2007) the following dimensions are addressed in Social Acceptability analysis:

- Degree of diffusion of a technology

11 (http://wordnet.princeton.edu)

12 (The American heritage dictionary of the English language; 2006; http://dictionary.reference.com)
• Technological culture in general
• Ethical predisposition for use
• Social expectations (expected benefits versus expected negative side effects)
• Risk perception
• Social representations for use precedents (reference cases via reference groups, peers)
• Social norm

Practical acceptability is also multidimensional – it includes perceived usefulness (which includes a distinction in utility and usability), and includes further the following dimensions:

• Perceived utility
• Individual technical culture
• Education level
• Experience with related technology
• Individual usability criteria
• Individual risk perception
• Subjective norm
• Satisfaction
• Cost
• Compatibility with existing systems

Usefulness = utility and usability

The usefulness of a system refers to the aspect, if the system can meet the needs of the user and help him to achieve his (expected) goals. According to Grudin (1992), usefulness should be split up in the dimensions of utility – which refers to the functional aspects of the system (the system is able to do what is needed) and usability – which concerns the aspects of the user’s general capacity to interact with the system (including installation and maintenance issues).

6.3 Social Acceptability of Technology and the Dimension of Aptitude and Access to Technology

To understand Social acceptability better, the analysis should not only limit itself on a “voluntaristic” perspective on potential users’ attitudes regarding their interest of using a technology. Another important dimension is the aptitude of using a technology in the sense of having (or having not) technological culture in the sense of first-hand user experience and access to new technologies (cf. Castells, 2002). For example, the notion of the “digital divide” applies perfectly to the domain of automotive technology, in the sense that the knowledge of how to use a computer is a condition to use most of the current on board navigation systems (knowledge of what is a “menu” or arborescence, for example).

Consequently, Social Acceptability includes the dimensions of the social conditions (cf. Bourdieu, 1979) and the cultural background, permitting access to new technologies’ use, which leads to the question of if there are specific socio-cultural factors which facilitate access and use of new technologies.
6.3.1 Apprenticeship and factors facilitating access to new technologies
Acceptability and potential use of new technologies cannot be disconnected from the users’ social roots, which means, the socio-cultural dispositions of the users has to be studied and user-profiles (ore merely, Acceptability profiles) should be developed. The identification of the apprenticeship process for specific social categories is a complementary dimension to investigate.

The linkage of the aptitude (social and technical) to use a technology, utility and usability has to be completed with the economic aspect for the user: is he willing and able to afford a new technology, dimension which not only relates to (sometimes overestimated) “willingness-to-pay” approaches, but to socio-economic conditions (budget and vital priorities) of the target users. Acceptability is multidimensional and its analysis requires multidisciplinary approaches; there are plenty of examples of technologies being perfectly usable but never socially accepted (cf. Shakel, 1991).

6.3.2 Social Acceptability Profiles
To improve Acceptability of Technology ‘Analysis, a further profiling of potential users regarding their degree of acceptability towards technology in general appears as an interesting perspective. For example, Rogers (1995) points out the role of categories such as “early adopters” or “innovators” which in fact constitute examples for Social Acceptability Profiles, regarding their role as “leaders” in the acceptance of innovations. On the other hand, it can be expected that there exist at least one profile with a less privileged access (or “refuter”-patterns) to technology that has to be decrypted as well, to be sure to have a complete scope on Social Acceptability.

6.4 The role of Acceptability of technology in FOT’s
Acceptability is the key issue for the diffusion of new technologies in the automotive sector and regarding the aspect of road safety improvement. In the framework of FOT, several arguments have to be considered regarding the aspect of Acceptability of technology:

- To integrate a maximum of useful criteria, which will help to analyze the conditions (and obstacles) that facilitate Acceptability of the technologies implemented through the FOT.
- To contribute, together with the analysis of Driver Characteristics, to a performing segmentation process, aiming to constitute a diversified target population for the FOT field phases.
- To determine, via the FOT research, what are Acceptability criteria for new technologies in the automotive sector and so contribute to improve public implementation strategies.

6.5 Concepts for measuring acceptability of technology

6.5.1 Diffusion of innovations (Rogers, 2003)
The basic concept of this model is to explain phenomena of adaptation and diffusion of innovations in general; five variables are supposed to have an influence regarding the individual adaptation of technologies:
• Relative advantage: on what extent a technology offers improvements over available technology.
• The compatibility with the value system of the reference group
• The level of complexity of the technology, ease of use and learning;
• The possibility to test the technology;
• The aspect of visibility / observability, on what extent the technology’s advantages are clear to see.

These five variables form together a system of predictors for the intentions of using a technology.

6.5.2 Theory of planned behaviour (Ajzen & Fishbein, 1975)
Fishbein and Ajzen (1975) proposed this general model aiming to explain and predict individual behaviour (see also Chapter 5). According to this theory, the behaviour of an individual is directly determined by his intention to realize this behaviour. The intention hereby is a function of three variables, being:

1. The attitude, which is formed by all the faiths as for the consequences of the realization of the behaviour, balanced by the importance that the individual grants to each of these consequences;

2. The subjective norm that refers to the system of beliefs of an individual, as for the opinion of persons or reference groups with regard to the fact that they do behave or act in a specific way.

3. The perceived behavioural control corresponds to the degree of perceived ease or difficulty that represents the realization of a behaviour for the individual. This variable reflects the presence of external factors, which facilitate or hinder the realization of a given behaviour, as well as the perception of the individual of its personal efficiency to realize this behaviour. This variable can act, in the same way as the attitude and the subjective norm on the intention, or can contribute to predict the behaviour, when this one is not under the individuals’ voluntary control.

6.5.3 Technology acceptance model (TAM) (Davis, 1989)
The model proposed by Davis (1989) is based on the theory of Fishbein and Ajzen (1975), but represents a variant which specifically applies to the behaviour of adoption of information technologies. According to the TAM, the intention to use a technology is the direct antecedent of the behaviour of use. However, contrary to the theory of the strategic behaviour, the TAM includes only the attitude in the forming process of the intention. Furthermore, according to the model of Davis (1989) the attitude is determined itself by two types of faiths: the perceived utility and the perceived ease of use.

6.5.4 The theory of interpersonal behaviour (Triandis, 1972)
Triandis’ theory of interpersonal behaviour includes peer influences and situational characteristics in explaining behaviour; this psychosocial model is used to understand the behaviour of adoptions of the technologies. According to this theory, a behaviour is directly determined by three variables:
1. The intention to adopt a behaviour;
2. The custom to execute this behaviour or a close behaviour;
3. The conditions facilitating the adoption, which dismiss to variables outside the person, who can have an influence on the adoption or not technologies.

In this behavioural model, the intention is determined by four factors: the social factors, the received consequences, the affects and the personal convictions. Triandis introduces a research paradigm, the “subjective culture”, which he defined as a social group’s specific way to perceive its social environment; the subjective culture forms a system of beliefs and meanings, interpersonal relationships, norms and values as well as attitudes that guide interaction of persons in various social contexts.

To measure the different dimensions, which constitute Acceptability in FOT, tools such as standardized Questionnaires, Focus Groups and individual interviews can be applied. Also, a performing method for self-reporting will complete the data collection on acceptability.

6.5.5 Socio-demographic data
To complete the analysis of Acceptability of technology, socio-demographic variables should be constantly integrated. Age, gender, education level, the professional situation as well as information on the geographic situation and habitat do contribute to complete the knowledge of factors for technology’ acceptability.

6.5.6 Context
Finally, an evaluation of Acceptability factors has to consider the context wherein the technology is supposed to be used. In the framework of driving, the context is constantly changing and the driver has to adapt, sometimes under emergency conditions. To fully understand if the users / drivers are willing and able to accept new technologies in their cars, the different dimensions of social and practical acceptability have to be examined in a variety of real world contexts.

6.5.7 Willingness to pay
A way of measuring acceptability is to look at willingness to pay. If the user accepts the technology and perceives the utility, he/she will be willing to buy a system. However, willingness to pay is also dependent on other factors, such as the financial situation of the user and the price of the system in comparison with other similar systems. Also the question whether other people, important for the user, are buying the system plays a role. Willingness to pay is an important indicator for acceptability, but it should be treated with caution. There are also systems that do not bring a clear individual benefit to the user, but provides social benefits, such as in the area of safety and environment. Willingness to pay may be much lower, but that does not mean that the technology is not acceptable or that users would not be ready to adopt the system.

6.6 Conclusion
Regarding Acceptability of Technology, there does not exist a unique model or theory today; there are several variables which altogether contribute to analyze, what are conditions that will enhance or hinder potential users’ acceptability of new technological systems.
Acceptability hereby has to be explored on an upstream level, whereas the dimensions of social acceptability such as technical culture, norms and beliefs have to be analyzed, towards a downstream level of practical acceptability, which refers, among others, to the individual capacity, perceived utility and understanding of technology. The aspects of user experience and training also impact the different level of Acceptability of technology, as well as the analysis of the context of its potential use. One suggestion for further research on Acceptability is to focus on the identification of “Acceptability Profiles” by a segmentation approach through the diverse Acceptability approaches collected in this paper. Regarding the specific FOT context, measuring of acceptability can be realized via (existing) standardized questionnaires, based on a methodology mix of the presented theoretical approaches, in-depth interviews before and after “use” (driving), and Focus Groups.
7 References


