The representativeness of driving cycles in real world traffic

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Christian Engström

Rototest AB, 2001
Foreword

This report analyses the extent to which driving cycles are representative of real-world traffic. The project was co-financed by the Swedish Transport and Communications Research Board (KFB and the Swedish National Road Administration (SNRA).

The report was written by Jonny Färnlund and Christian Engström, Rototest AB, with Färnlund as project manager. The project plan was discussed with Håkan Johansson at the Environment and Natural Resources Division of the SNRA prior to implementation.

We would like to take this opportunity to express our appreciation to Håkan Johansson, SNRA and Göran Friberg, KFB for their encouragement and support.

Rönninge, January 2001

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# Table of contents

Foreword................................................................................................................................. 2
Table of contents ......................................................................................................................... 3
Summary..................................................................................................................................... 4
Introduction................................................................................................................................. 7
Basis for comparison..................................................................................................................... 8
General comparison.................................................................................................................... 9
  Speed distribution .................................................................................................................. 9
    Comparison related to time ................................................................................................. 10
    Comparison related to distance ......................................................................................... 12
  Distribution of acceleration................................................................................................. 12
    Comparison related to time ................................................................................................. 12
    Comparison related to number ......................................................................................... 12
Sequence agreement.................................................................................................................. 12
  Objectives of driving cycles ................................................................................................. 12
  Why compare sequences? ..................................................................................................... 12
  Method of comparison .......................................................................................................... 12
  Result....................................................................................................................................... 12
    Agreement between the driving cycles and real-world traffic..................................... 12
    Mean agreement .................................................................................................................. 12
    Specific sequence lengths ............................................................................................... 12
    Unique sequences in real-world traffic ............................................................................. 12
    Sensitivity analysis ............................................................................................................ 12
Conclusion and discussion......................................................................................................... 12
References................................................................................................................................... 12

Appendix A – Method .................................................................................................................. 15 pages
Appendix B – Representativeness of driving cycles ................................................................. 5 pages
Appendix C – Driving cycles .................................................................................................... 5 pages
Appendix D – Sensitivity analysis ............................................................................................ 2 pages
Appendix E – Distribution of acceleration .................................................................................. 11 pages
Appendix F – Test vehicles SDPS-98 .......................................................................................... 1 page
Summary

All industrialised countries today test vehicles in order to approve them for use in traffic. All these tests are based on the same principle: running the vehicle through a simulated driving cycle comprising a certain distance and varying speed profiles on a so-called rolling road while measuring emissions and energy consumption. The test cycles are used today in developing emissions models, in fuel consumption declarations and as test methods for technical development, etc. However, one question still remains unanswered: how well do these driving cycles represent real-world traffic?

Driving cycles have two main objectives
• to provide a representative indicator of vehicle emissions and energy consumption at the local and national level,
• to function as a control instrument in connection with certification or I/M (Inspection and Maintenance).

Using a driving cycle that is intended for control, for example, as a representation of emissions, would probably result in considerable error.

How well driving cycles represent real-world traffic has been shown in this report to be remarkably low from the perspective of driving pattern sequences. The mean agreement percentage is presented in the table below.

Table 1 – Mean agreement from the perspective of driving pattern sequences

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Mean Agreement Percentage*</th>
</tr>
</thead>
<tbody>
<tr>
<td>FTP75</td>
<td>17 %</td>
</tr>
<tr>
<td>A9</td>
<td>12 %</td>
</tr>
<tr>
<td>EDC</td>
<td>9 %</td>
</tr>
<tr>
<td>US06</td>
<td>5 %</td>
</tr>
</tbody>
</table>

* Weighted mean

The low level of representativeness raises the question as to whether it is applicable to use the results from today’s driving cycles as a basis for emissions models. Further studies are needed to ascertain whether standardised driving cycles can be used for this purpose.
The material used as the basis for the comparisons in this study was extracted from the logged driving patterns collected in a study conducted by the SNRA and the Lund Institute of Technology. This study, which involved test subjects, was conducted in and around Västerås in 1998 and is designated SDPS-98. As this study was restricted to one average size city (by Swedish standards), material is lacking from the larger Swedish cities: Stockholm, Göteborg and Malmö. It is therefore essential that measurements also be conducted in these regions, which account for most of the vehicle mileage in Sweden. This would make it possible to compare the representativeness of driving cycles in these metropolitan areas as well, where very different driving patterns would probably be found under certain circumstances (e.g. rush hour traffic).

The first part of the report contains a general comparison. It concentrates on the distribution of speeds and accelerations in the EDC, FTP75, US06 and A9 driving cycles in comparison with real-world traffic.

Conventional comparisons of EDC, FTP75, US06 and A9, i.e., with time as a reference, showed that FTP75 represents real-world traffic better than the others. There is a clearly larger proportion of low speeds compared to real-world traffic in the speed distribution for EDC. FTP75 lacks the higher speeds while US06, and to a certain extent A9 as well, have a large proportion of higher speeds. When comparisons were made as regards the distribution of the number of accelerations, it was seen that A9 complied best.

The mean and median speeds for the different cycles are compiled in Table 2. It is interesting to note the differences between the mean and median figures. In the case of US06, the median time is considerably higher than the mean time while the opposite applies to A9. There is even a substantial difference between the mean and median figures when comparing the speed in relation to the distance. What is most striking here, compared to the time-related distributions, is the considerably higher speeds. The mean speed is 19-36 km/h higher when related to the distance than to the time. The corresponding median figures are 6-59 km/h. Even SDPS-98 increased 22 and 23 km/h through the same comparison. It was therefore concluded that both the time and distance relation should be used when comparing speed distributions.

<table>
<thead>
<tr>
<th>Speed [km/h]</th>
<th>EDC</th>
<th>FTP75</th>
<th>US06</th>
<th>A9</th>
<th>SDPS-98</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (time)</td>
<td>33</td>
<td>48</td>
<td>78</td>
<td>46</td>
<td>50</td>
</tr>
<tr>
<td>Mean (distance)</td>
<td>62</td>
<td>68</td>
<td>97</td>
<td>82</td>
<td>72</td>
</tr>
<tr>
<td>Median (time)</td>
<td>32</td>
<td>44</td>
<td>96</td>
<td>37</td>
<td>50</td>
</tr>
<tr>
<td>Median (distance)</td>
<td>56</td>
<td>76</td>
<td>102</td>
<td>96</td>
<td>73</td>
</tr>
</tbody>
</table>
The mean accelerations divided into positive and negative (decelerations) in relation to time and number are compiled in Table 3. What can be observed is that the figures for the cycles that are based on real-world driving cases (all except EDC) are approximately twice as high when related to number as opposed to time.

<table>
<thead>
<tr>
<th>Mean acceleration [m/s²]</th>
<th>EDC</th>
<th>FTP75</th>
<th>US06</th>
<th>A9</th>
<th>SDPS-98</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negative (time)</td>
<td>-0.71</td>
<td>-0.54</td>
<td>-0.80</td>
<td>-0.56</td>
<td>-0.49</td>
</tr>
<tr>
<td>Negative (number)</td>
<td>-0.80</td>
<td>-0.94</td>
<td>-1.50</td>
<td>-0.98</td>
<td>-1.03</td>
</tr>
<tr>
<td>Positive (time)</td>
<td>0.58</td>
<td>0.41</td>
<td>0.66</td>
<td>0.53</td>
<td>0.44</td>
</tr>
<tr>
<td>Positive (number)</td>
<td>0.71</td>
<td>0.78</td>
<td>1.58</td>
<td>0.92</td>
<td>0.92</td>
</tr>
</tbody>
</table>

The second part of the report discusses how representative driving cycles are of real-world traffic through the comparison by sequence method. A driving pattern sequence is described as a defined speed profile in a given time interval.

A basic reason for using driving pattern sequences in comparisons is that engine behaviour is not completely consistent. From this originally having been attributed to variations being more or less random, recent years have seen a trend towards variations that are more controlled, e.g. through variable valve timing and varying amounts of EGR.

Rototest has developed a sequence comparison method, COMPASS (“COMPAriSon by Sequence”). The primary advantage of this method is its simplicity, which promotes greater acceptance of the results. It can be described as choosing a driving pattern sequence of time length “t”, and searching for this sequence in a specific data aggregate. The method has proved to be very useful and easy to apply in data aggregates that are both large and varied.

A driving cycle intended solely for inspection control purposes should contain a large quantity (if not all) of the unique sequences that are represented in real-world traffic. From the perspective that it is to contain all the unique sequences that are 15 seconds long, the driving cycle must be close to 100 hours long.
Introduction

All industrialised countries today test vehicles in order to approve them for use in traffic. All these tests are based on the same principle: running them through a driving cycle comprising a certain distance and varying speed profiles on a so-called rolling road while measuring emissions and energy consumption. The test cycles are used today in developing emissions models, in fuel consumption declarations and as test methods for technical development, etc. However, one question still remains unanswered: how representative are these driving cycles to real-world traffic? It is the intention of this study to answer that question.

Rototest has performed vehicle emission measurements since 1991 and conducts over a hundred vehicle analyses per year on behalf of public authorities, the media and vehicle manufacturers. Apart from the measurements performed in the laboratory environment, measurements have been conducted on vehicles in real-world traffic since 1993. Based on its experience in these activities, Rototest has been somewhat sceptical about the multi-faceted use of standard driving cycles, such as EDC, FTP75, etc. This scepticism has been expressed in various contexts since 1994, and has also been brought up in several studies.
Basis for comparison

In order to be able to study how well a driving cycle represents real traffic, a sufficient amount of material on which to base a comparison is required. The material referred to as real-world traffic in this study, and which provided the basis for the comparisons, was obtained from the driving pattern logs of the study involving test subjects conducted by the SNRA and the Lund Institute of Technology in and around Västerås. This study was carried out in 1998 and is designated SDPS-98 (Johansson H et al, 1999). Västerås, with some 126 000 inhabitants, was chosen as representative of an average Swedish city with respect to type of street and topography. This study was conducted during a 12-week period, between September and December 1998, and included 5 different 1998 car models, and involved 30 different families. The vehicles, which each family loaned for 14 days, were comparable to their own both as regards engine power and size. The test subjects were randomly selected by the Lund Institute of Technology and ranged between 17 and 79 years of age. Apart from the family member borrowing the car, husbands/wives, cohabts and/or children still living at home were also at liberty to drive it. A questionnaire sent out after the conclusion of the study showed that 45 drivers had taken part. Of these, 29 percent were women and 50 percent were between the ages of 36 and 59. The questionnaire also showed that 79 percent had used the borrowed vehicle as much as they normally used their own, while 18 percent said that they used the vehicle less than normal.

All in all, the driving pattern logged for all the vehicles in the study covered a distance of 18 945 km (Engström C et al, 1999). 2 551 trips were registered and the total data aggregate amounted to 1.6 gigabytes (about 350 hours). Due to the data from the Volkswagen Polo (2 688 test km) being somewhat uncertain, it was decided to completely exclude this data from the reference material for this study.

The driving cycles used as reference material are:
- EDC, European certification cycle.
- FTP75, (Federal Test Procedure), American certification cycle.
- US06, supplement to FTP75.
- A9 (modem cycles), combination of four cycles developed within the joint European project called DRIVE (André M et al, 1998).
- EFUA, combination of the foregoing driving cycles designed by Rototest for this study, i.e., a combination of EDC, FTP75, US06 and A9.
General comparison

The motion resistance that a vehicle must overcome is primarily related to the speed of the vehicle and its acceleration. Other contributory factors are gradient, surface conditions, wind velocity, etc. These external factors are not treated in this study. This section focuses on the speeds and accelerations in the EDC, FTP75, US06 and A9 driving cycles compared to SDPS-98.

Speed distribution

Driving cycles are defined using a nominal speed at a given point of time. Measurements on roads are also often done on a fixed time basis. In the case of SDPS-98, the time resolution was 0.1 second. It is therefore natural that comparisons are made with time as a reference. There is, however, always a risk of unintentional misinterpretation.

Mean speed is the most commonly used indicator to describe speed, probably because it is the easiest to measure and understand. Unfortunately, it can just as easily be misinterpreted or used incorrectly. Mean speed, in its ordinary sense, conveys the information that a distance is being travelled in a certain time. A more correct term would be time-based mean speed. What it actually indicates is a measure of mobility, i.e., that a certain distance can be covered in a certain time. On the other hand it does not say anything about how fast one is travelling.

Using distance as a reference provides another indicator of speed distribution. The disadvantage of this indicator is that it is not at all as easy to measure. It requires continuous logging followed by post-calculation to determine the mean speed over the distance covered. The difference is best illustrated by a theoretical example where, for the sake of simplicity, the acceleration times are set at zero.

Table 4 – A simple comparison

<table>
<thead>
<tr>
<th>Distance</th>
<th>Speed</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 km</td>
<td>60 km/h</td>
<td>4 min</td>
</tr>
<tr>
<td></td>
<td>0 km/h</td>
<td>2 min</td>
</tr>
<tr>
<td>4 km</td>
<td>60 km/h</td>
<td>4 min</td>
</tr>
<tr>
<td>8 km</td>
<td></td>
<td>10 min</td>
</tr>
</tbody>
</table>
This example illustrates a constant speed broken by a pause after half the distance. The normal, mean speed related to the time is then given through 8 km being covered in 10 minutes, corresponding to 48 km/h. (Despite the fact that this never was the speed driven.) The mean speed related to the distance is 60 km/h instead. By adding the time for the pause, the mean speed related to the time decreases while the mean speed in relation to the distance is not affected. This example illustrates that the mean speed related to distance provides a better indicator of the speed driven.

An example of a mean value based on distance, and one that is used very often, is a vehicle’s average fuel consumption. Unfortunately, this value is often used together with the mean speed based on time. In principle, this would be, if not incorrect, at least highly uncertain, and shows how easy it is to draw the wrong conclusions!

**Comparison related to time**

The speed profiles for EDC, FTP75, A9 and US06 are shown in Figures 1 to 4. These are presented as a given speed at each specific time. The most obvious differences between the cycles is that EDC has more straight segments, with less variation than the others and that US06 has a much greater percentage of higher speeds.

![Figure 1- EDC driving cycle](image-url)
Figure 2 - FTP75 driving cycle

Figure 3 - US06 driving cycle
This is also reflected in Figure 5 where the cumulative time distribution for the driving cycles is compared with SDPS-98.

Worth noting is the substantially higher percentage of idling in the case of EDC, approximately 27% of the time, compared to FTP75.
and A9 at 12% and 14% respectively, with US06 clearly the lowest at 6%. Otherwise, EDC has a clear preponderance of low speeds, while US06 is distinguished by a large proportion of higher speeds. FTP75 largely complies with SDPS-98, except at the higher speeds. The mean speeds related to time are compiled along with the cumulative levels in table 5.

Table 5 – Comparative values for speeds related to time

<table>
<thead>
<tr>
<th>Cumulative level</th>
<th>EDC</th>
<th>FTP75</th>
<th>US06</th>
<th>A9</th>
<th>SDPS-98</th>
</tr>
</thead>
<tbody>
<tr>
<td>25% lower quartile</td>
<td>0</td>
<td>26</td>
<td>45</td>
<td>10</td>
<td>23</td>
</tr>
<tr>
<td>50% median</td>
<td>32</td>
<td>44</td>
<td>96</td>
<td>37</td>
<td>50</td>
</tr>
<tr>
<td>75% upper quartile</td>
<td>50</td>
<td>77</td>
<td>107</td>
<td>78</td>
<td>77</td>
</tr>
<tr>
<td>Max</td>
<td>120</td>
<td>96</td>
<td>129</td>
<td>129</td>
<td>140</td>
</tr>
<tr>
<td>Mean</td>
<td>33</td>
<td>48</td>
<td>78</td>
<td>46</td>
<td>50</td>
</tr>
</tbody>
</table>

It is interesting to note the differences between the mean and median values. For US06 the median is considerably higher than the mean while the opposite applies to A9.

Comparison related to distance

Figures 6 to 9 show what is obtained when presenting EDC, FTP75, A9 and US06 with respect to distance. The most obvious difference compared to the foregoing is the basic lack of idling sections and that the sections with higher speeds are proportionally larger. Although both of these are self-evident, this can still give rise to some reflection.

Figure 6 - EDC driving cycle related to distance
Figure 7 - FTP75 driving cycle related to distance

Figure 8 - US06 driving cycle related to distance
The cumulative distribution of speeds also looks different. Figure 10 shows that EDC has a larger proportion of lower speeds than SDPS-98, that FTP75 lacks the higher speeds while US06, and to a certain extent A9, have a larger proportion of higher speeds.
The mean speeds related to distance and different cumulative levels are compiled in Table 6.

Table 6 – Comparative values for speeds related to distance

<table>
<thead>
<tr>
<th>Cumulative level</th>
<th>EDC</th>
<th>FTP75</th>
<th>US06</th>
<th>A9</th>
<th>SDPS-98</th>
</tr>
</thead>
<tbody>
<tr>
<td>25% lower quartile</td>
<td>35</td>
<td>46</td>
<td>91</td>
<td>52</td>
<td>53</td>
</tr>
<tr>
<td>50% median</td>
<td>56</td>
<td>76</td>
<td>102</td>
<td>96</td>
<td>73</td>
</tr>
<tr>
<td>75% upper quartile</td>
<td>81</td>
<td>87</td>
<td>112</td>
<td>109</td>
<td>91</td>
</tr>
<tr>
<td>Max</td>
<td>120</td>
<td>96</td>
<td>129</td>
<td>129</td>
<td>140</td>
</tr>
<tr>
<td>Mean</td>
<td>62</td>
<td>68</td>
<td>97</td>
<td>82</td>
<td>72</td>
</tr>
</tbody>
</table>

This comparison also shows a substantial difference between the mean and median values. What is most striking in comparison to the distributions related to time are the much higher speeds. The mean speed is between 19-36 km/h higher when related to distance as opposed to time. The corresponding median value increased 6-59 km/h. This even increased for SDPS-98 by 22 and 23 km/h respectively in the same comparison.

The conclusion that can be drawn is that in order to compare speed distributions, the speed in relation to both time and distance should be used.

**Distribution of acceleration**

Acceleration is a measure of the change in speed. The amount and distribution of accelerations can provide an indicator describing the irregularity of the driving. It can also provide an answer concerning which levels of acceleration are most common.

As is the case for speed distribution, the usual way to indicate accelerations is as a time distribution. This could be sufficient, depending on what is to be described. Unfortunately, even here there can be a risk of misinterpretation.

**Comparison related to time**

For a distribution with time as the reference, acceleration equal to 0 will be represented by idling and constant speed. Figure 11 shows the relative time distribution over all speeds.
EDC shows a high percentage of idling and constant speeds, about 62%, while the other driving cycles range from 17% to 30% with SDPS-98 at 25%. Through reducing this by the idling times in the foregoing section, the following percentages of constant speed are obtained: 35% for EDC, 18% for FTP75, 11% for US06 and 8% for A9. The corresponding figure for SDPS-98 is 13%.

This large discrepancy is also illustrated in Figure 12, where the cumulative time distribution of the accelerations shows that the total amount of positive accelerations for EDC differs widely from the others. US06 is also distinguished by a distribution that deviates from the others.
Appendix E shows corresponding time distributions for speeds of 30, 50, 70, 90 and 110 km/h.

**Comparison related to number**

Making a correct comparison of an acceleration distribution depends on what is to be described. The foregoing shows distributions from a time perspective. However, if the intention is to describe how many accelerations occur at different levels, a comparison related to number would be more justified. A faster acceleration represents a shorter amount of time, but is the same in number as a slower acceleration. A concrete problem that arises in connection with minor accelerations is that small variations in speed can be given a very large percentage of time despite no intention on the part of the driver to accelerate. This problem can be reduced considerably by using the number relationship. Appendix E describes how to convert a time-related distribution into one that is based on number.

The effect of the shift in balance that occurs when changing from a time- to a number-based distribution of accelerations is evident in Figure 13, showing FTP75 and a distribution across all speeds. The other profiles are presented in Appendix E.
That which only looked like a tiny hump in the distribution related to time, about 2% at 1.5 m/s², is shown in the distribution related to number to contain 10% of all accelerations, and thereby the most common level of positive acceleration. The same thing applies to the negative acceleration at -1.4 m/s². In other words, there is an obvious risk of misinterpreting the results.
Figure 14 shows the relative distribution of positive accelerations for EDC, FTP75, A9, US06 and SDPS-98. Up to a little over 1 m/s² FTP75 and A9 have a similar distribution quite comparable to SDPS-98. On the other hand, FTP75 differs substantially at the higher acceleration levels while A9 continues to follow SDPS-98. EDC, however, does not have much in common with the others with its three distinct peaks and without any representation at the higher levels. US06 is also considerably different, with a lower percentage at the lower accelerations and a higher percentage at the higher accelerations. Figure 15 shows the relative distribution of number of negative accelerations, where agreement is similar to the positive accelerations.
From the cumulative distribution in Figure 16, it is seen more clearly that EDC is quite different with its mainly low accelerations. US06 differs through its even distribution across the entire field. A9 is the driving cycle that is most similar to SDPS-98 in this respect.
It is interesting to note that all have about 55% positive accelerations.

Appendix E shows the corresponding distribution of number of accelerations at 30, 50, 70, 90 and 110 km/h.

Table 7 – Mean acceleration related to time and number

<table>
<thead>
<tr>
<th>Mean acceleration [m/s²]</th>
<th>EDC</th>
<th>FTP75</th>
<th>US06</th>
<th>A9</th>
<th>SDPS-98</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negative (time)</td>
<td>-0.71</td>
<td>-0.54</td>
<td>-0.80</td>
<td>-0.56</td>
<td>-0.49</td>
</tr>
<tr>
<td>Negative (number)</td>
<td>-0.80</td>
<td>-0.94</td>
<td>-1.50</td>
<td>-0.98</td>
<td>-1.03</td>
</tr>
<tr>
<td>Positive (time)</td>
<td>0.58</td>
<td>0.41</td>
<td>0.66</td>
<td>0.53</td>
<td>0.44</td>
</tr>
<tr>
<td>Positive (number)</td>
<td>0.71</td>
<td>0.78</td>
<td>1.58</td>
<td>0.92</td>
<td>0.92</td>
</tr>
</tbody>
</table>

Table 7 is a compilation of the mean accelerations divided into positive and negative (decelerations) in relation to time and number.

What can be observed is that the values for the driving cycles based on real-world driving cases (all except EDC) are about twice as high when related to number as opposed to time.
Sequence agreement

In this section, the driving cycles are compared with logged driving patterns through sequence searching.

Objectives of driving cycles

Driving cycles have two main objectives

- to provide a representative indicator of vehicle emissions and energy consumption at the local and national level,
- to function as a control instrument in connection with certification or I/M (Inspection and Maintenance).

The design of a driving cycle should be governed by its purpose. This is due to the fact that a driving cycle that is intended to represent emissions or energy consumption, shall contain the right type of driving pattern sequences with the right internal distribution. A driving pattern sequence is described as a defined speed profile in a given time interval. A driving cycle intended for inspection control purposes should have as many sequences as possible represented in order to reduce the risk of sub-optimisation of engine control systems, what is known as "cycle-beating". Interchanging these two approaches, through for instance using a driving cycle intended as an inspection control instrument to represent vehicle emissions, would probably result in considerable error.

Why compare sequences?

A basic reason for using driving pattern sequences is that engine behaviour is not completely consistent. From this originally having been attributed to variations being more or less random, recent years have seen a trend towards variations that are more controlled. In other words, deliberate variation. Three main areas can be mentioned (with examples):

- Post-treatment
  - Oxygen storage function in the catalytic converter (Holmgren A, 1998)
  - Burn-off in the particulate filter system (Salvat O et al, 2000)

- Basic characteristics
  - Variable intake systems
  - Variable valve timing
  - Variable turbine geometry

- Engine functioning
  - Lean burn – Lambda 1 – Enriched fuel mixture
  - EGR
Heat-related effects (Westerberg B, 2000)

Time-related effects

In certain extreme cases, pure “cycle-beating” can also be found, where the aim has simply been to meet the legal requirements through a certain kind of behaviour. In many cases, the line between “cycle-beating” and emissions reduction measures can be very diffuse. The higher processor capacity in engine control systems makes it much more possible to vary engine behaviour. This justifies the necessity of longer sequences.

Through its continuous testing activities, and when designing the emissions model for VW Golf (Johansson H et al, 1999), Rototest has noticed that there are considerable "memory effects" with regard to vehicle emissions, varying from a few seconds up to 30 seconds or more. This effect can be explained by the fact that modern catalytic converters have a built-in oxygen storage capacity. This has been confirmed by Bengt Andersson, Chemical Reaction Engineering at Chalmers Institute of Technology, adding that about three percent of the coating applied to modern catalytic converters consists of ceric oxide intended specifically for oxygen storage.

Method of comparison

The problem can be formulated as follows:

"To find an indicator that describes how well one data aggregate is represented by a second independent data aggregate through comparing sequences."

Needless to say, this descriptive indicator can be designed in a number of more or less complicated ways. The method designed by Rototest for this purpose is called COMPASS (“COMPariSon by Sequence”). The primary advantage of this method is its simplicity, a factor which promotes greater acceptance of the results. It can be described such that a “comparison sequence” between 1 and 30 seconds long is chosen. The presence of this sequence is then matched in a given data aggregate. Figure 17 below describes how the sequences are chosen and figure 18 describes the search for a match.
Figure 17 – Choice of “comparison sequence”

Figure 18 – Search for a match

**Tolerance**

In order to find any agreement whatsoever, a tolerance margin must be added to the driving pattern sequence. The basic speed tolerance used was ± 3 km/h, which is normal in emission tests on so-called rolling roads (SNV, 1992). Added to this is a tolerance margin for the
acceleration corresponding to an acceleration of half the speed tolerance in one second. This is to aid comparison of similar sequences, particularly the shorter ones. Quite naturally, the acceleration tolerance is of lesser importance for longer sequences. Figure 19 illustrates the problem. See Appendix A for a more detailed description of the method.

![Figure 19 - Effect of acceleration tolerance on an approved profile](image)

If a tolerance margin only applied to speed, a speed profile such as the "maximum acceleration level without acceleration tolerance" would be approved. This shares very little in common with the profile being searched. By adding an acceleration tolerance, the profile being searched is made to agree better with the one wanted.

**Result**

**Agreement between the driving cycles and real-world traffic**

**EDC**

The current European emissions certification driving cycle, EDC, is a synthetic product (Henke M, 1999), in other words, unlike FTP75 for example, it is not composed of logged driving sequences. This means that the agreement with real-world traffic can, understandably, be relatively low. As shown in Figure 20 below, the agreement for 30-second sequences is only apparent at two points: at the idling stage, which makes the greatest total contribution, and at the steady speed phase of 100 km/h at the end of the cycle.
A comparison of all the sequence lengths showed that the agreement decreases substantially as the length of the sequence increases, from 50 percent for 1-second sequences down to 30 percent when the sequence length increases to 5 seconds.
FTP75

The FTP75 driving cycle looks completely different than EDC, which can be explained by the fact that parts of it were produced from a logged driving pattern from real-world traffic in Los Angeles at the beginning of the 1970’s (Henke M, 1999). FTP75 is used in the driving cycles intended for emissions certification in the USA. The FTP75 components used in this study are Yct+Yht+HDC. Yct and Yht are also called UDDS, Urban Dynamometer Driving Cycle, and are to correspond to urban traffic. HDC stands for Highway Driving Cycle. A comparison between FTP75 and EDC revealed, as could be expected, better agreement in the case of the former for all the sequence lengths, but especially for the very short sequences. An interesting observation is that FTP75, like EDC, only has a few points (three sections) that make any kind of contribution at the 30-second sequence length: the second idling stage, where the contribution is considerably less than EDC, and at the beginning and end of the cycle, where the speed is in the vicinity of 90 km/h.

Figure 22 – Cumulative agreement

Figure 23 shows that the agreement for FTP75 does not decrease as sharply as for EDC with the increase in sequence length, and that this is closely proportional to the sequence length in the range of 1 to 10-second sequences. The results for the other driving cycles are presented in Appendix B.
Based on the assumption that longer sequences have a greater influence than short ones, and that this is proportional, a common indicator can be produced whereby the agreement of every sequence length is weighted by its own length. In other words, a sequence length of 30 seconds is given 30 times greater weight than a sequence length of 1 second, and consequently, a sequence length of 20 seconds is given twice the weight of a 10-second sequence. The result becomes a weighted mean agreement whereby the representativeness of a driving cycle can be expressed in numerical terms. A composite driving cycle, EFUA was developed in order to illustrate the complexity involved in designing driving cycles. EFUA is described in Figure 24, and consists of EDC, FTP75, US06 and A9. The results given in Table 8 describe how representative the driving cycles included in this study are of real-world traffic. The table clearly shows that there is no relation between the mean agreement of the individual cycles and that obtained when combining them (EFUA). The explanation is that, although the driving cycle is almost 6000 seconds long, the distribution of the input sequences is also an important variable in attaining close agreement. This does not automatically occur through combining several driving cycles.

Figure 23 – Agreement as a function of sequence length
Figure 24 – EFUA driving cycle, a combination of EDC, FTP75, US06 and A9

Table 8 – Mean agreement percentage

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Mean Agreement Percentage*</th>
</tr>
</thead>
<tbody>
<tr>
<td>EFUA</td>
<td>23 %</td>
</tr>
<tr>
<td>FTP75</td>
<td>17 %</td>
</tr>
<tr>
<td>A9</td>
<td>12 %</td>
</tr>
<tr>
<td>EDC</td>
<td>9 %</td>
</tr>
<tr>
<td>US06</td>
<td>5 %</td>
</tr>
</tbody>
</table>

*Weighted mean  ¦ Combination of EDC, FTP75, US06 and A9

**Specific sequence lengths**

A few interesting results are found when comparing agreement at different specific sequence lengths. Table 9 shows, for example, that the driving cycle referred to as A9, which was produced from a number of driving pattern sequences (Henke M, 1999), has the same agreement as FTP75 at the 1-second sequence while this is considerably lower otherwise. Even though EFUA has by far the highest agreement, it must be kept in mind that this driving cycle design entails a driving time of 98 minutes (1 hour and 38 minutes), which due to its length alone can result in certain technical problems with respect to operation and measurement.
Table 9 – Agreement with regard to sequence length

<table>
<thead>
<tr>
<th>Sequence length</th>
<th>EDC</th>
<th>FTP75</th>
<th>US06</th>
<th>A9</th>
<th>EFUA^</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-second sequence</td>
<td>50 %</td>
<td>67 %</td>
<td>38 %</td>
<td>68 %</td>
<td>79 %</td>
</tr>
<tr>
<td>5-second sequence</td>
<td>30 %</td>
<td>51 %</td>
<td>20 %</td>
<td>46 %</td>
<td>60 %</td>
</tr>
<tr>
<td>15-second sequence</td>
<td>12 %</td>
<td>22 %</td>
<td>5 %</td>
<td>16 %</td>
<td>30 %</td>
</tr>
<tr>
<td>30-second sequence</td>
<td>3 %</td>
<td>6 %</td>
<td>1 %</td>
<td>3 %</td>
<td>9 %</td>
</tr>
</tbody>
</table>

^ Combination of EDC, FTP75, US06 and A9

Unique sequences in real-world traffic

During the course of the project, the Swedish National Road Administration expressed its interest in finding an answer to the question of how long a driving cycle should be. This had not been included in the original project specification, but was considered to be relevant enough to be included in this study. The length of a driving cycle depends on its main purpose. A driving cycle intended solely for inspection control purposes should contain a large quantity (if not all) of the unique sequences that are represented in real-world traffic. A unique sequence is defined as one that is represented at least once. If a sequence appears more than once, it is only counted the first time. The distribution of these sequences is of less priority since the desired answer is approved / not approved. On the other hand, a driving cycle that is to represent some form of "average" should be designed to include a large quantity of unique sequences, and above all the right distribution.

Based on the point of view that a driving cycle used as a control instrument should include all the unique sequences from real-world traffic, the following figure shows that the driving cycle must be at least 100 hours long for the 15 second sequence length. This is the minimum time, i.e. the increase required for the sequences to fit together has not been included. On the other hand, the so-called overlap effects are included, i.e., a 20-second sequence can contain five 15-second sequences (overlapping) and is therefore only counted as 5 seconds.
A study was made of the degree to which unique sequences were represented in the current EDC and FTP75 driving cycles, i.e., how large a percentage of the unique sequences that are found in real-world traffic are also included in the driving cycles. For FTP75, this is less than 1 percent for sequences longer than 5 seconds. The same applies to EDC for sequences longer than 3 seconds.

**Figure 25 – Minimum length containing all unique sequences**

**Figure 26 – Degree of representation of unique sequences**
If instead it is desirable that the driving cycle contains a representative distribution of sequences, a relation can be determined where the agreement depends on how the logged driving pattern in real-world traffic has been compressed. For example, if an agreement of 70 percent for 15-second sequences is desirable, the following graph shows that the logged driving pattern can be compressed to 24 percent of its original length and still maintain a representative distribution of the remaining sequences. This means, however, that the driving cycle must be about 78 hours long.

![Figure 27 – Agreement as a function of compression](image)

Studies have also been conducted to provide a picture of the extent of agreement with a driving cycle of "reasonable" length. The results show that it is not possible to attain any notable agreement with the length of the driving cycles that are commonly used today (0.5 to 1 hour). The graph also shows that every redoubling of the driving cycle length only results in a linear increase in agreement.
Sensitivity analysis

All the comparisons in this study, unless specified otherwise, are based on the same tolerance margin containing two defined parameters: speed and acceleration. This tolerance margin was set at ± 3 km/h and ± 0.4 m/s². For an idea of the significance of the effect of this tolerance margin on the results, two others were studied. One of these entailed a doubling of the acceleration tolerance margin to ± 0.8 m/s² while retaining the same speed tolerance margin. In the other, the speed tolerance margin was increased to ± 5 km/h with the acceleration tolerance margin kept relative to the speed tolerance, i.e., ± 0.7 m/s². The analysis revealed that the acceleration tolerance margin had little impact on the sensitivity at all sequence lengths. The speed tolerance margin was of larger significance when comparing longer sequence lengths while the effect on short sequences was moderate.

Table 10 – Sensitivity analysis of the tolerance margins for FTP75

<table>
<thead>
<tr>
<th>Sequence length</th>
<th>± 3 km/h ± 0.4 m/s²</th>
<th>± 3 km/h ± 0.8 m/s²</th>
<th>± 5 km/h ± 0.7 m/s²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-second sequence</td>
<td>67 %</td>
<td>70 %</td>
<td>71 %</td>
</tr>
<tr>
<td>5-second sequence</td>
<td>51 %</td>
<td>56 %</td>
<td>59 %</td>
</tr>
<tr>
<td>15-second sequence</td>
<td>22 %</td>
<td>26 %</td>
<td>37 %</td>
</tr>
<tr>
<td>30-second sequence</td>
<td>6 %</td>
<td>7 %</td>
<td>18 %</td>
</tr>
</tbody>
</table>
Conclusion and discussion

A traditional comparison of EDC, FTP75, US06 and A9, i.e., using time as the reference revealed that FTP75 represents real-world traffic better than the others. When the comparison was conducted on the basis of the distribution in number of accelerations, it was found that A9 agreed best.

The greatest deviation as far as EDC is concerned, is found in the higher percentage of low speeds and accelerations compared to real-world traffic. The percentage of idling and steady speeds is also considerably higher than in real-world traffic.

Clear objectives are essential when producing driving cycles to be able to develop a representative design. This study shows that there is remarkably little agreement between many of the driving cycles used today and real-world traffic. It also shows that the driving cycles tend to become “impossibly” long if an acceptable level of agreement is to be attained. Driving cycles intended solely for inspection control purposes should contain a large quantity (if not all) of the unique sequences that are represented in real-world traffic. Even this type of driving cycle tends to become extremely long if it is to hold a high percentage of unique sequences.

The study does not cover how representative the driving cycles are as far as vehicle emissions are concerned. As far as warm emissions are concerned, the comparisons conducted during the SDPS-98 study showed very large differences between real-world traffic and driving cycles, up to a factor of 10 (Andersson N, 2000). A strong contributing factor is probably the fact that 3 to 5 percent of the time was represented by driving outside closed-loop control areas. This in turn places much higher demands on the choice of sequences if these are to provide a representative picture of the vehicle emissions.

Another complicating factor is the rapid development of more complicated types of engine and emission post-treatment systems. One example is the new Peugeot 607 HDi (model year 2001) with a diesel engine. It comes fitted with a particulate filter, which is cleaned using a burning process at 300 to 400 km intervals. Even the new direct injection petrol engines can have considerably different emissions depending on the control strategy chosen.

The material used as the basis for the comparisons in this study was extracted from the logged driving patterns collected in a study conducted by the SNRA and the Lund Institute of Technology. This study, which involved test subjects, was conducted in and around Västerås in 1998, and is designated SDPS-98. As this study was
restricted to one average size city (by Swedish standards), material is lacking from the larger Swedish cities: Stockholm, Göteborg and Malmö. It is therefore essential that measurements also be conducted in these regions, which account for most of the vehicle mileage in Sweden. This would make it possible to compare the representativeness of driving cycles in these metropolitan areas as well, where very different driving patterns would probably be found under certain circumstances (e.g. rush hour traffic).
References

Andersson N, Ny Teknik, Artikel “Nya bilar släpper ut för mycket avgaser” 18/11 1999


Statens Naturvårdsverks författningssamling, “Kungörelse med föreskrifter om avgasrening för lätta bilar, miljöklasserna 1 och 2; A14-Regulation”, 1992

Westerberg B, Chalmers Tekniska Högskola, “FTIR Studies and Kinetic Modelling of NOx Reduction and NOx Storage”, 2000
Method

The problem can be formulated as follows:

"To find an indicator that describes how well one data aggregate is represented by a second independent data aggregate through comparing sequences."

Needless to say, this descriptive indicator can be designed in a number of more or less complicated ways. The method designed by Rototest for this purpose is called COMPASS ("COMPariSon by Sequence"). The primary advantage of this method is its simplicity, a factor, which promotes greater acceptance of the results. In simplified terms, the method can be described such that a sequence between 1 and 30 seconds long is chosen for comparison. The presence of this sequence is then searched in a given data aggregate. Figure 29 below describes how the “comparison sequences” are chosen and Figure 30 describes the search for a match.

Figure 29 – “Approval area” for a “comparison sequence”
Figure 30 – Search for a match of the sequence

Each search produces a number of matches. If this number is divided by the number of sequences, a relative frequency of the sequence is determined as follows

\[ R_{i,\varepsilon} = \frac{\gamma_{i,\varepsilon}}{q_\varepsilon} \]

where

- \( R_{i,\varepsilon} \) is the relative frequency of occurrence of sequence \( i \)
- \( \gamma_{i,\varepsilon} \) is the number of matches for sequence \( i \) and sequence length \( \varepsilon \)
- \( q_\varepsilon \) is the number of sequences with sequence length \( \varepsilon \)
The number of sequences in a data aggregate is dependent on the sequence length, determined as follows

\[ q_e = \text{int} \left( \frac{n}{f_m} \right) - \varepsilon + 1 \]

where

- \( q_e \) is the number of sequences with sequence length \( \varepsilon \)
- \( n \) is the number of measurement values
- \( \varepsilon \) is the sequence length expressed in seconds
- \( f_m \) is the measurement frequency for the data aggregate expressed in Hz.

The above can be described through an example.

Assume that you want to compare five-second sequences in the FTP75 driving cycle with measurements from 2 hours driving in real-world traffic. Both data aggregates are represented by 0.1-second values. The total length of the driving cycle is 2138 seconds. The number of 5-second sequences is derived from the equation above and found to be 2134. Assume that the first 5-second sequence from the driving cycle agree with real-world traffic 650 times. The relative frequency then becomes \( 650 / (2 \times 3600 \times 10^{-5} + 1) = 0.09 \).

The relative frequency provides an indicator of how often the “comparison sequence” is represented, but does not clearly describe agreement with the entire driving cycle at a certain sequence length. A cumulative frequency says more, but if the relative frequencies are added together, a value is obtained that is greater than one that depends on two factors: that the sequences overlap one another (in 10 seconds there are six 5-second sequences) and that the driving cycle repeats itself within the tolerance margin.

Figure 31 shows the relative frequency of 5-second sequences when comparing the EDC driving cycle with itself. As the graph clearly shows, there is a very high level of agreement in the idling sections.
Figure 31 - Relative frequency of approved five-second sequences

To avoid over-representation, the relative frequency must be corrected for overlap and repetition. Figure 32 shows the correction factor for five-second sequences for the EDC driving cycle.

Figure 32 – Correction factor for five-second frequencies

Appendix A
The correction factor is obtained through

\[ c_{i,e} = \frac{1}{\gamma_{i,e}} \]

where

- \( c_{i,e} \) is the correction factor for sequence \( i \) and sequence length \( e \)
- \( \gamma_{i,e} \) is the number of matches for sequence \( i \) and sequence length \( e \)

The indicator we are looking for will be equal to one, or 100 percent, if there is complete agreement, i.e., that all the sequences are found and with the same internal distribution. This means that if a sequence is represented within itself (internal distribution) at 10% but that the corresponding sequence is represented 8% in the data being compared, the degree of representation is 8%. If on the other hand there is 12% representation in the data being compared, the degree of representation is 10%.

The adjustment of the relative frequency is performed as follows

\[ r_{i,e} = \min(R_{i,e}^{DC}, R_{i,e}^{RD}) \]

where

- \( r_{i,e} \) is the adjusted relative frequency for the real-world driving pattern sequence \( i \) with sequence length \( e \)
- \( R_{i,e}^{DC} \) is the relative frequency in the driving cycle for the sequence \( i \) with sequence length \( e \)
- \( R_{i,e}^{RD} \) is the relative frequency in the real-world driving pattern for sequence \( i \) with sequence length \( e \)
The cumulative frequency is calculated as follows

\[ H_{j,x} = \sum_{i=1}^{j} r_{i,x} \cdot c_{i,x} \]

where

- \( H_{j,x} \) is the cumulative frequency summed up to sequence \( j \) with sequence length \( \varepsilon \)
- \( r_{i,x} \) is the adjusted relative frequency for sequence \( i \) with sequence length \( \varepsilon \)
- \( c_{i,x} \) is the correction factor for sequence \( i \) with sequence length \( \varepsilon \)

Figure 33 - Cumulative frequency for the EDC driving cycle compared to itself
Tolerance

In order to find any agreement whatsoever, a tolerance margin must be added to the driving pattern sequence. The basic speed tolerance used was ± 3 km/h, which is normal in emission tests on so-called rolling roads (SNV, 1992). Added to this is a tolerance margin for the acceleration corresponding to an acceleration of half the speed tolerance in one second. This is to aid comparison of similar sequences, particularly the shorter ones. Quite naturally, the acceleration tolerance is of lesser importance for longer sequences. Figure 34 illustrates the problem.

**Figure 34 - Maximum permitted acceleration between two time increments both with and without acceleration tolerance**

An example:

Assume that a sequence has a length of 1 second and that the level of acceleration is +0.5 m/s\(^2\). This means that without an acceleration tolerance, a sequence with an acceleration level between -1.2 and +2.2 m/s\(^2\) is approved, provided that the speed was within the tolerance margin. With an acceleration tolerance, the level is reduced to between -0.1 and +0.9 m/s\(^2\), which roughly would better describe whether it actually is possible to compare the sequence.

In order to be able to check whether the tolerance level is reasonable, a comparison was made with a measured driving sequence on a rolling road where the driver was requested to follow the driving profile. (VTT, Dec 1998).

Appendix A
Figure 35 – Logged driving pattern for EDC

When comparing the entire nominal driving cycle with the entire driven driving cycle, the latter falls well within the tolerance margin described in the foregoing, i.e., there is total agreement (expressed as 1). If instead the comparison is made with sequence lengths ranging from 1 to 30 seconds, a somewhat different result is obtained: the agreement then is 95 percent for all the sequence lengths. This could at first appear a little strange. The explanation can be found in the effects ensuing from using absolute tolerance. That the agreement fails to reach 100 percent is not due to a lack of agreement for any sequence, but rather because the distribution is not exactly the same, in other words, overlapping occurs in a somewhat different way. Figure 36 shows the matches for a one-second sequence at a steady speed of 32 km/h when the comparison is performed on a nominal driving cycle.
If the comparison is carried out on the driven driving cycle instead, another pattern occurs (Figure 37). As can be seen, there are some "matches" missing. This is due to the fact that even the 35 km/h field is approved in nominal driving cycle comparisons, while this speed lies outside the tolerance margin \((32 + 3 = 35 \text{ km/h})\) in the driven driving cycle, and therefore not counted. In simple terms, it can be said that the driven driving cycle does not repeat itself in exactly the same way as the nominal driving cycle. The deviation from the nominal cycle showed a mean error of 0.4 km/h and maximum error of 2.1 km/h.

**Figure 36 – Matches for one-second sequences of 32±3 km/h in relation to the nominal driving cycle**

Appendix A
An indication of the magnitude of this effect can be given through a comparison of the nominal driving cycle and the same cycle to which half the tolerance is added and half is subtracted. The result is shown in Figure 38.

Figure 37 – Matches for one-second sequences of 32±3 km/h in relation to the logged driving cycle

Figure 38 – Effect of tolerance margins on the total agreement

Appendix A
In conclusion, it can be stated that the case above shows that an agreement of about 91 percent can in fact mean complete agreement.

**Unique sequences**

Another interesting indicator is how long a driving cycle should be to represent all the unique sequences (within the tolerance margin). The degree of repetition is searched in a data aggregate of adequate length.

The following equation is used to determine the “minimum length” for a driving cycle to contain only unique sequences. This equation does not take into consideration any additions needed to fit together the different sequences in the driving cycle; hence the “minimum length”.

\[
\varphi_\varepsilon = \frac{\sum_{i=1}^{q_\varepsilon} 1}{q_\varepsilon} \\
\]

where

- \(\varphi_\varepsilon\) is a reduction factor that describes the extent to which the examined data aggregate can be reduced and only contain unique sequences of sequence length \(\varepsilon\).
- \(q_\varepsilon\) is the number of sequences with sequence length \(\varepsilon\).
- \(\gamma_{i,\varepsilon}\) is the number of matches for sequence \(i\) with sequence length \(\varepsilon\).

Figure 39 illustrates an example of the application of the foregoing theory for FTP75.

**Appendix A**
The foregoing indicator could be of special interest when wanting to know the percentage of the unique sequences in a driving cycle that occur in a real driving pattern. Low agreement, less than 50%, indicates that more than half of the unique driving cycles represented in the driving cycle do not exist at all in the real-world driving pattern.

The representation of the unique sequences in a driving cycle in a real-world driving pattern is calculated as follows

\[
\sum_{i=1}^{\epsilon} \min \left( \cdot, \gamma_{i,\epsilon}^{RD} \right) \cdot c_{i,\epsilon}^{DC}
\]

where

- \( u_{\epsilon} \) is the representation of the unique sequences of sequence length \( \epsilon \) in the driving cycle that exists in the real-world driving pattern
- \( c_{i,\epsilon}^{DC} \) is the correction factor for sequence \( i \) and sequence length \( \epsilon \) in the driving cycle
- \( \gamma_{i,\epsilon}^{RD} \) is the number of matches in the real-world driving pattern for sequence \( i \) with sequence length \( \epsilon \)

**Figure 39 – Cycle length required as a function of sequence length**

The original length of the FTP75 cycle is 2138 seconds. The graph shows the cycle length required as a function of sequence length.
$q_{e}^{DC}$ is the number of sequences of sequence length $e$ in the driving cycle.

Further, the representation of the unique sequences of the real-world driving pattern in the driving cycle can be calculated as follows:

$$y_e = \sum_{i=1}^{DC} C_{i,e}^{DC}$$

where

- $y_e$ is the representation of unique sequences of sequence length $e$ in the real-world driving pattern that exist in the driving cycle.
- $C_{i,e}^{DC}$ is the correction factor for sequence $i$ and sequence length $e$ in the driving cycle.
- $C_{i,e}^{RD}$ is the correction factor for sequence $i$ and sequence length $e$ in the real-world driving pattern.
- $q_{e}^{DC}$ is the number of sequences of sequence length $e$ in the driving cycle.
- $q_{e}^{RD}$ is the number of sequences for sequence length $e$ in the real-world driving pattern.

**Compression**

Designing a compressed driving cycle from a representative data aggregate of sufficient length while maintaining 100% agreement presumes that all the sequences are represented more than once. If these are all represented at least twice, the data aggregate can be compressed two or more times without losing the agreement. If this is not the case, agreement will be lost at the expense of a higher degree of compression.

Figure 40 illustrates agreement in relation to degree of compression for FTP75.

Appendix A
Figure 40- Agreement as a function of degree of compression and sequence length

Agreement is calculated as follows

\[ F_{h,\varepsilon} = \frac{p_{h,\varepsilon}}{q_{\varepsilon}} \]

where

- \( F_{h,\varepsilon} \) is the agreement with the lowest number of matches \( h \) and sequence length \( \varepsilon \)
- \( p_{h,\varepsilon} \) is the number of sequences with the lowest number of matches \( h \) and sequence length \( \varepsilon \)
- \( q_{\varepsilon} \) is the number of sequences for sequence length \( \varepsilon \)

The degree of compression is described as

\[ \beta = \frac{1}{h} \]

where

- \( \beta \) is the degree of compression.
- \( h \) is the lowest number of matches for a given sequence
The total compression with agreement $F_{h,e}$ is calculated as follows

$$\kappa_{\beta,e} = \beta \cdot F_{h,e}$$

where

- $\kappa_{\beta,e}$ is the compression expressed as the proportion of the original length for sequence length $e$ and degree of compression $\beta$
- $\beta$ is the degree of compression
- $F_{h,e}$ is the agreement with the lowest number of matches $h$ and sequence length $e$
The representativeness of driving cycles

Figure 41 - EDC cumulative frequency

Figure 42 - EDC Agreement as a function of sequence length

Appendix B
Appendix B

Figure 43 - FTP75 cumulative frequency

Figure 44 - FTP75 Agreement as a function of sequence length

Appendix B
Figure 45 - US06 cumulative frequency

Figure 46 - US06 Agreement as a function of sequence length
Appendix B

Figure 47 - A9 cumulative frequency

Figure 48 - A9 Agreement as a function of sequence length

Appendix B
Figure 49 - EFUA cumulative frequency

Figure 50 - EFUA Agreement as a function of sequence length

Appendix B
Driving cycles

Figure 51 - EDC driving cycle

Figure 52 - FTP75 driving cycle
Figure 53 - US06 driving cycle

Figure 54 - A9 driving cycle

Appendix C
Figure 55 - EFUA driving cycle
Sensitivity analysis

Figure 56 - FTP75 cumulative frequency, ± 3 km/h and ± 0.8 m/s²

Figure 57 - FTP75 Agreement as a function of sequence length, ± 3 km/h and ± 0.8 m/s²

Appendix D
Figure 58 - FTP75 cumulative frequency, ±5 km/h and ±0.7 m/s²

Figure 59 - FTP75 Agreement as a function of sequence length, ±5 km/h and ±0.7 m/s²

Appendix D
Distribution of acceleration

The basic data was grouped in a distribution matrix where the speed was divided into increments of 10 km/h. Speed v=30 km/h then includes the range of $25 \leq v < 35$. Accelerations are divided in the same way in increments of $0.1 \text{ m/s}^2$. Speed and acceleration are related to a time resolution of 0.1 second. Each cell in the matrix will then contain the number of occasions when the combination of speed and acceleration in the cell have been fulfilled.

By normalising the sum of the entire matrix to 1, a number is obtained in each cell in the matrix that indicates the relative occurrence in relation to the total time, i.e., a time-based distribution.

**Conversion of a time-based distribution to one that is number-based**

To obtain a number-based distribution, the relative time percentage can be corrected to compensate for the fact that a slower acceleration is given a greater time percentage. The correction is directly proportional to the actual acceleration.

Example:
Two accelerations from 50 to 60 km/h are to be compared. One is assumed to take 10 seconds while the other only takes 5 seconds. Over a total driving time of 500 seconds, the first acceleration at 0.28 m/s$^2$ is given a time percentage of 2%. The other acceleration, at 0.56 m/s$^2$, is given a time percentage of 1%. By correcting the latter by the relation of acceleration ($0.56/0.28=2$) both obtain an equal percentage. This is a question of one acceleration in both cases.

In practice, this means that the distribution matrix, that contains a time distribution, is changed through every cell being multiplied by the actual acceleration. The new matrix must then be normalised again so that the sum of the whole will amount to 1. Each cell will then represent the relative number of accelerations in relation to the total number, i.e. a number-based distribution.
Figure 60 - Relative time distribution; 30 km/h

Figure 61 - Relative time distribution; 50 km/h

Appendix E
Figure 62 - Relative time distribution; 70 km/h

Figure 63 - Relative time distribution; 90 km/h
Figure 64 - Relative time distribution; 110 km/h

Figure 65 - Relative time distribution; all speeds
Figure 66 - Cumulative time distribution; all speeds

Figure 67 - Relative number distribution; 30 km/h

Appendix E
Figure 68 – Relative number distribution; 50 km/h

Figure 69 - Relative number distribution; 70 km/h

Appendix E
Figure 70 - relative number distribution; 90 km/h

Figure 71 - Relative number distribution; 110 km/h

Appendix E
Figure 72 - Relative number distribution; all speeds

Figure 73 - Cumulative number distribution; all speeds

Appendix E
Figure 74 - EDC relative acceleration distribution; time and number

Figure 75 - FTP75 relative acceleration distribution; time and number

Appendix E
Figure 76 - US06 relative acceleration distribution; time and number

Figure 77 - A9 relative acceleration distribution; time and number

Appendix E
Figure 78- SDPS-98 relative acceleration distribution; time and number
Test vehicles SDPS-98

The following vehicles were used in the SDPS-98 study involving test subjects. All vehicles were equipped during the test period with an completely automatic logging system, ROTOTEST IVAS, for continuous measurement of driving patterns at a time resolution of 10 Hz.

Ford Mondeo 2.0 1998 model
- Front wheel drive
- Engine 1988cc, 97 kW (6000 1/min), 180 Nm (4000 1/min)
- Kerb weight 1454 kg
- Logged distance driven 5441 km, number of trips 641

Toyota Corolla 1.3 1998 model
- Front wheel drive
- Engine 1332 cc, 63 kW (5400 1/min), 120 Nm (4200 1/min)
- Kerb weight 1195 kg
- Logged distance driven 4137 km, number of trips 533

Volvo 940 2.3T (Estate) 1998 model
- Rear wheel drive
- Engine 2316 cc, 121 kW (4800 1/min), 264 Nm (3450 1/min)
- Kerb weight 1566 kg
- Logged distance driven 3088 km, number of trips 485

Volkswagen Golf 1.6 1998 model
- Front wheel drive
- Engine 1595 cc, 74 kW (5600 1/min), 145 Nm (3800 1/min)
- Kerb weight 1170 kg
- Logged distance driven 3590 km, number of trips 352