Transmitted by the expert from OICA

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Experience of the Development of a Test Cycle - Data Collection, Processing and Assessment

1. Summary

This presentation gives an overview of the different steps that are necessary for the development of a test cycle used within a type approval procedure.

It is based on the experience gained during the WHDC and WMTC cycle development work.

The steps can be summarised as follows:

- Collection of in-use data (second by second data of vehicle speed and engine speed),
- Collection of data about fleet composition and vehicle use.
- Data preprocessing (plausibility and consistency checks, smoothing),
- Reference database (created by a combination of steps 1 and 2),
- Candidate test cycle (derived from the reference database by statistical analysis of dynamic parameters),
- Cycle modifications (in order to improve driveability and thus reproducibility),
- Definition of vehicle classes (in good alignment to the cycles),
- Gearshift prescription development (based on in-use data analysis and taking into account gear shift indicators).

It can be concluded that WMTC cycle development approach can be used as good basis for the WLTP but needs to be completed by aspects like gearshift indicators, OBD requirements, Hybrid vehicles etc.

It can further be concluded that the CADC cycle does not fulfil the described requirements for a type approval cycle and even needs to be substantially modified for the use of emission factor calculations.

2. Introduction

This presentation gives an overview of the different steps of cycle development necessary in order to get a well balanced test cycle, which is:

- representative of world-wide on-road vehicle operation,
- able to provide the highest possible level of efficiency in controlling on-road emissions,
- capable of providing a reliable ranking of exhaust emission levels from different engine types,
- consistent with the development of appropriate emission factors.

The described approach was used for the WMTC cycle development.

3. Collection of statistical data

The basis of the cycle development is the collection and analysis of driving behaviour data and statistical information about vehicle use for different regions of the world.

This data has to include all relevant real life vehicle operations and build the basis for the cycle development.

In order to enable a gearshift analysis second by second data of vehicle speed and engine speed is necessary for different vehicle classes and road categories.

In a second step the in-use driving behaviour data has to be combined with the statistics on vehicle use in order to create a reference database that is representative for worldwide driving behaviour.

This can be achieved by using a classification matrix for the most important influencing parameters. In the final WMTC classification matrix different regions, different vehicle classes and different road categories were included.

4. Collection of statistical data

One important point within the cycle development procedure is the data preprocessing, which has to be carried out before the statistical analysis. The data preprocessing covers plausibility and consistency checks and in addition to these a check of the acceleration resolution.

If this resolution is not high enough ($\leq$ 0,01 m/s^2) it could happen, that consecutive changes between negative accelerations and 0 or 0 and positive accelerations or even negative and positive accelerations are found even for cycle parts with nearly constant speed.

This behaviour is caused by too high uncertainties in the vehicle speed measurement.

Figure 1 shows as an example the first 600 seconds of the motorway part of the CADC cycle. This cycle was developed in the frame of the EU 5th framework project ARTEMIS. This project aimed at developing a standard European method for modelling emissions from all transport modes.

The acceleration pattern in figure 1 shows quite often consecutive changes between -0.14 m/s² and 0 m/s² or 0 m/s² and +0.14 m/s² or even -0.14 m/s² and +0.14 m/s² especially for parts with nearly constant speed.

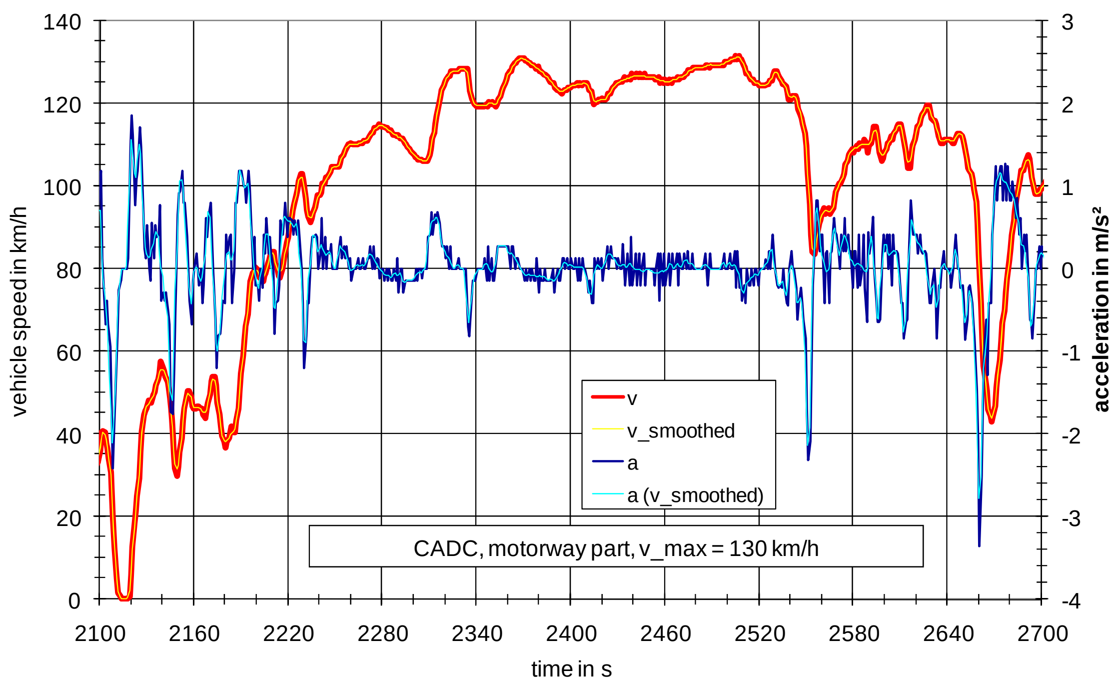

Figure 1: Time series of a part of the CADC

This acceleration scatter is a clear indication that the CADC is a “raw” cycle. The smoothed pattern also shown in figure 1 are more representative for real world driving behaviour.

During the development of the WMTC cycle as well as the WHDC cycle (type approval cycle for heavy duty vehicles) similar uncertainties of the vehicle speed pattern were found in parts of the in-use data.

In these cases the vehicle speed pattern were smoothed prior to further analysis.

In The WHDC and WMTC cycle development phases the data was smoothed by a T4235 Hanning filter (see Annex A), which was found to be most appropriate for the smoothing.

5. Analysis of reference database

The reference database has then to be analysed with respect to the following parameters:

- Road category,
- Driving modes,
- Vehicle speed and acceleration distributions
- and their descriptors, like average, min, max, standard deviation.

With respect to road categories 3 different categories (urban, rural, fast rural/motorway) were found to be sufficient for the WMTC database.

With respect to driving modes 4 different modes were defined during the WMTC data analysis, as shown in the following table.

4 modes	Definition
idle mode	**vehicle speed** < 5km/h and -0.5 km/h/s (-0.139 m/s^2) < **acceleration** < 0.5 km/h/s (0.139 m/s^2)
acceleration mode	**acceleration** >= 0.5 km/h/s (0.139 m/s^2)
deceleration mode	**acceleration** =< 0.5 km/h/s (0.139 m/s^2)
cruise mode	**vehicle speed** >= 5km/h and -0.5 km/h/s (-0.139 m/s^2) < **acceleration** < 0.5 km/h/s (0.139 m/s^2)

Table 1: Driving modes definition

For the acceleration the “relative positive acceleration” (RPA) was found to be a good descriptor for the dynamics of a cycle. RPA is the integral of vehicle speed multiplied with the time interval and the positive acceleration, divided by the total distance of the cycle.

6. Development of a test cycle

The next step then is to compact the reference database into test cycle parts of the desired length in time.

For the WMTC this length was set to 600 s for each part so that the total duration for 3 parts is 30 min.

For this step a “module” analysis was carried out for the whole database. A module is a driving pattern part that starts from standstill and ends with standstill.

Then appropriate modules have to be chosen from the reference database and linked by stops in that way that the desired length is met.

The statistical characteristics of this number of modules have then to be compared to those of the corresponding database.

The modules and stops have to be chosen/arranged in that way that the highest correlation between the cycle and the reference database is achieved with respect to

- Driving mode percentages and idle time distribution,
- Vehicle speed/acceleration distribution.

This requires a computer search programme for the module selection and a chi-squared based analysis for the comparison.

7. Cycle modifications

It has to be foreseen that the first draft test cycle needs to be modified on the basis of an evaluation concerning driveability and practical points related to the measurement procedure.

Since this process is iterative by nature, several adaptation rounds including the first step of a validation programme have to be carried out.

11 modifications were made during the validation phase and the driveability tests of the WMTC, related to

- Replacement of modules by more representative modules,
- Correction of the idle time distribution,

- Rearrangement of the rank order of the modules in part 1 with respect to cold start requirements,
- Modifications of the maximum speed of part 3,
- Further smoothing procedures and a limitation of the change in acceleration rate in order to reduce the risk for tyre slip.

8. Test cycle and vehicle class

Other important points in the context of the development of type approval cycles is the driveability or in other words the capability for the vehicle to follow the cycle within the given tolerances and the ratio between v_max of the cycle and v_max of the vehicle.

These points are related to the question what percentage of full throttle operation would be acceptable and reasonable. They are, of course, related to the vehicle classification.

In case of the WMTC 3 vehicle classes were defined on the basis of engine capacity and maximum vehicle speed.

The developed test cycle consists of 3 cycle parts, representing urban, rural and fast rural/motorway operation, with maximum speeds of 60 km/h, 95 km/h and 125 km/h.

During the cycle development phase it was agreed that the ratio between the maximum speed of the cycle and the maximum speed of the vehicle should be limited below 1 in order to guarantee good traceability and avoid unrealistic high percentages of wide open throttle operation.

The discussions in the working group resulted in a factor of v_max_cycle <= 0,85*v_max_vehicle as a good balance for the cycles and the vehicle classification.

In order to further smooth the transition between the vehicle classes, cycles with reduced top speeds for all parts were developed that should be used for those vehicles whose speed factor (0,85*v_max) is below but close to the maximum speed of the original cycle part.

This compromise and additional requirements from India at a later stage are now reflected in the current WMTC cycle and vehicle class definitions.

Finally weighting factors were defined for the different cycle parts for the calculation of the final results. These factors were derived on the basis of the statistics about vehicle use.

Since the CADC has been shown already as an example, it should be mentioned that this cycle would not fulfil the above mentioned driveability criteria for low powered M1 and N1 vehicles.

9. Gearshift prescriptions

At first it should be mentioned that gearshift prescriptions are only necessary for vehicles with manual transmissions.

Vehicles with automatic transmissions and different modes should be tested in that mode which is most appropriate for the test cycle. It can be foreseen that the definition of the most appropriate mode needs further discussions.

Apart from that cycle bypass prevention measures should ensure that no special gearshift mode is used for the test cycle in case of automatic transmissions.

The development of the gearshift prescriptions for vehicles with manual transmissions should be based on an analysis of the gearshift points in the in-use data.

It can be foreseen that shift points based on engine speeds will be more appropriate than shift points based on vehicle speeds. This was the case for motorcycles and is also in line with the author’s analysis results for M1 in-use data.

The most important advantage of such an approach is that the shift speed prescriptions are independent of the number of gears and thus performance related rather than design related.

In order to get generalised relations between technical specifications of the vehicles and gearshift speeds the engine speeds should be normalised to the utilisable band between rated speed and idling speed.

In a second step the end speeds (vehicle speed as well as normalised engine speed) for upshifts and downshifts have to be determined and collected in a separate database.

The averages of these speeds for each gear and vehicle have to be calculated and correlated with technical specifications of the vehicles.

In case of motorcycles the best correlation between gearshift speeds and technical data was found for normalised engine speeds and the power to mass ratio of the vehicle.

For cars the use of gearshift indicators should be included in the gearshift prescription development.

Concerning the CADC it should be mentioned that 4 different gearshift strategies are accompanied with the CADC, depending on power to mass ratio and the vehicle speed in 3. gear at rated engine speed. In each case the shift points are vehicle speed based.

Apart from the fact that the rationale behind the class division is not quite clear, the prescriptions suffer from the fact that 6-speed gearboxes are not foreseen and that the prescriptions for modern Diesel cars are not in line with practical use.

Annex A - T4253H smoothing filter

T4253H smoothing (description in the SPSS calculation software):

The smoother starts with a running median of 4, which is centred by a running median of 2. It then re-smoothes these values by applying a running median of 5, a running median of 3, and hanning (running weighted averages). Residuals are computed by subtracting the smoothed series from the original series. This whole process is then repeated on the computed residuals. Finally, the smoothed residuals are computed by subtracting the smoothed values obtained the first time through the process. This is sometimes referred to as T4253H smoothing.

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