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"Transfer functions" in the European RDE legislation: to be or not to be?

Some background and brainstorming

1) Transfer functions: principle

The main task of the RDE data evaluation task force for the drafting of the 2nd RDE regulatory package agreed by the previous TCMV meetings is the development of the *"complementary boundary conditions"*, i.e. a set of constraints to individual PEMS trips trying to ensure that the driving is performed in an unbiased manner. However, at recent meetings of the RDE data evaluation task force (after the last TCMV of 1 July 2015), vehicle manufacturers have requested firmly the introduction of so-called *"transfer functions"* into the European RDE legislation.

"Transfer functions (TF)" are a new concept, which would attribute different conformity factors $CF_{applicable}$[1] applicable to a PEMS trip or parts of it, depending on some measureable dynamical or ambient characteristics, such as transient driving (described e.g. by the product of vehicle velocity and acceleration $v*a$, vehicle load, ambient temperature, etc.), i.e.:

$$CF_{applicable} = CF_{legal} * TF(p_1, \ldots, p_n), \qquad (*)$$

Where:

- CF_{legal} *is a fixed value for the conformity factor defined in the legislation*

- p_i $(i = 1,\ldots,n)$ *are parameters describing one of the said characteristics, either on an instantaneous basis or aggregated for the entire PEMS trip*

The parameters p_i are considered to be linked to the "severity" of emission control since vehicle emissions are expected to perform better under moderate/average driving conditions as under more challenging conditions. The identification of the relevant severity parameters as well as of the quantitative variations of the applicable conformity factors as a function of them would be basically done as follows:

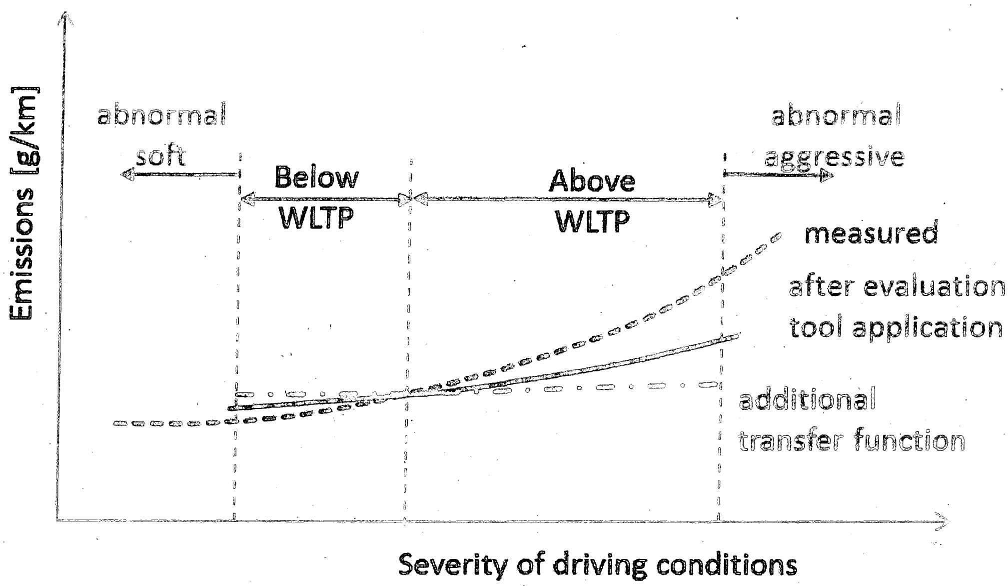
[1] The conformity factor CF is defined as the ratio of the not-to-exceed (NTE) emission limit to be met at a PEMS trip (or parts of it) and the regulatory Euro 6 emission limit (defined in table 2 of Annex I to Regulation (EC) 715/2007.

a) A first "expert guess" of relevant severity parameters[2].

b) Analysis of emission performance of existing Euro 6 vehicles in PEMS trips (from physical tests and simulations) with varying conditions.

c) Regression analysis to obtain the "best" relationship describing the emissions analysed at b) as a function of the parameters estimated at a).

d) Verification (via technical expert/political discussions and possibly further simulations of "idealised" Euro 6 vehicles, not existing yet), whether the dependence of the obtained regression function on individual parameters should be retained in a future regulation.



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2) Transfer functions: first assessment

The concept of introducing transfer functions into the RDE legislation must be considered with great care. The reasons are basically twofold:

– It has been suggested to use only the lowest conformity factor (= best environmental case) provided by the transfer function for air quality arguments or communication to the (non-expert) public. In the language of equation (*) this would mean that the transfer function $TF(p_1,..., p_n)$ would almost always be ≥ 1, but only the fixed value CF_{legal} defined in the legislation is considered politically and for air quality assessments.

The main argument (brought forward by some stakeholders) for this suggestion is that the severity parameters delivering the best environmental

[2] Industry has provided an initial list of severity parameters, which is available in their presentation.

[3] Figure extracted from presentation given by Prof. Stefan Hausberger/TUG on 19 August 2015 at the RDE data evaluation task force.

situation (corresponding to *TF =1*) describe the most common driving situations and the more demanding cases (leading to *TF > > 1*) "rarely occur on the road...". These arguments are however not well demonstrated. In any case, also the more demanding conditions will always have some contribution to real driving and cannot be neglected. The assumption of a "best environmental case" for the TFs is therefore misleading and would lead to an underestimation of the actual emissions at real driving.

Moreover, even the frequency, with which driving events occur, may not be a reliable indicator of their relevance for air pollution. On-road measurements have shown that less-frequent high-load driving events can contribute a substantial, and not negligible, amount to trip-average NOx emissions and thus the ambient air pollution - much higher than their actual mileage share suggests, because the respective distance-specific emissions are very high.

- The suggested approach to derive the TFs from driving data of existing Euro 6 vehicles risks to preserve the existing poor calibration of the emission control systems (e.g. switching EGR off at high engine loads, low urea injection by SCR systems, etc.) in future vehicles. The legislation would effectively give credit for such shortcomings by mapping the future regulatory requirements to the existing empirical emission performance of vehicles. There would be limited incentives to improve the calibration of existing emission control technologies and practically no incentives to bring new technologies (e.g. SCR systems already operational at lower temperatures) to the market.

In addition, general concerns about making the RDE test procedure even more complex and less understandable for non-experts, without a clearly marked benefit, exist.

On the other hand it should be acknowledged that an entirely "flat" optimisation of a vehicle's emission performance leading to almost constant distance-specific emissions under all circumstances may not be cost-efficient and achievable in short-term, at least not with (serious) conformity factors necessary for achieving the legal air quality objectives.

As a consequence transfer functions could be considered for the future RDE legislation only if:

a) Their environmental impact and the statistical distribution of the underlying severity parameters are assessed in a comprehensive manner (using e.g. the WLTP database or ambient data).

b) Their effect on real driving emissions allowed, i.e. the resulting "real" emission factors, is communicated in a transparent and honest manner. Not only the "best case" of conformity factors but the resulting statistically weighted conformity factors must be communicated and considered for the political/environmental discussion.

In the language of equation (*) this means that on the basis of a legal conformity factor CF_{legal} the statistically weighted average of the transfer function $TF(p_1,\dots,p_n)$ equals 1 when integrated over the parameter space[4]:

$$\int TF(p1,\dots,pn) * Q(p1,\dots,pn)\, dp = \int Q(p1,\dots,pn)\, dp \quad (**)$$

Where:

- dp represents the integral over the entire space of the parameters p_i (i = 1,...,n)

- $Q(p_1,\dots, p_n)$, is the probability density of an event corresponding to the parameters p_i (i = 1,...,n) in real driving (to be determined e.g. from the WLTP database)

c) Only severity parameters having an effect on emissions due to intrinsic "basic physics" (e.g. emissions at highly transient driving are more difficult to control) reasons rather than the specific calibration of the emission control systems (e.g. switching off the EGR system or reduction of urea injection at certain conditions) are acceptable as input for the TFs. Redundancy of parameters that affect the emissions through the same mechanism should be controlled for in the design of CFs. This assessment is not straightforward and has to be done for each severity parameter in a transparent manner using expert judgment and possibly vehicle simulations.

   It has to be understood as well that this analysis will be specific to the NOx emissions of diesel vehicles and the resulting TFs are specific to this case. If the concept of transfer functions should also be applied to other pollutants (this is an open question) a separate analysis, following similar principles, would be necessary.

d) Obviously the assessment mentioned in c) can only be done on the basis of known technology concepts for emission control, such as EGR, SCR or DeNOx. In general it is impossible to anticipate whether the estimated functional dependence of emissions on a certain severity parameter will also inherently exist for potential new emission control technologies, e.g. advanced SCR systems using new ammonia storage concepts or other reduction agents. Since the latter should be incentivised or at least not be discouraged by legislation, TFs determined now should only be applied temporarily to facilitate the transition to the fully effective RDE legislation. Concretely, TFs should not be applied automatically and unchanged after the 2nd step of conformity factors is introduced.

3) Transfer functions: options available and timing

The estimate of TUG (on request of industry) shows that even under optimistic assumptions transfer functions cannot be developed before end October 2015. Obviously the environmental impact of such proposal would need to be assessed very carefully, which requires at least 1 – 2 months (including political discussions). Since normally the RDE conformity factors can only be determined

[4] It is well understood that the validity of this equation cannot be verified in a strict mathematical sense in short-term, because the necessary data are not available. It represents however the relation to be assessed as closely as possible for future political decisions.

after the transfer functions are available, a first (informal) 2nd regulatory RDE package, proposing conformity factors in conjunction with transfer functions, could be discussed at TCMV in January/February 2016 at earliest. This means that a respective vote in TCMV would be almost impossible before May/March 2016, given the high political relevance of the issue and the experience from the 1st regulatory RDE package.

Therefore the following political options appear to be available for developing the 2nd regulatory RDE package:

a) No change of strategy: complete the development of conformity factors for steps 1 and 2, including complementary boundary but without transfer functions, according to the principles agreed at the TCMV of 1 July. Transfer functions may be implemented at a later stage and their development could continue parallel to the regulatory process, but regulators would not take any commitment in this respect for the time being.

b) Develop the transfer functions as suggested and accept the resulting time delay. This would effectively reduce the lead time for industry from the publication of the 2nd regulatory RDE package to the application of the 1st step of conformity factors by <u>at least 6 months</u>.

c) From a manufacturer's perspective transfer functions are mainly relevant for in-service-conformity/surveillance testing, since the conditions at type approval testing are largely under their control - at least it can be assumed that at the initial type approval tests vehicles are not driven in the most challenging areas of the severity parameter space permitted by the RDE procedure. Therefore the following approach could be considered:

   - Agree on a 2nd regulatory RDE package defining conformity factors (i.e. the values CF_{legal} in equation (*)) as soon as possible and according to the timeline discussed at the TCMV of 1 July 2015.

   - Introduce transfer functions TFs together with in-service-conformity testing for the 4th regulatory RDE package. Once developed TFs would of course also apply to new initial type approval tests.

   - TFs must be implemented in a balanced manner such that the statistically weighted conformity factors $CF_{applicable}$ (determined by the TFs) will equal a single value conformity factor defined in the 2nd regulatory RDE package. In the language of equation (*) this means that the fixed value CF_{legal} is decided in the 2nd regulatory RDE package, together with the condition (**) for the TFs. The functional shape of $TF(p1, \dots, pn)$ itself however would only be adopted in the 4th regulatory RDE package.

Member States are requested to give their views on these options at the TCMV of 10 September 2015.

[redacted]