TNO-paper
VM0004

In-Use Compliance testing of passenger cars in the Netherlands

By

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Presented at
Intertech's 6th International Clean Transport Conference
Vehicle In-use Compliance Testing
15 – 17 October 2000
Berlin, Germany

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Abstract

In 1987 TNO automotive started the execution of a large scale in-use compliance program for passenger cars. The initial goal of the program was: *Monitoring the emission performance of passenger cars in-use and relating this performance to the situation at type approval.* In the early years the program proved to be very useful for detection of emission reduction technology not performing up to the type approval specifications, while in use. With increasing performance and reliability of passenger car technology, the number of failing cars decreased significantly, only diesel cars still shows some problems. Over the years, the program has proved to be a very important data source for determining emissions of the Dutch national car fleet. The Dutch national emission modeling is based on data from the in-use compliance program. Especially emission data gathered on real world test cycles prove to be of increasing importance.
Because of changes in the European emission regulations (Euro III), new fields of in use compliance testing have to be addressed. The main new topics are: Ultra low emissions, EOBD and cold start at -7° C.

1. Introduction

Since more then 12 years TNO-automotive has been executing a large scale in-use compliance testing program. This program is executed for light duty as well as heavy duty vehicles. This paper summarizes the some major information gathered during the execution of the program for light duty vehicles until the end of 1999 (up to Euro II).

2. Background

In 1986 the Dutch government introduced a tax incentive scheme, in order to stimulate the introduction of cars with decreased emissions. Until that moment cars in the Netherlands were sold under the European 15-04 regulation. This concerned vehicles with no special emission reduction technology. The tax incentive scheme which lasted until the early nineties, stimulated the introduction of (for that time) new emission control technology. This technology include items like exhaust gas recirculation (EGR), up to the first catalyst technology. In order to monitor the performance of the cars sold under the tax incentive, the Dutch government decided to initiate an in use compliance program for passenger cars.
Along with the initial goal of monitoring the performance of the cars sold under the tax incentive scheme, some additional components ware added to the program. These concerned:

- monitoring the effects of aging of the systems installed on cars, in order the increase their emission quality, because the technology was new and there were not yet any data on long term stability.
- gathering of realistic emission data of cars in the field, to be used in emission inventories.

The need to investigate the factors mentioned above lead to the start of 'The Dutch in use compliance program for passenger cars' in 1987. It has been executed annually for more then 12 years now. The program started with testing 300 vehicles annually. Later this number was reduced to 150 cars per year. Up to the year 2000 more than 3000 cars have been tested.

3. Setup of the program

The execution of the program has always been based on the type approval procedure for passenger cars in Europe (70/220/EEC and later amendments. This was an absolute necessity, because the programs basic purpose has always been: *Monitoring the emission performance of passenger cars in-use and relating this performance to the situation at type approval.* Because of the absence of a legal international procedure limiting in-use deterioration until recently, the program has had limited legal possibilities in order to confront manufacturers with the results of the TNO measurements. This absence of legal status has not been felt as a problem. Most manufacturers have reacted spontaneously on detection of problems regarding their products, based on their product liability.

Although the emission limit values related to this procedure have been tightened in five steps during the execution of the Dutch program (figure 1), the basic test procedure has only gone through minor changes during the last decade. Starting with directive 91/441/EEC the procedure has always consisted of testing vehicles on their emissions of CO, HC, NOx and PM (diesel) using the EU type approval test cycle (UDC + EUDC). The test starts with a cold engine and the emissions are determined using a 3-bag split. The only mayor change in the procedure has been the resent deletion of the 40 second non sampled period after starting the car (under Euro III).

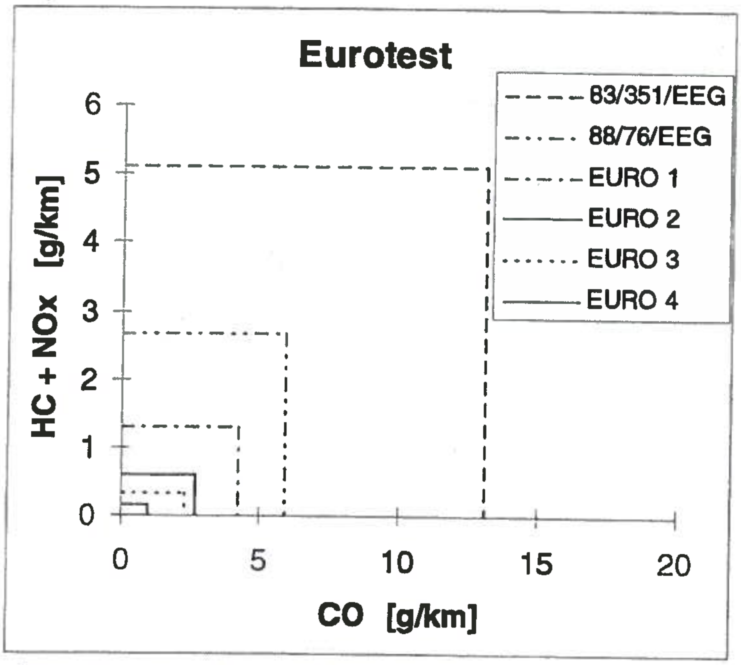


Figure 1: Emission limits on the Eurotest cycle

Note that the early limits have been 'translated' to the Eurotest, based on the IUC program results.

The procedure is applied to 3 basic types of vehicles:

1. standard petrol cars
2. standard diesel cars

3. petrol cars with retrofit LPG fueling (this type is tested on 2 LPG compositions in order to determine the adaptivity of the of the LPG ECU to this change)

In order to be able to access a vehicle's emission status, a typical procedure based on the Eurotest was set up. This procedure is presented below.

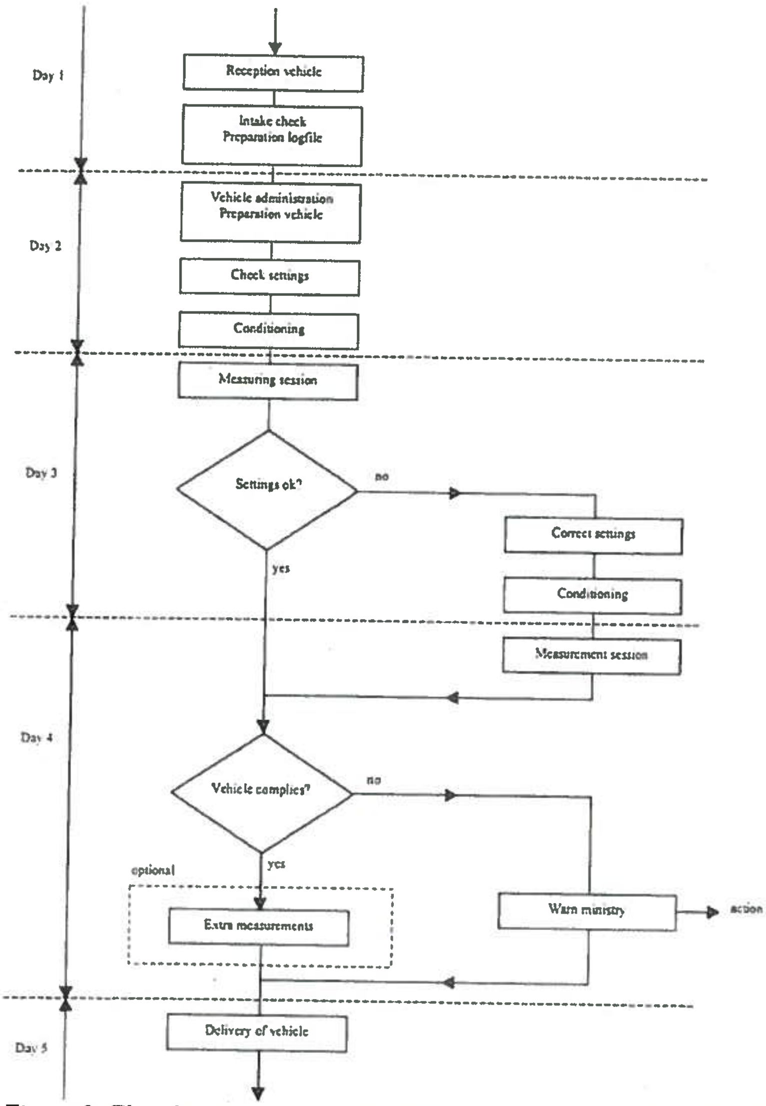


Figure 2: Flowchart of the activities during the measurement of a vehicle for the IUC program

The selection of the vehicles that are submitted to the test is based on sale-figures in the Netherlands. Periodically a new selection is made, based on the sales data of the previous. The evaluation of the sales data is executed based on engine types, not on models. This way of looking at the sales decreases the amount of selectable types significantly, especially since car manufacturers are increasingly using platform technology. Next to the actual sales over the previous period, earlier testing of similar engine types is taken into account during the selection.

Per year about 50 types are selected, leading to actual testing of three to five vehicles per engine type. The procedure starts with the measurement of three vehicles. If one of these

vehicles fails the test, two additional vehicles will be tested. The actual vehicle types selected for testing are the best sold types using the engine selected. So for instance the 1.6 8V engine of the VAG group will be tested in a VW Golf.
After the selection has taken place, an inquiry is send at random to 25 persons which are registered to own the type of car required. From people with a positive reply (mostly about 25%), 3 vehicles which are closest to the Dutch average are selected. This Dutch average includes items like: mileage, type of use, regular maintenance etc. Additional attention is paid to the fact that a certain part of the tested vehicles is leased instead of privately owned.

4. Results

During the duration of the execution of the Dutch in use compliance program, a large amount of data have been collected. A summary of the most striking results is given next.

Emissions

The figures below give a general view on the emissions (and their reduction over the years) of the vehicle classes that have been investigated. A steady drop in emissions can clearly be observed.

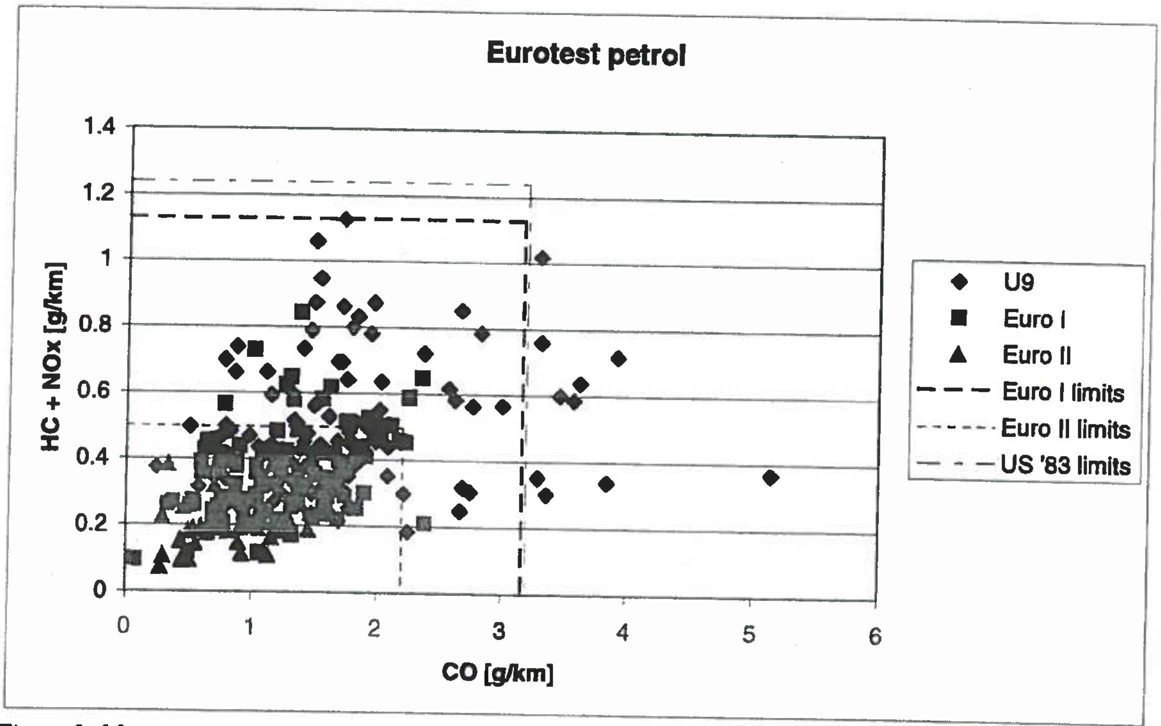


Figure 3: Measurement results of the IUC program for petrol fuelled vehicles on the Euro test

Figure 3 clearly shows this decrease of emission with progressing emission limitations. From the figure it can also be concluded, that petrol cars at low average mileage are mostly one step ahead of the emission class they are type approved on. The actual emissions of Euro II approved cars, mostly prove to be up to the level of Euro III limit values already.
Figure 4 underlines this effect even more clearly, showing some (late) Euro II cars complying with Euro IV limits already.

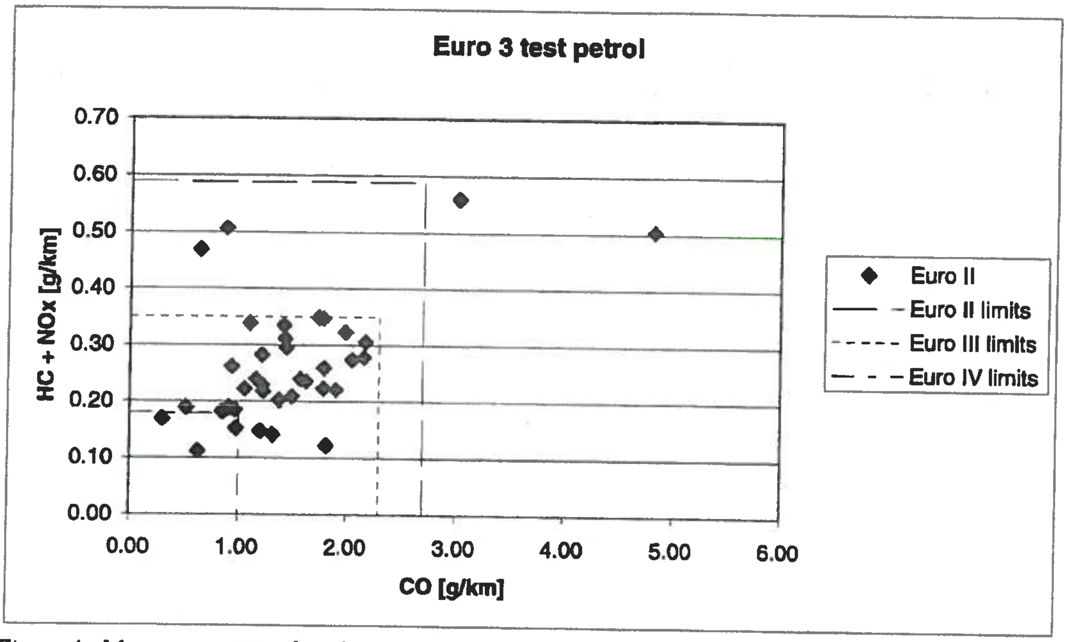
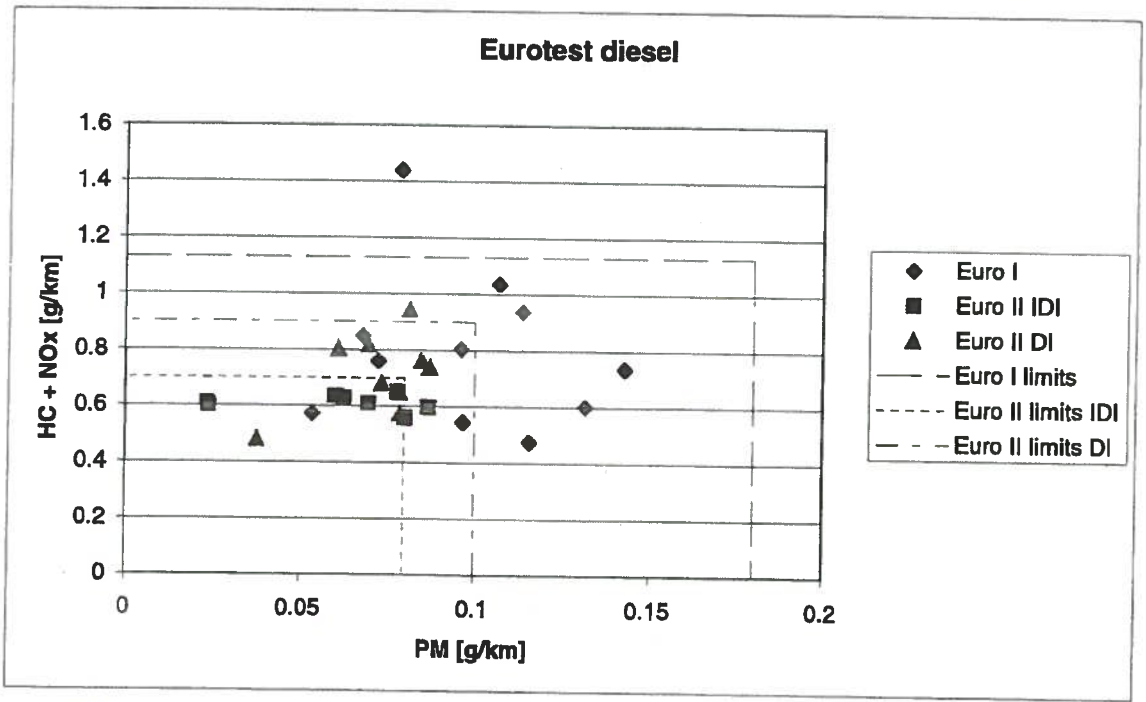


Figure 4: Measurement results of the IUC program for Euro 2 petrol fuelled vehicles on the Euro3 test

Diesel cars however do not show this phenomenon. Their 'give away' at low mileage in relation to the limit is much smaller than for petrol cars. The critical emission components of diesel cars (NOx and PM), prove to be very close to the limits, especially for Euro II cars. First investigations on Euro III diesel cars, indicate an even further decrease of the distance to



the Euro III limits.

Figure 5: Measurement results of the IUC program for diesel fuelled vehicles on the Euro test

In the Netherlands special attention is paid to petrol cars with LPG retrofit fueling. LPG fueling using the newest third generation equipment (G3), are stimulated in the Netherlands by a road tax incentive. These latest systems receive this tax incentive based on Euro II type approval values being 30% under the type approval values of relevant petrol types . Once in use these vehicles show significantly increased NOx emissions, while especially CO emissions are rather low. An in-use shift to lean operation seems to be the cause of the effect mentioned. The effect is presented in figure 6.

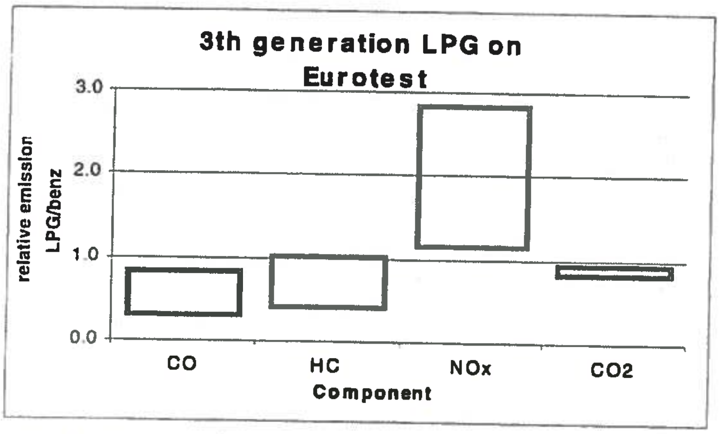


Figure 6: Relative emission factors for 3th generation LPG on Eurotest

Detected failures

During the years the Dutch in-use compliance project is running, the number and type of detected failures after service and repair, leading to cars not being in compliance, has changed dramatically.
The figure below shows that the program was very effective in detecting failures in its early years. Especially the first emissions reduction systems, proved to be unreliable while in use. Once closed loop 3-way catalyst technology was introduced under the Euro I regulation, almost no severe failures occurred. This does not imply that no minor failures were found. These minor failures concerned small technical problems that could be repaired easily, without being the result of major basic construction errors.

With decreasing emission limits, the settings of the cars fueling and ignition system have become more and more electronically controlled. The adjustment of the settings has become rather critical and has in some cases lead to increased emissions. Readjustment mostly solved the problems. In some cases, failures of mechanical components also caused increased emissions, but these problems always showed to be incidental and repairable. Typical problems were bad electrical contacts and defective seals.
What often showed to be a critical item was the maintenance of the (latest) cars. Many cars that failed their initial test, did pass the test after the car being serviced properly. The appliance of sensitive components and technology (actuators, sensors etc.), increases the need for proper and regular service (by authorized personnel). Catalyst failure almost never (<2% of the cases) proved to be the cause of enhanced emissions.

With the introduction of Euro II limits for diesel fueled cars, the number of failures increased again. Especially the emissions of PM did often not comply with the limits. As can be seen in figure 5 diesel engine emissions during type approval are much closer to the limits than petrol engines, leading to more exceeding on emission limits in-use. Measuring the PM emissions of diesel cars is also becoming more and more a problem. Newest diesel vehicles show the tendency to store particulate matter in the exhaust system. This storage seems to be dependant on the way the vehicle is driven before testing. Long term defensive (low rev's) driving seems to accommodate the storage of particles. Once driving the ECE test cycle enhanced emissions of PM occur, although this test cycle is rather defensive itself. Test results indicate that dynamic preconditioning of a diesel car will decrease the PM emissions measured on the ECE test.

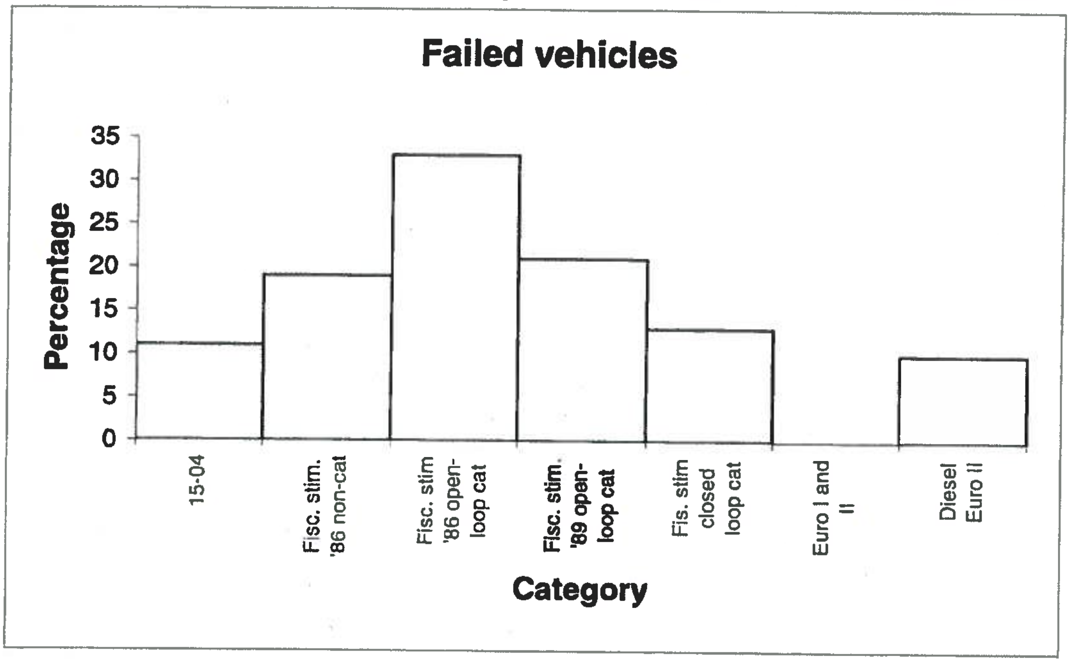


Figure 7: Percentage of failed vehicles during the IUC program

Durability

Because of the setup of the vehicle selection criteria, the mileage of the tested vehicles can vary widely. This variation enables a (limited) assessment of durability factors of passenger cars. Table 1 gives an overview of the average durability factors (80.000 km or 5 years) per emission category of petrol cars, determined from the Dutch program, next to the fixed value factors from the US en European legislation.

Table 1: Average durability factors of petrol cars determined from the Dutch program

Category	Test	Cars Tested	CO	HC	NOx	FC
no/unreg. kat	UDC	12	1,15 ± 0,2	1,1 ± 0,3	1,1 ± 0,3	1.0 ± 0,1
U9	FTP	57	1,8 ± 0,25	1,6 ± 0,15	1,5 ± 0,15	1,0 ± 0,03
Euro 1/Euro 2	Eurotest	15	1,6 ± 0,25	1,5 ± 0,25	1,7 ± 0,5	1,0 ± 0,05
Fixed value factors	FTP		1.2	1.3	1.1	
Fixed value factors	Eurotest		1.2	1.2 (NOx + HC)		

This table shows the actual deterioration to be bigger than expected. For diesel engines the factor seems to be much smaller (max. 1.29 for PM), but the amount of data available is not sufficient to draw conclusions. The data in this table are based on data from vehicles without technical defects. The reason for this approach is based on the available data from the program, that prove that gross emissions are always caused by technical defects. Including data caused by technical defects, would pollute the deterioration factors calculation.

5. Additional investigations

During the execution of the in-use compliance project, the data gained proved to be very valuable for other purposes as well. Because of the large amount of emission data available from a representative vehicle sample, TNO decided to use these data for the purpose of estimating the emissions of the Dutch car fleet. Based on the data TNO developed a passenger car emission model. This model called VERSIT (traffic situation model) is used as the Dutch national standard procedure for calculating emission factors. VERSIT uses correlation's between emission levels and the traction energy needed to overcome rolling, air and acceleration resistance. Based on measurements from the Eurotest, emissions can be derived for driving different cars, being driven on different types of trips. Figure 8 shows an example of the use of bag measurements from which TNO obtains their correlation's. The interrelations shown in figure 8 between traction energy and some form of emission factor (g/kg, g*km/h or g*h/km) have no direct physical explanation but have proven to be the best out of several tested correlation's.

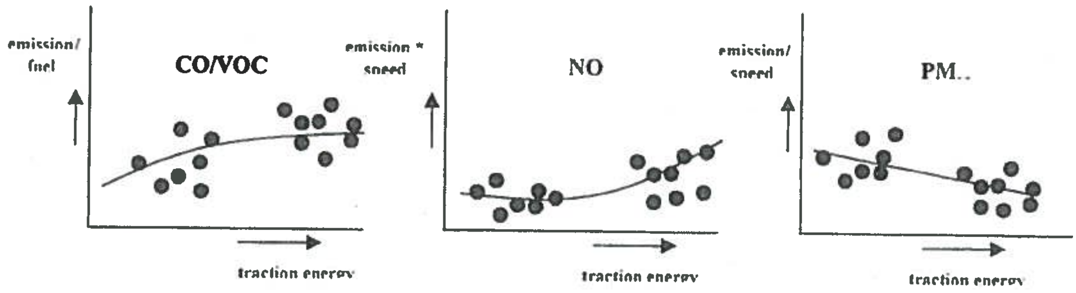


Figure 8: Bag measurements and the interrelations between traction energy and some form of emissions factor

The Dutch in-use compliance program has always been set up in a way that cars could be tested, twice in case of the first test proved to exceed the limits. With a decreasing amount of failing cars, additional tests could be executed in order to examine other fields of interest. In the past additional work has been done on:

- Cold start emissions. By adding an additional test to the standard procedure, (ECE urban cycle starting with a warm engine), the effect of a cold start could be determined in g/start. This was very useful information for modeling the annual Dutch passenger cars emissions (using VERSIT).
- The effect of the deletion of the 40 sec startup time (in Euro III) could be determined by testing Euro II cars additionally on the Euro III procedure.
- A more precise determination of the deterioration of cars is under investigation, by testing 5 typical cars every 20.000 km over 100.000 km.
- Establishment of real world emission factors.

Real world emissions

This last topic is of great interest at this moment. Over the years the test cycle used in the ECE type approval procedure, has proved to be less representative for real world driving. With increased congestion and new ways of traffic regulation, the emissions measured on ECE test cycle are no longer representative for real life situations on the road. The main difference between real world driving and driving the ECE test cycle can be seen in de differences in driving dynamics (more than in average speed).
TNO has been investigating ways to compensate emissionfactors for the differences in driving dynamics. The investigations have started by testing all cars from 1998 onwards on a more representative test cycle as well. The cycle used has been the MODEM driving cycle from INRETS.
One of the key points in this investigation, has always been the utilisation of all data in the TNO in use compliance database (because in 2000 still 30% of all vehicle miles is made with cars older then 10 years). Because all data are only available in a 3 bag split, the dynamics compensation can not be based on remodeling all data (second to second). This led to an approach in which a certain type of the total trip is described by its average speed and the average driving dynamics (expressed in 'relative positive acceleration', RPA).
As an example of this approach the Eurotest and the MODEM cycle are characterised below.

Table 2: Characteristics of various driving cycles

Cycle	time (s)	distance (m)	Avg. speed (km/h)	max. speed (km/h)	RPA (m/s^2)
UDC (urban)	780	4 052	18.7	50.0	0.15
EUDC (extra urban)	400	6 955	62.6	120.0	0.09
Total (Eurotest)	1180	11 007	33.6	120.0	0.12
MODEM					
'slow urban'	428	1 705	14.3	42.3	0.28
'free-flow urban'	355	2 248	22.8	62.3	0.32
'road' (secund. weg)	712	8 485	42.9	109.2	0.23
'motorway'	452	12 683	101.1	128.7	0.12
Total	1947	25 121	46.4	128.7	0.19

The low average dynamics of the Eurotest is very clearly shown in the table. The next table shows the relative increase of emissions of real world driving. The comparison is made bases on comparing emission results of:

- the UDC with the combined emissions of 'slow urban' and 'free-flow urban'
- the EUDC with the combined emissions of 'road' and 'motorway'

Table 3: Relative increase of emissions of real world driving

	Petrol		Diesel	
	Urban/UDC	Ex.urban/EUDC	Urban/UDC	Ex.urban/EUDC
CO	3.3	1.7	1.2	1.5
HC	1.5	0.6	1.3	1.35
NOx	2.05	2.1	1.0	1.55
CO2	1.25	1.15	1.2	1.3

In line with the shift to real world driving patterns in emission modeling, the in-use compliance program has gone another step in being the 'emissionfactor generator' for the Dutch situation.

Because of the continuity of the program over the years, TNO has always a large number of in-use cars at its disposal for testing. Lately the major Dutch programs on determining real world emission factors (Driving styles and emissions, Congestion and emissions) have been linked to the in-use compliance program. Many additional tests were executed, using the cars that were available at TNO for the standard in-use compliance testing. This combination of investigations guarantees high representativity of emissions measured for reasonable costs. These large amount of data will also be made available to international projects like

6. Future topic's

With emission legislation evolving over the years, the demands on in-use compliance programs has changed as well. The latest steps in emission regulation for passenger cars (Euro III and after that Euro IV) will have large impact on the basic setup of the Dutch in-use compliance project. The main factors in this area are:

- Ultra low emissions.
  With the decrease of limit values, cars become so clean that the detection limits of the analyzers used and the background emission levels in the test cell environment are in the same order of magnitude of the emissions of the cars that have to be tested. Many Euro III petrol cars already fulfill Euro IV specifications, causing problems regarding the accuracy of the measurement results. New ways of sampling (partial dilution) are under investigation.
- In 2001 all new passenger cars will have to be equipped with European On Board Diagnostics (EOBD). This way of monitoring the emissions of a passenger car, could (in time) decrease the need for real in-use compliance testing. Monitoring of the EOBD systems will always be necessary in order to fulfil in-use compliance monitoring. Before that time the existing in use compliance programs will be of great importance in order to determine the actual representativity of the EOBD systems in use. For the time being TNO will focus on gathering data on correlation's between measured emissions and EOBD warnings.
- With the introduction of a cold start test at -7° C, test facilities for type approval testing will have to be upgraded. These upgrades are very expensive, and because of this (in combination with the introduction of EOBD) it is still an unanswered question if a -7° C test should be part of an in-use test procedure.

Because of the increasing discrepancy between type approval emission data and real world emission data, the need for a representative driving cycle is increasing as well. TNO will keep testing on real life test cycles in the in-use compliance program. The introduction of a new driving cycle, will be of great value for the representativity of in-use testing for real life applications.

Acronyms

Bag	Integrated measurement of emissions over a certain part of the testcycle
Eurotest	Test procedure for type approval of passenger cars in Europe
EUDC	Extra urban driving cycle. Second part of the testcycle used for Eurotest
EURO II	European emission regulation from 1996 until 1999
EURO III	European emission regulation from 2000 until 2004
EURO IV	European emission regulation from 2005 onwards
EOBD	European on board diagnostics. Expert system for in-use on- board
LD	Light duty. Passenger cars and small vans
Modal	second to second measurement of emissions
MODEM	Real world driving cycle, build from European real world driving data
UDC	Urban driving cycle. First part of the testcycle used for Eurotest
VERSIT	Traffic situation model. Dutch standard model for emissions calculations