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DRAFT PROJECT REPORT RPN2098

Tampering prevention in L-category vehicle approval legislation

Impact assessment on powertrain tampering prevention with recommendations for cost effective measures

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Executive summary

On 4th October 2010, the European Commission (EC) published a proposal[1] for L-category vehicles, with the aim of introducing a revision of type approval requirements in terms of simplification, functional vehicle safety, environmental requirements and market surveillance, as well as improving the ability of the technical requirements to deal with new technologies.

TRL was commissioned by the EC to investigate possible measures to prevent or restrict harmful tampering to the powertrain of L-category vehicles. 'Harmful tampering' was defined as *"modifications to the powertrain that result in detrimental effects on emissions, safety or noise"*.

COM 542 (2010) included proposals for new tampering control measures. The intended purpose of tampering prevention measures is to reduce the incidence of tampering events that result in increased emission levels and reductions in the safety level offered by the vehicle, and which thereby detract from efforts to improve and guarantee the level of safety and environment protection offered by L-category vehicles. Anti-tampering measures are not targeted at preventing general modification of a vehicle or the desire of vehicle owners to carry out *'custom tailoring'* providing that these changes do not result in 'harmful tampering' as defined earlier.

The aim of this study was to quantify the potential effects of tampering on the powertrain of L-category vehicles, and to identify potential tampering control measures that could be used to prevent or restrict tampering. The specific aims of this study were to:

- produce an impact assessment on powertrain tampering prevention (limited to prevention of modifications of powertrain systems and components that have detrimental effects on functional safety, emissions or noise); and
- develop options and rationale for:
  - an appropriate method (which can be verified in the field by enforcement agencies) to measure the maximum continuous rated power for the propulsions listed in Article 4(3) of COM 542(2010);
  - pragmatic requirements to enable components and separate technical units to be marked effectively such that type approved components can be distinguished from non-approved alternatives.

In order to produce an impact assessment, the research aimed to identify and prioritise harmful tampering events using objective analysis based on the same principals as a Failure Modes and Effects Analysis (FMEA). This estimated prioritisation was verified and adjusted by quantifying actual effects on emissions, safety and noise using physical testing involving a paired comparison between 'untampered' and 'tampered' L-category vehicles. A test programme involved 16 different vehicles covering the broad range of L-category vehicles. The main conclusions of the project can be summarised as follows:

[1] URL: http://ec.europa.eu/enterprise/sectors/automotive/files/com-2010-542_en.pdf

- Powertrain tampering using methods which are in use in the current L-category vehicle fleet can have adverse effects on safety (e.g. increases in maximum vehicle speeds in excess of maximum design speeds for vehicles limited in maximum design vehicle speed and/or power), emissions and noise (e.g. increases above legislative limits).
- Some tampering types undertaken with the aim of achieving increased power or speed resulted in only minor increases with respect to these areas, but much larger increases in tailpipe emissions to levels far in excess of regulatory limits.

With respect to the test results, the main findings of the test programme were:

- Removal of the CVT (constantly variable transmission) limit resulted in large increases in maximum vehicle speed. In conjunction with other modifications, increases of nearly one and a half times the original maximum vehicle speed were observed. The removal of the CVT limit was the single modification that had the most effect on maximum vehicle speed.
- Tampering with the exhaust orifice and air filter resulted in large increases in emission levels on some vehicles: up to more than 20 times the original levels of Hydrocarbons (HC), twice the level of Methane (CH_4) and a 50% increase in Carbon Dioxide (CO_2).
- Fitment of an aftermarket exhaust with a catalyst bypass resulted in increased maximum vehicle speed (7%) and propulsion power (24%), but even greater negative effects on emissions - approximately 170% increases in Hydrocarbons (HC) and 160% increases in Oxides of Nitrogen (NO_x) and Methane (CH_4). Fuel consumption also by increased (48%) and the mean motion sound level increased by 24%.
- Differences in the magnitude of effect on different L-category vehicles were noted for the same or similar tampering types. This highlights that the effect from tampering may vary between sub-categories and also perhaps between vehicle make, model and propulsion type, dependent on precise technical characteristics.
- Significant increases in noise levels were found for the three tampering modes which involved replacement of the exhaust. For combined tampering types on L1Be vehicles mean stationary sound levels rose up to 14 dB(A). On a single L3e-A3 vehicle, the same measure increased to 95.1 dB(A) from 88.6 dB(A).
- No substantive evidence could be found that L-category vehicles that are unlimited in power or maximum vehicle speed in the EC Co-decision proposal should be subject to anti-tampering measures related to performance.
- Significant evidence was found to suggest all vehicles should be covered by legislation preventing increases in noise and gaseous emissions, however not to the detriment of safety. It is anticipated that the control of noise will be improved as soon as the latest amended UN Regulations 9, 41, 63 and 92 are fully implemented in the EU, thereby replacing the proposed requirements originating from Chapter 9 of Directive 97/24/EC in the proposed Regulation for environmental and propulsion performance requirements.

- The test programme was successful at quantifying the effects of a range of prioritised tampering types on L-category vehicles. However, the limited amount of vehicles tested in each area has implications for how generally applicable the results are. To expand on these results a significantly larger test programme would be required.

A benefit estimate used the test results to value the effects and a basic break-even analysis was conducted with the aim of scoping the likely break-even value of tampering control measures. This analysis identified three areas of vehicle design which, based on the information from the test programme and the assumptions made in the analysis, are candidates for the development of cost-effective anti-tampering measures. An additional area was added to ensure that future measures remain in line with anticipated advances in technology. These are measures aimed at preventing tampering of the:

- CVT on speed restricted vehicles (i.e. category L1e and L6e)
- Air intake (on learner motorcycles)
- Exhaust
- ECU/PCU[2]

The potential measures that this study has identified that could be used to control harmful L-category vehicle tampering are as follows:

- The CVT could be specifically included in the anti-tampering legislative requirements. Furthermore, technical measures have been discussed which, if implemented, could reduce the extent of tampering in this area:
    - The cones of the CVT could be so designed that the rotational speed limiting rings are fundamental to the structural integrity of the part and removing them would destroy the component. In some vehicles, the limiter is a plate at the back of the cones; the same principle could be applied.
    - The speed limiting addition could be required to be fitted to a specific cone which is not widely available in the current market.
    - The diameter of one or more cones could be such that, if the limiters where removed, the belt would slip out of position and loose traction, thereby preventing the operation of the vehicle if the limiting rings or plates were removed. This could be dangerous if this occurred while riding, therefore appropriate warnings should be placed within the transmission.
    - Sealing the transmission to prevent access, apart from with special tools, is not considered feasible. Maintenance requires that the belt is checked at specific intervals and if special tools become more widely available (for example on the internet) then this measure can be easily bypassed.

[2] Although not identified in the benefit assessment, ECU/PCU tampering is considered to have similar effects to other forms of tampering which were quantified.

- Measures to prevent the removal of the orifice in the exhaust system by integrating the orifice into the fundamental exhaust design. Changes to UN Regulations currently underway come to the same conclusion and detail appropriate anti-tampering measures.

- For the air intake system, there is currently an obligatory choice of three methods specified to restrict the air intake on learner motorcycles (L3e-A1 vehicles): A removable sleeve fitted inside the air inlet, a restricted section in the intake pipe (visible from the outside), or a restriction in the air inlet to the engine itself. The stakeholder study indicated that the first option is generally known to be easy to circumvent and the requirement that the object itself must be destroyed in the process of removal to prevent it being reinstalled before an inspection does not prevent its removal. Therefore, the option of a removable sleeve could be removed as a permissible design. The current legislation already covers this area, and so any measure here is simply a strengthening of existing requirements.

- Some evidence from electrically powered cycles suggests that simple tampering to activate the motor at levels greater than intended should be prevented. Measures (both direct and those aimed at preventing the realisation of effects from other tampering types) taken by manufacturers should have the effect of restricting the possibility of this occurring. The addition of this area to anti-tampering legislative requirements would have the effect of requiring manufacturers to address this issue.

In addition to measures aimed at specific tampering types, a range of further measures have been identified which have the potential to improve the effectiveness of anti-tampering regulation. These can be summarised as follows:

- Changes to the structure of the legislation with the intended effect of allowing greater clarity and understanding of the legislation. This was identified as a difficulty in the test programme undertaken as part of this research and by manufacturers, testing authorities, enforcement authorities, and end-users.

- Specific inclusion of all powertrain propulsion systems under the anti-tampering legislative requirements, including new technologies (e.g. electric)

- Improvements in markings used on components to provide effective information to enforcement authorities. In particular:

    - Exhausts for off-road, racing, or multi-functional use on all categories of L-category vehicle could be required to have prominent markings to aid detection on the road where their consequences for both noise and emissions have been found to be substantial.

    - The stakeholder consultation also indicated other issues which could be improved, such as how the data, in terms of test results, anti-tampering methods used, and marking locations could be better utilised. With the exchange of information enforcement authorities could better detect tampering and generate a better evidence base on which to determine effective countermeasures.

- With respect to the scope of anti-tampering legislation, measures which restrict performance could be applied only to performance restricted vehicles. These could be defined as: *'Performance restricted vehicle' - a vehicle in a category with an upper propulsive power or vehicle speed limit which is used by EU and/or national legislation for vehicle classification and licensing.* However, there are some aspects of the legislation which prevent environmentally damaging design features or easily bypassed propulsion performance restrictions, such as the prevention of restrictions in the air intake and exhaust and prohibiting the use of environmentally unfriendly spark retard and inhibiting strategies. It may be beneficial if these practices were applied to the entire L-category fleet, therefore these parts which are not performance limiting or anti-tampering related, could be moved to another more suitable section of the type-approval legislation.
- The testing results also showed that in addition to vehicle age, other factors (e.g. ambient temperature, fuel octane grade) affected the environmental and propulsion performance. To allow roadside enforcement to account for this, suitable tolerances should be defined with respect to the limits achieved at type approval. Alternatively if future studies find that this has become a significant issue for performance restricted vehicles, then further tests may be required as part of the type-approval process.
- To enable users to make modifications that may have an effect on propulsion performance and/or emissions, but are part of existing seasonal or normal use, the requirement for re-approval of the modified vehicle would not be needed if the original type approval took account of common modifications. Thus type approval evidence could be used to approve the vehicle with a range of specific components, thereby negating the need for re-approval if the part is changed in use.
- Changes could be made to the current rules on the compatibility of replacement parts. Adding requirements for the PCU/ECU and potentially their sensors and actuators relevant to the environmental and propulsion performance would keep pace with technological developments. Additionally, a common standard specifying certain fittings for vehicle speed/power limiting parts would mean that more effective controls could be implemented, making it more difficult to tamper with these areas.
- Any type of regulatory change that requires changes to the technical requirements has the potential to involve investment to realise any benefits over the longer term. This may have a proportionately greater effect on SMEs compared with larger companies, who may be able to absorb any additional capital or time costs more easily. Therefore, in general the effects on SMEs are likely to be greater, although this was not quantifiable with the information gathered in this study.

Abstract

The purpose of this study was to identify and develop options to prevent or restrict harmful tampering on L-category vehicles. In doing so, the project identified harmful tampering events using a FMEA-type analysis and quantified the impacts of a range of tampering events on safety and the environment through physical testing.

A cost benefit analysis using the results of the test programme provided initial estimates of any possible benefit that might be achievable with the introduction of effective tampering control measures. Options for tampering control measures are presented along with potential changes to current legislation.

1 Introduction

1.1 L-category vehicles and background to COM542 (2010)

Framework Directive 2002/24/EC and its implementing directives specify current type approval requirements for L-category vehicles. L-category vehicles comprise of two and three-wheeled light vehicles (mopeds, motorcycles and tricycles), but also includes four-wheeled quadricycles and light 'car-like' four-wheeled vehicles, referred to hereafter as 'quadri-mobiles'.

Figure 1-1 provides an overview and examples of different L-category vehicle characteristics according to the classification used in COM542 (2010) and Appendix D.1 outlines in more detail their classification criteria.

Figure 1-1. Examples of vehicles in the scope of the L-category classification - COM 542(2010)[3]

[3] Picture from ACEM, European association of powered two-wheel vehicle manufacturers

Following the recommendations for regulatory simplification made by the CARS21 initiative, the European Commission proposed simplifying the legislation relating to these vehicles by repealing the present framework Directive and its 14 associated implementing Directives. It is intended that these will be replaced by five Regulations; one covering the main umbrella of measures adopted in co-decision, and four containing the detailed technical requirements and administrative provisions adopted.

On 4th October 2010, the European Commission (EC) published a proposal[4] on approval and market surveillance of two- or three-wheel vehicles and quadrimobiles that included measures to:

- Simplify the legal framework by replacing Directive 2002/24/EC and their separate directives like e.g. Directive 97/24/EC, with a single Regulation and four delegated and implementing acts;
- Improve the technical requirements with the aim of reducing emissions, increasing the level of safety, dealing with new technologies and strengthening market surveillance. These proposed changes to technical requirements include:
    - More stringent emission limits and additional environmental measures such as durability requirements and evaporative emission limits with associated test harmonised test methods to strengthen the environmental performance for new types of L-category vehicles placed on the EU market, in particular for Hydrocarbons, Carbon Monoxide, Nitrogen Oxides and in the future as well Particulate Matter;
    - Revision of the measures to limit the adverse environmental and safety effects of powertrain tampering;
    - Mandatory advanced braking systems for motorcycles;
    - Improving the ability to approve vehicles that are fitted with new technologies not covered by the existing legal framework;
    - Measures to prevent selling and registration of certain vehicles, systems, components or separate technical units imported into the EU market which do not comply with the current type-approval requirements, thereby ensuring a high level of vehicle safety and/or environmental protection.

This report was proceeded by two other reports the 'Study on possible new measures concerning motorcycle emissions' (Leonidas Ntziachristos, 2009) which is referred to as the LAT report by industry and 'Anti-Tampering Devices relating to Two or Three Wheeled Motorcycles' which is referred to as the TÜV report (Dittmar, et al., 2003).

The LAT report highlighted the disparity in emissions from M-category (cars) and L-category vehicles. For every kilogram of fuel they consume, some L-category vehicles are currently permitted to produce two to four times as much toxic emissions. The legislation has this feature because of the design constraints of L-category vehicles, which work in differing conditions compared to M-category vehicles. However, the LAT report (Leonidas Ntziachristos, 2009) goes on to say that some of these design

[4] URL: http://ec.europa.eu/enterprise/sectors/automotive/files/com-2010-542_en.pdf

constraints do not necessarily apply to some of the L-category fleet for general road use (see Figure 1-2).

Table 1-1: Comparison of emission limits for L and M category vehicles [emissions per kg of fuel consumed] (Leonidas Ntziachristos, 2009)

Vehicle / Stage	Category	Fuel consumption (g/km)	CO (g/kg fuel)	HC (g/kg fuel)	NOx (g/kg fuel)
Moped					
Euro 1	≤ 50 cc	15	400	196	4
Euro 2	≤ 50 cc	12	83	98	2
Motorcycle					
Euro 1	2-Stroke	27	296	148	4
	4-Stroke	29	448	103	10
Euro 2	< 150 cc	29	190	41	10
	≥ 150 cc	29	190	34	10
Euro 3	< 150 cc	29	69	28	5
	≥ 150 cc	35	57	9	4
Gasoline Passenger Car					
Euro 1		44	72	15	11
Euro 2		42	52	7	5
Euro 3		41	54	5	4
Euro 4		39	25	3	2

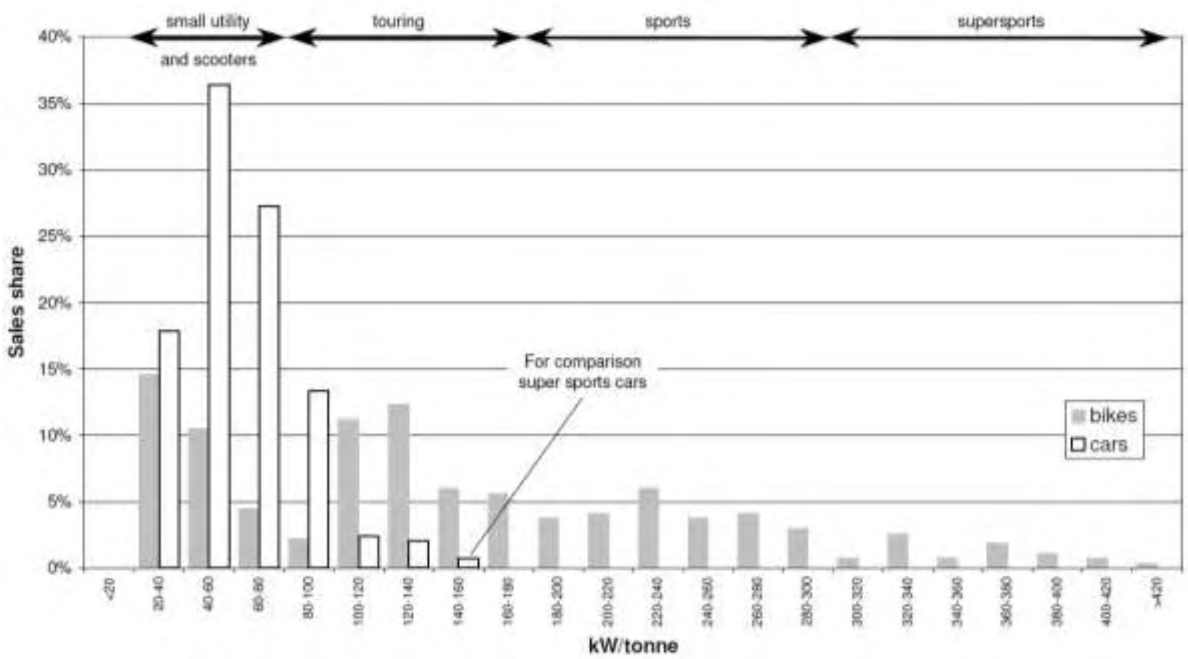


Figure 1-2: Comparison of power over weight ratios (kW/tonne) of L and M category vehicles on the market (Leonidas Ntziachristos, 2009)

The TÜV report (Dittmar, et al., 2003) was focussed on many of the same issues as this study (see also Appendix D). They reported on tampering types in the L-category fleet together with a study of the market to uncover and quantify the size of the tampering

industry. Some of the tampering methods they found were tested in this project and others have subsequently been addressed by changes to the UN regulations on noise which will be acceded by the EU.

1.2 Rationale for tampering prevention measures

Tampering measures are aimed at ensuring that a vehicle which meets the emission and safety technical requirements at type approval remains compliant over its useful life, and that adverse changes to the powertrain which have negative impacts on safety and the environment are discouraged. This covers criteria such as: maximum design vehicle speed, maximum power, noise limits, exhaust and evaporative emission limits, braking ability, and other functional safety features etc.

The scope of this report covers only the powertrain, as already covered by Directive 97/24/EC Chapter 7 (see Section 2). However, the aim is to extend the scope of this section from only safety to functional safety, environmental performance and noise. The existing measures are currently in place for specific vehicle speed and/or power restricted groups of two-wheel L-category vehicles.

There is a lack of data relating to tampering in the L-category fleet, which ultimately means that the effectiveness of the existing legislation and the magnitude of the effects resulting from tampering are difficult to quantify. Previous studies on the subject (Dittmar, et al., 2003) highlighted that the main reason for this is the lack of relevant data. Although there are various sources that highlight high incidences of tampering (particularly for specific vehicle types), there is no systematic fleet-wide recording scheme for tampering, meaning that the cost-effectiveness of any measures is difficult to calculate. This means that the scale of the effects of tampering in the L-category fleet is largely unknown, and will remain so until such data exists to enable this analysis. However, evidence from the market demonstrates that riders throughout Europe can obtain instructions and products used for tampering (see section 3.3). Logically, the existence of a market for such information and products supports the hypothesis that tampering of various types does occur in the European fleet.

In addition, while discussing harmful modifications, the European traffic police association TISPOL reported in MCWG meetings (of 16th September and 14th December 2011) that roadside inspection authorities frequently suspect that vehicles are tampered with, but are unable to prove it. This is because appropriate reference data from type-approval is unavailable, or measurement data from type-approval cannot accurately be reproduced without using the same complex and expensive test equipment which is not feasible at the roadside.

With this in mind, ensuring that the technical performance demanded at type approval cannot easily be compromised by tampering at the expense of safety and the environment is important to road users and to the wider society.

1.3 Aims and objectives of the tampering prevention project

This study focuses on only one of the areas covered by COM542 (2010): anti-tampering requirements. The purpose of this report is to analyse the current anti-tampering measures in terms of their relevance to current technology and to identify changes or potential additional anti-tampering measures for L-category vehicles.

In doing so, the research aims to identify harmful tampering events (those which have a negative outcome for any or all of environmental, functional safety or sound performance) using objective analysis, quantify the impacts of tampering events on safety and the environment by measuring the effects found during testing.

The specific aims of this study are to:

- Produce a cost benefit analysis on powertrain tampering prevention (limited to prevention of modifications of powertrain systems and components that have detrimental effects on functional safety, emissions or noise) with recommendations for cost-effective measures.
- Develop options and rationale for:
    - An appropriate method (which can be verified in the field by enforcement authorities) to measure the maximum continuous rated power for the propulsions listed in Article 4(3) of COM 542(2010);
    - Pragmatic requirements to enable components and separate technical units to be marked effectively such that type approved components can be distinguished from non-approved alternatives.

In relation to the main aim of the study, several sub-tasks are also necessary in order to meet the overall objective. The methodology used is described in more detail in section 3 and the sub-tasks required can be summarised as:

- Identification and prioritisation of tampering events in terms of their effect of safety, emissions and noise;
- Quantification via testing of the environmental and safety consequences of tampering events

Note that it was *not* within the remit of this research to generate new data to quantify the frequency and effects of tampering within the L category vehicle fleet, as recommended by Robinson et al. (2009). Previous research has highlighted that there is a lack of fleet-wide data on this subject, e.g. (Dittmar, et al., 2003) (Robinson, et al., 2009) and no current data-gathering scheme exists which could be used to obtain the information. However, these studies and the information gathering during this research, found evidence that tampering currently occurs on mopeds despite existing legislation, as well as occurring on other types of L-category vehicle. Similar tampering strategies could, in principle, be used on other L-category vehicles as demonstrated by (Dittmar, et al., 2003).

In conjunction with the more stringent tailpipe emission limits, control of durability and test for evaporative emissions in the EC proposal COM542 (2010) final, measures to prevent or reduce tampering at type-approval could help ensure the environmental emissions, noise and safety delivered by L-category vehicles over the vehicle’s useful life.

It is not expected that measures identified will prevent all tampering with harmful consequences, but that the measures will reduce the risk of this outcome and will ensure that measures are in place at the type-approval stage to make harmful tampering less attractive to carry out.

1.4 Additional studies

In addition to the work specifically within the area of anti-tampering there are a few areas, either directly or partially related, which have also been investigated, these are the classification of the vehicle categories, the measurement of power, and the modification of modern electric and hybrid vehicles.

1.4.1 Engine Power

The difficulty with legislating based on limits of engine power is partly due to the incompatibility of using this criterion to classify the powertrain of some (at the present time, uncommon) new vehicles. This means that the classification requirements for L-category vehicles other than conventional powertrains are open to interpretation. Small amendments to the vehicle category criteria have been made in an ad-hoc fashion to some sub-categories, presumably as and when new vehicles came onto the market.

The increase of power is one area that is under investigation as part of this report, which when combined with the current trend toward alternative drives in the full range of categories and sub-categories of L-category vehicles, means that this area requires clarification. The investigation into this area is presented in the sub-report in Annex 1.

1.4.2 Classification of 3 wheeled L category vehicles

There are currently two classes for 3-wheelers (EC, 1997); L2e and L5e, which are three wheel mopeds and all other three wheelers respectively.

It is either implied or assumed that three-wheeled mopeds can be split in the same manner as the two-wheeled variety, i.e. into L1Ae and L1Be. However this is not clearly expressed and the need for this clarification is evident with the rise of stabilised mopeds for commuters bearing two closely spaced front wheels. However, some of these vehicles will be defined as L1e or L3e due to Article 3(59) on 'twinned wheels'.

The larger tricycle classification extending above the 45 km/h and 4 kW limit is expressed in similar terms as the four-wheeled L6e and L7e vehicles. However, it could be said that some vehicles in this category should be defined in the same fashion as L3e motorcycles. It is very difficult, using simple characteristics, to separate the "motorcyle-like" and "quadricycle-like" designs.

1.4.3 Classification of 4 wheeled L category vehicles

In the current legislation, four-wheeled vehicles are defined as one group; however these are now defined as five distinct sub-types: light and heavy on-road quads, light and heavy quadrimobiles and heavy all-terrain quads.

Some areas of the categorisation of four-wheeled L-category vehicles are being investigated in a separate European Commission project on the "Categorisation of Side by Side Vehicles (SbS)", in particular where they are designed for use in agriculture.

1.4.4 Electric vehicles

Additional testing on a limited range of electric vehicles, including power-assisted bicycles, mopeds and motorcycles, has also been undertaken. This is presented in a supplementary annex to the main report (see Annex 2).

2 Current legislation

The legislation currently in force covers three areas; the maximum power of the type of vehicle used by learner motorcyclists, the noise produced by motorcycles and mopeds, and the maximum design vehicle speed of mopeds:

- For example, in the UK, motorcycle learner riders were first restricted to 250 cm^3 engines in 1960, after these vehicles started being able to achieve vehicle speeds of over 161 km/h (100 mile/h) this was further reduced to $125cm^3$ in 1983;
- Mopeds were restricted to ~48 km/h (30 mile/h) in the UK in 1977, and $125cm^3$ motorcycles had a noise limit set at 86 dB in 1982 (this came into force in 1970)[5];
- Anti-tampering legislation was proposed in 1992 (Noordzij, *et al.*, 2001), in Directive 92/61/EEC it is indicated that Anti-tampering measures for mopeds and motorcycles should be checked according to each Member States' legislation and Directive 97/24/EC brings this up to a consolidated EU wide check in 1997 (this came into force in 2001).

The current anti-tampering legislation in relation to the powertrain of L-category vehicles is in Directive 97/24/EC, chapter 7 "Anti-Tampering measures for Two-Wheel Mopeds and motorcycles".

It should be noted that although the title specifically mentions two wheeled vehicles it is accepted that this is simple a synonym of the L-category i.e. light vehicles between pedal bicycles and cars. Similarly, the term "mopeds" includes all light vehicles within the category with a ≤50 cm^3 capacity engine and a maximum design vehicle speed ≤45 km/h and "motorcycles" includes all other in the category with a greater maximum design vehicle speed and/or engine capacity.

The anti-tampering legislation only mentions the possible effect on gaseous emissions in one article, which concerns the increase of HC (hydrocarbon) emissions caused by a performance restriction measure. Similarly, noise is not specifically used as a measure in the anti-tampering chapter, although silencers in the air intake and exhaust are mentioned as requiring markings.

The chapter is laid out into the following areas:

- Categorisation method
    - This area of the legislation lays out four groups which covers the entire L-category. This categorisation system was superseded by the L number system in Directive 2002/24/EC, however not transferred into this Directive. Only the first two A and B are covered by this chapter, i.e.:
        - A = mopeds, maximum design vehicle speed of ≤45 km/h and maximum engine capacity of ≤50 cm3. Categories L1e (two-wheel mopeds), L2e (three-wheel mopeds), L6e (light quadricycles)

[5] Chronology of Motorcycle Legislation in Britain The First Century. Thames Valley Regional Motorcycle Action Group. 1998. Accessed 12/03/2012. URL: http://thames-valley-region.mag-uk.org/Pages/legisla_chronology_of_motorcycles.htm

    - B = low-performance motorcycles, maximum engine capacity of ≤125cm^3 and a power not exceeding 11 kW, category L3e-A1 and some L5e & L7e
    - C = motorcycle with maximum Net power ≤ 25 kW, and a power to weight ratio ≤0.16 kW/kg. Category L3e-A2 and some L5e & L7e
    - D = all other motorcycles (tricycles and quadrimobiles). Categories L3e-A3 and some L5e & L7e
- Definitions
    - This indicates that an 'unauthorised modification' means a modification which is not permitted by this chapter
- 'Interchangeability' of parts
    - The manufacture is required to not make parts for this or other vehicles which can fit this vehicle be exchanged allowing the vehicle to exceed a given criteria
- Compulsory requirements
- Conditional modifications, dependent on results of tests
- Markings

2.1.1 Design of vehicle speed and power criteria

Throughout the chapter the following criteria are used to define whether a design feature is required or not and additional criteria are sometimes also specified:

- The maximum design speed of a moped must not increase by >5 km/h
- A low-performance motorcycle's maximum power must not increase by >10 %
- Additionally, neither measure is permitted to exceeded the limits defined by their category

2.1.2 'Interchangeability' of parts

The first set of requirements is related to the 'interchangeability' of parts. This stipulates that the manufacturer must not make parts which fit the vehicle if they would increase the performance of the vehicle as defined by the criteria above in section 2.1.1. This does not mention parts made by other manufactures or third party aftermarket suppliers. Only specific parts are included in this rule and these are dependent on the type of engine as follows:

- Two-stroke vehicles: cylinder/piston combination, carburettor, intake pipe, exhaust system
- Four-stroke vehicles: cylinder head, camshaft, cylinder/piston combination, carburettor, intake pipe, exhaust system

2.1.3 Compulsory requirements

The next area of the chapter is on two specific compulsory requirements, one for low-performance motorcycles on the air intake and a second for mopeds.

For motorcycles, the manufacturer must fit one of three restrictors; an 'unremovable sleeve' in the inlet conduit, a 'restricted section' as part of the intake pipe, or a 'restricted section' as part of the cylinder head. Additionally, no other part of the air inlet system must cause an increase in performance if removed.

For mopeds it is specified that removing the air filter should not increase the maximum achievable speed by more than 10% i.e. ≥5 km/h for a ≤45 km/h moped or ≥2.5 km/h for a ≤25 km/h moped.

2.1.4 Conditional requirements

These anti-tampering requirements are only required if the vehicle has a certain component or, when modified in a specific area, the performance of the vehicle exceeds the criteria in section 2.1.1:

- The following requirements apply if the vehicle exceeds the above criteria when modified:
  - Cylinder head gasket maximum thickness
  - Cylinder/crankcase gasket maximum thickness (2 stroke only)
  - Piston not to cover inlet port at top dead centre (2 stroke only)
  - Piston must not increase performance if rotated (2 stroke only)
  - No restriction is permitted in the exhaust system (however this does not override compulsory requirements)
  - Pipe inside exhaust silencer must not be removable
  - Any component which limits full engine load is forbidden (i.e. throttle stop) see Article 3.7, Appendix P.
- The following requirements apply if the vehicle has a specific component
  - For mopeds, if an electronic speed limiter is used this must not allow an increase of speed by more than 10 % if removed/deactivated
    - Systems which inhibit or retard the spark angle must not result in an increase in fuel consumption or HC emissions (the only mention of environmental impact)
    - If the vehicle varies the spark angle, this must not allow an increase of vehicle speed by more than 10%
    - If the vehicle varies the spark angle, the setting used to achieve the maximum vehicle speed must be within ±5° of that for the maximum Net power[6]

[6] Maximum vehicle speed and Net power are defined in Directive 95/1/EC

- If the engine has reed valves these must be affixed with shear bolts or special tools

It is not clear whether the second set of articles, which are applied if the vehicle has a specific component fitted (article 3.8.), is also covered by the article at the start of the section (article 3.) which states that an article only applies if the modification increases performance over set limits. This is a similar issue with the following area of markings which also comes under article 3..

The section on markings provides a comprehensive list of the parts which must be marked. The markings must stay legible in normal use and be destroyed if removed, i.e. they cannot be transferred to a replacement part. The marking must be visible from the outside of that part (not necessarily the outside of the vehicle as a whole).

It also details the requirements of an 'Anti-tampering control plate', which lists the code numbers of the components in the powertrain, manufacturer, model, information used to calculate the ratio of transmission gears and the final drive.

2.1.5 Registration, licensing and insurance

Another important aspect of the anti-tampering concept is that of the legality of users performing modifications. The type-approval legislation is concerned only with requirements on the design and manufacture of the vehicle prior to first registration or entry into service on the public highway within the European Union. However, the type approval categorisation of these vehicles is used as the basis for other legislation.

Only when the vehicle's category, the vehicle's registration, the rider's licensing requirements, vehicle insurance, and road tax are taken into account together do the full implications emerge.

Firstly, if a moped or low-performance motorcycle is modified to remove any of the requirements of the anti-tampering legislation then it is no longer in that category. The vehicle is converted to the next appropriate category or categories with higher specifications. Table 2-1 provides an example of this concept.

Table 2-1: Category progression

Original vehicle		Changed characteristic		New vehicle
Moped	⇨	Exceeds 45 km/h	⇨	Low-powered motorcycle
Low-powered motorcycle	⇨	Exceeds 11 kW Net	⇨	Medium-performance motorcycle

Once categorised, a vehicle must then abide by all the rules and requirements of that category. For instance, an important area in regards to safety is the braking distance. While a moped must stop from 40 km/h in a distance of 22m, a motorcycle must stop from 60 km/h in 37m. If the braking system of a moped was designed to be just adequate for a maximum speed of 45 km/h, it may suffer problems when braking from higher speeds, particularly in terms of energy dissipation, temperature and fade. Secondly, a motorcycle must pass the Euro III emission limits using the WMTC driving

cycle, which includes a cold start, whereas a moped has only to pass more lenient Euro II limits tested using the UNECE R47 cycle, where the emissions are only measured once the vehicle has warmed up (see Appendix L). It is considered unlikely that a vehicle can achieve this without a catalytic converter.

It is possible for a vehicle to be modified in such a way that does not require it to change categories and therefore the only requirement for its legal use would be whether the insurance covers modified vehicles. Unmodified is stipulated by the majority of insurers.

If the vehicle is unable to pass the requirements of that category, while not exceeding a performance value to push into another, then it is not permitted for that vehicle to be used on public roads. It could, however, be used off the public highway, so long as it passed the requirements of the either the Machinery and/or Non-Road Mobile Machinery (NRMM) Directives and a Member State would allow such a machine (not subject to type-approval legislation) to access pubic roads .

Assuming a modified L-category vehicle is capable of passing all of the requirements of its new category, it must then be checked by a technical service to be re-registered as a vehicle within this new category.

The next constraint is insurance. It is a requirement of Directive 2009/103/EC that all vehicles have at least third party insurance cover to be used on the road in the EU. The only obstacle here to modified vehicles is that the details in the policy must match the vehicle, if it has changed categories then this must be changed on the policy for it to be valid. It is also stipulated in most insurance policies that the vehicle be unmodified; insurance must be obtained that stipulates that it covers modified vehicles.

Another consideration is road tax. For example, in the UK, L-category road tax is not based on vehicle performance or CO_2 emissions as with category M and N vehicles. Instead, this is based on engine capacity and therefore, unless the engine is changed or cylinder capacity modified, the tax category is unlikely to require changing[7]. This may not be the situation in other Member States.

The fourth and final constraint is the rider's driving licence. The rider must have a licence allowing them to use that category of vehicle on the road. For instance to ride a moped which has been converted into a low-performance motorcycle the rider must have a driving licence marked A1 at least.

If all of these four criteria are passed then the rider is allowed to use the vehicle on the road. However taking these criteria it generates four groups of vehicle/users:

The cost of vehicle tax for cars, motorcycles, light goods vehicles and trade licences.

Directgov. Accessed 15/3/2012.

URL:http://www.direct.gov.uk/en/Motoring/OwningAVehicle/HowToTaxYourVehicle/DG_10012524

Table 2-2: Documentation obtained and legality of vehicle

Group	Category	Registration	Insurance	Tax	Licence
Legal modifiers	✓	✓	✓	✓	✓
Insurance cost avoidance	✓	✗	✗	✓/✗	✓
Unlicensed / Inexperienced riders	✓	✗	✗	✓	✗
Vehicle not for use on public highway / unsafe used on the road	✗	✗	✗	✓/✗	✓/✗

It is the scope of this study to investigate harmful tampering, i.e. modifications from the vehicle's original state that result in detrimental effects on emissions, safety or noise, therefore, it is the final two groups of Table 2-2 that are of primary concern, although all groups will be considered in the study.

3 Methods

The study consisted of a three initial tasks: stakeholder information gathering, literature review and a tampering prevention competition. These tasks are described in detail in the following section and ran in parallel to the other project tasks. The information from these tasks, along with that from the theoretical analysis, was used to identify harmful tampering types which were quantified in the test programme. The results of the tests were used to quantify the effects of those tampering and used as an input to the cost benefit analysis. This provided an estimate of the effects of that tampering type assuming a range of relevant L-category fleet are currently subject to tampering of this type. Figure 3-1 below provides a diagram showing the main project tasks and their interaction.

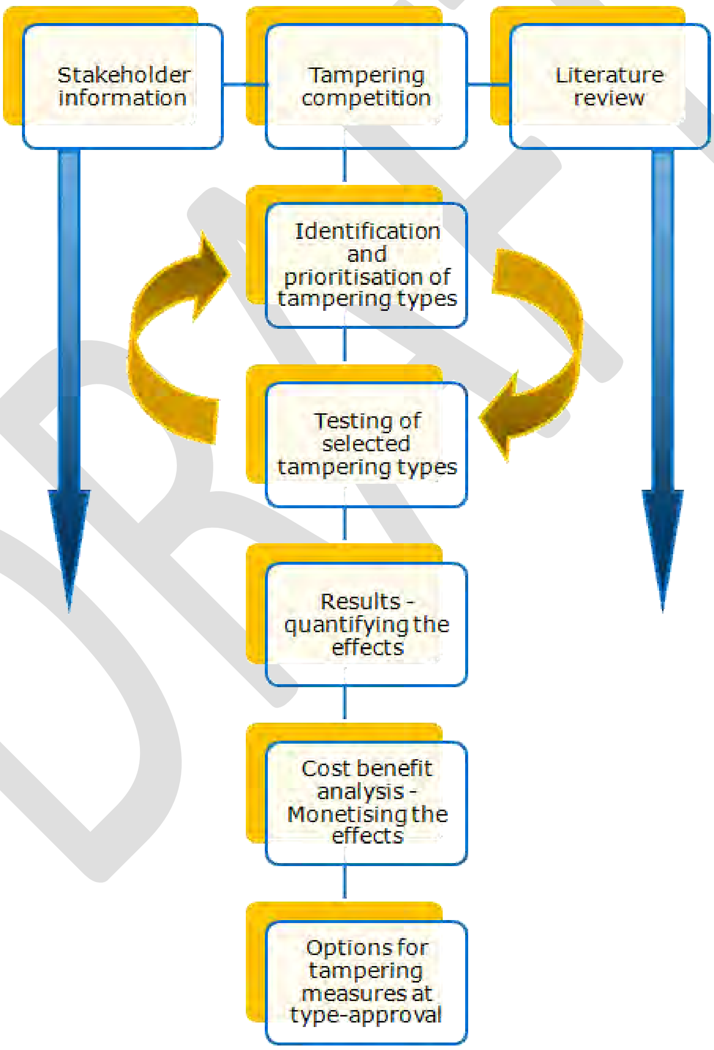


Figure 3-1: Diagrammatic representation of project

3.1 Stakeholder engagement and existing tampering information

The purpose of the Stakeholder information gathering was to solicit data and views from a range of stakeholders on the subject of anti-tampering. This was achieved via a series of face-to-face meetings with stakeholders, as well as an online questionnaire (see Appendix B). Previous studies also carried out a similar exercise and one in particular was conducted in 2003. Two main comments were made on the study carried out by Dittmar, *et al.* (2003). Firstly, not all stakeholder groups were contacted, with the riders being unrepresented. Secondly, the questionnaire response was low and the project team back in 2003 was unable to obtain a large number of individual responses, despite additional efforts to obtain more stakeholder feedback.

It was acknowledged at the outset of this project that obtaining people's views on the subject of tampering would be difficult. People, especially those engaged directly in the activity, are unlikely to divulge their involvement or methods for fear of personal repercussions. This is a difficult factor to overcome, but in this project, a competition was developed aimed at gathering information from members of the public, particularly those groups not previously involved or not interested in filling out questionnaires by Dittmar *et al.* (2003). In an attempt to ensure a good response rate, this project developed targeted questionnaires aimed at different stakeholder groups, as well as arranging meetings with those providing information. The stakeholder groups were carefully selected and included representation from Industry, regulators and rider groups. The stakeholders included all members of the European Motorcycle Working Group, and for this reason a positive and engaged response was anticipated.

3.1.1 Project website

The project website was an important tool in the information gathering process and the engagement with stakeholders. It was developed and populated with information about the project aim and methods (see Appendix A). It also provided an interface with stakeholders to exchange information. Both the competition and information gathering were described and publicised on the website, with a series of emails being sent to stakeholders to inform them of the project activities and inviting them to become involved in the project.

3.2 Tampering prevention competition

The aim of the competition was to invite members of the public to demonstrate (via digital media and written description) effective tampering prevention measures, with a series of prizes offered for the best entries. The aim was to use these entries as input for potential tampering prevention measures. The competition was open to everyone, but was aimed primarily at L-category vehicle users and (technical) student teams. Previous research (see Appendix D) highlighted a strong customisation culture from riders and that many modify their vehicles Again, only harmful modifications to the powertrain were in the scope of the project and the aim was to develop anti-tampering measures that target only harmful modifications of the powertrain; those that have adverse effects on the functional safety or on the environmental performance of the vehicle. The measures are not targeting customisation and the majority of modifications made to vehicles today will remain possible in the future.

The competition was launched in April 2011 on the project website. This included a description of what was required along with a 'registration of interest' online form to notify the project team of the intent to participate in the competition. Flyers were developed and written in five European languages and were distributed in hard copy at an event in the Netherlands on 6th of April 2011, and by email (see A.1).

3.3 Stakeholder information gathering

Four main information gathering methods were used:

- a dedicated stakeholder consultation meeting on 2nd December 2011;
- three Motorcycle Working Group meetings in 2011;
- questionnaires to 166 identified stakeholders (including Motorcycle Working Group, UNECE WP.29 and UNECE GRSG (general safety working group) delegates), and;
- parallel meetings and discussions with specific groups and European organisations including FEMA, ACEM, and AECC, but also individual L-category vehicle manufacturers and suppliers etc.

TRL developed a series of information gathering questionnaires tailored to each individual stakeholder group, with the aim of improving the level of response by making all the questions relevant to the specific recipient. Emails were sent to the stakeholders that included direct links to online forms with the dual aims that the stakeholder participants could easily enter the information and that it could be collected efficiently by the project team. The online forms were password protected and assigned random URL suffixes to ensure that only the requested stakeholders could gain access to the questions.

3.4 Literature review

The literature review comprised the following primary sources:

- A review of previous studies that have examined the L-category tampering issue, [notably (Dittmar, et al., 2003) and (Robinson, et al., 2009)A TRL library search using keywords was used to identify and review other research relevant to tampering on L-category vehicles.
- An internet survey of components aimed at, or potentially aimed at, tampering with an L-category vehicle that could subsequently be used on the public road).
- A review of the current and proposed legislation in the EU, European states and the UNECE.
- A review of studies supplied through the stakeholder consultation

The results of the review are described throughout the results section, where relevant, and presented in full in Appendix D.

4 Identification and prioritisation of tampering measures

A detailed analysis of the types of tampering that could potentially have adverse effects on safety, emissions or noise was undertaken to compile a wide-ranging list. This list was generated using three different approaches to reduce the risk of omitting any potential tampering modes:

- A review of literature, legislation, previous studies and internet;
- Analysis of the reasoning for a modification;
- Study of the construction of L-category vehicles.

4.1 Literature and internet study

A literature study (see Appendix F, collected information throughout the stakeholder consultation and internet search tasks. In addition, the main previous reports Dittmar *et al.* (2003) and current legislation, (Directive 97/24/EC, Chapter 7) on the subject were reviewed

The shortcomings of using only this approach are that tampering types at the extremes of the ease and cost scale may be omitted or underrepresented, i.e. difficult methods may be discussed intensively or conversely left to experts or only mentioned in specialist circles. Furthermore, some sources of information, for example that from enforcement authorities, concentrate on the effect of the tampering (i.e. increased maximum design vehicle speed or increased noise levels) rather than the identification of the specific tampering mechanism(s).

4.1.1 Rider overall aims for modification

Modification of a vehicle is usually intended to change a specific characteristic. The method chosen to obtain that change will be based on: the design of the vehicle, its powertrain, the technical capabilities of the user, the cost of the components ,tools or methods required and the magnitude of change expected. Therefore it is important to look at the motivation for the change, to understand the anticipated effect of the modification and work back from this to identify the technical measures capable of delivering the change in powertrain performance. From this analysis a short list was drawn up:

1. Increase powertrain performance
   a. Increase maximum vehicle speed;
   b. Increase power as prerequisite to achieve greater vehicle speed;
   c. Increase maximum torque as prerequisite for faster acceleration;
   d. mass reduction in order to benefit from effects of increased power/mass ratio;
2. Increase noise;
3. Reduce fuel consumption;

One other reason for modification found was to cause the vehicle to generate smoke by using a very rich air fuel mixture. However, this practice has a very low frequency and if performed, the vehicle is not left in this state for general use. For these reason this was excluded from the study.

Maintenance was also excluded because it is the general intention to keep or return the vehicle to its original form and/or performance

The rationale in this section was used not just to research more tampering methods, but also to filter out some of those found and to devise ones that are likely to be performed but may not be documented.

4.1.1.1 Areas of the powertrain

The third method used to compile the list of possible tampering modes, was a full analysis of L-category vehicles design. Specific attention was focussed on the powertrain. This was done with all L-category classifications in mind. This approach was particularly important for considering tampering on new types of powertrains, and where previously unused techniques could be considered, such as tampering with electronic powertrain control devices.

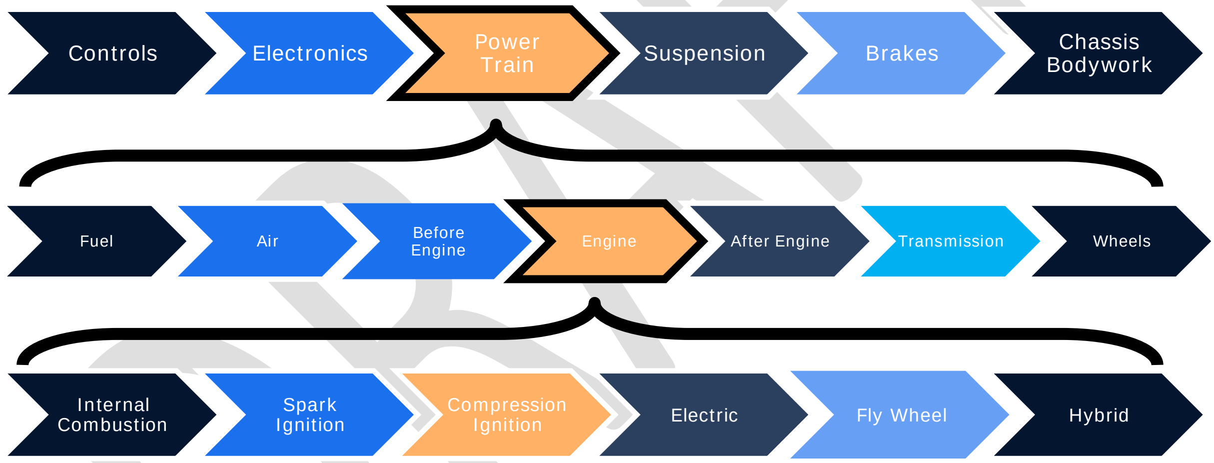


Figure 4-1: Tampering modes: Vehicle analysis overview

These tampering types were ordered logically and grouped (see Figure 4-1 above). Where a split occurs i.e. petrol or diesel they are listed consecutively. Similar parts were grouped even if they may be positioned differently within alternative drives.

4.1.1.2 Compiled modification list

The technologies used in the various powertrains and propulsion types overlap across the vehicles within the L-category. Similarly, different modification in various areas of the vehicle can result in the same effect i.e. changing a lambda sensor, altering its signals or reprogramming the ECU could all change the air/fuel ratio by the same amount in anticipation of an increased power output.

Therefore, the list of modifications and grouping of the vehicles was organised as a combination of the aim of the modifications and technology which it affects.

It is important to note that some tampering types that could potentially have negligible safety or environmental effects have been included for completeness. However, because the assessment of the associated harm was low, these were not investigated further in the testing programme.

The compiled list of modifications contained 76 tampering modes, this included 62 that are part of the powertrain, plus 14 which were out of scope and should be considered separately. It was found that vehicles with electric and hybrid propulsion have such differing control systems to those of conventional vehicles equipped with only an internal combustion engine (ICE) that current methods of modification are not suitable. For this reason, a separate dedicated testing programme was undertaken (see Annex 2).

4.2 Overview of the TRL SENOD tool

In order to prioritise those modifications of greatest concern the tampering modes were ranked by the level of risk involved. TRL developed Risk Priority Numbers (RPNs) for each tampering type, building on the background work reported in the TÜV study, in particular Appendix A9. The assessment was made by the project team, drawing on a group of technical experts within TRL.

The method developed was called 'SENOD' to represent the five areas used to obtain the risk value; S-Safety, E-Emissions, N-Noise, O-Occurrence, D-Detection.

As per standard Failure Mode and Effects Analysis (FMEA), tampering types were assessed in respect of:

- Severity – the scale of the effect of the tampering event
  - Scored from 1 (positive effect) to 5 (no effect) to 10 (negative effect)
- Occurrence – how often each tampering event is believed to occur
  - Scored from 1 (very unlikely) to 10 (very likely)
- Detection – how often each tampering event is detected through e.g. enforcement authorities
  - Scored from 1 (obvious) to 10 (undetectable)

For severity, the same approach was used for each of the three consequences with which the project is concerned:

- Safety;
- Emissions;
- Noise.

A weighting factor could be applied to each to put emphasis on any of the overall categories of safety, emissions or noise. However, at this stage, the prioritisation treated these effects as equally important. The weighted scores from each of these severity items were then summed to produce an overall severity score which was then multiplied by the occurrence and detention values.

Detection was used in the TRL SENOD system as a special case. By changing how it was analysed the RPN values could be used in a range of ways:

- With the values left as entered the resulting RPN number would indicate which of the modifications were easy to see;
  - This can be used to generate a list of modifications for road side inspectors or enforcement agencies which could be easily looked for and found;
- By inversing the detection values the TRL SENOD would instead prioritise which of harmful modifications were difficult to detect.
  - These types of modification are the most important types to try to prevent at the design and type approval stage, as their use would be difficult if not impossible for road side inspectors or enforcement agencies to spot and rectify;
- The third option was to deactivate the value all together, this allowed the severity and occurrence to be analysed independently.

The scoring was given a subjective rating by the project team, based on technical knowledge and information gathered within the project. These were then reviewed and adjusted by a group of TRL experts in safety, noise and emissions. This process was necessarily subjective because the results of the testing were not known; given the uncertainty involved, ranges were used for the factors rather than point scores. As data for each of these factors were identified from the testing, from stakeholders and from literature for each means of tampering, these were fed into the model. The model was therefore updated in parallel with the testing and information gathering tasks on the project. The initial high RPN scores as output of the model were used to narrow down the test programme matrix to only test those modifications which were anticipated to pose a high risk on negatively impacting functional safety and/or the environmental performance of a vehicle. This strategy helped to keep the complexity and cost of the test programme low by focussing on those areas considered to be most important. In parallel, the model was updated in an iterative fashion as data was generated from the testing programme and information gathering tasks on the project. This helped to increase the accuracy of the model and to validate the initial RPN scores.

The scoring system also allowed an estimate the proportion of the fleet affected to be taken into account. This was used later in the process in the cost-benefit analysis stage so that those tampering measures most likely to be cost effective were put forward.

Each of the modifications or area of the vehicle was analysed using the data obtained (see Appendix H), from which the values and ranges for each of the areas was compiled before entering it in to the TRL SENOD tool for analysis.

4.3 Results of tampering analysis

The RPN values obtained from the TRL SENOD tool were ordered using a variety of scenarios to gain a fuller picture of which tampering modes should be tested.

Table 4-1: TRL SENOD analysis schemes overview

Criteria used to rank the RPN values	Explanation of SENOD scheme
Best estimate, excluding detection Appendix J.1	This chart is ordered by the best estimate of Severity and Occurrence. Detection is excluded. This measure gives information on the theoretical impact of the modification on the fleet.
Best estimate, difficult to detect Appendix J.2	This chart is ordered by the best estimate of Severity and Occurrence. This is then multiplied by detection, with "difficult to detect" having a higher value. This was used to indicate which modifications are of higher importance to protect against at the type approval stage.
Best estimate, easy to detect Appendix J.3	This chart is ordered by the best estimate of Severity and Occurrence. This is then multiplied by detection, with "easy to detect" having a higher value. This was used to indicate which modifications could be easily looked for at road side inspections
High estimate, excluding detection Appendix 0	This chart is ordered by the greatest RPN values. Detection is excluded. This is used to indicate a worst case for each of the modifications.
Difference, excluding detection Appendix J.5	This chart is ordered by the magnitude of the difference between low and high. This ranking is used to highlight which modifications are likely to require more research. This measure also shows which modifications have a high variance in the effect depending on the vehicle's technology.

The results from all of these charts were averaged and ranked. Then, using the principles of Pareto analysis, the top 20% of the modifications were chosen to be passed through to the testing programme (see Appendix J.6) where the effects of each tampering type was quantified.

4.4 Filtering process and expert analysis

Following the selection of the top 20% a filtering process was performed to rationalise the tampering modes indicated by the TRL SENOD tool. This was to:

- Avoid repetition by consolidating equivalent modifications;
- Disregard modifications which would be impractical to prevent such as changing consumables;
- Disregard modifications which are equivalent to environmental effects such as changing the vehicles cooling strategy;
- Match possible modifications the technologies fitted to the available vehicles;
- And to match the common sale of aftermarket parts.

These specific areas are described below.

Some of the modifications in the top 20% were in effect the same as others in the list or produced a very similar effect. These are indicated in Appendix J.6 as being equivalent, or in Figure J.1 to J.5 denoted with a red square. Some modifications involved the replacement of regularly replaced standardised parts (such as belts) or consumables and these were excluded because it would be impractical to prevent. In these cases, the items on the list were excluded and lower ranked modifications considered forming the highest ranked 20% of tampering types.

The testing programme was designed to cover all L-category vehicles and a large proportion of the sub categories. This meant that there was only a limited number of vehicles from each of the L-categories. The selection of vehicles was based on their popularity in the fleet; this used the frequency in the fleet as a proxy for the frequency of occurrence of the tampering.

The choice of modifications to test has to take into account the time when the legislation is likely to start being implemented. For instance, the information obtained from enforcement authorities is for vehicles approximately 2-3 years old, the extent to which some of these technologies are used in the fleet has changed since that time and is likely to change further given the requirements of the new Euro emission limits and the fast developments in technology in the L-category vehicle sector.

To take these considerations into account, in addition to the 13 modification methods identified by the Pareto analysis, 10 others were chosen. Therefore out of the 64 modifications identified as being in scope and further 13 out of scope, 23 were chosen to be investigated in the test programme. This led to 27 experiments because some modifications were duplicated on different vehicles to show the effect on other vehicles or to verify the effect on similar vehicles.

5 Quantification of tampering effects: test programme

5.1 Introduction

This section focuses on an overview of the tests performed, the data collected, the type of information these would provide, and the testing matrix (the arrangement of the vehicles to modifications and tests). The full range of L-category vehicles were used in the testing programme was based on the draft categorisation from COM542 (2010), published in October 2010.

The type and complexity of the propulsion system dictated how and to what extent a modification could be applied. Taking into account the initial prioritisation from the TRL SENOD tool (see Appendix J.6), the testing concentrated on the tampering types that could be applied in the test phase. Figure 5-1 shows a simplified matrix of the tests performed, where one modification was performed on each vehicle, and then for some special cases, a single vehicle was chosen to perform multiple tests. The full test matrix used can be found in Appendix H.

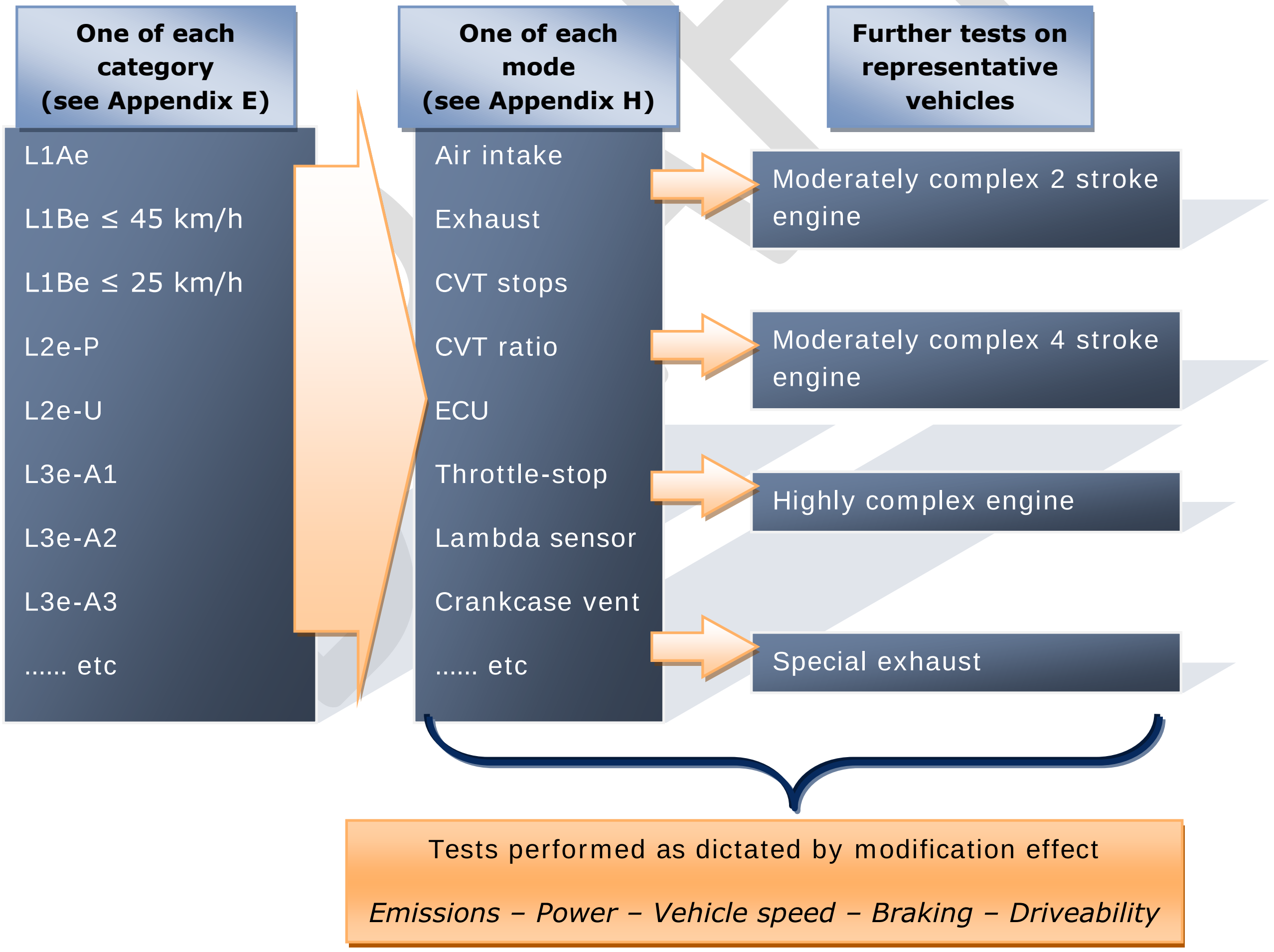


Figure 5-1: Testing matrix

The three vehicles chosen for testing of combined tampering types were: a moderately complex 2 stroke engine, a moderately complex 4 stroke engine, and a highly complex 4 stroke engine. These represent the majority of the L-category fleet, and also allowed the effects of technologies which may progress to the low power vehicles in the future to be tested.

Modifications that change the performance, safety or emissions of a vehicle can occur intentionally, unintentionally and even as part of maintenance such as changing a spark plug. It can be a single change or a combination of changes working together. Some intentional modifications can have no effect in the area intended, and inversely, some adjustments to a vehicle can produce harmful effects without actually being intentional, such as attempting to increase the vehicle speed by adjusting the air fuel ratio, but actually increasing the toxic emissions.

The testing programme, in some part, covered all of these eventualities, with the intention of providing the most comprehensive picture possible to address the possible concerns of all stakeholders. Inevitably, although parts of every testing regime were followed, the sheer scale meant that not every eventuality and permutation could be carried out. However, through the theoretical base of the SENOD tool RPN scores and the range of filtering processes used, a large proportion of the most concerning areas were investigated.

5.2 Tests

5.2.1 Overview

Three test types were performed on all vehicles in both their original, unmodified state and tampered state: an emissions test, a power test, and a maximum vehicle speed test. Additionally, on some vehicles a steady state engine speed (RPM) test was also performed.

All of these tests were performed in a temperature controlled testing booth fitted with a brake dynamometer (which could also function as an inertia dynamometer) connected to a gas analyser which measured data both in real time and from bags at the end of each test.

It was decided that, although in a post-modification state, a vehicle might meet the requirements of a different category, the driving cycle corresponding to the vehicle’s original classification should be used in the test programme (see Appendix L for plots of the emission driving cycles). This would allow comparison of the effect on emissions without the results being affected by a change of driving cycle.

To ensure that the effects of higher engine loads and speeds on emissions were measured, a new steady state engine load and speed (RPM) test was devised (see below).

5.2.2 Steady state RPM (engine speed) test

In this test, the throttle is controlled to attain a steady engine speed at each testing point; this is contrary to the 'Maximum vehicle wheel power test' shown below that keeps the vehicle speed fixed while the engine speed changes as dictated by the load.

Each vehicle was driven on a dynamometer in inertia mode simulating real-world rolling and aerodynamic resistances, through a range of engine speeds and loads, while measuring the tailpipe emissions and power output. Firstly, the vehicle was driven at a set of vehicle speeds (5, 10 or 20 km/h intervals, depending on its capability). This gave a benchmark to which the emissions of all vehicles could be directly compared. Secondly, a slow deceleration and a WOT (Wide Open Throttle) acceleration to maximum vehicle speed (or 130 km/h) were performed to measure the emissions during acceleration.

This test gave an indication of the performance of the new MPTP (maximum peak total power) test (see Annex 1, section 4.2). Similarly, the power measurement test provided an indication of the performance of the MCTP (maximum continuous total power) test (see Annex 1, section 4.1).

It should be noted that for some vehicles, especially after modification, holding the vehicle speed steady was a difficult requirement to achieve (see Figure 5-2).

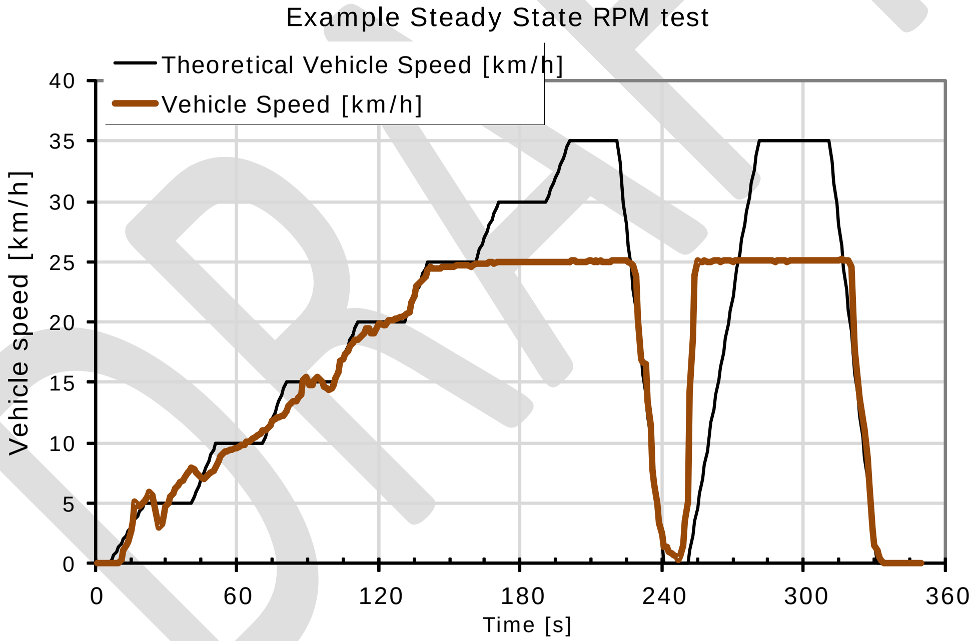


Figure 5-2: Graph of actual vehicle speed against target vehicle speed of a tampered vehicle in Steady State RPM test on a chassis dynamometer

5.2.3 Maximum vehicle wheel power test

The maximum vehicle wheel power test is similar to the steady state RPM test except that the dynamometer was in brake mode, rather than inertia mode. In this state, the dynamometer progressively applied load against vehicle torque running at full throttle to keep it at a fixed engine speed. This braking force was measured to indicate the power output of the vehicle. Using the engine's rotational speed, it was also possible to calculate an indication of the torque, although this was not very accurate because of the

mixing of measurement locations (i.e. power was measured at the wheel, but engine speed measured at the engine) and the lack of information on the instantaneous gear ratio due to difficulties measuring it on an automatic gear box which the majority of L-category vehicles use (see section 6.4).

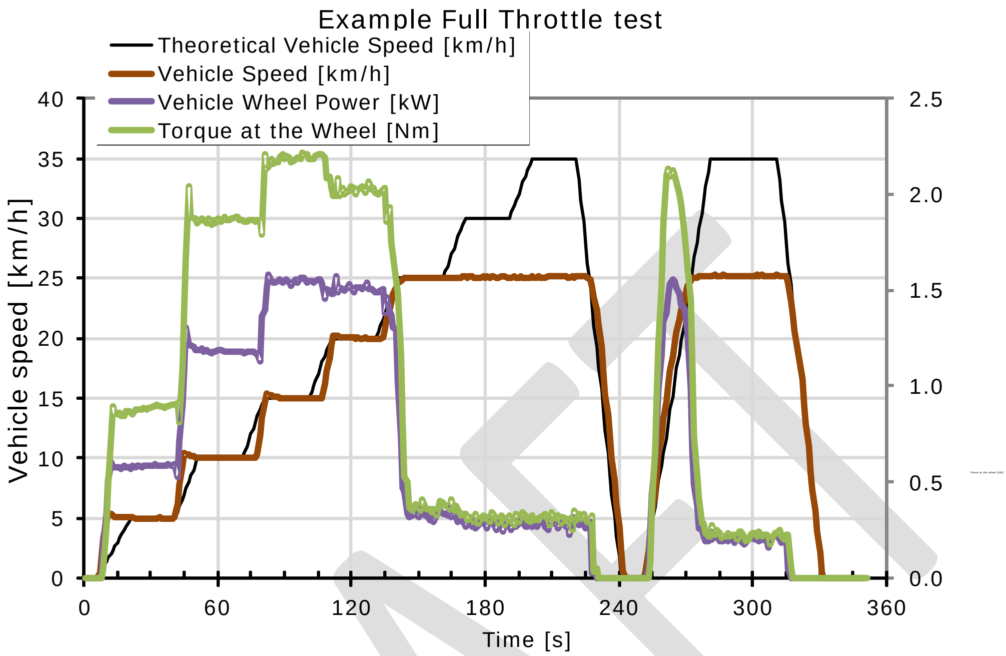


Figure 5-3: Graph of vehicle wheel power and Torque at the wheel

5.2.4 Maximum vehicle speed test

The maximum vehicle speed of the vehicle was drawn from three sources: the steady state rpm test, the maximum vehicle power test, and the published data from the manufacturer. The third method was only used if the vehicle was capable of vehicle speeds that exceeded the capabilities of the dynamometer (> 130 km/h) and therefore could not be directly measured.

The steady state RPM test indicated the maximum vehicle speed at two measurement points: at the final interval of the stepped speed increases, and during the wide open throttle (WOT) section. For the majority of vehicles, these two points should indicate the same value; however, in rare cases there is a mismatch. In some cases this discrepancy has been hypothesized to be a product of the way a CVT (continuously variable transmission) behaves. Centrifugal force is used to set the gear ratio, therefore a rapid acceleration will provide a greater force and change the ratio in a different way to if the vehicle accelerated at a slower rate (see Figure 5-4).

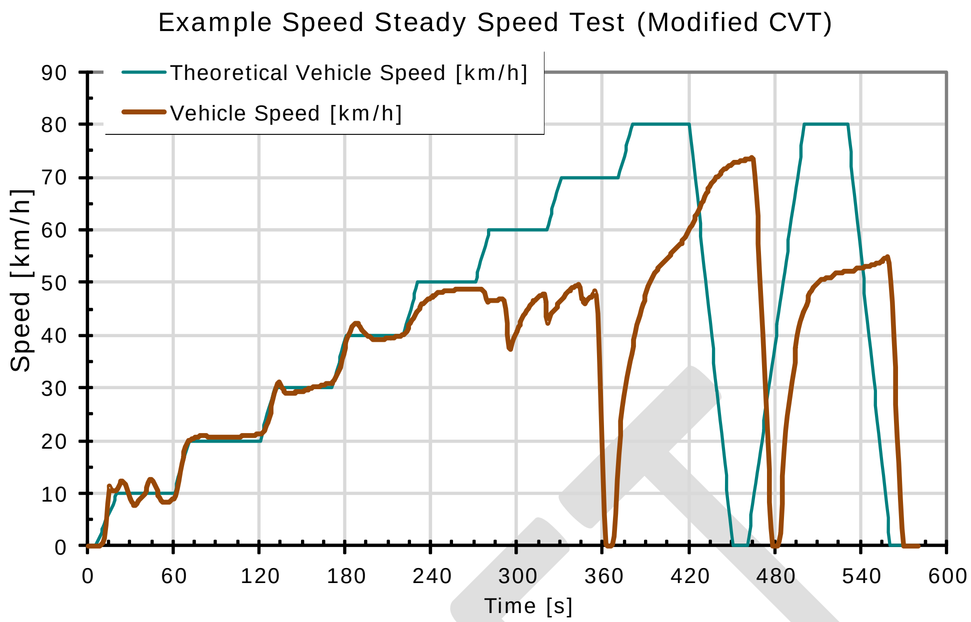


Figure 5-4: Graph showing the variation in measured maximum vehicle speed depending on the initial vehicle speed and acceleration rate

The steady state vehicle speed test and the power test were not performed in strict adherence to the requirements of Directive 95/1/EC. More specifically, evidence that the test had achieved a steady state engine speed or that the prescribed fluid temperatures had been met was not provided. Consequently, the results should be interpreted with these small inaccuracies in mind.

5.2.5 Sound test

A sound or noise test was performed on three vehicles, two mopeds and a motorcycle. The tests followed the method outlined in Chapter 9 of Directive 97/24/EC as amended

Directive 78/1015/EEC (European Communities, 1978) establishes limits for the permissible sound level of motorcycles and requirements for exhaust or intake silencer(s). Several amendments have been made to this act and it is currently integrated into Directive 97/24/EC. This introduces a harmonised testing procedure with limit values for three categories of motorcycles from 66 dB(A) to 80 dB(A).

UN Regulation 41 (United Nations, 1994 as amended to 2006) outlines the provisions relating to the type-approval of motor vehicles having two or three wheels with regard to noise. Similarly to Regulation 51, which contains the sound test procedure for passenger cars, noise emissions are measured using the methods defined by the current versions of ISO 5130 (stationary test) and ISO 362 (pass-by test), but only the result from the acceleration test is used for type-approval purposes.

Please note: The UN regulations (Numbers 9, 41, 63 and 92) on noise for various L-category vehicles were in the final stages of a major amendment during this project. They come into force between the testing and the publishing of this report. For this reason, the latest acceded tests before this implementation were used.

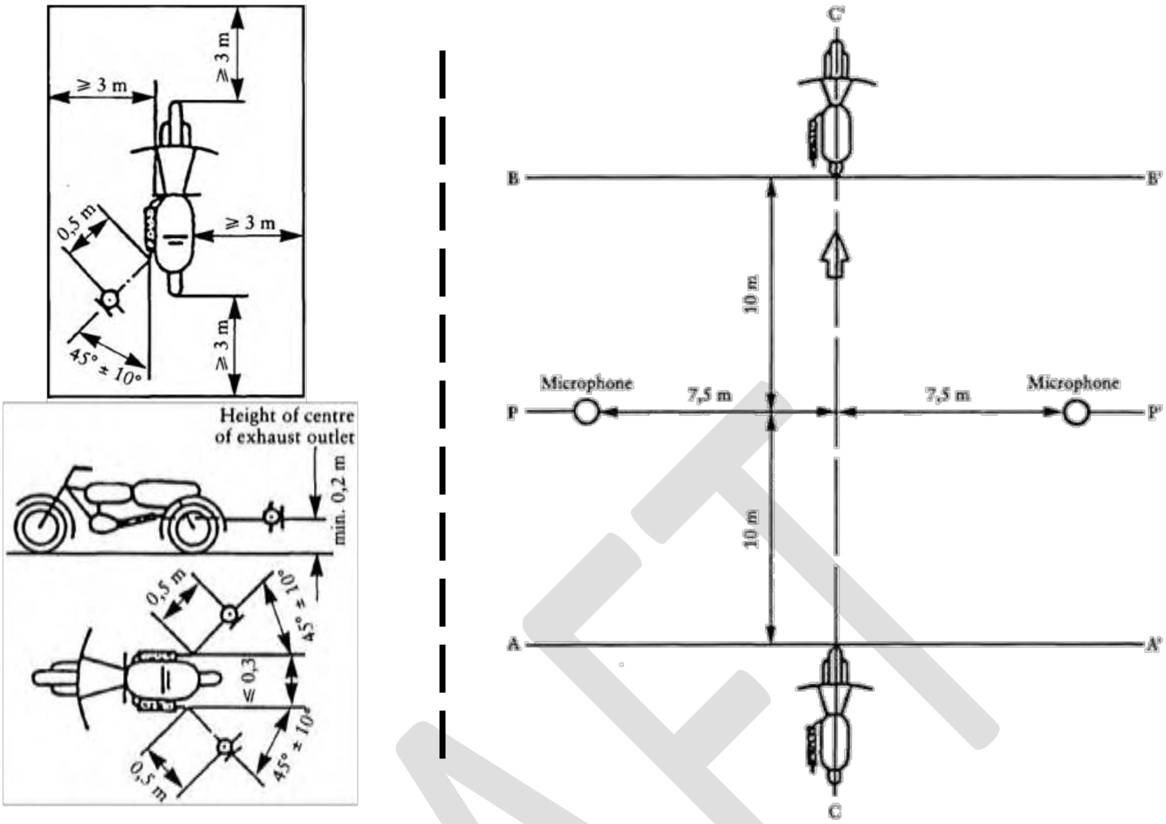


Figure 5-5: Stationary and Motion vehicle sound test Directive 97/24/EC

Both tests are measured in dB(A), which is the sound pressure level weighted to human perceived loudness. This weighting method particularly shows how higher frequency sounds will be perceived as being louder than lower frequencies of the same sound pressure level.

The measurement of sound is defined using a logarithmic scale, differences in dB can be considered using these rules of thumb (Smith, et al., 1996):

- A 10 dB increase in noise level is equivalent to a doubling of the perceived loudness.
- Subjectively, an increase in level of 3 dB is just noticeable.
- A 1 dB increase is just detectable under the most favourable laboratory conditions.

5.2.6 Driveability

A test was developed to assess the changes to driveability caused by a modification. The test assessed to what extent the modification affected driveability and whether any change constituted a safety risk. The vehicle tested for driveability was ridden over a range of manoeuvres based on the DSA (Driving Standards Agency) motorcycle practical test, and assessed using a standard driveability assessment scale (see Appendix L).

The test was only performed if the results from the Maximum wheel power test indicated an increase of at least 5%, or if it was considered relevant for a particular modification.

5.2.7 Braking

The braking test was based on a reduced set of tests from ISO 8710:2010 (see Appendix H) which is similar in parts to UN regulation 78. The test was only performed if the result of the maximum vehicle speed test indicated an increase of the greater of 5% or 5km/h, or if it was considered relevant in some other way for a particular modification or vehicle.

5.3 Limitations

The scale and scope of this testing programme led to a series of practical and logistical challenges that resulted in limitations on the modifications that could be quantified. The acquisition of vehicles was carried out to coincide with the availability of test equipment, using the Just-in-time (JIT) strategy. This reduced storage and hiring costs, as well as allowing flexibility on the choice of following vehicle if an interesting result required a different vehicle for a follow-up test.

Initial problems required adjustments to the testing methodologies at the start of the testing programme. Any changes required were adjusted quickly so that the changes did not affect comparability between test results.

The modifications which could be tested depended on the design and features of the specific vehicles obtained. The vehicles were selected according to their popularity across Europe rather than simply to match the modification that was to be tested. This disconnected selection method was done to further filter and refine the values for the probable occurrence of any given modification.

The modification methods were further assessed by the skilled mechanics tasked with performing the modifications on the vehicle. Those which were deemed impractical were side-lined in preference to the more likely modifications.

Although the initial test programme could not be fulfilled as planned in the originally testing regime, these adaptations and the flexibility that allowed them, has led to significant findings that may not otherwise have been identified.

The modifications of the vehicle sometimes made testing difficult and the results less clear. A large proportion of modifications changed the characteristics of the vehicle beyond its design capability and in some of these cases the control of the vehicle speed and power was not as stable as would be expected.

Cost and scheduling constraints meant that testing all possible permutation was not possible and not desirable, as the theoretical approach narrowed down the amount of permeations significantly. The options selected for testing were based on optimising the use of the resources available.

5.4 Testing of cumulative modifications

While it was the original aim to test each modification in isolation so that the effects could be linked to a specific change, in some cases the effects of several cumulative modifications were tested. This was because several modifications were required to obtain the intended effect of the tampering, and to replicate the types of changes that may be commonly made by a user (see section 6.6 for further information). Therefore, in some tests the previous modification was not deactivated; instead the cumulative

effect of multiple modifications was tested. This is indicated in the table at the start of each sub section in Chapter 0.

6 Test results

The main findings are presented in this section. The data is shown as a comparison between the test results obtained from the original vehicle and those obtained after it has had a particular modification performed on it. The significance of a particular change was assessed against the various legislated limits and tolerances as follows:

- A single power restricting part must not allow an increase of more than 10% upon its removal (Directive 97/24/EC, Chapter 7)
- A single part restricting the vehicle speed must not allow an increase of more than 5 km/h upon its removal (Directive 97/24/EC, Chapter 7)
- A vehicle must not exceed 25 km/h to be used on a cycle path (e.g. national legislation in the Netherlands)
- The type approval limits (Directive 97/24/EC, Chapter 5; Com(2010) 542 final)
- If a vehicle is in a certain speed restricted category then the act of modifying itself is not permitted (Directive 97/24/EC, Chapter 7)
- If the vehicle is in a power restricted category, the act of modifying the restrictor is not permitted in an uncontrolled way and if not subject to type approval (Directive 97/24/EC, Chapter 7)
- Depending on the vehicle, region and metric, when exceeded these could either indicate a reprimand for the user or manufacturer (national legislation)

Efforts were made to select popular models for the test programme, but the vehicles used were also constrained to those available to JRC-ISPRA. Additionally, some of the vehicles in the test programme were not new vehicles, so while they were taken from the fleet, their performance in relation to that at type approval may have been affected by ageing and wear.

6.1 Altering the Air/Fuel ratio

The perfect balance of air and fuel for an internal combustion engine is defined as the stoichiometric air/fuel ratio, which is the mass of air (oxygen) divided by the mass of fuel (hydrocarbons) required to produce only carbon dioxide and water. For spark ignition engines, this is approximately 14.7 kg of air to 1 kg of fuel; for compression ignition engines it is approximately 14.6. The exact amount varies depending on the oxygen content of the air and the specific composition of the fuel, which varies dependent on the grade, season, country and producer.

The ratio between the actual and the stoichiometric air/fuel ratio is defined as λ (lambda).

Equation 1: Definition of Lambda

A lower ratio than stoichiometric (<14.7) or a $\lambda<1$ is called rich or a richer mixture.

A higher ratio than stoichiometric (>14.7) or a $\lambda>1$ is called lean or a leaner mixture.

Additionally however, air contains nitrogen which, in high temperature, oxygen rich environments, will react with oxygen to produce oxides of nitrogen NOx.

The best balance chemically however, is not best for performance. The following list points out some of the beneficial effects of deviating from the stoichiometric ratio; this is illustrated in Figure 6-1 below.

- Highest power is found when the mixture is rich, as every oxygen molecule can react with a fuel molecule;
- Highest torque is found when the mixture is rich;
- Lowest NOx emissions are achieved when the mixture is rich, due to the lower temperature and lack of free oxygen (not used in the combustion of fuel)
- Best fuel economy is found when the mixture is lean, as with excess oxygen in relation to the fuel, the majority of the fuel is able to be used in the combustion process
- Lowest HC emissions are achieved when the mixture is lean (at the peak economy point)
- Lowest CO emissions are achieved when the mixture is lean

Extreme deviations from the stoichiometric ratio will result in partial (misfire) or no combustion. Misfire owing to partial combustion can lead to unburned or still burning fuel being evacuated into the exhaust which is then oxidised in the catalyst leading to a catalyst temperature excessively exceeding operating temperature (>1,000°C) eventually leading to melting of the washcoat (the coating of the catalytic converter monolith which hold the catalyst in place). However there is a specific type of fuelling strategy called "ultra lean burn" with ratios beyond ~20, where the NOx reduces again, but this requires very closely controlled fuelling.

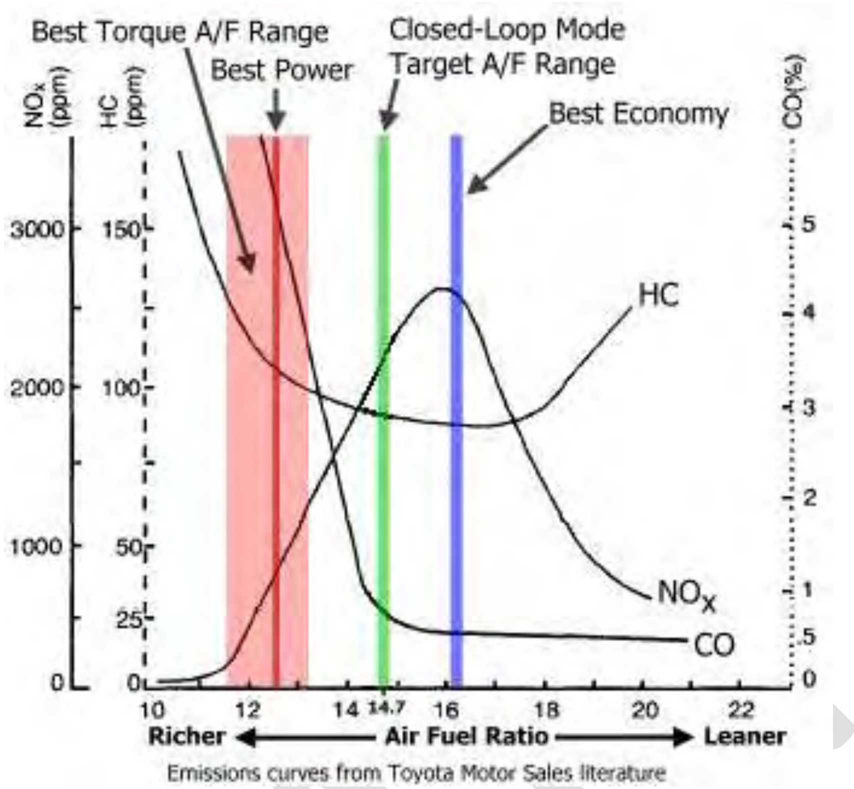


Figure 6-1: Air/Fuel ratio consequence on emissions, power and efficiency 8

Three way catalytic converters aim to reduce emissions of CO, THC and NOx. To complete the combustion of the THC and CO extra oxygen is needed, therefore a lean mixture is preferred. This however leads to exponentially increasing NOx as indicated in Figure 6-1. To separate NOx back into nitrogen and oxygen a deficit of oxygen is required, therefore rich is preferred. For these reasons the optimum ratio (although not the best for each individual gas) is at the stoichiometric point. Some designs of catalytic converter separate out these two actions and inject extra air when required to get best of both worlds. These "duel bed" catalysts require a slightly rich mixture to function. Therefore a slightly rich fuel bias (max -2% or 14.5 A/F) and toggling to stoichimetry 14.7).

In the case of a closed loop fuelling system, the engine management system (EMS) reads the oxygen concentration in the exhaust through an oxygen (lambda) sensor and adapts the fuelling accordingly. If the mixture is measured rich, the EMS will reduce the amount of fuel. The resulting lean mixture, measured by the oxygen sensor, will trigger the EMS to increase the amount of fuel. This constant toggling around the stroichiometric point leads to the lowest achievable HC, CO and NOx values. Any deviation over approximately ±2% from the stoichiometric point will lead to either high HC and CO (rich mixture) or high NOx (lean mixture) and would therefore jeopardise this sensitive equilibrium to minimise pollutant emissions.

Some mopeds are equipped with a simple mechanical secondary air injection system, which means that the base mixture in the combustion chamber can be tuned rich to

[8] http://www.endtuning.com/afr.html, EndTuning

optimise driveability and performance. As a large airflow is added after combustion directly into the exhaust containing an excessive amount of oxygen, the resulting HC and CO emissions from the rich mixture leaving the combustion chamber are "after-burnt" in the exhaust (and not in the catalyst). This heats up the catalyst rapidly after a cold start and ensures that it reaches operating temperature after 30 – 60 seconds. The catalyst performs its catalytic function most effectively above a threshold temperature. If the catalyst operating temperature is too low, the catalyst efficiency is too low to perform its function; but if the operating temperature is too high (>950 °C), there is an increased risk that the carrier material of the catalyst begins to disintegrate, causing a decrease in catalyst efficiency. Temperature control of the catalyst by the EMS is therefore very important in order to achieve the lowest pollutant emissions and to protect the catalyst from thermal damage.

A vehicle manufacturer must optimise this by balancing the vehicle performance (power and torque), fuel economy and CO_2 emissions, as well as the pollutant emissions. This carefully optimised balance may be tuned by the manufacturer during the 2-3 year development phase prior to introducing a new vehicle type on the market. A vehicle can easily be damaged when optimising only one of these parameters, increasing power and torque will often result in increases CO_2 emissions, fuel consumption and pollutant emissions. Even minimising fuel consumption may lead to reduced vehicle performance and/or increased pollutant emissions, therefore a balance has to be set with regards to the effect of a vehicle on the environment.

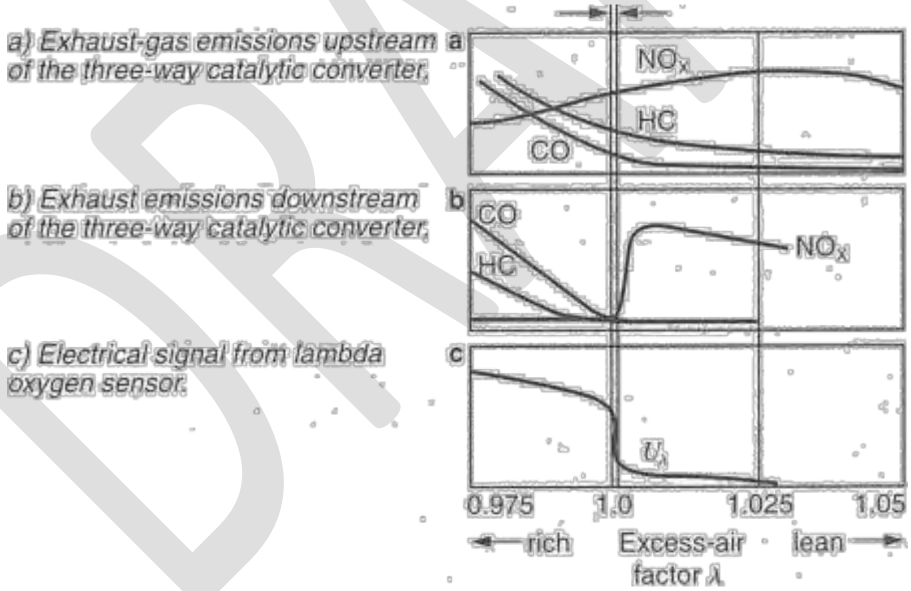


Figure 6-2: Change in emissions using a three way catalyst 9

As the throttle is increased to wide open throttle (WoT = 100% throttle position) the performance of the engine in relation to air/fuel ratio changes (see Figure 6-3). Again table 16 shows that stoiciometric operation would be the optimum trade-off between low fuel consumption (maximum fuel economy) and achieving optimum performance (high power) from mid part load up to full throttle (50 – 100% throttle position).

[9] Bosch, Automotive Handbook, 7th Ed, 2007, ISBN 987-0-7680-1953-7

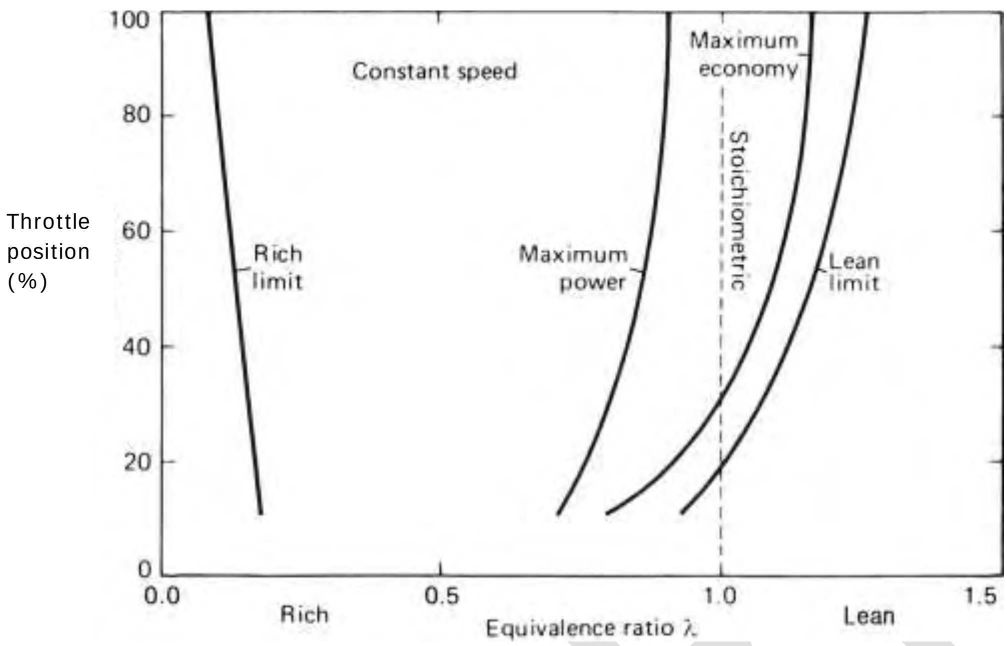


Figure 6-3: Change in peak power and efficiency with throttle position [10]

For the sake of smooth driveability a significant richer mixture than stoichiometric is preferable, but this leads to high HC and CO emissions.

Deviating by a large amount from the optimum air/fuel ratio for the catalyst may result in damage, which if performed for long periods can be permanent; too rich and it could clog the catalyst or poison it, too lean and it could overheat and stop functioning.

In older fuel supply systems, there was a need to manually tune the engine periodically. With lambda sensor based control loops this is no longer necessary as these are self-adapting. The lambda sensor detects the difference in oxygen content between the exhaust gas and a reference opening connected to fresh air (see Figure 6-2), this is performed in real-time, constantly adjusting the injected fuel flow to compensate any deviation. However, the sensor itself does wear over time as it is operating in the same hostile environment as the catalyst and may need to be replaced after many operation hours owing to thermal ageing and poisoning.

Taking all of this into consideration it can be seen that vehicle manufacturers will tune the vehicle to optimise propulsion performance, fuel consumption (CO_2 emissions) and toxic emissions (HC, CO, NOx and PM) and to create optimum conditions for the propulsion to perform in this optimum way over the vehicle's useful life, while others may wish to achieve other optima to the detriment of the other optimised variables:

- Increase power (rich) leading to smooth driveability, but also to increased fuel consumption (CO_2 emissions) and toxic emissions (HC and CO);

[10] Introduction to internal combustion engines, 2nd Ed, Richard Stone, 1992, ISBN 0-333-55084-6

- Reduce fuel consumption (lean) possibly leading to bad combustion (misfire, knocking combustion, bad driveability), decreased engine and catalyst durability and increased toxic emissions (NOx).

There are several approaches which can result in a changed air/fuel ratio. Adjustments include changes to 'hardware' either to alter mechanical parts, the addition of 'electronic' devices to provide false information to the vehicle's ECU or 'software' changes to alter the strategy in the vehicle's ECU:

- Hardware
    - Adjust the carburettor
    - Replace the carburettor nozzle
    - Replace the carburettor
    - Adjust the fuel pump stroke length for mechanical injection (CI)
    - Replace the ECU with ECU containing optimum performance propulsion map, but compromising the optimum setting by the manufacturer.
    - Replace the fuel injector or tamper the electric circuit between ECU and fuel injector.
- Software
    - Change the instructions used by the ECU (The engine map)
    - Trick the ECU into using alternate engine maps, such as for cold weather or engine cold start
- Electronic
    - Fit a piggyback ECU to adjust the signals it produces;
    - Alter the signal entering the ECU from sensors providing input to the ECU;
    - Alter the signal leaving the ECU to actuators such as the throttle or fuel injector.

The chosen modification method depends on the configuration and sophistication of the specific vehicle.

Two specific pieces of hardware which can change the air fuel ratio; adjusting the fuel pump in CI engines and the carburettor in PI engines, have been looked at separately in sections 6.1.3 and 6.1.4 respectively.

6.1.1 *Air/Fuel ratio (rich)*

Several tampering modes were attempted with the intention of making the air/fuel mixture richer. These were as follows:

Table 6-1: Rich Air/Fuel ratio modification: Vehicles and modification

Vehicle	Category	Modification	Cumulative tampering methods
9	L3e-A1	Change engine map (rich)	No
11	L3e-A3	Install RB2 ECU. Remove RPM limiter, A/F target: 13.2 (rich)	No
		ECU: A/F target:13.8 (rich)[11]	Partially
13	L3e-A3	Intake air temp sensor, simulate -20°C	No
		Intake air temp sensor, simulate 0°C	Partially
		Intake air temp sensor, real ambient temperature -7°C	No

Vehicle 9 had a modified engine map uploaded onto the ECU. Vehicle 11 had a secondary ECU fitted which took data from the original ECU and modified the signals in real-time to achieve a specific air/fuel ratio.

Vehicle 13 had a device fitted to alter the signal from the air intake temperature sensor, a low temperature will generally cause an ECU to run rich. When the air temperature was simulated the ambient temperature was as defined by Directive 97/24/EC Chapter 5 Appendix 1, article 6.1.1. as being between 20°C and 30°C. The results from these tests are presented and discussed in Section 6.8.2.

[11] Data from this modification was not analysed since lambda data indicated that A/F ratio was not altered from the original condition

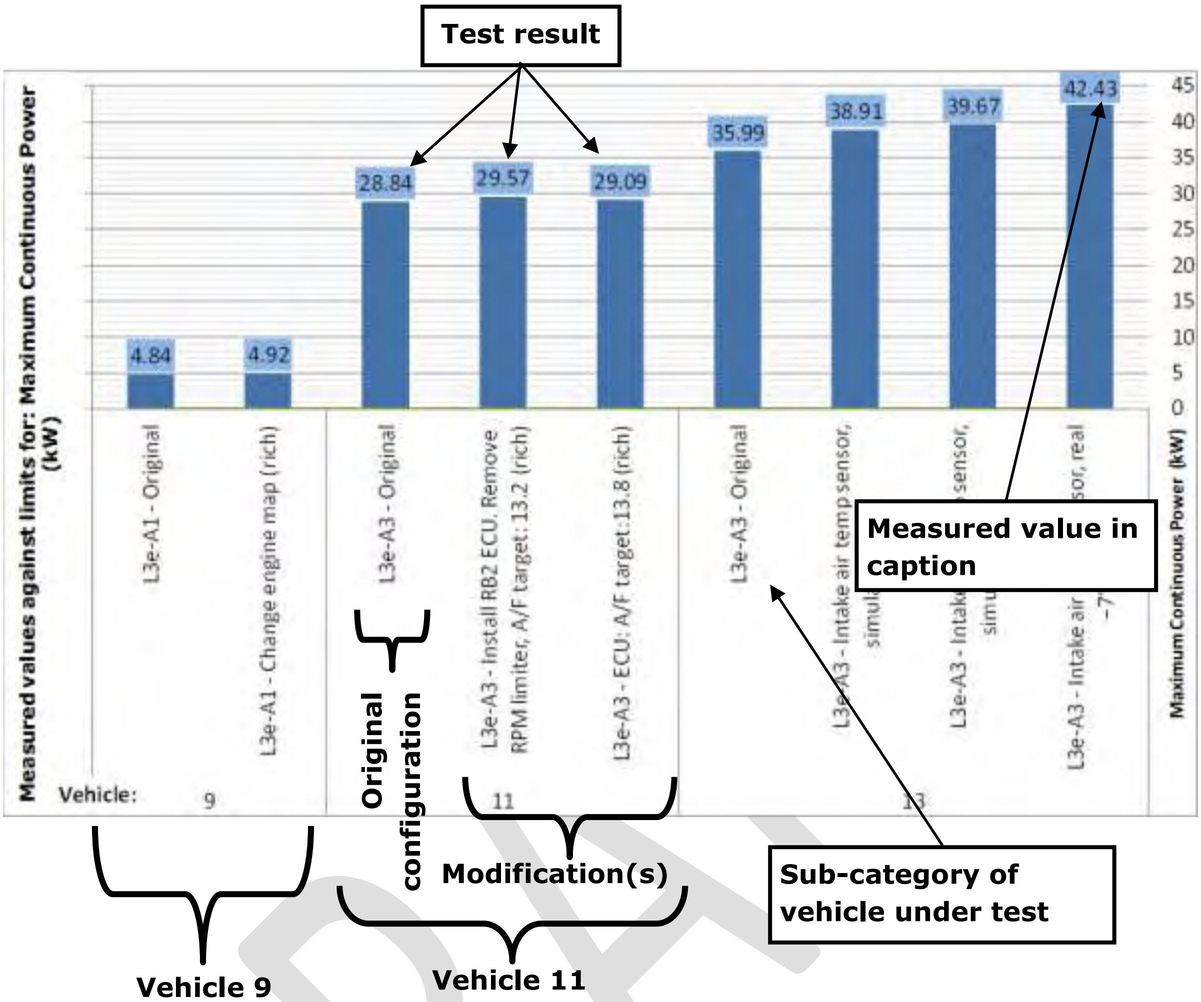


Figure 6-4. Example showing interpretation of results graph

In all vehicles with this type of tampering the effect on power was negligible (see Figure 6-5), with less than 2% change from the original, untampered test result.

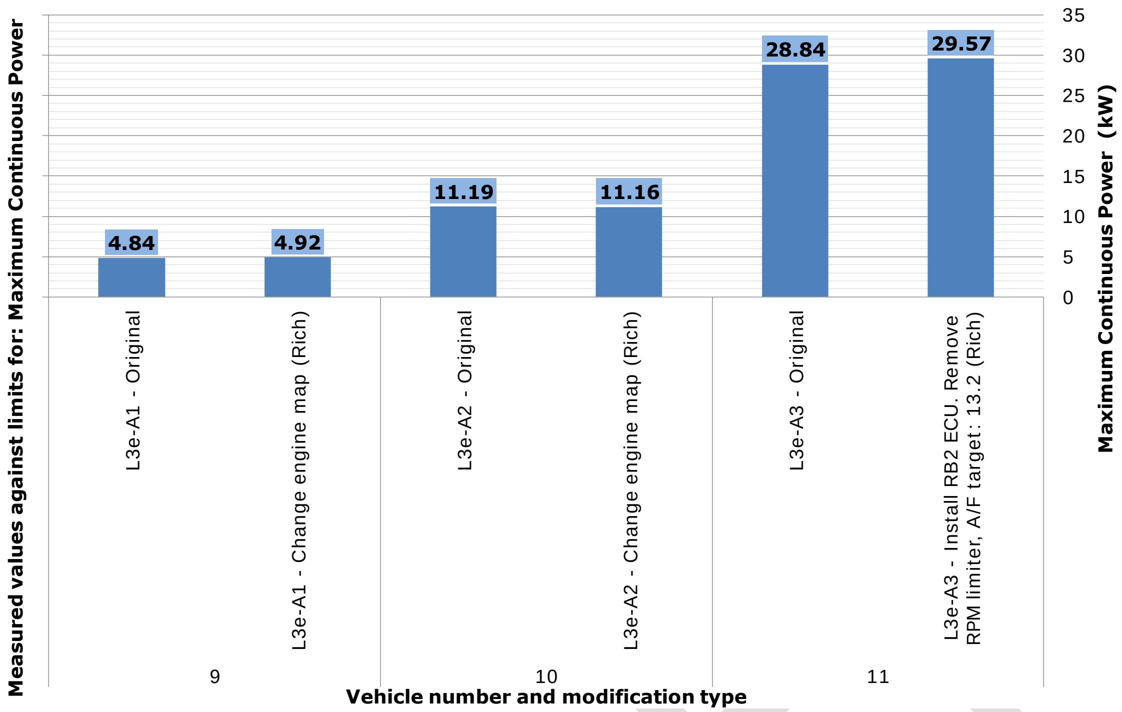


Figure 6-5: Rich Air/Fuel ratio modification: Maximum Power [kW]

With respect to vehicle speed, vehicle 9 had a slight vehicle speed increase of 3%. The others exceeded maximum road speed and for this reason were not tested.

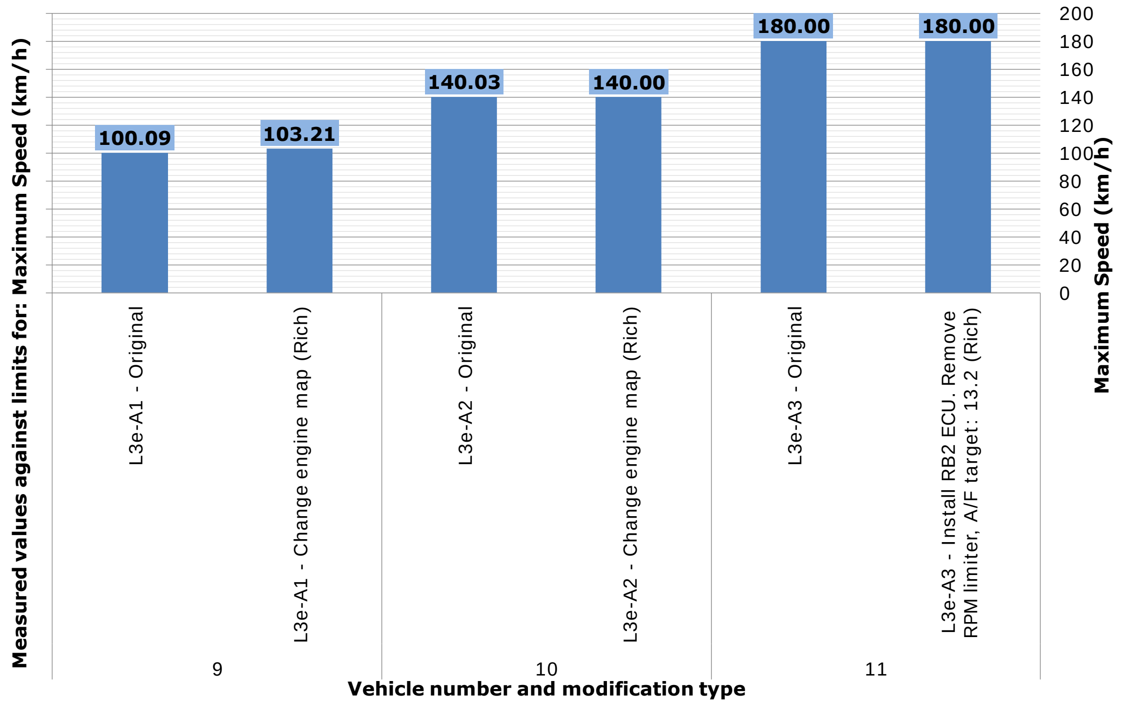


Figure 6-6: Rich Air/Fuel ratio modification: Maximum vehicle speed [km/h][12]

[12] Note: vehicle speeds significantly above 130 km/h could not be measured and the figures shown are from product literature.

The final test carried out on vehicle 11 was not a modification at all. The vehicle and test chamber were cooled to -7°C, possibly triggering the vehicle to use a special cold weather air/fuel ratio map and achieving the highest power increase to 118%. This effect may have also occurred because of the natural effect of increased volumetric efficiency resulting from cold intake air flowing into the engine (more intake air mass owing to temperature dependency of gas density with the consequence of a higher injected fuel mass at the same commanded air-fuel ratio). This will be looked at further in section 6.8.2. The first and second modifications to this vehicle used an aftermarket electronic component, which adjusted the signal from a temperature sensor in the air inlet, tricking the ECU into performing the same action. However, in these cases, although more fuel is added the air is less dense and so there is less oxygen at the same commanded air-fuel ratio in the combustion cycle.

Fuel consumption for vehicle 9 was not greatly affected, increasing by 8%. The fuel consumption of vehicle 10 reduced by 31% showing a fuel economy benefit. Similarly, the fuel consumption of vehicle 11 exhibited reductions in consumption of 30%. These results are somewhat surprising and are the opposite of the trend that would be expected.

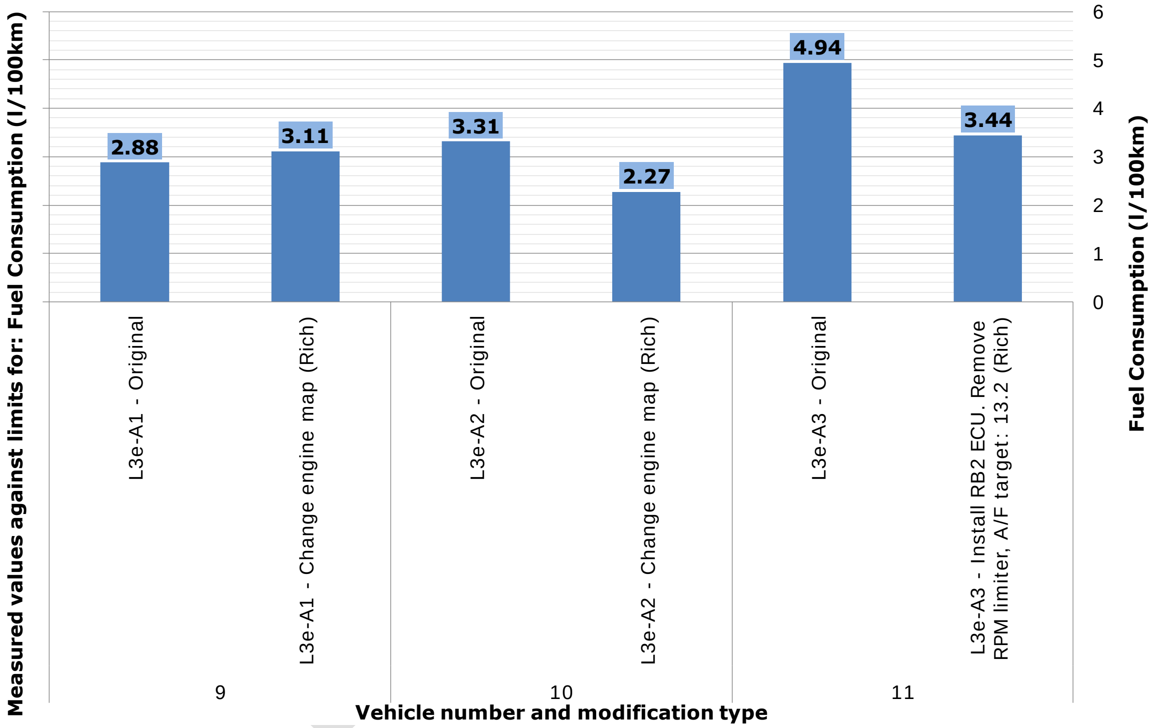


Figure 6-7: Rich Air/Fuel ratio modification: Fuel consumption [l/100km]

With reference to Figure 6-8, the Carbon Monoxide emissions from vehicle 9 exceeded the Euro 2 limit, with emissions approximately four times the original value. For vehicle 10, Carbon Monoxide emissions were increased approximately five times from a value compliant with Euro 6 to values compliant with Euro 3. Vehicle 11 also showed the same trend with an increase in emissions of this type of over 12%.

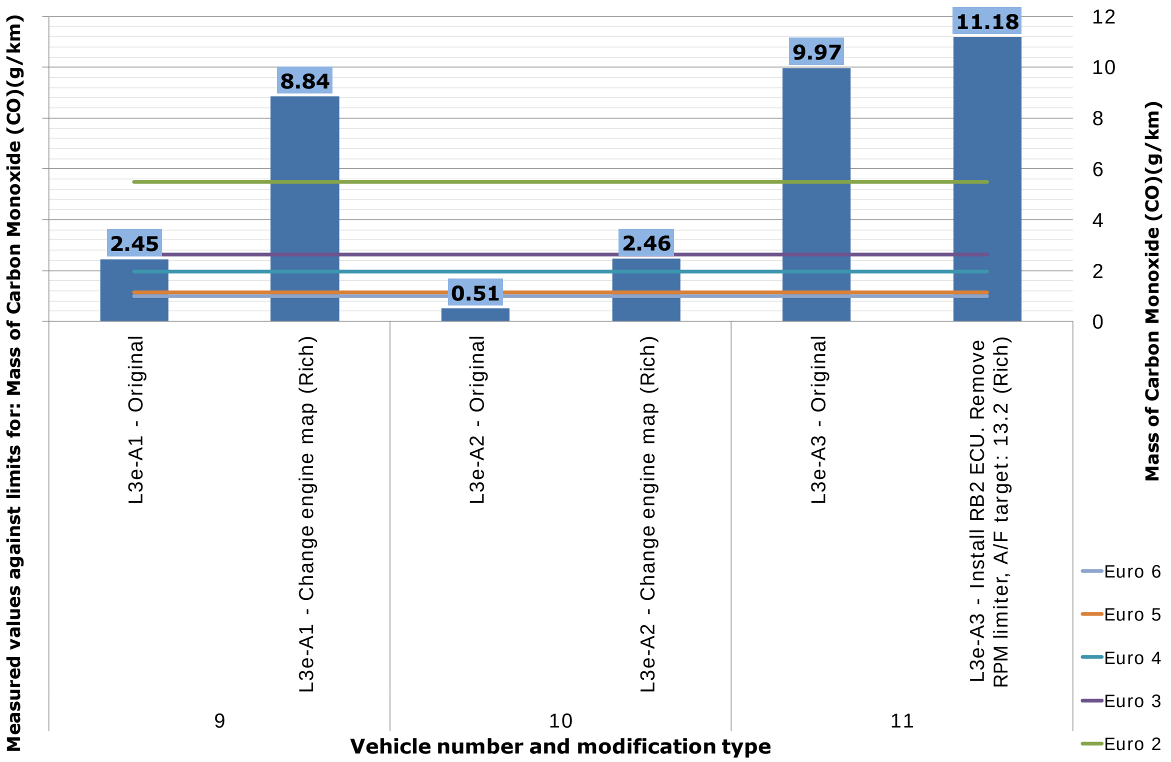


Figure 6-8: Rich Air/Fuel ratio modification: CO [g/km]

In terms of Carbon Dioxide emissions, a reduction in CO_2 levels was found, with reductions of 8%, 36% and 30% for vehicles 9, 10 and 11 respectively.

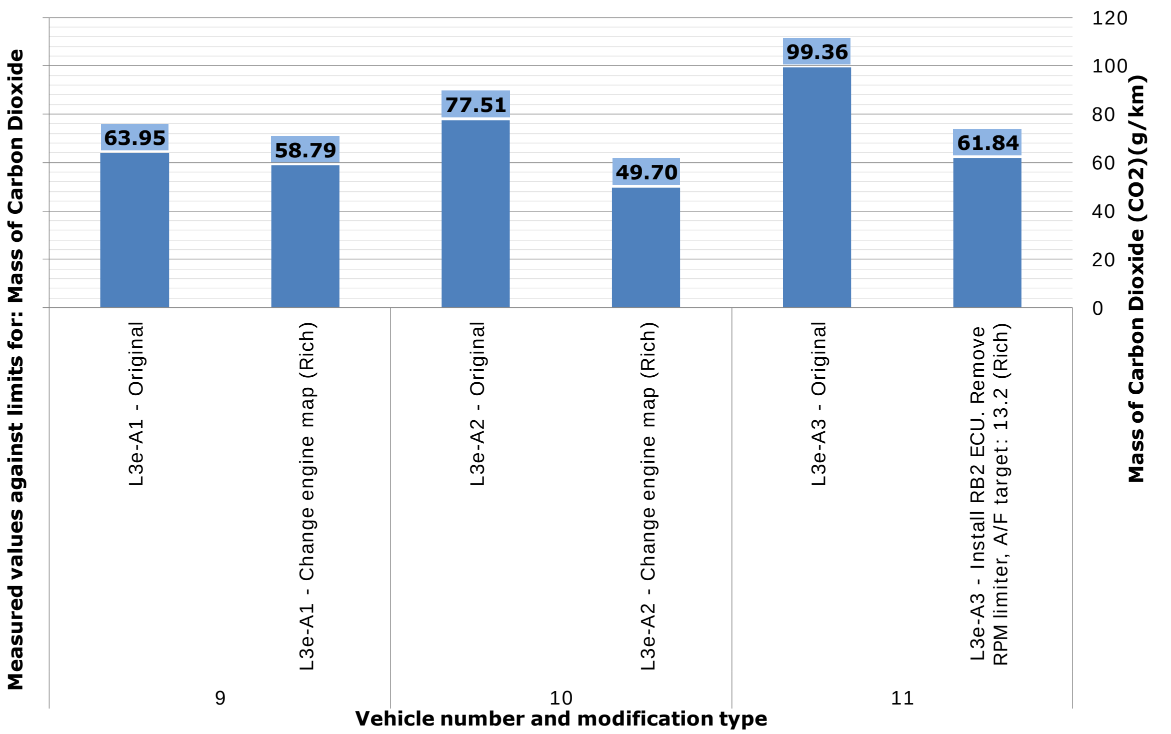


Figure 6-9: Rich Air/Fuel ratio modification: CO_2 [g/km]

For vehicles 9 and 10, the amount of unburnt fuel (THC) increased too, increasing by approximately 50% for vehicle 9 to a level which was still below the Euro 5 limits.

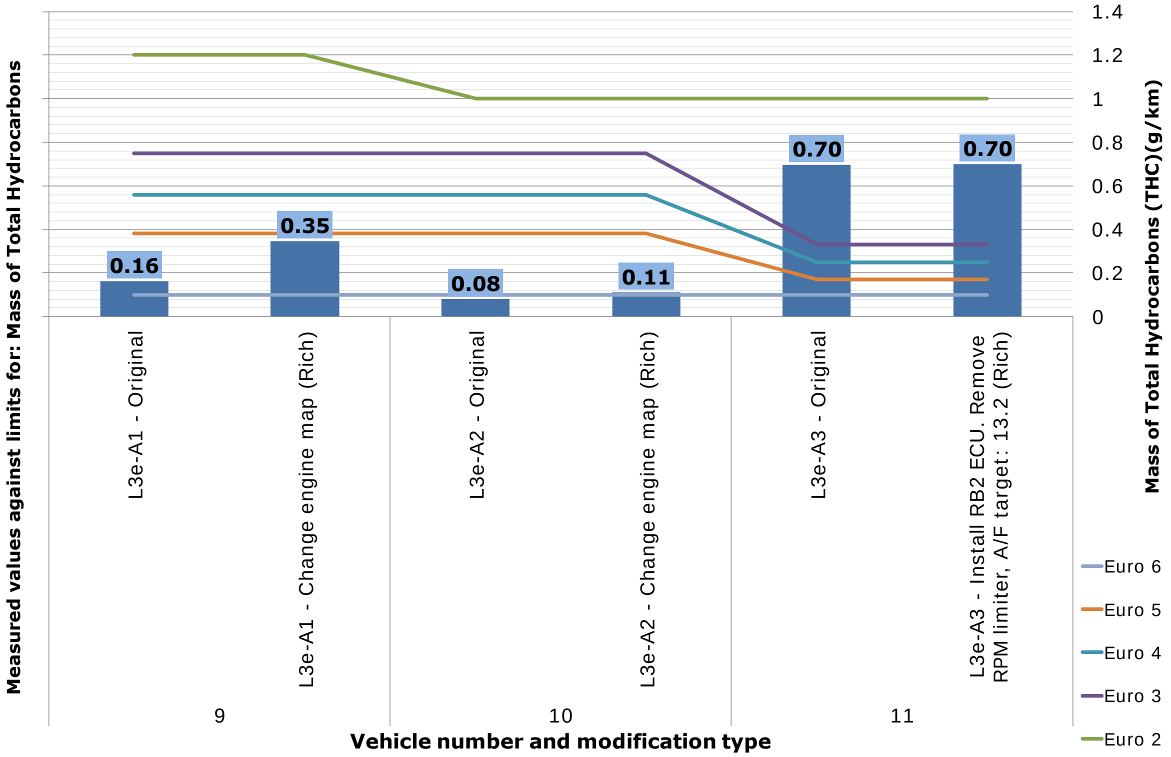


Figure 6-10: Rich Air/Fuel ratio modification: THC [g/km]

As would be expected from a rich fuel mixture, the NOx emissions for all four vehicles, reduced by 31%, 60% and 41% for vehicles 9, 10 and 11 respectively (see Figure 6-11).

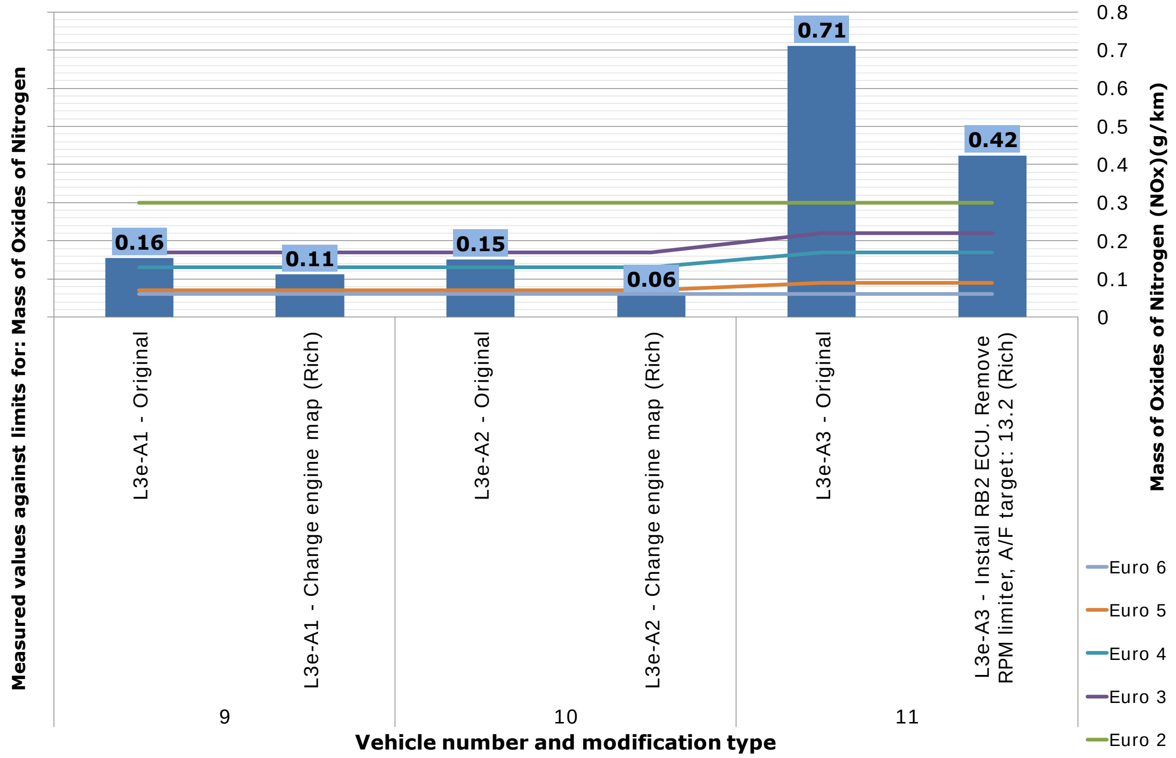


Figure 6-11: Rich Air/Fuel ratio modification: NOx g/km

6.1.2 Air/Fuel ratio (lean)

Several tampering modes were attempted with the intention of making the air/fuel mixture leaner. These were as follows:

Table 6-2: Intended lean Air/Fuel ratio modification: Vehicles and modification

Vehicle	Category	Modification	Cumulative
	L3e-A2	Change engine map (lean-save fuel)	No
		Change injection: A/F target: (lean)	No
	L3e-A3	ECU: A/F target: (Lean)	No
13	L3e-A3	Modify ECU – Change injection (Lean)	No
15	L7Ae	Remove air filter, shut crankcase ventilation, adjust carburettor (Lean)	No

When the data was analysed in relation to the air/fuel ratio it was noted that only some of these tests actually achieved a lean air fuel ratio. Consequently, only the tests in Table 6-3 were analysed.

Table 6-3: Actual lean Air/Fuel ratio modification: Vehicles and modification

Vehicle	Category	Modification	Cumulative
13	L3e-A3	Modify ECU – Change injection (Lean)	No
15	L7Ae	Remove air filter, shut crankcase ventilation, adjust carburettor (Lean)	Yes

Vehicle 13 had a modified engine map uploaded onto the ECU and vehicle 15 had a combined modification which aimed to achieve a lean configuration.

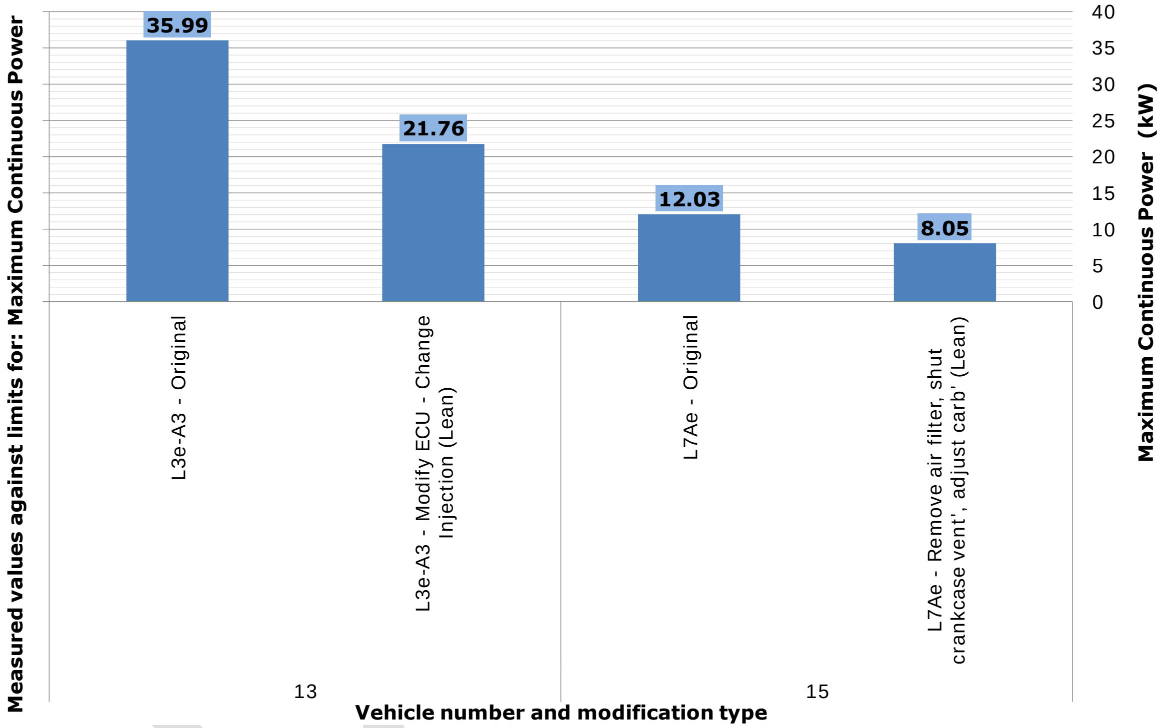


Figure 6-12: Lean Air/Fuel ratio modification: Maximum power kW

The power of vehicle 13 reduced by 40% while the power of vehicle 15 reduced 33%. The maximum speeds of these vehicles were not measured because the capabilities of the dynamometer were exceeded.

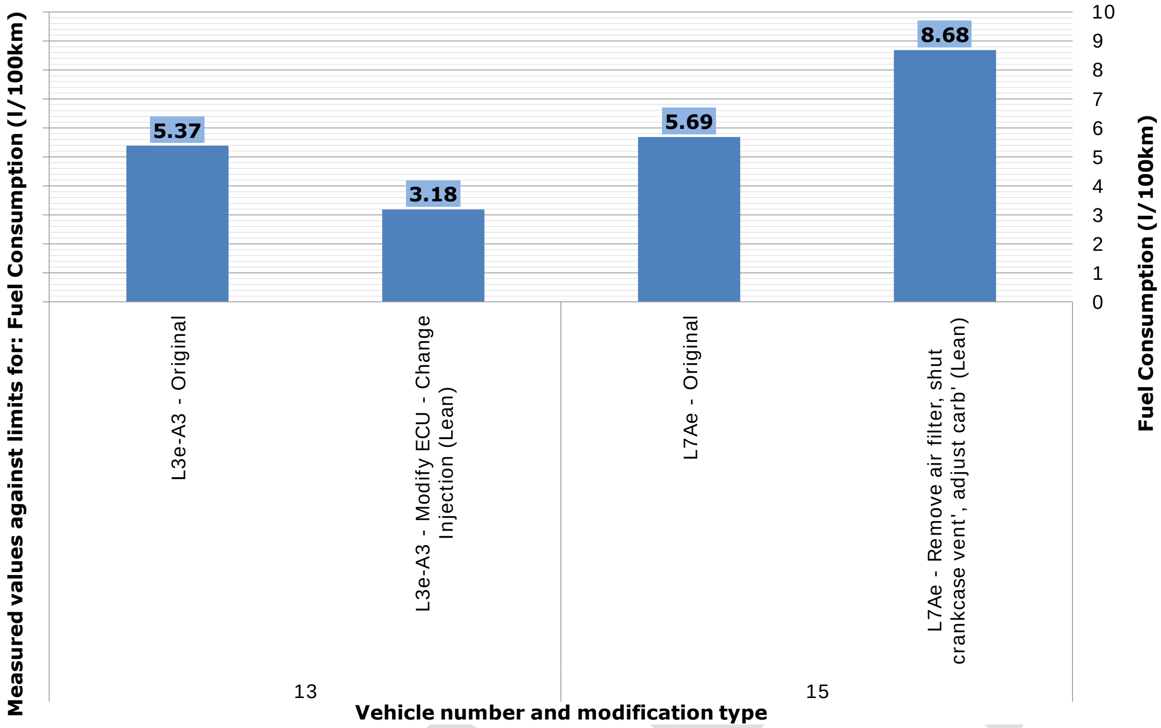


Figure 6-13: Lean Air/Fuel ratio modification: Fuel consumption [l/100km]

Fuel consumption decreased by 30% for vehicle 13. In contrast, the cumulative modification on vehicle 15 resulted in an increase in consumption of 52%.

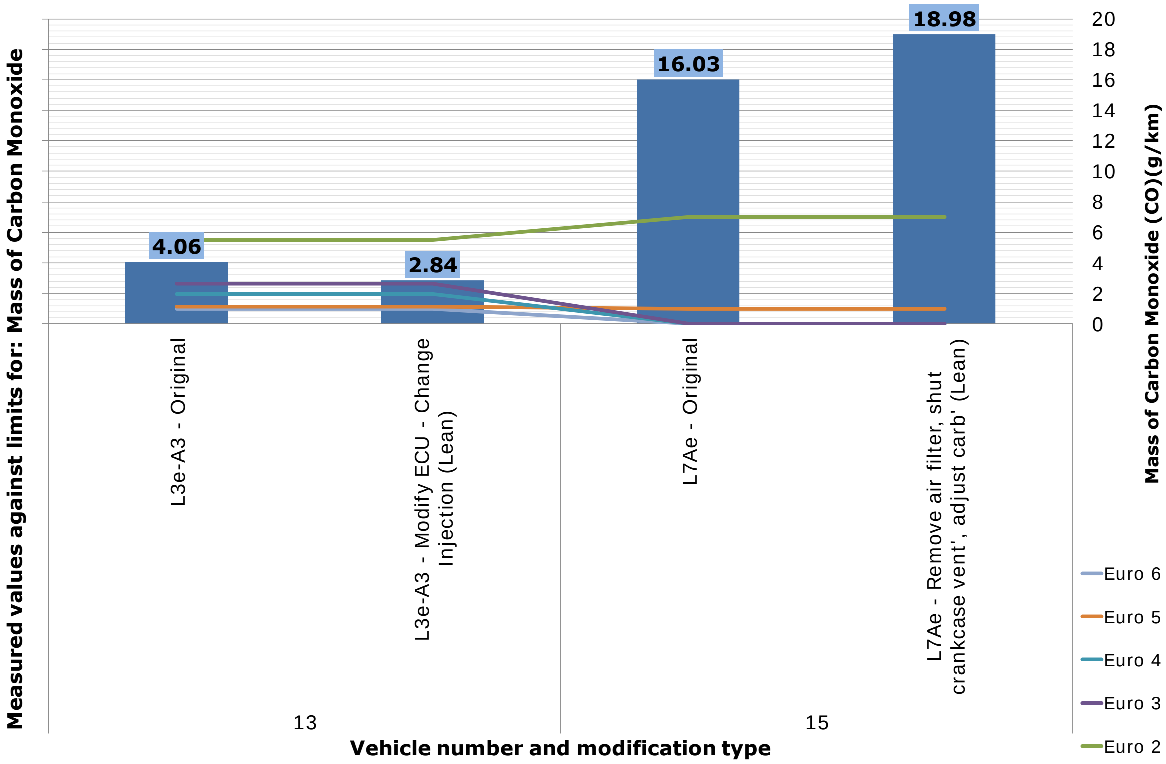


Figure 6-14: Lean Air/Fuel ratio modification: CO [g/km]

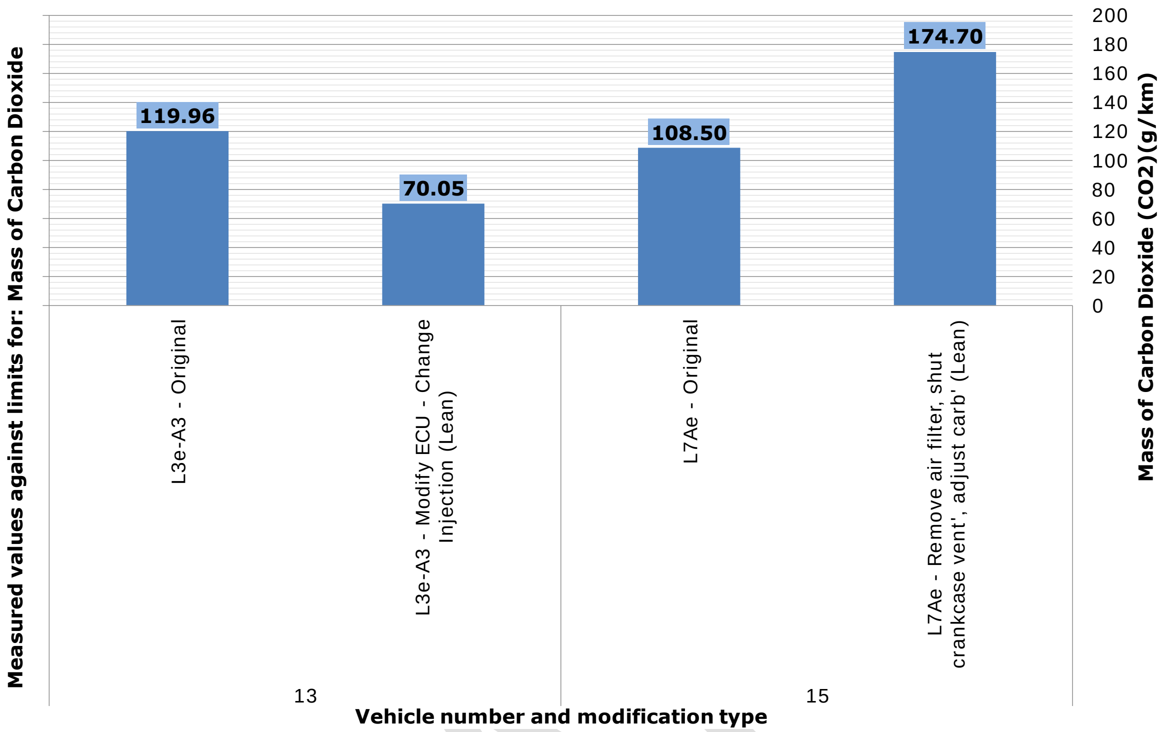


Figure 6-15: Lean Air/Fuel ratio modification: CO_2 [g/km]

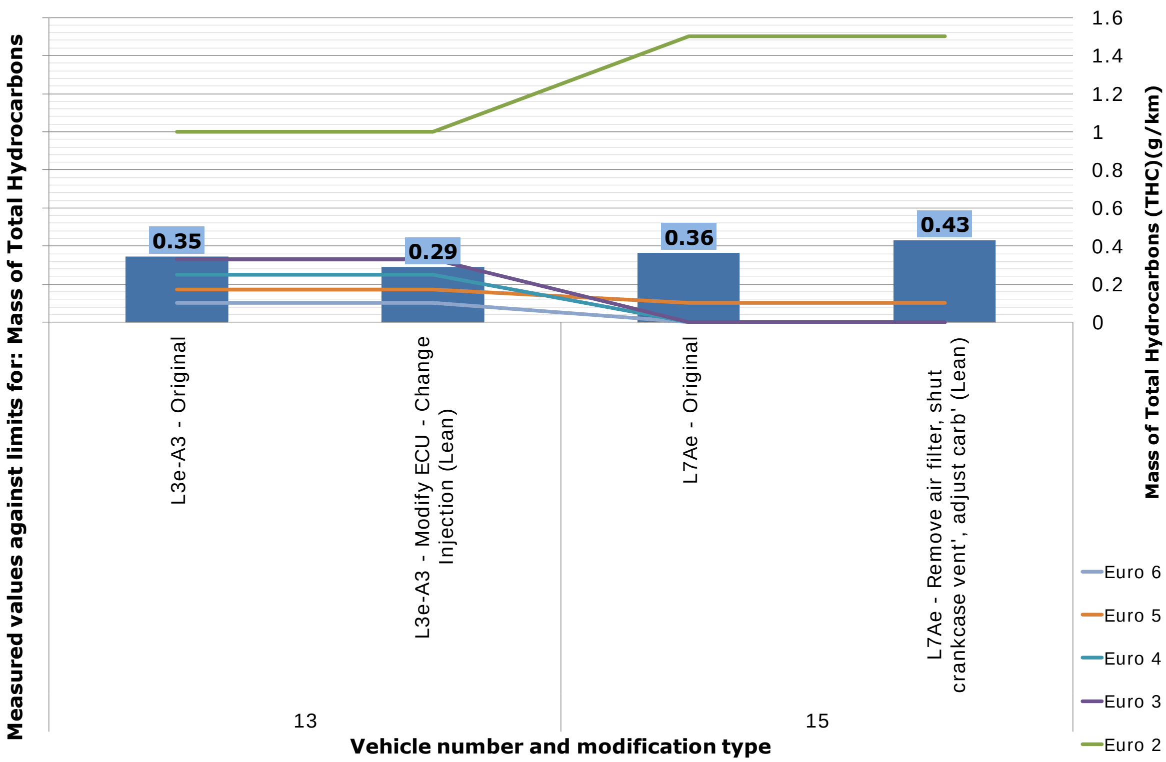


Figure 6-16: Lean Air/Fuel ratio modification: THC g/km

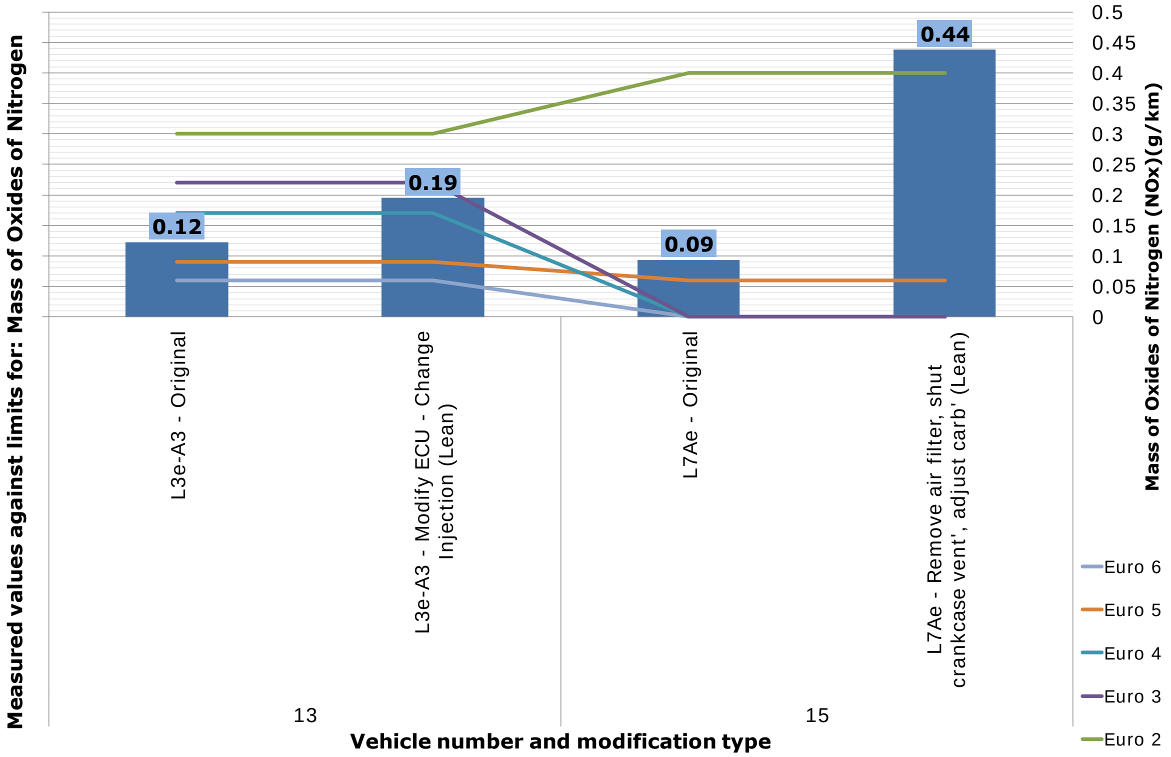


Figure 6-17: Lean Air/Fuel ratio modification: NOx g/km

These test results were only based on two vehicles, with only one of these vehicles (vehicle 13) involving a single modification to achieve a lean configuration. This modification showed reductions in power, fuel consumption, CO, CO_2 and THC emissions, but increases in NOx emissions. These results are in line with expectations for an engine running lean. For the combined modification on an L7Ae vehicle, the effect was seen to be a reduction in power, but increases in fuel consumption as well as CO, CO_2, THC and NOx emissions.

6.1.3 Fuel pump

Diesel fuel burns in a different way to petrol and so CI engines are designed in a different way and use self-ignition of air-fuel mixture owing to a high pressure and temperature in the combustion chamber, not needing a spark plug to induce combustion. The fuel is fed directly into the cylinder and is added to compressed hot air.

Simpler forms of CI engines use a piston attached to the rotating part of the engine, this provides a sustained injection of fuel synchronised to the correct part of the stroke. The amount of fuel injected is set by the length of the piston stroke which can be adjusted with a small screw on the side.

In a diesel or CI (compression ignition) engine the air fuel ratio is in effect always lean. As the fuel is injected it combusts and uses the oxygen in the compressed hot air to react, if the pump is adjusted correctly then just the right amount of fuel should be added to use all the available oxygen. When the pump is adjusted to add more fuel, it also increases the engine speed at which it is added. Simpler CI engines are not equipped with a throttle as used in a PI engine to control the mass of air flowing into the

engine, but use the quantity of fuel and its injection timing to control engine speed and load.

The fuel pump is adjusted to increase the amount of fuel delivered and the engine speed at which it does so. The aim of this modification was to increase the power produced by the engine by increasing the energy generated from each stroke. This modification was carried out on a single L5Ae vehicle.

Table 6-4: Carburettor modification: Vehicles and modification

Vehicle	Category	Modification	Cumulative modification
14	L5Be	Increase fuel pump stroke length	No

The modification to the fuel pump in this vehicle increased the maximum power by 11%. However the maximum vehicle speed decreased by 1%.

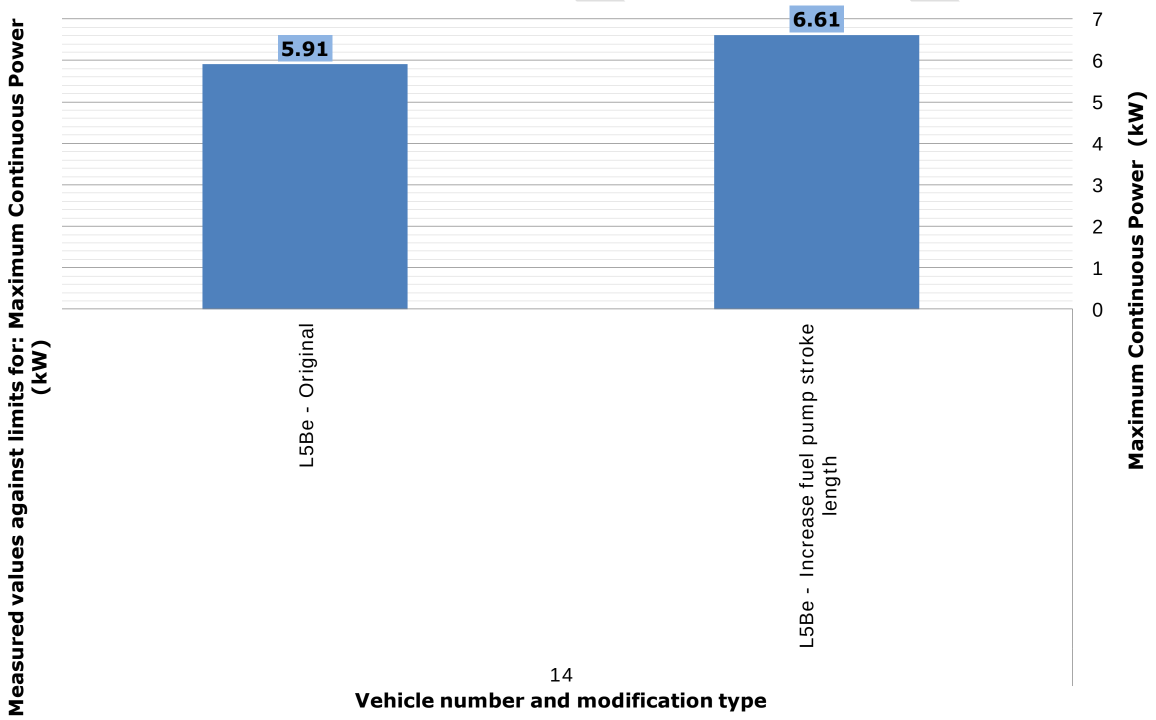


Figure 6-18: Fuel pump modification: Maximum Power [kW]

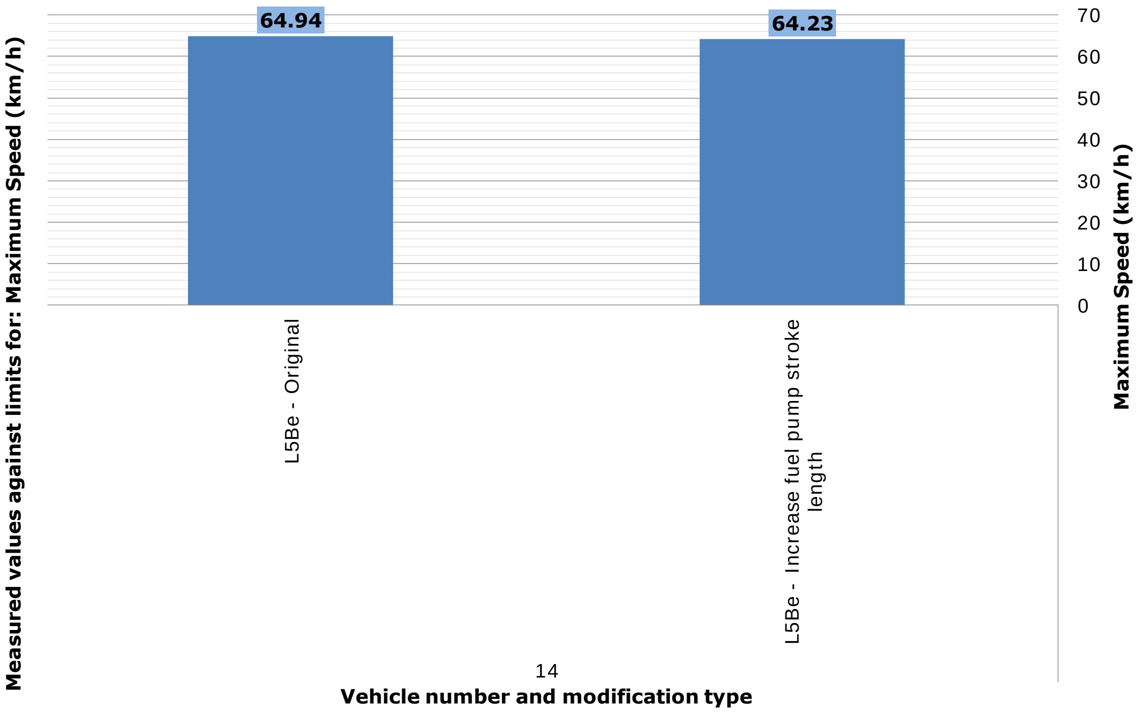


Figure 6-19: Fuel pump modification: Maximum vehicle speed [km/h]

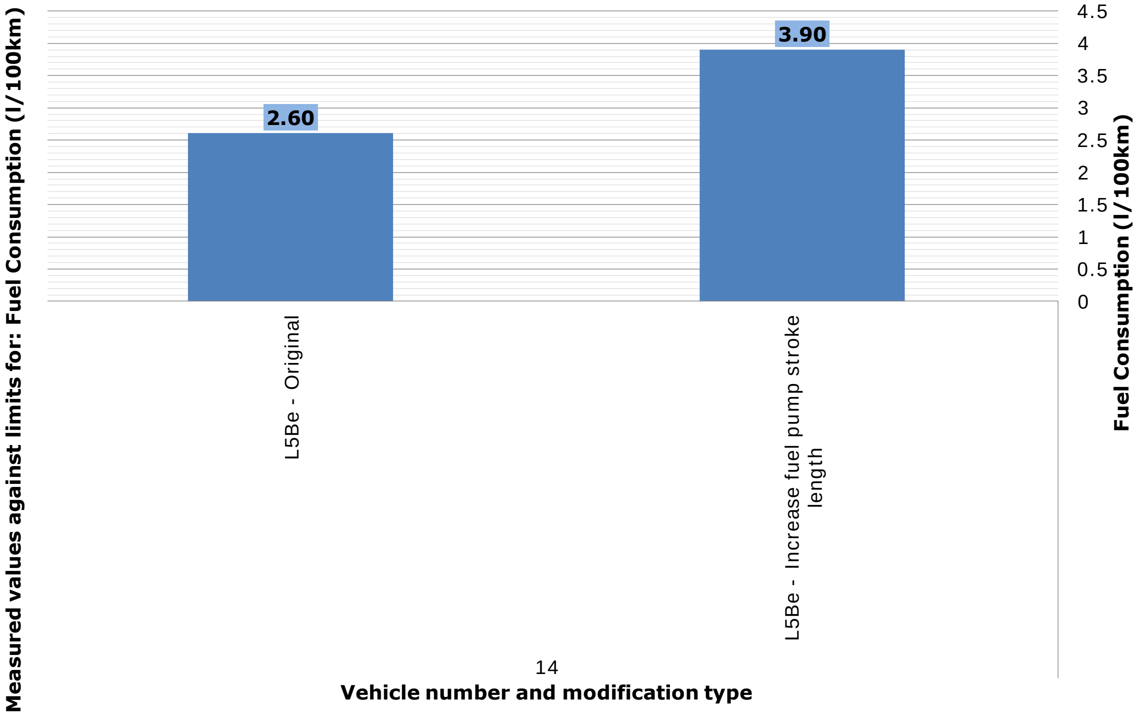


Figure 6-20: Fuel pump modification: Fuel consumption l/100km

This modification had negative effects on the fuel consumption, increasing the fuel pump stroke increased consumption from 2.6 l/100 km to 3.9 l/100 km; an increase of 50%.

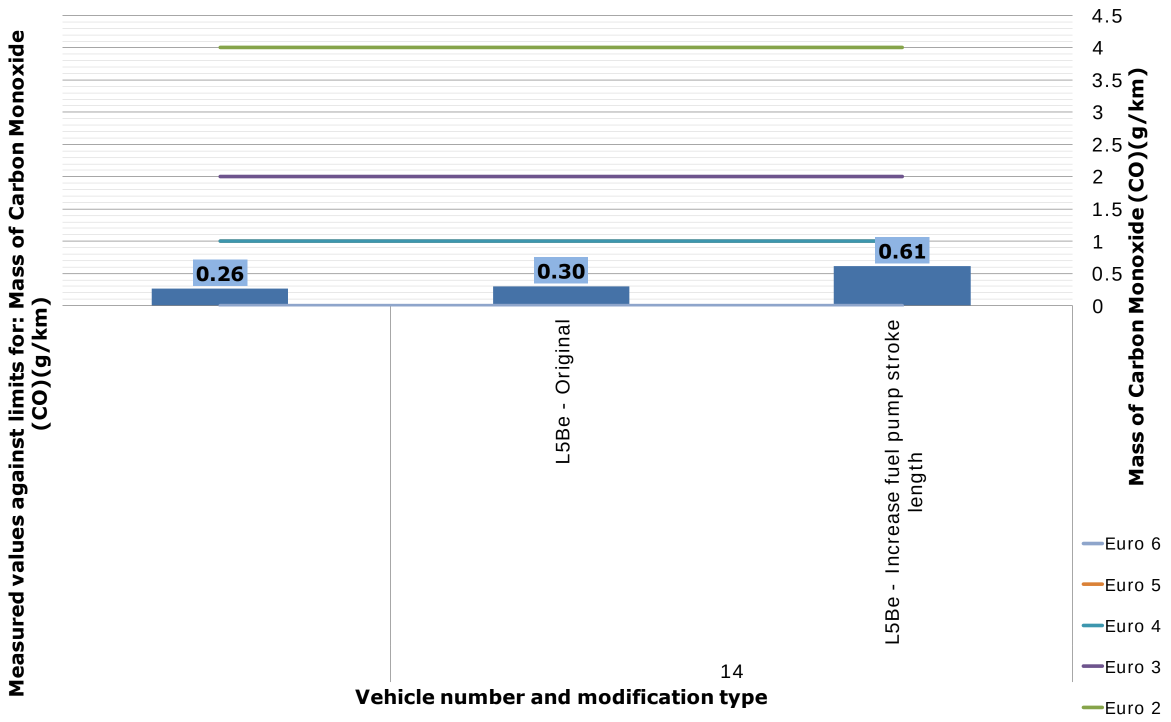


Figure 6-21: Fuel pump modification: CO g/km

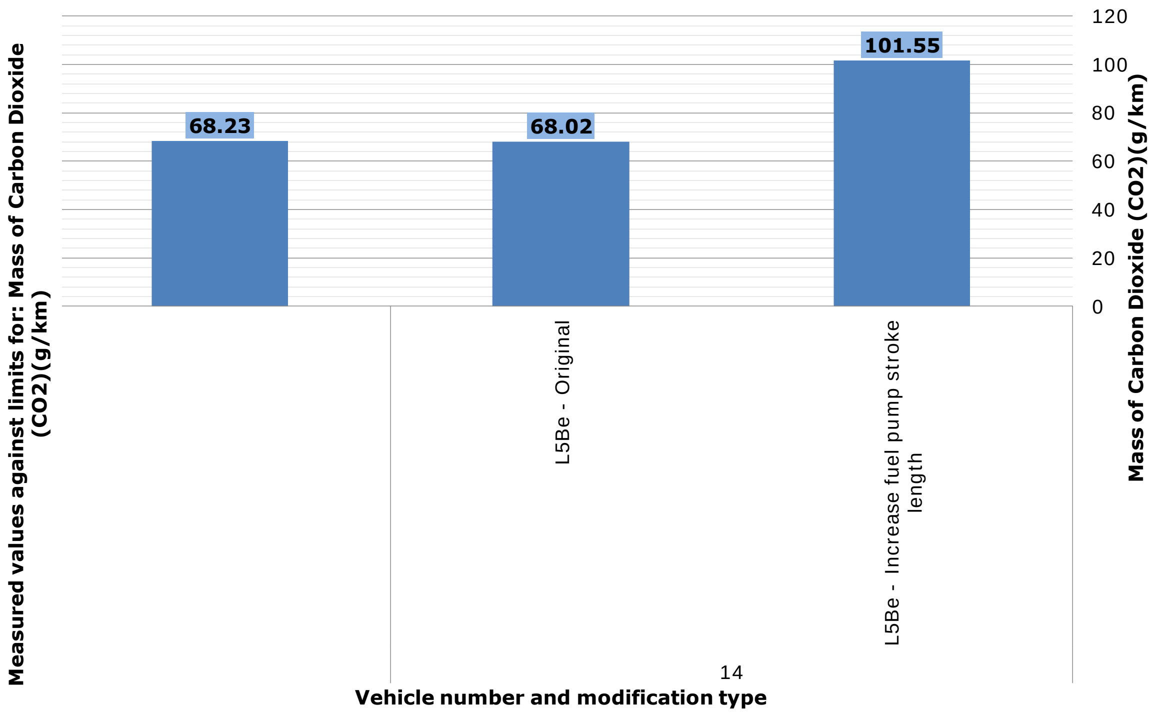


Figure 6-22: Fuel pump modification: CO_2 g/km

The above figures show that in the original configuration CO emissions are approximately 0.26-0.30 g/km. The effect of the tampering event increased CO emissions by 103%, and the CO_2 emissions by 49% to 101.55 g/km.

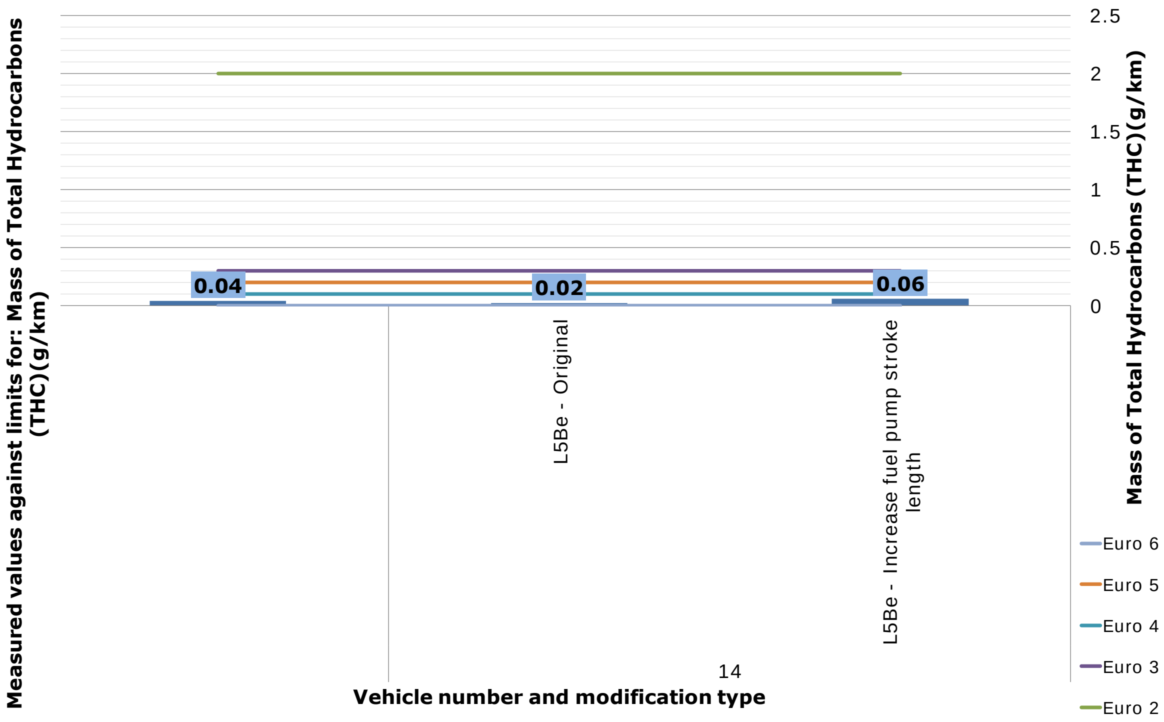


Figure 6-23: Fuel pump modification: THC g/km

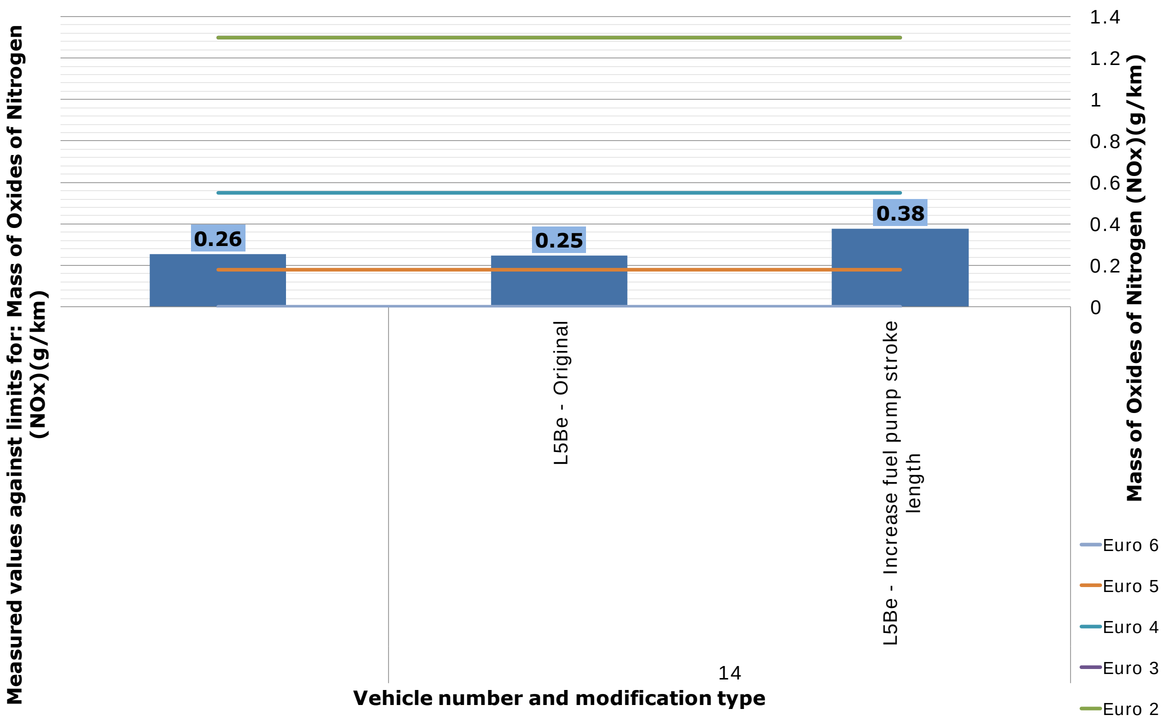


Figure 6-24: Fuel pump modification: NOx g/km

The above figures show that the effect of the tampering event increased the THC emissions by 144% or 236% (using the first and retest data respectively), although the

amounts were negligible in all cases. The NOx emissions increased by 49% or from 0.255 g/km to 0.38 g/km.

Overall the data shows that this modification dramatically reduced the fuel efficiency of the vehicle; however, although the emissions increased they remained well below the current and future emission limits. The modification did not increase the maximum vehicle speed of the vehicle. It could be seen that for this particular vehicle, an increase in maximum power may be the ultimate aim thereby allowing it to transport a greater load or accelerate faster while carrying it.

6.1.4 Carburettor

It should be noted that the carburettor was one of the most used fuel metering devices on L-category and was selected for its low price and product availability. Emission requirements were not very strict and therefore fuel metering by using a carburettor was cost effective. However, since 2001, there has been a trend that even the low-end, cheap L-category vehicles are equipped with electronic fuel injection and spark angle control. This technology trend is not only driven by the Euro 2 emission step that entered into force in 1998 (all L-category vehicles with exception of motorcycles that are approved as Euro 3 vehicles since 2006), but also owing to the increased importance of fuel consumption to customers and greater flexibility to optimise the engine performance, which requires accurate fuelling as can only be delivered by fuel injection systems and electronic spark control.

A carburettor mixes the air and fuel before it is fed to the cylinder, this uses a Venturi to cause the air flowing past an aperture (jet) to draw out a certain amount of fuel in proportion to the air. The fuel then evaporates and mixes with the air before entering the engine. The air fuel mixture is controlled by restricting the fuel flow to the aperture (jet), so that a greater or lesser air flow is required to pull through a give quantity of fuel.

The carburettor is modified for the following reasons:

- Adjust
    - Maintenance
        - It must be adjusted periodically to ensure that the engine idles correctly
        - It must be adjusted periodically to tune the air/fuel ratio to stay as required
    - Make lean or rich
        - Rich to gain more power
        - Lean to decrease fuel use
- Modify
    - Replace the carburettor nozzle to increase the maximum fuel flow
    - Replace the carburettor to gain different characteristics
        - Greater fuel efficiency
        - Greater power output

Due to the strict air fuel ratio requirements for catalytic converters, only ECU controlled carburettors with exhaust lambda sensors in a closed loop fuel metering system can be used with them. To adjust these, the ECU, sensors or signals between them must also be modified.

The following two vehicles had their Carburettors adjusted or modified to change the air fuel ratio and maximum fuel flow.

Table 6-5: Carburettor modification: Vehicles and modification

Vehicle	Category	Modification	Cumulative
5	L1Be (≤25 km/h)	CVT ratio, replace ECU, carburettor nozzle size	no
15	L7Ae	Remove air filter, shut crankcase vent', adjust carburettor (lean)	no

Vehicle 5 had an electronically controlled carburettor and its' needle was replaced to provide a larger fuel flow. As mentioned previously the ECU was replaced also to allow this modification. This was part of a combined modification where the CVT was modified to change the ratio as well as removing the speed limiter.

Vehicle 15 also had a combined modification performed on it; the air filter was removed, crankcase ventilation was closed and the carburettor was adjusted to create a leaner combustion.

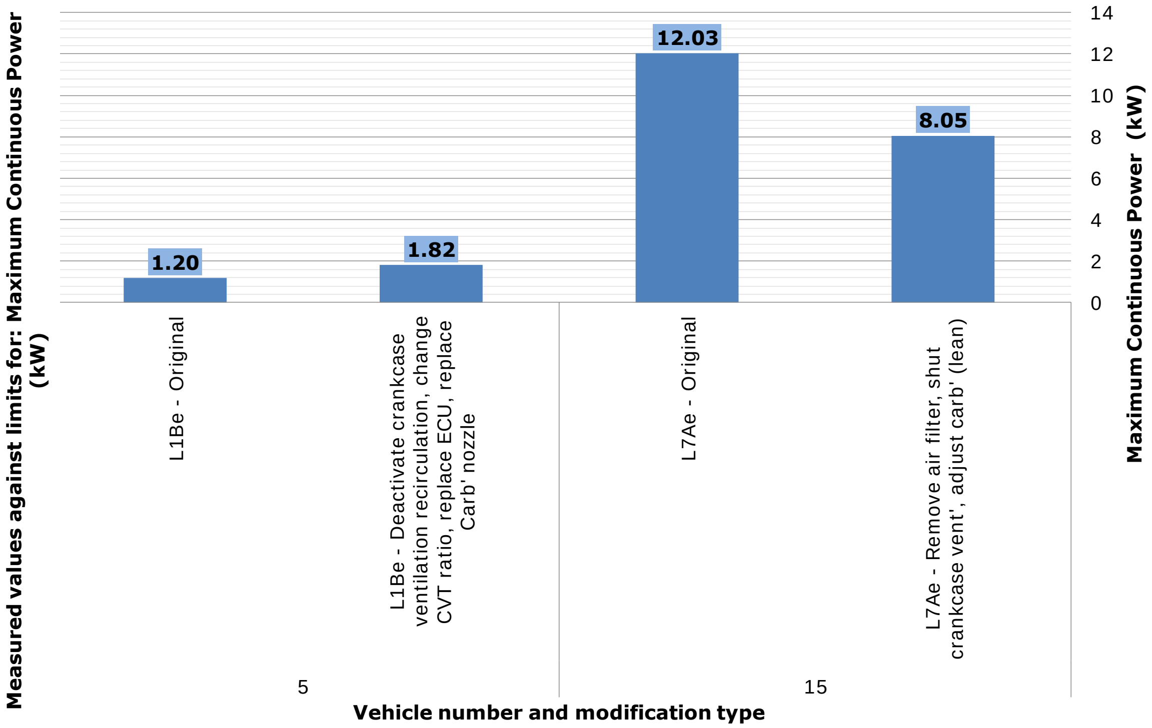


Figure 6-25: Carburettor modification: Maximum Power [kW]

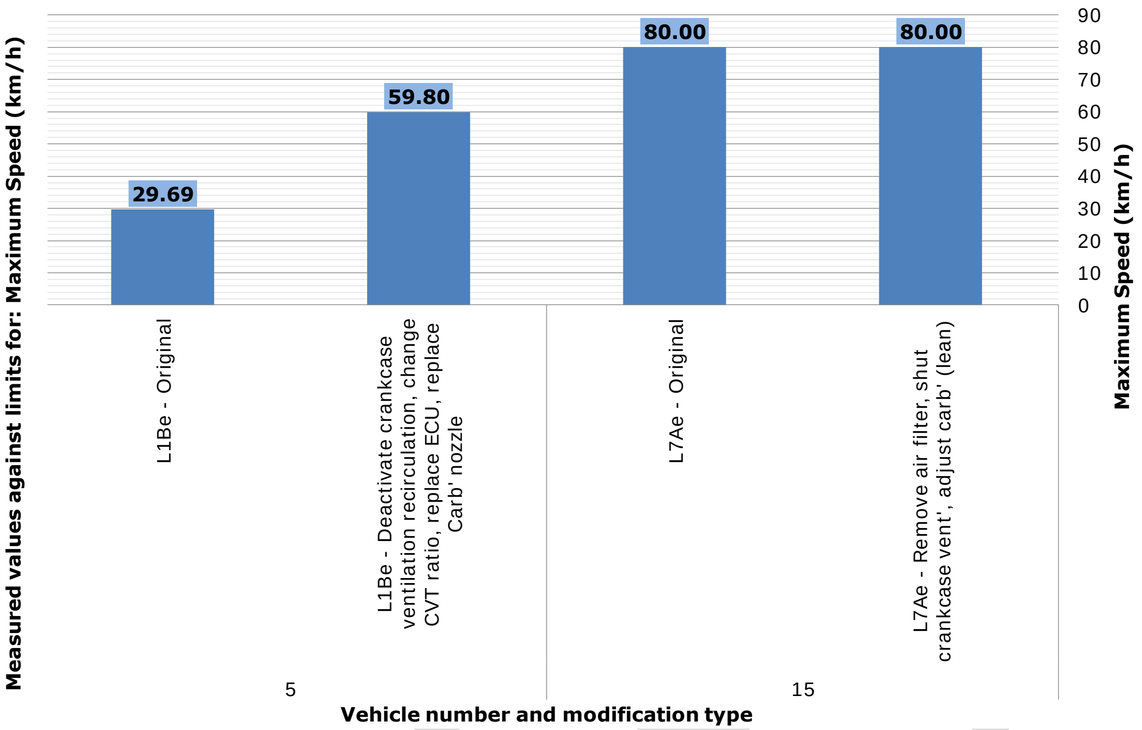


Figure 6-26: Carburettor modification: Maximum vehicle speed (km/h)

Vehicle 5 showed power increase of 52%, but a vehicle speed increase of 101%. As this vehicle involved combined modifications it is difficult to pinpoint which tampering event caused the effects measured. However, from the section on the modification of the CVT (see section 6.4.1 below) it can be shown that the change of transmission ratio and removal of the vehicle speed limiter should not significantly affect power output. The removal of the vehicle speed limiter could result in a ~25% vehicle speed increase even without an additional modification. Additionally, the change in ECU was required to allow the carburettor to be modified to provide the greater fuel flow.

For vehicle 15 the power measured at the wheels reduced by approximately 4kW in the test case for this modification, a reduction of 33%. The maximum vehicle speed of this vehicle could not be found due to safety concerns. As for the consequence of combined modifications, removal of the air filter seems to only provide a small power increase (11-17%, see section 6.1) and the shutting of the crankcase ventilation valve may reduce power and vehicle speed by approximately ~8% (see section 6.5).

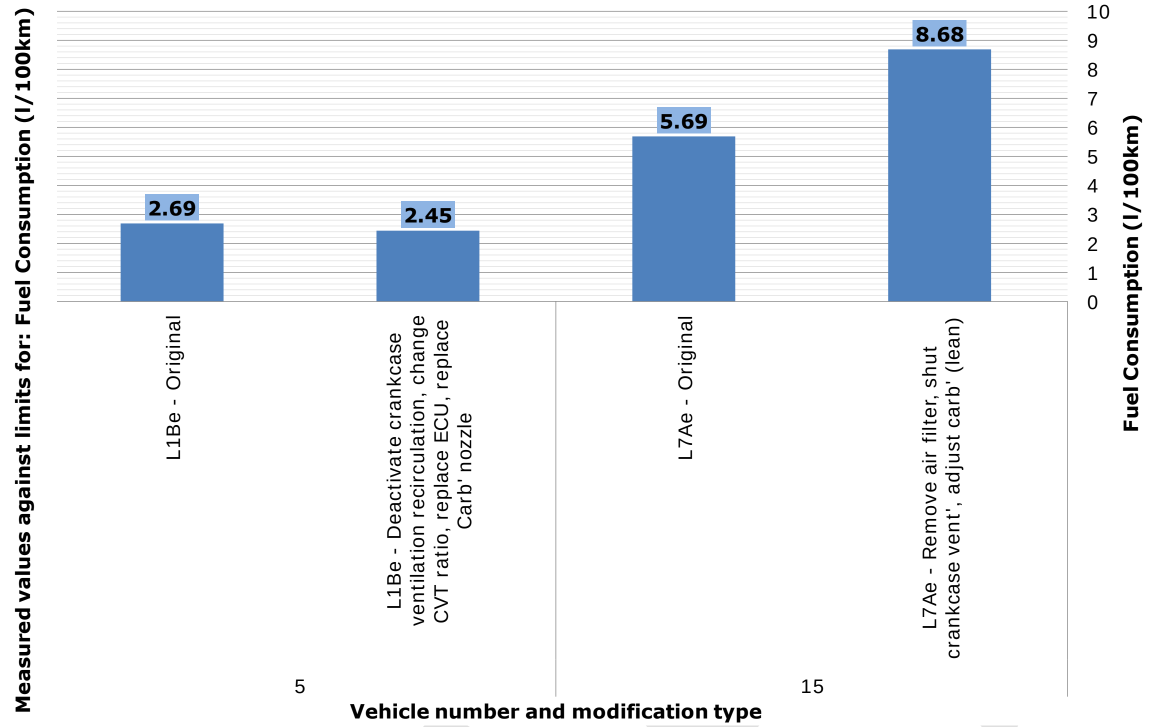


Figure 6-27: Carburettor modification: Fuel consumption l/100km

Vehicle 5 reduced its fuel consumption by 5% while for Vehicle 15 it increased from 6.7 l/100km to 8.7 l/100km; a 52% increase.

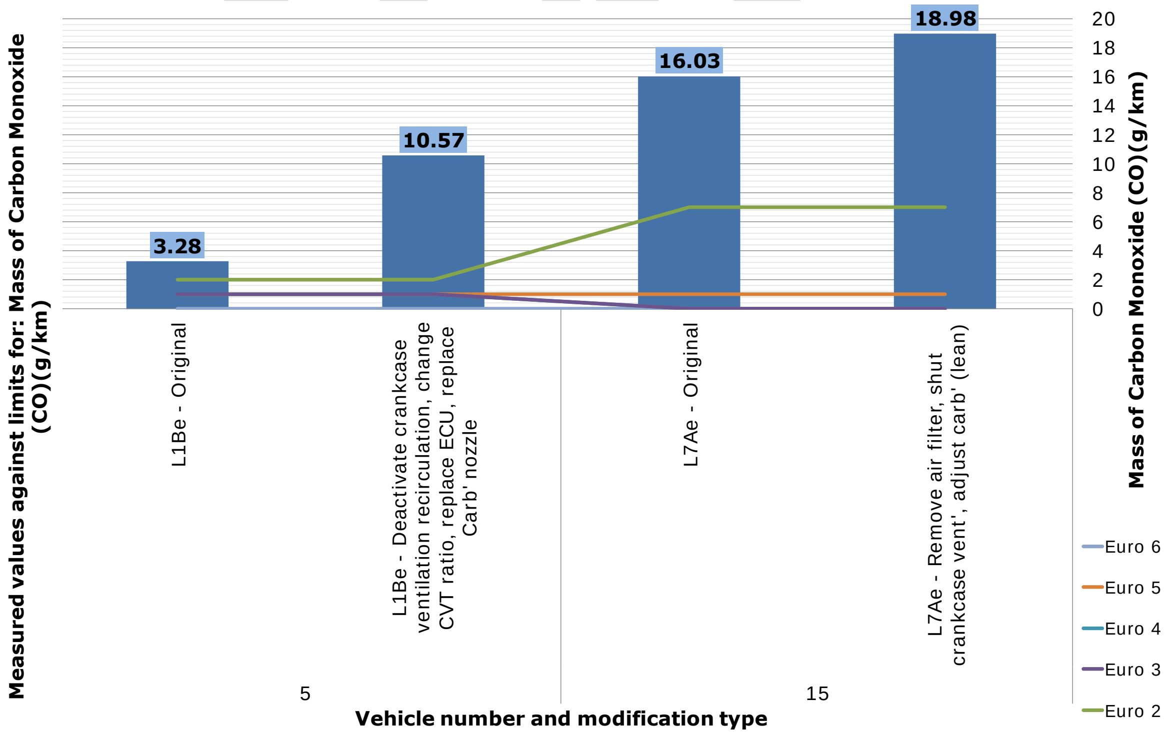


Figure 6-28: Carburettor modification: CO [g/km]

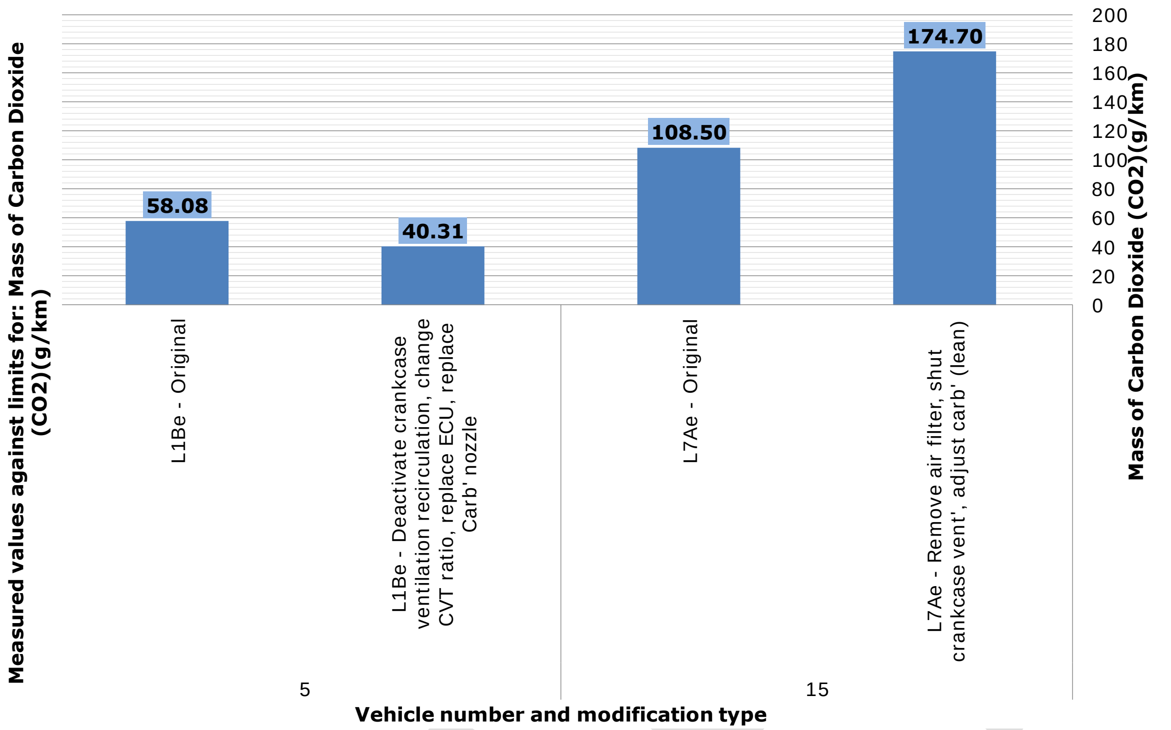


Figure 6-29: Carburettor modification: CO_2 [g/km]

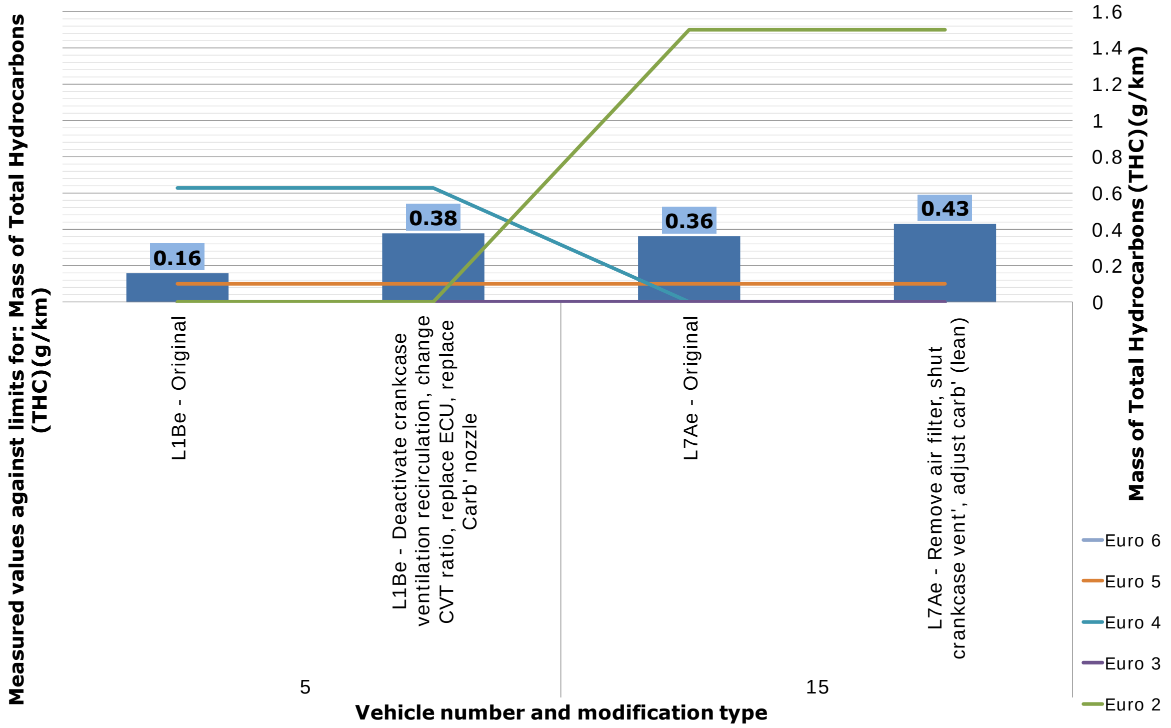


Figure 6-30: Carburettor modification: THC [g/km]

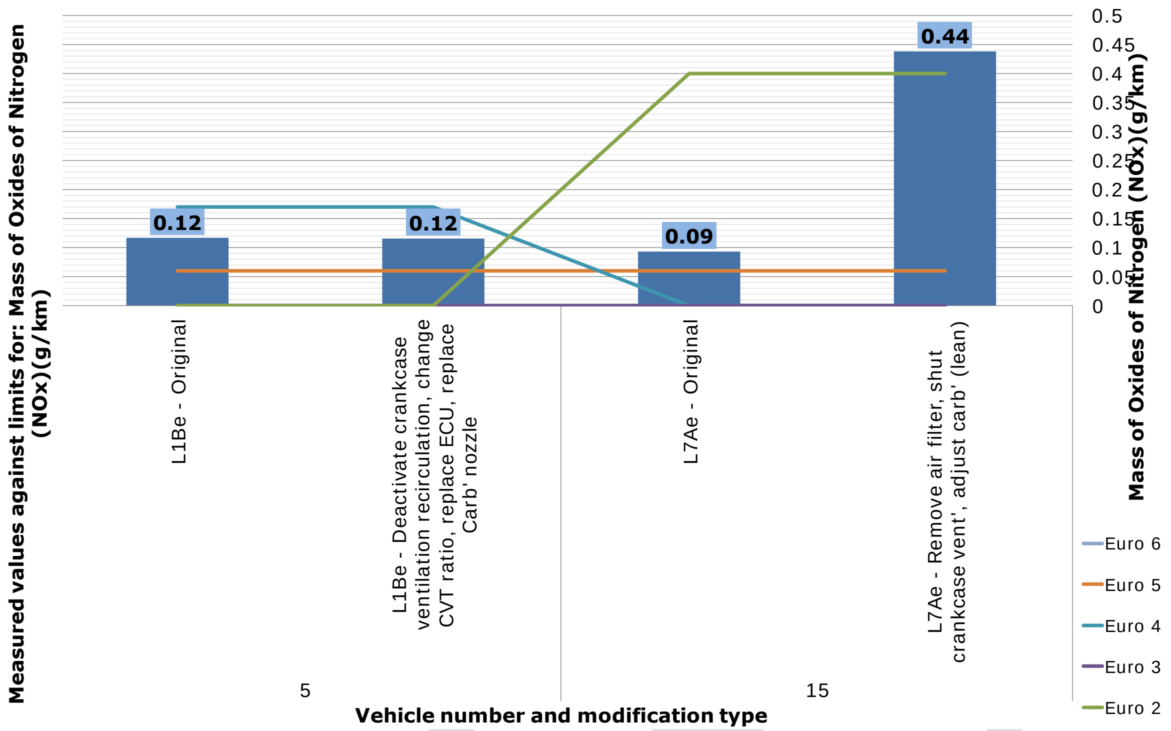


Figure 6-31: Carburettor modification: NOx [g/km]

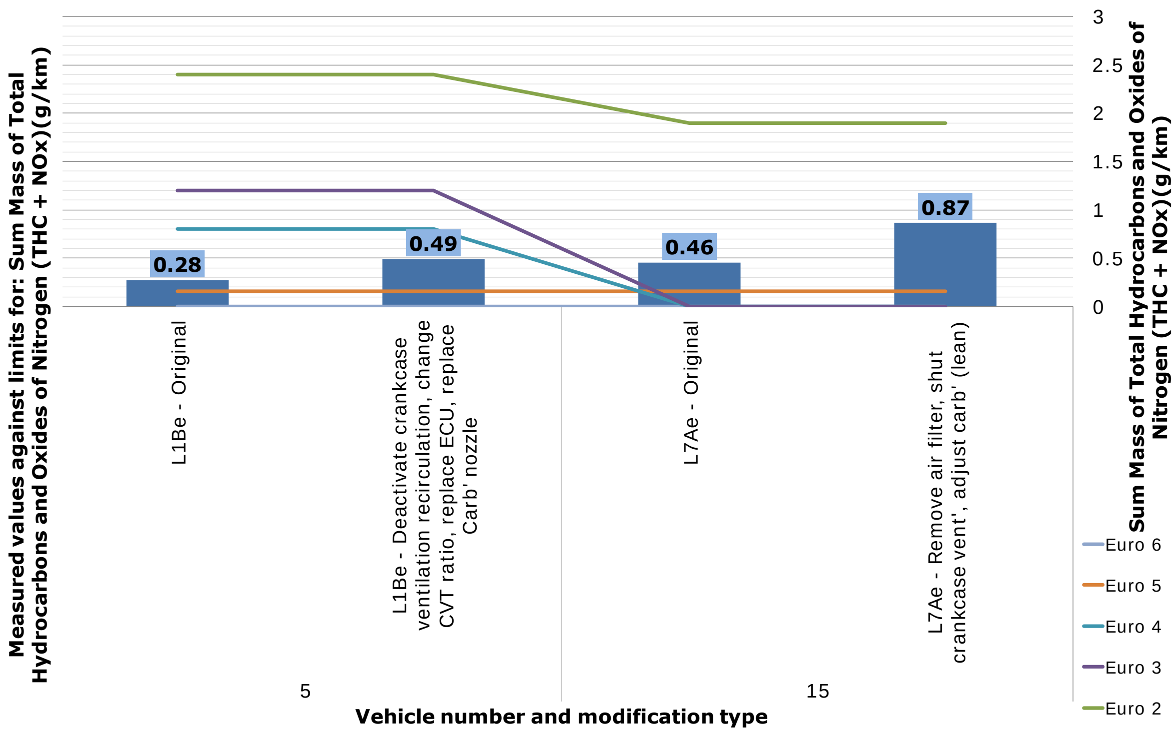


Figure 6-32: Carburettor modification: THC+NOx [g/km]

CO emissions from vehicle 5 increased by 206%, and THC by 138%, this is reflected in a drop of 31% of CO_2 emissions. The NO_x emissions however were unaffected (see Figure 6-31).

The CO after modification exceeds the Euro 1 limits by 76% and Euro 2 by 528% the original value, however was already exceeding the Euro 2 limit by 64% but was below the Euro 1 limit.

For vehicle 15, CO increased by 18%. The original configuration test was found to exhibit CO emission levels significantly in excess of regulatory limits. As indicated by Figure 6-1 NOx should increase when an engine runs leans and this is shown by an increase of 389% (see Figure 6-31), a value which exceeds the Euro 2 regulatory level.

6.2 Air intake

Table 6-6: Carburettor modification: vehicles and modification

Vehicle	Category	Modification	Cumulative
1	L1Ae	Air filter (removed)	no
2	L1Be ≤24 km/h	Replace Exhaust system & Air filter	no
6	L1Be ≤24 km/h	Remove air filter and "intake air pipe"	no
15	L7Ae	Remove air filter, shut crankcase vent', adjust carburettor (lean)	no

As part of the testing programme one L1Ae, two ≤25 km/h L1Be, and one L7Ae vehicle had their air intake modified. These have been defined as vehicle 1 to 4 in order of their position on the graphs.

The modification of the air intake is intended to increase the flow rate of air and therefore the mass of air (oxygen) available in the combustion cycle.

The quantity of fuel needs to be increased to take advantage of the additional oxidiser, keeping the same or similar air/fuel ratio balance. For (Positive ignition) PI, this happens automatically either through a carburettor or lambda sensor and fuel injection control loop. The same might be true for (compression ignition) CI, but in other cases secondary modification of the fuel pump system may be required.

When combined, this allows either a larger power output per piston stroke and/or a higher engine speed. However, such a modification can have negative effects on the life expectancy of the engine due to the risk of particulates entering the engine during modification. The modification can involve the:

- Removal of the air-filter
- Replacement of the air-filter with a free-flow filter
- Removal of the air intake cowling
- Removal of a restriction orifice
- Expansion of the inlet orifice to the engine
- Replacement of the carburettor with a larger air flow capacity

Vehicle 1 had the air filter removed. Vehicle 2 had the air filter replaced in conjunction with the replacement of the exhaust with an aftermarket part (the effect of combined

modification will be looked at further in section 6.5 below). Vehicle 6 had the entire air intake cowling, pipe and filter removed with no other supplementary modifications. Vehicle 15 had the air filter removed, the duct of the crankcase ventilation system shut and the carburettor airflow screw adjusted from 1.5 turns open to 0.5 turns open; all part of an effort to make a lean air/fuel mixture.

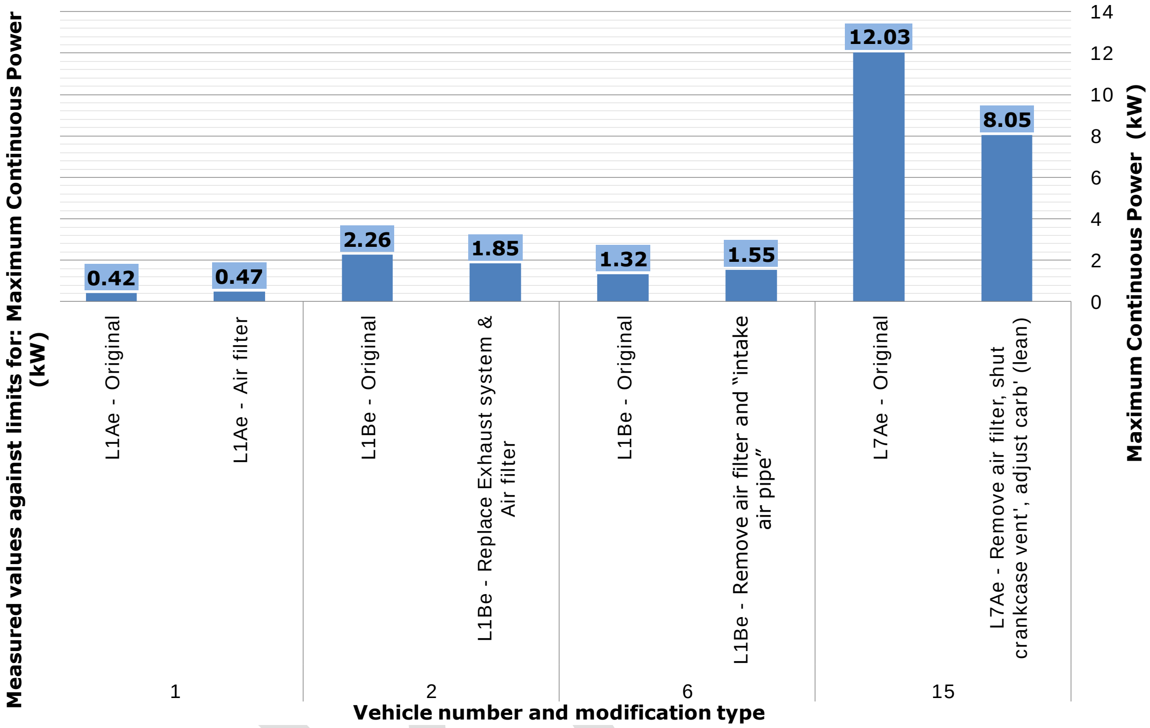


Figure 6-33: Air intake modification: Maximum power

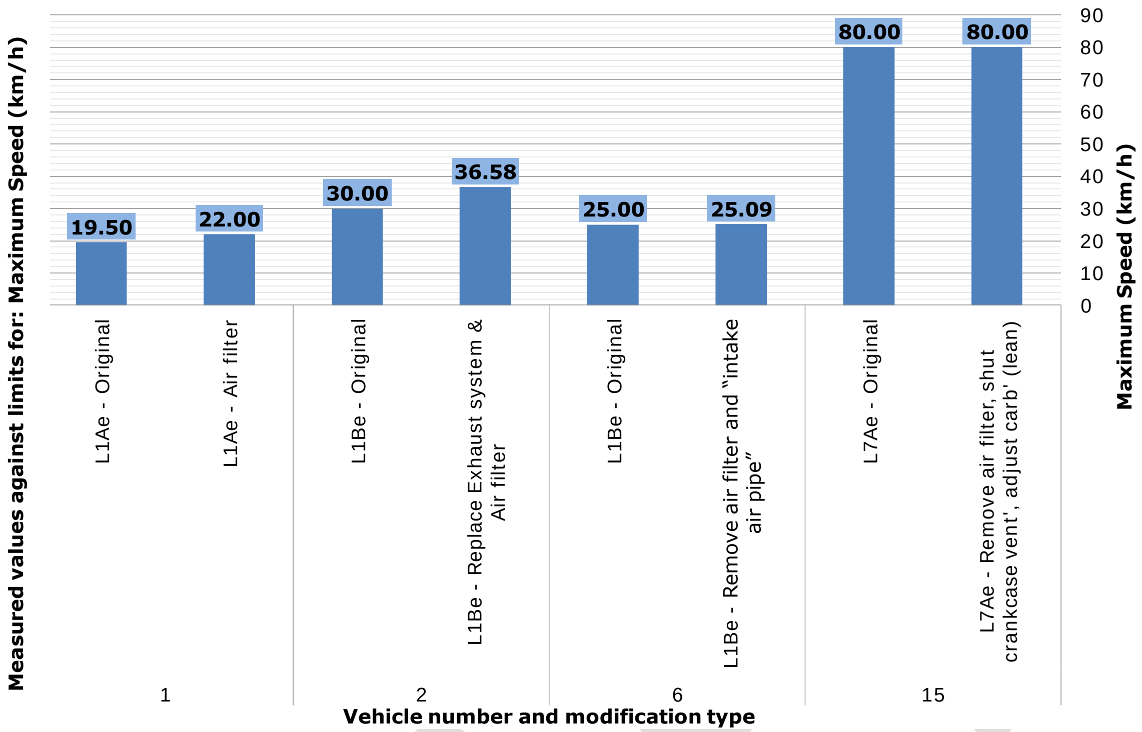


Figure 6-34: Air intake modification: Maximum vehicle speed

After the modification vehicle 1 experienced an increase in vehicle power from 0.42 kW to 0.47 kW, although this is small it constitutes an increase of 12%, 2% more than any restricted modification is permitted by the legislation to achieve. It does seem counter intuitive that a reduction in power and increase in speed occur at the same time, however, the testing method used for power may provide an explanation.

It is possible for an increase in maximum vehicle speed to be caused by the same modification which shows a decrease in maximum net power, as the test for power only looks for and measures the peak over the range of possible engine speeds. If, for instance, the peak power was at 4,000 r/min and the maximum vehicle speed was also attained at that engine speed, then there would be a direct relationship between the increase in one and the other. If however, the maximum vehicle speed was at another engine speed, for example 6,000 r/min, then the peak power value at 4,000 r/min is of little consequence; the overall peak power may have decreased while the power at maximum vehicle speed has increased. As long as this power level at the maximum vehicle speed is below that at peak power, the change would not show up in the test results. With the type of modifications being performed, this kind of fundamental change to the engine characteristics is considered possible.

Conversion from vehicle power to Net power using an approximate transmission loss of 10-30% gives an approximate value of 0.6 kW, this is still below the legislated 1 kW limit for this category of vehicle (L1Ae; Low speed moped) and so is likely to not result in a penalty to the user.

It should be noted that the approximate values for transmission losses are based on L3e vehicles. Values for L1Ae (or power assisted bicycles) are not available, but the relative simplicity of their powertrains means that losses are likely to be lower.

Vehicle 1 experienced an increase in maximum speed of 12.8%. This is still 3 km/h below the limit for this category.

Vehicle 2 experienced a decrease in maximum vehicle power of 18% (see Figure 6-33), so does not exceed its legislated limits. However, it had an increase in the maximum vehicle speed of 22% (see Figure 6-34). This particular vehicle is designed to already exceed the maximum speed up to the allowed tolerance in the Netherlands (≤ 25 km/h + 5 km/h) where it is marketed, this gives very little margin for error during testing. This increase would result in a penalty to the user.

Vehicle 6 experienced a power increase of 17%. How this relates to the legislated limits is unknown since net power cannot be measured on a whole vehicle. Given that the power values in relation to the limits are 33% and the 39% before and after modification respectively, and that a usual transmission loss is approximately 10-30%, then it is unlikely that this vehicle will exceed the limits. The maximum speed of this vehicle increased by less than 1%.

Vehicle 12 had a power loss of 33% after modification. Unfortunately, due to safety concerns resulting from high tailpipe temperatures (over 800°C), this vehicle could not be tested to its maximum speed; the test was stopped for both the safety of the test rider and for fire concerns. In current legislation this vehicle group has no speed restriction.

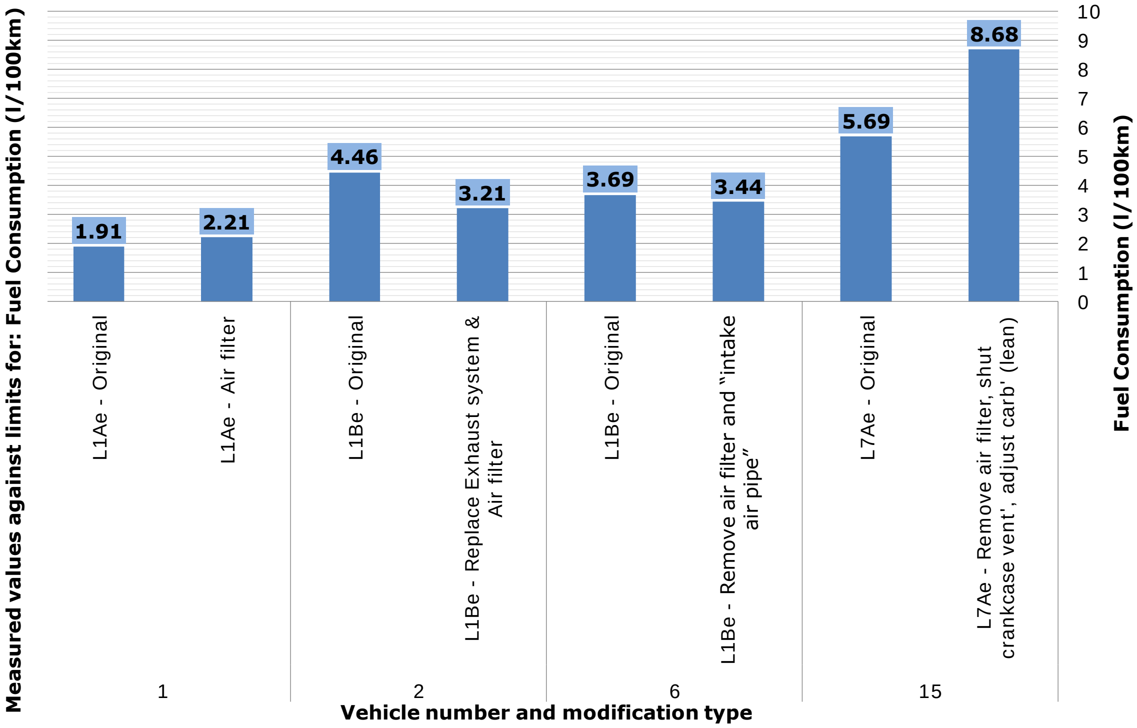


Figure 6-35: Air intake modification: Fuel consumption[13]

[13] The fuel consumption is an estimate, calculated from the quantity of carbon based molecules measured in the exhaust (THC, CO2, and CO)

A third reason for intentional modification is the reduction of running costs by way of fuel economy (see Figure 6-35).

The removal of the air filter for vehicle 1 increased fuel consumption by 15%, where a similar modification to vehicle 15 increased fuel consumption by 6.7%; this equates to an increase of 0.25 litres per 100 km (or 5.5 mpg imperial - see Appendix N).

The combined effects of tampering with the air filter and exhaust modification on vehicle 2 reduced fuel consumption by 28% over the emission test cycle. It cannot be determined which of the two modifications were responsible for this effect.

The modification on Vehicle 15 resulted in a 52% increase in fuel consumption, with this increasing by almost 3 litres per 100 km.

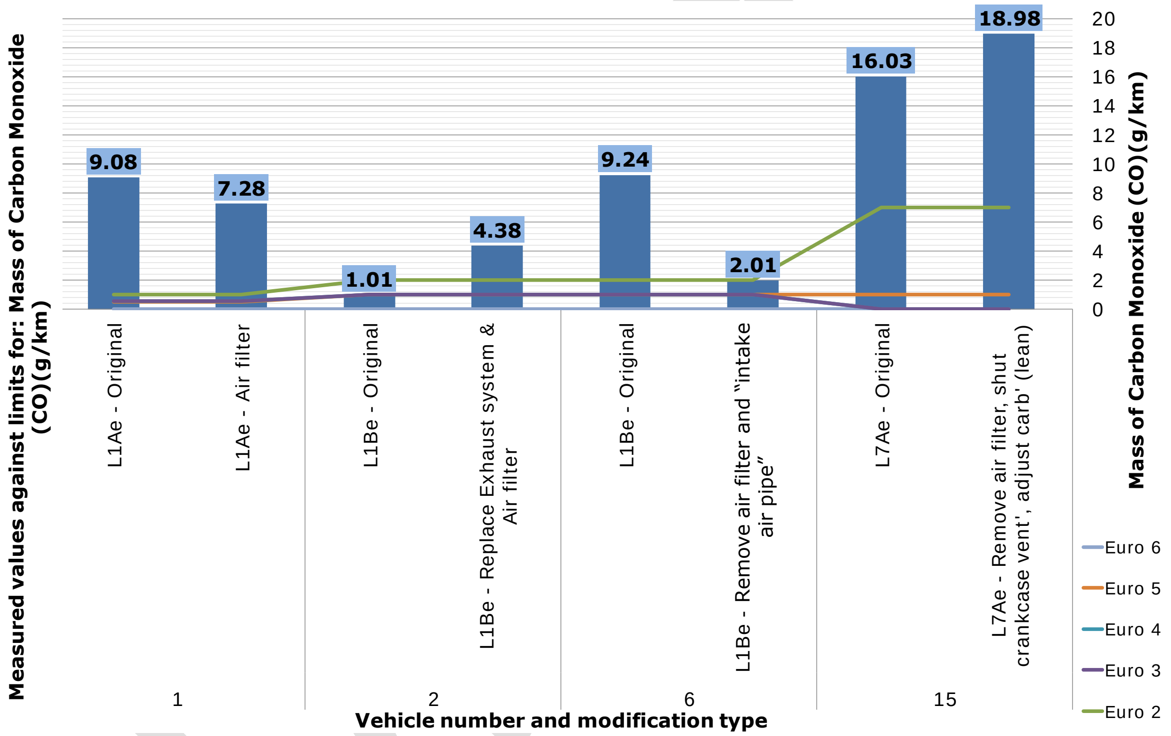


Figure 6-36: Air intake modification: CO [g/km]

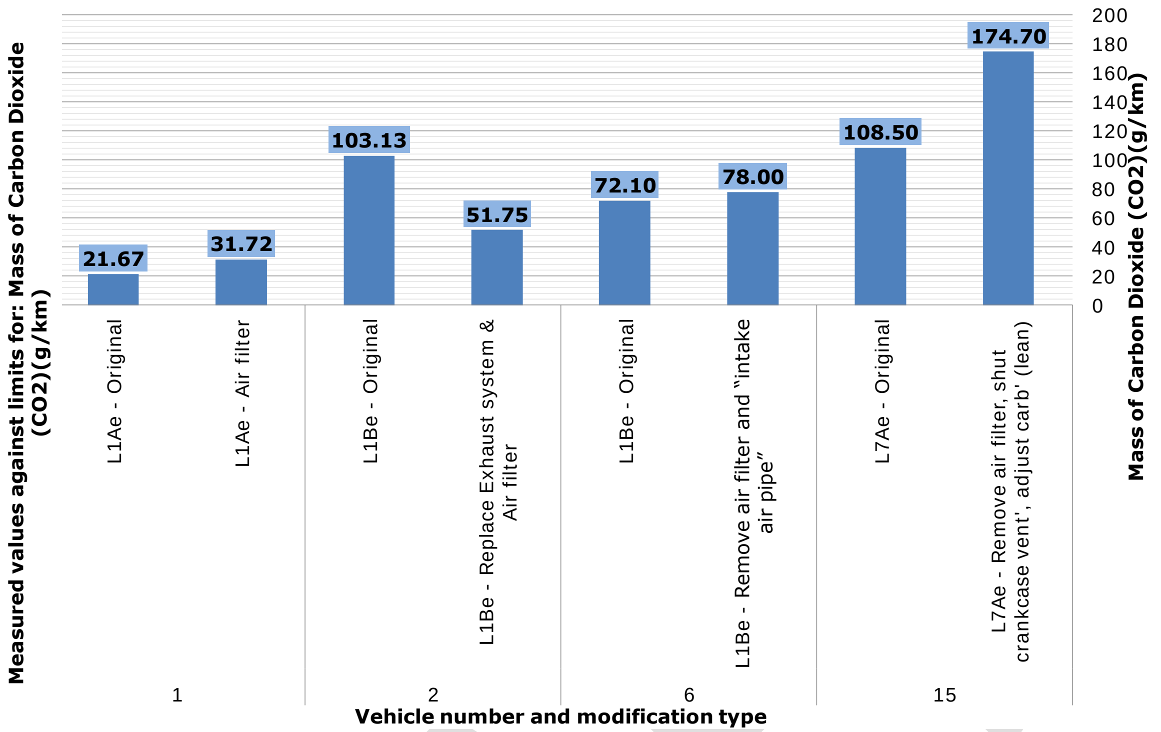


Figure 6-37: Air intake modification: CO_2 [g/km]

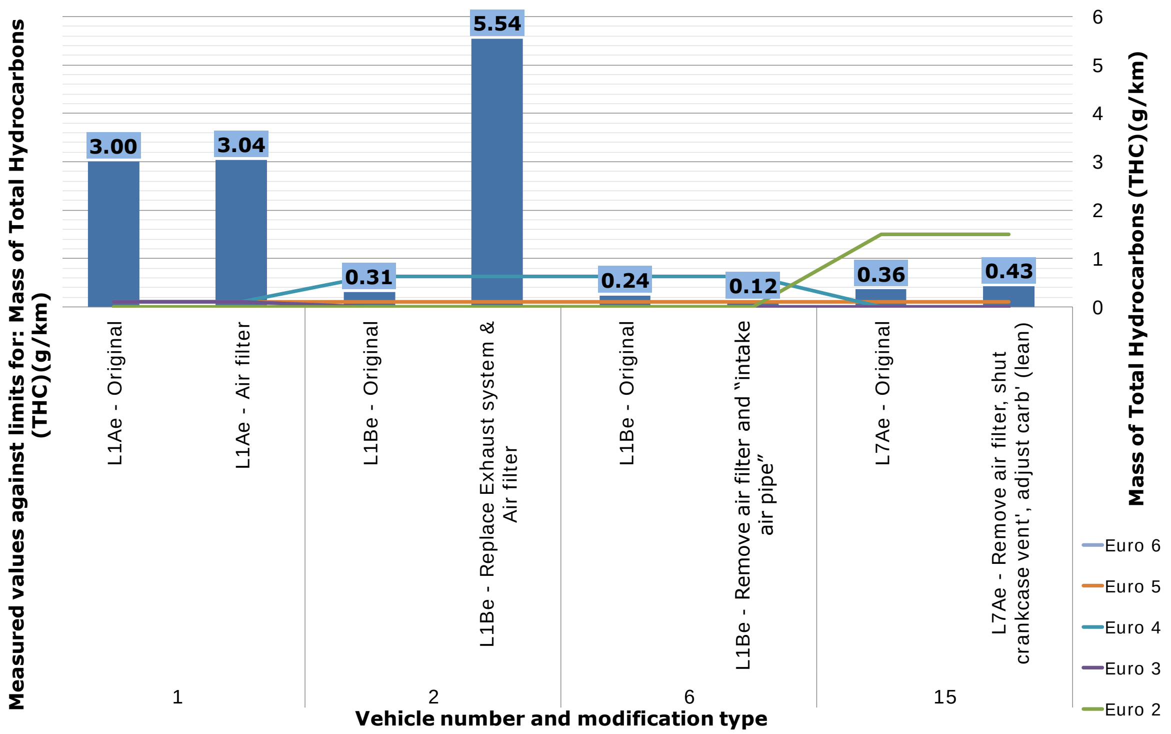


Figure 6-38: Air intake modification: THC [g/km]

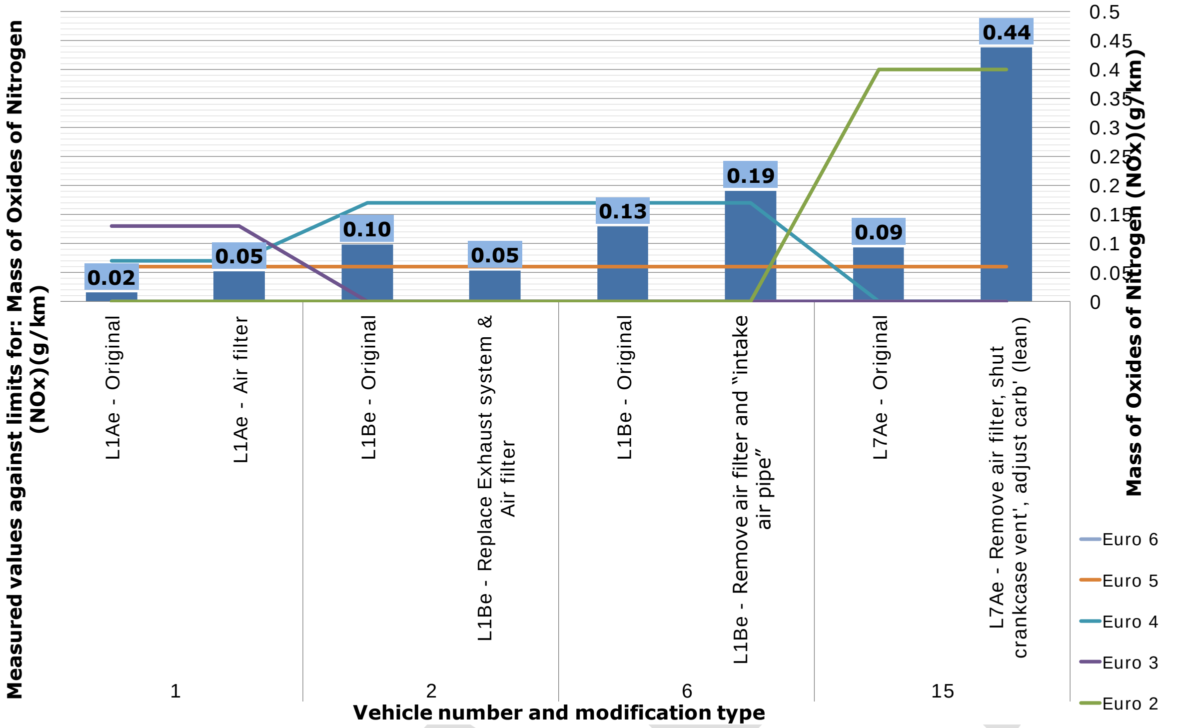


Figure 6-39: Air intake modification: NOx [g/km]

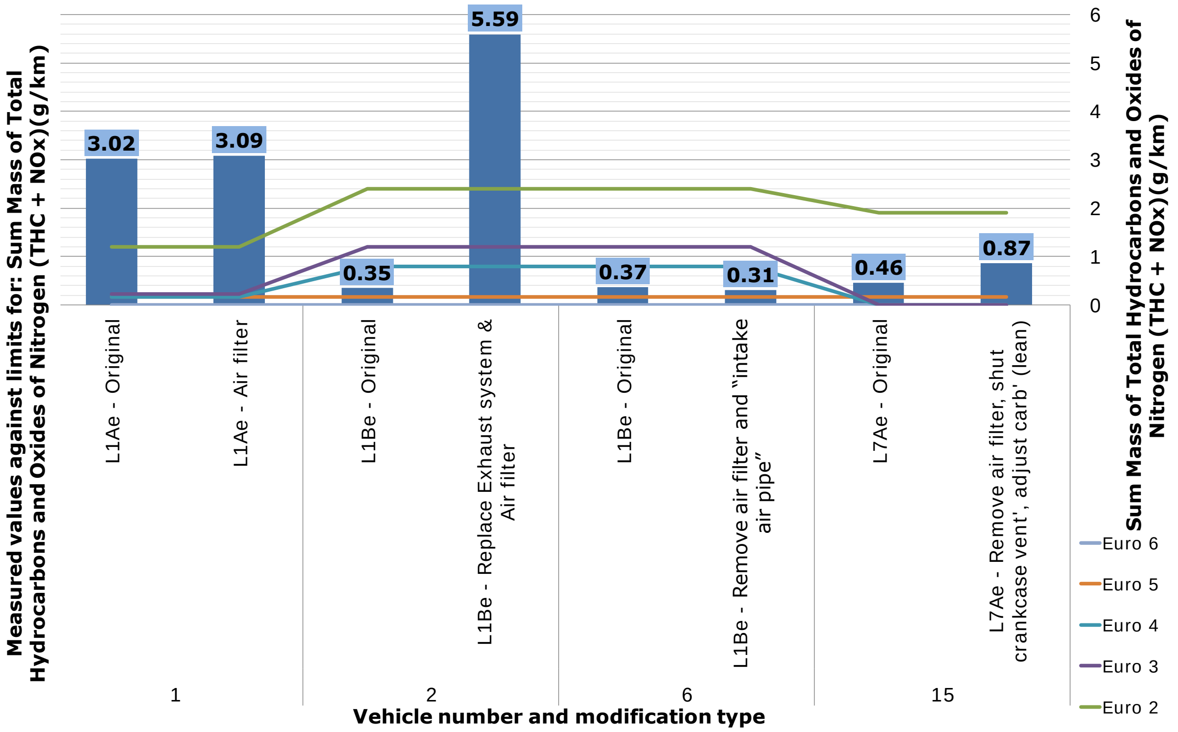


Figure 6-40: Air intake modification: Sum of THC and NOx [g/km]

The CO emissions from vehicle 1 decreased by 20% and CO emissions both before and after tampering were significantly in excess of current limits. At the same time, CO_2 emissions increased 46%. THC emissions stayed steady, rising from 3 to 3.04 g/km.

NOx emissions increased by 150%; however, this was an increase of only 0.03 g/km. For this vehicle, the sum of THC and NOx has a legislated limit of 1.2 g/km. Therefore, the modification increased the emissions from 251% to 257% of the limit. Overall, this modification caused an improvement in emissions.

The CO emissions from Vehicle 2 increased 333% from half the current limit to more than double the current limit. Emissions of CO_2 decreased 50% and so the sum of these emissions dropped by 53%. The vehicle's THC increased nearly 17 times. The NOx emissions reduced by 50% and the sum of the two increased about 15 times, going from 14% to 233% of the legislated limit. Overall, this modification had a significantly negative effect on emissions.

CO emissions from vehicle 6 reduced by 78%, equating to a change from 462% of Euro 2 limits to 100% of Euro 2 limits. CO_2 increased 8% and overall this gave a reduction to 98% of the limit for the sum of the two emissions. THC reduced by 50% while NOx increased to 46%. The sum of the two emissions dropped to 83% of the limit value. This equates to a drop from 15% to 12% of its Euro 2 limit. Emissions were found to comply with Euro 3 and 4 limits. Overall, this modification caused an improvement in emissions.

CO emissions from vehicle 15 increased by 18%, increasing from 229% to 271% of the current Euro 2 limits. Emitted CO_2 increased by 61%.

THC also increased by 19%, equating to an increase from 24% to 28% of the Euro 2 limit. NOx emissions increased by 388%, from 0.09 to 0.44 g/km, therefore just exceeding the Euro 2 limit of 0.4 g/km. Overall this modification had a negative effect on the emissions.

6.3 Exhaust

The exhaust can be modified or replaced for a range of reasons:

- To reduce air resistance allowing the exhaust gasses to flow from the engine more easily allowing fresh intake air to flow into the cylinder more easily (improving the volumetric efficiency), thus increasing the vehicle's power
- To change the back pressure characteristics - 2 stroke engines rely on a reflective wave of energy during each cycle to prevent the fresh air-fuel mixture from escaping the cylinder before the exhaust port is closed. This can be adjusted to increase the vehicle's power. However, as ignition timing is crucial it may be that owing to changed backpressure the air-fuel mixture is already evacuated from the cylinder before being ignited, hence, resulting in a power loss.
- To change or reduce the noise suppression capabilities
- Due to the high temperatures combined with water vapour in the exhaust gases, exhausts are likely to suffer from corrosion and may require replacement in order to retain the vehicle's original characteristics

The first three of these can be achieved through a range of modifications:

- Change of the effective length of the exhaust by shortening internal sections
- Remove the disrupter or 'stubber pipe', a short length of pipe sealed at one end and fixed to the exhaust which generates back pressure

- Remove the restriction orifice, a disk fitted inside exhausts to restrict the vehicle's power
- Remove the baffle material from the silencer
- Bypass the silencer
- Bypass the catalytic converter
- Remove the catalytic converter
- Replace the exhaust system with a non-road legal 'race' exhaust with for power optimised low backpressure characteristics.

Several tampering modes were attempted with the intention of reducing the restrictions on the flow of exhaust gasses into the atmosphere. These were as follows:

Table 6-7: Exhaust modification: Vehicles and modification

Vehicle	Category	Modification	Cumulative modification
2	L1Be ≤25 km/h	Replace Exhaust system & Air filter	Yes
		Remove Exhaust orifice	
		Remove CVT speed limiter	
12	L3e-A3	Replace Exhaust (throttle cat bypass)	No

Two exhaust modifications were performed one on a ≤25 km/h L1Be moped and the other on an L3e motorcycle. The L1Be had three cumulative modifications performed on it: one to replace the exhaust (the aftermarket model having easily removable restrictions), a second where the replacement exhaust had a flow restricting orifice removed, and a third non-exhaust related modification where the transmission has a vehicle speed limiter removed, this third modification will be looked at further in section 6.4 below. The L3e vehicle had a racing exhaust fitted; this bypassed the catalytic converter when the throttle was opened, preventing heat damage at high loads, but also increasing the gaseous and noise emissions.

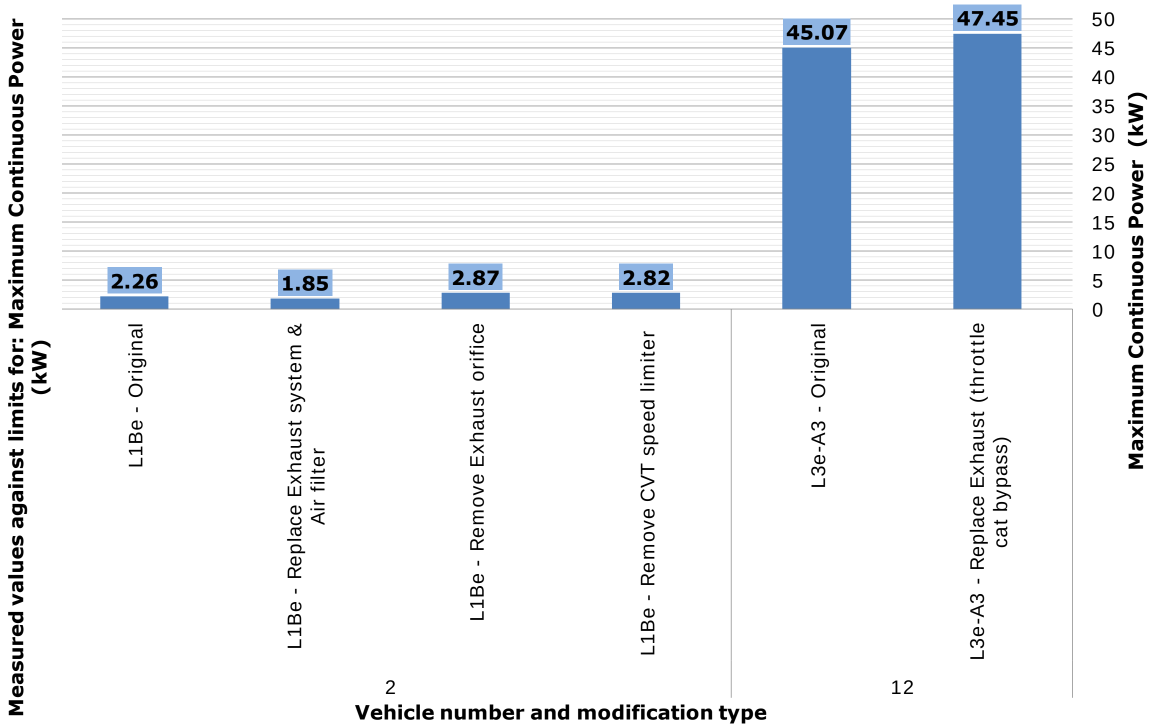


Figure 6-41: Exhaust modification: Maximum power [kW]

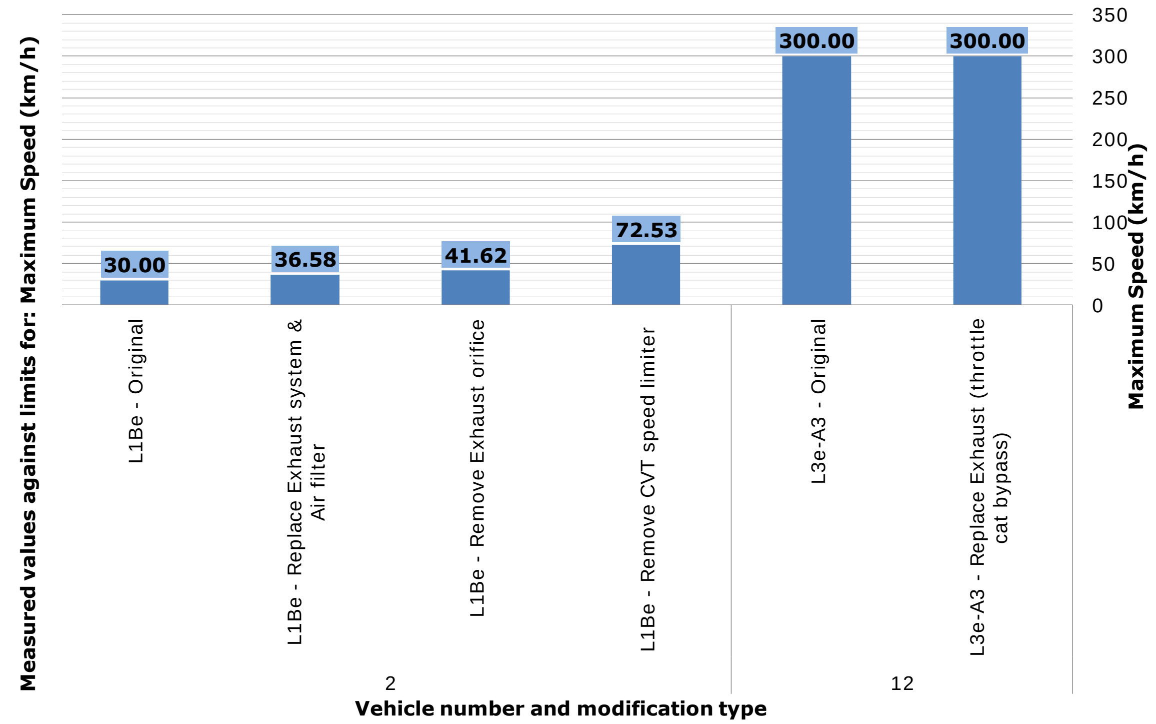


Figure 6-42: Exhaust modification: Maximum vehicle speed km/h

The modifications on vehicle 2 first decreased and then increased the maximum power at the wheel (down to 81%, then up to 126% of the original value). Both steps consecutively increased the maximum vehicle speed, first by 22% and then by a further

14%. This vehicle then had a third modification performed taking it to over 72 km/h; this will be examined further in the section below on combined modifications. Both vehicle speed steps would be likely to result in a penalty to the user.

The maximum power of vehicle 2 at the wheel increased only slightly by 5%. Considering that the power test is performed at full or wide-open throttle (WOT) the catalytic converter bypass will have been activated reducing the back pressure slightly, but as a non speed or power restricted vehicle, this was not a large change. The speed of this vehicle was substantially greater than the maximum speed limits and advisory speed limits used in the EU; therefore the data shown is the published maximum speed.

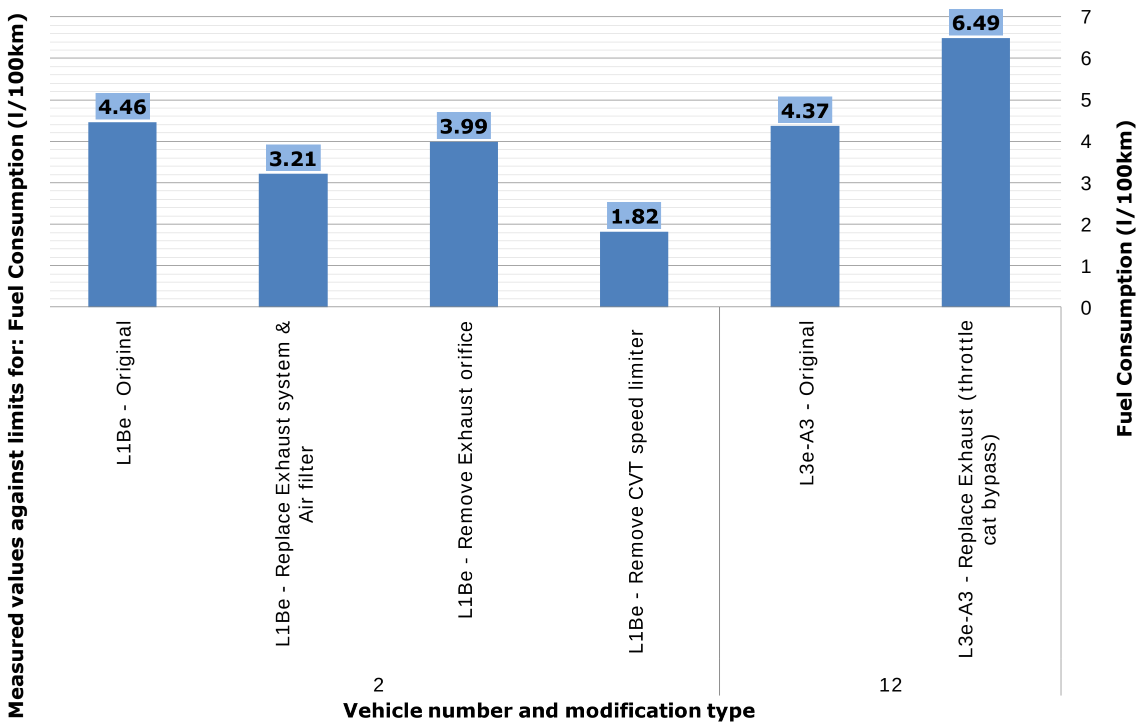


Figure 6-43: Exhaust modification: Fuel consumption l/100 km

For vehicle 2, the first two modifications reduced the fuel consumption to 71% and then 89% of the original result. The third modification reduced fuel consumption to 41% of the original value.

Vehicle 12 increased its fuel consumption by 48%, using 2 more litres per 100km travelled.

The differences in fuel consumption between the two modifications highlight a trait of the test cycle as much as the differences in vehicle performance. For vehicle 2, the improved performance means less energy is required to perform the cycle, but also in the first three states, vehicle 2 would struggle to meet the required speed profile (see Appendix L.1). As the performance is increased, the vehicle would struggle less and therefore perform less of the cycle at high load and full throttle, decreasing the fuel consumption. Vehicle 12 is able to follow the speed profile as required in both states (see Appendix L.2), therefore a truer indication of the change can be seen.

During the maximum vehicle wheel power test (see section 5.2.3) emissions were measured and therefore fuel consumption could be calculated. The data for the two vehicles is shown below in Figure 6-44. Due to the differing capabilities of the two vehicles, different speed steps are shown for each. Additionally, the third modification to vehicle 1 is also shown.

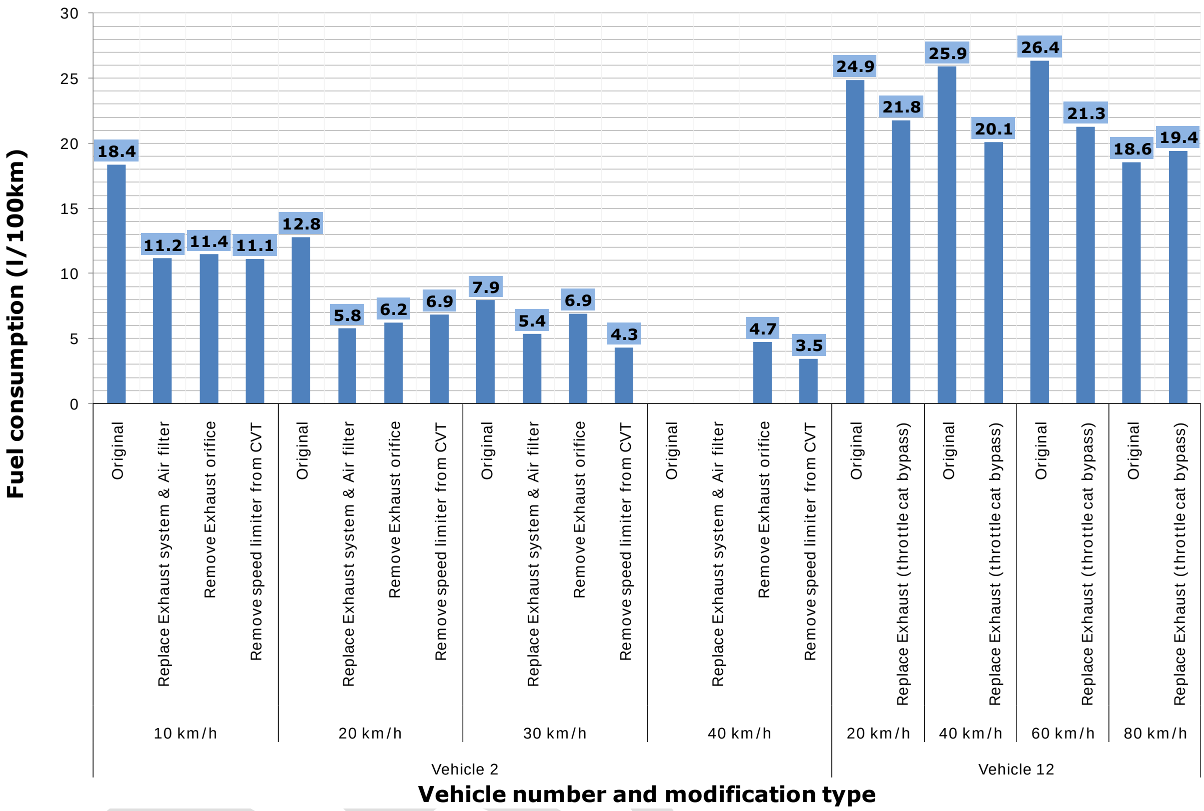


Figure 6-44: Exhaust modification: Fuel consumption during maximum vehicle wheel power test

For both vehicles the speed increase brings them closer to their most efficient engine speed and load and therefore their overall fuel consumption drops.

With vehicle 2, as the speed increases the difference between the pre and post modification fuel consumption reduces. The difference between the pre and average of the post modification states decreased from 7, to 6.5 and finally 2.5 l/100km. Overall, for both vehicles the reduction in back pressure reduced fuel consumption.

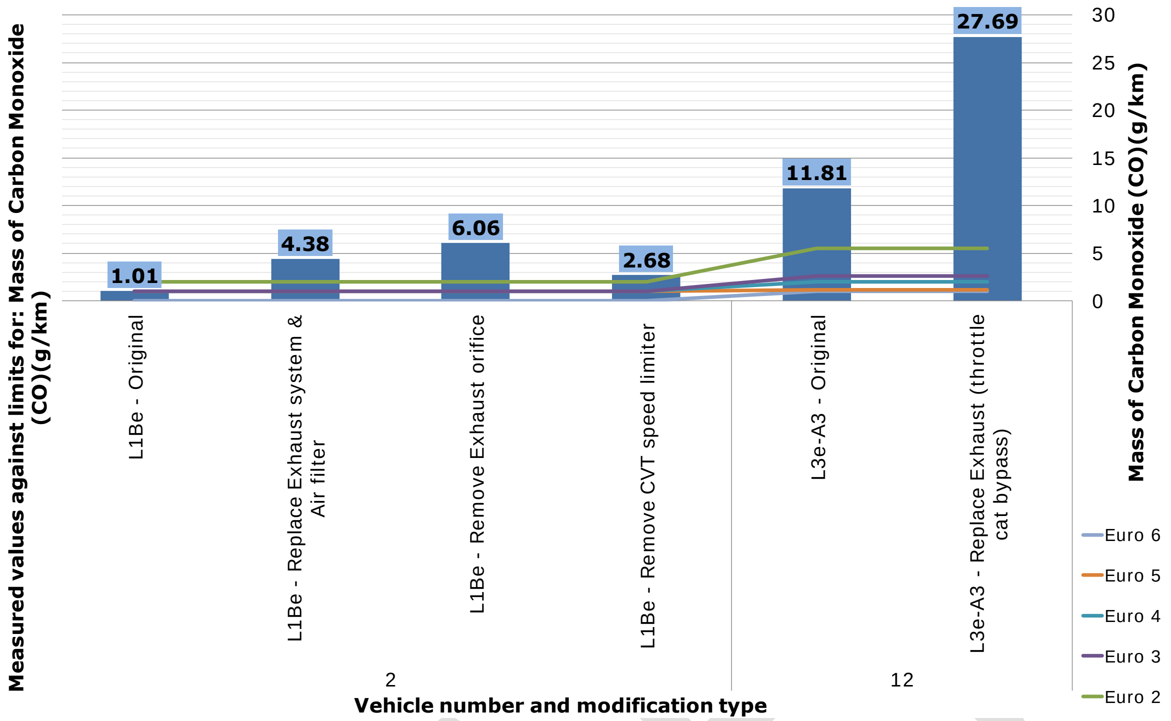


Figure 6-45: Exhaust modification: CO g/km

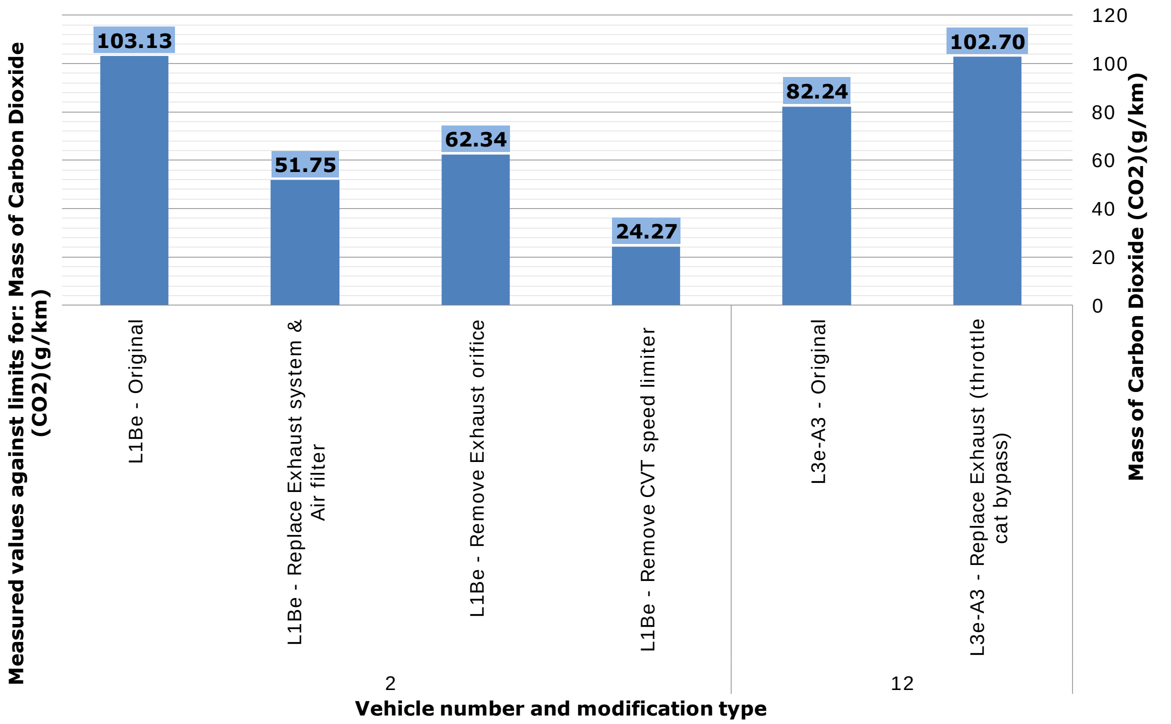


Figure 6-46: Exhaust modification: CO_2 g/km

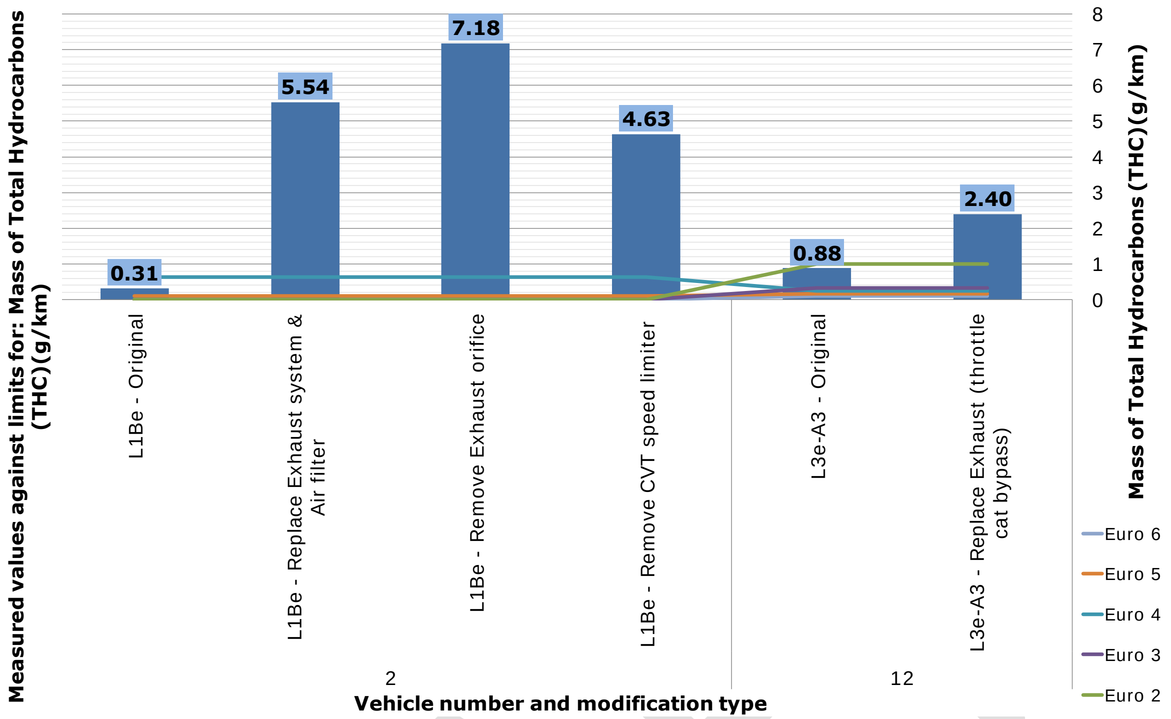


Figure 6-47: Exhaust modification: THC g/km

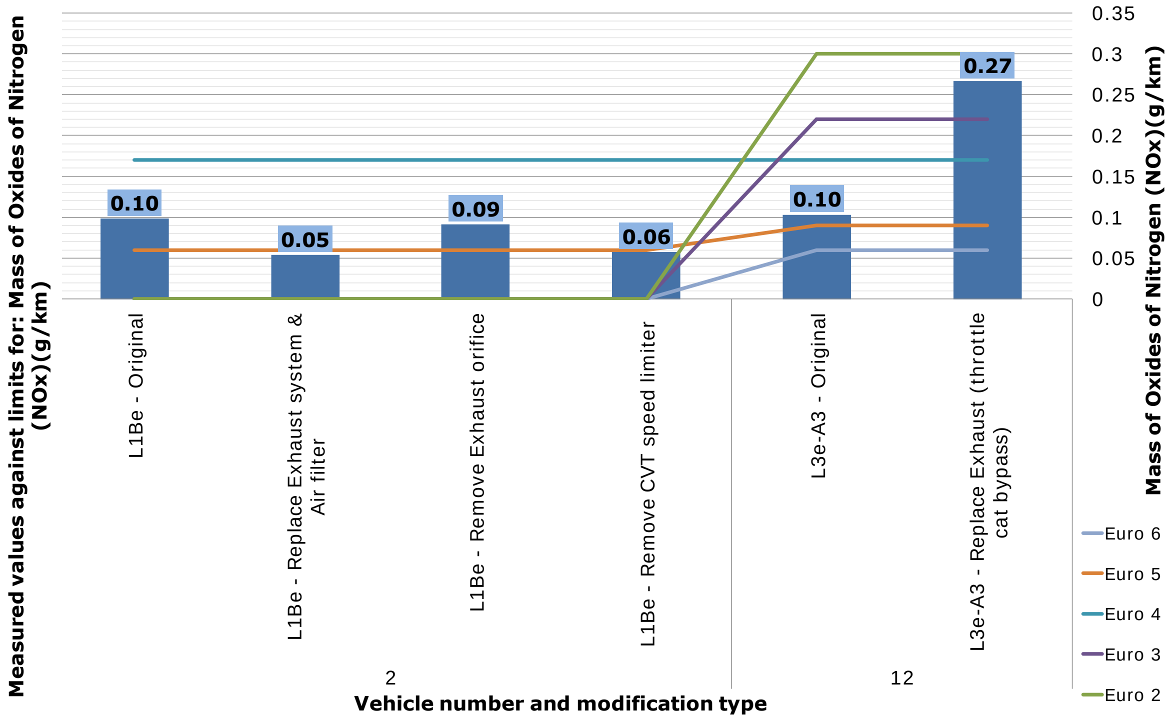


Figure 6-48: Exhaust modification: NOx g/km

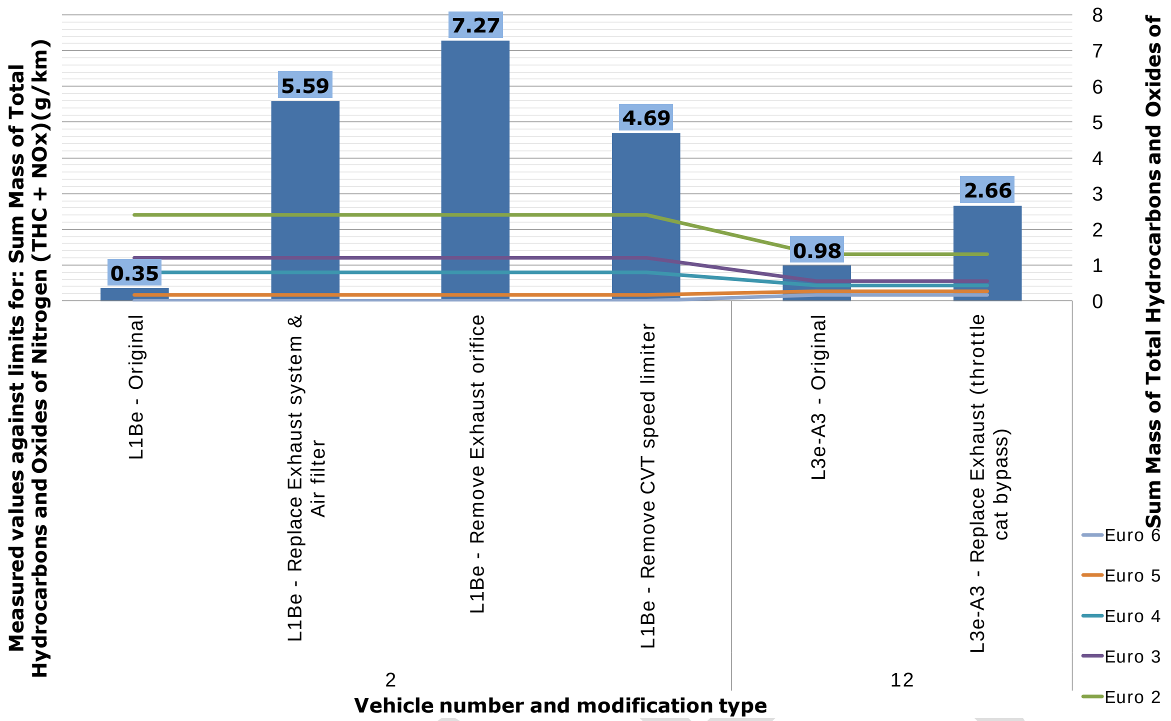


Figure 6-49: Exhaust modification: THC + NOx g/km

The CO emissions of vehicle 2 were at 50% of the Euro 2 limits in the original configuration. The first modification took this to 218% of the limit, or an increase of 334% compared to the original value. The second modification increased the emissions a further 38%, while the third reduced the level by 56% from the second modification step. This drop is likely to be due to the same effects mentioned above about fuel consumption, but the values noted here are still very high. Compared to the untampered test result, the result on CO_2 emissions of the three modification steps was a decrease by 50%, then 60%, and finally 24%.

The THC emissions increased considerably, first by 1,801%, then 2,336%, and finally to 1,506% of the original, untampered value. NOx emissions, on the other hand, reduced to 55%, then 92%, and finally 58% of the initial value. Considering the sum of THC and NOx emissions, the values equated to an increase to 1,602%, then 2,084%, and finally 1344% of the original result. The emissions against the current Euro 2 limits, increased from the original value of 14%, jumping to 233%, then 303%, and finally 195% of the limit value.

The drop in CO_2 was partially due to the reduction in fuel consumption and partially because more of the fuel was being either incompletely burnt or not burnt at all, exiting the exhaust as CO or THC respectively.

The emissions of vehicle 12 all increased; CO by 134% of the (exceeding the Euro 3 limit by more than 10 times), THC by 173% (exceeding its Euro 3 limit by approximately 7 times), and NOx by 159% (exceeding its Euro 3 limit by 21%). CO_2 emissions also increased by 25%; therefore, the increase in CO is not entirely due to a reduction in the proportion of incompletely burnt fuel.

Initial THC and CO emissions also exceeded the Euro 3 limits, by 351% and 166% respectively. With all other parts of the vehicle being unchanged from the original configuration, this can be assumed to be related to fuelling perturbations far outside the acceptable window (0 - +2% of stoichiometry) for an efficient catalytic reaction. Even a fresh non-aged catalyst with maximum efficiency is not able to cope with poor fuelling.

6.4 Transmission

6.4.1 CVT

Constantly variable transmission (CVT), Variomatic or Vario is a type of automatic gearbox based on two sets of two cones (each set makes up one variable width pulley) and a belt. Increasing the distance between one set of cones and decreasing it for the other allows the belt to move down into the groove of one and be pushed out of the other (see Figure 6-50), this effectively changes the ratio between the two sets of cones and consequently changes the rotational speed and torque.

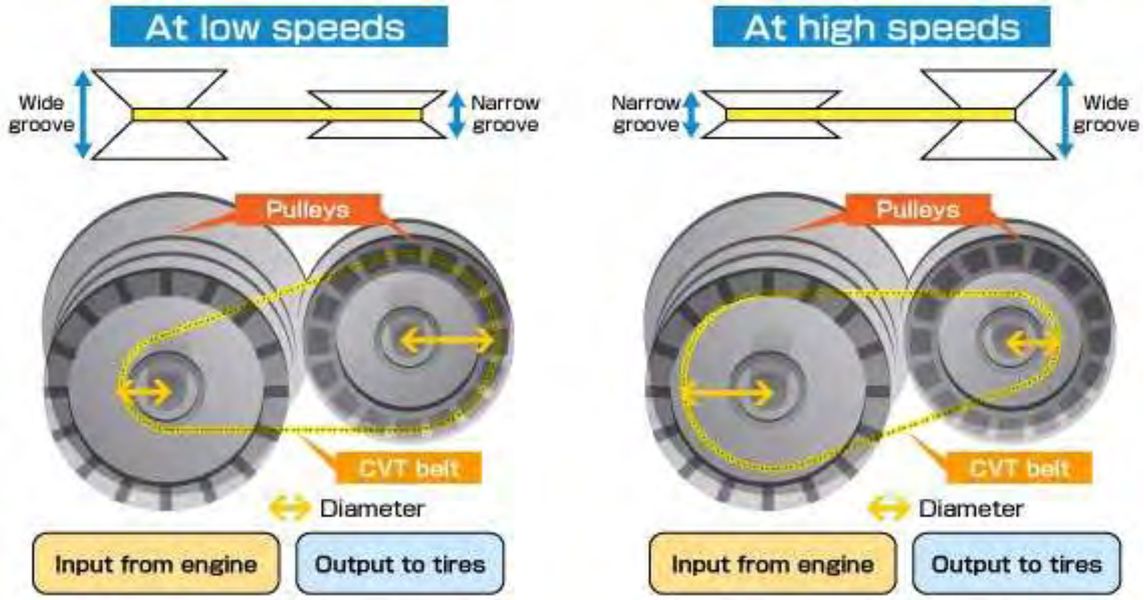


Figure 6-50: CVT basic concept[14]

Combined within the same assembly are an automatic gearshift system and an automatic clutch. The gear changing system is based on a number of rollers or masses which use centrifugal force to push the cones together as the engine vehicle speed increases (see left of Figure 6-51), this force is counteracted with a spring pushing the cones together in the other pulley.

[14] URL: http://freeze4you.blogspot.com/2010/10/cvt.html

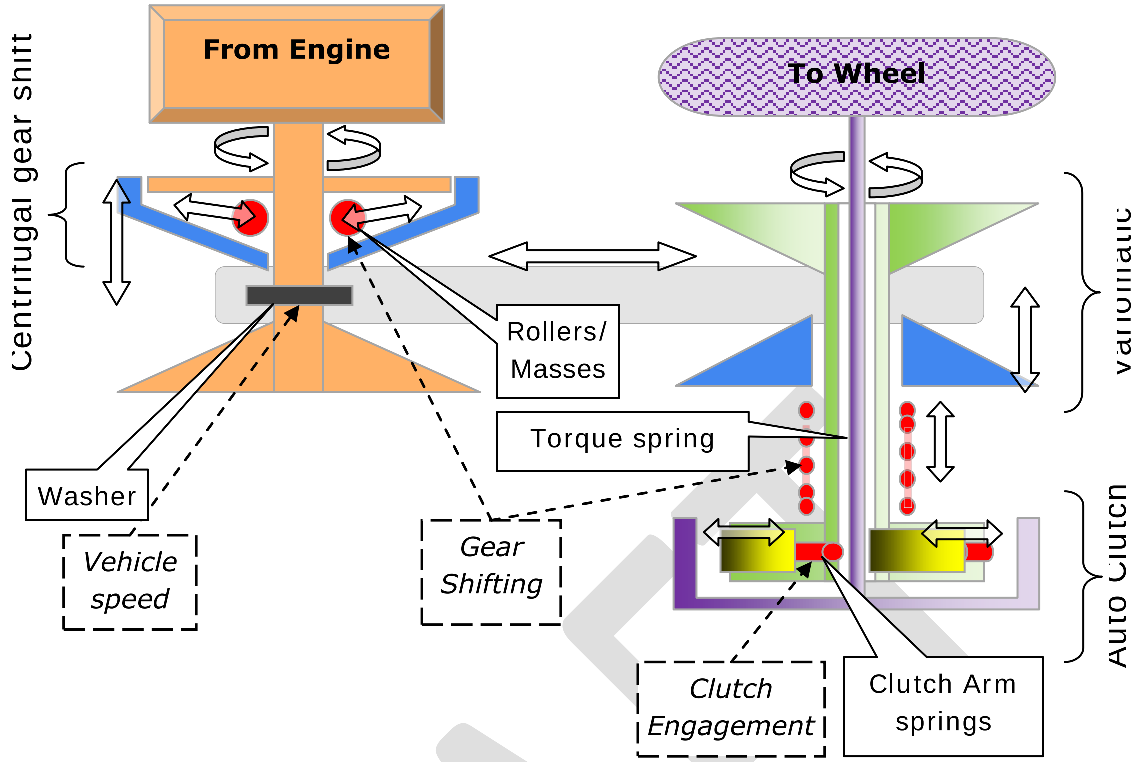


Figure 6-51: Top view cut-out of a CVT, with parts which effect performance and characteristics highlighted[15]

Either the masses, spring or both can be changed to modify the power to engine vehicle speed curve. By itself the adjustment of the ratio cannot increase the engine power, although it could affect the measurement at the wheel. Changing gear ratio does not affect the engine power but will affect the torque available at the wheel and thus the acceleration potential. It may also affect the maximum vehicle speed depending on the exact characteristics. Changing the masses can affect the vehicle speed, but this is limited by the maximum ratio of the transmission or vehicle speed limiter. The following quote from a quadricycle aftermarket parts supplier explains the outcomes:

"- Lighter roller weights …	*will give more torque at the cost of some maximum vehicle speed.*
"- Heavier roller weights …	*will allow higher maximum vehicle speed at the expense of torque -*
"- In the middle range …	*is a combination of the two."*[16]

What weights that these three groups correspond to depends on the engines' capabilities.

The automatic or centrifugal clutch has a set of springs which allow the engine to reach the required vehicle speed before transmitting power to the wheels. When the ratio is changed with heavier weights a higher RPM must be reached before engaging the wheel

[15] Diagram from TRL

[16] Buggy Parts NW. 2009. CVT System [online] [Accessed 7/12/2012]. Available from World Wide Web: <http://www.buggypartsnw.com/bpnw-info-center-introduction/6-cvt>

to prevent the engine from stalling. This is done by replacing the clutch arm springs with heavier ones.

Table 6-8: CVT modification: vehicles and modification

Vehicle	Category	Modification	Cumulative modification
2	L1Be ≤25 km/h	Remove exhaust orifice and air filter	Yes
		Remove CVT speed limiter	
4	L1Be ≤25 km/h	Remove CVT speed limiter	No
5	L1Be ≤25 km/h	CVT ratio, replace ECU, Carburettor nozzle size	Yes
7	L1Be ≤25 km/h	Change masses in CVT	No
		Change masses in CVT (Track)	No
8	L1Be ≤25 km/h	Change ratio of CVT	No
16	L6Be-P	Remove CVT speed limiter	No

Of the 6 vehicles which had their CVT modified, three had just the speed limiter removed (vehicle 1, 4 and 16). One (vehicle 7) had the rollers (or masses) of the centrifugal gear-shifting mechanism changed, and the final two (vehicle 3 and 5) had the gear change ratios changed with a combination of the masses, torque spring and/or clutch arm springs.

Where the masses or ratio was modified, the speed limiter was also removed, and it can be assumed that any increase to the maximum vehicle speed can be attributed to this.

Vehicle 2 had the CVT modification subsequent to modifications to the air intake and exhaust, so comparisons were made with the previous step rather than the original configuration. In addition, two sets of results are presented for some of the tests on vehicle 7, the second set were performed at the test track and are presented to show the differing performance which can be obtained after a modification of the CVT.

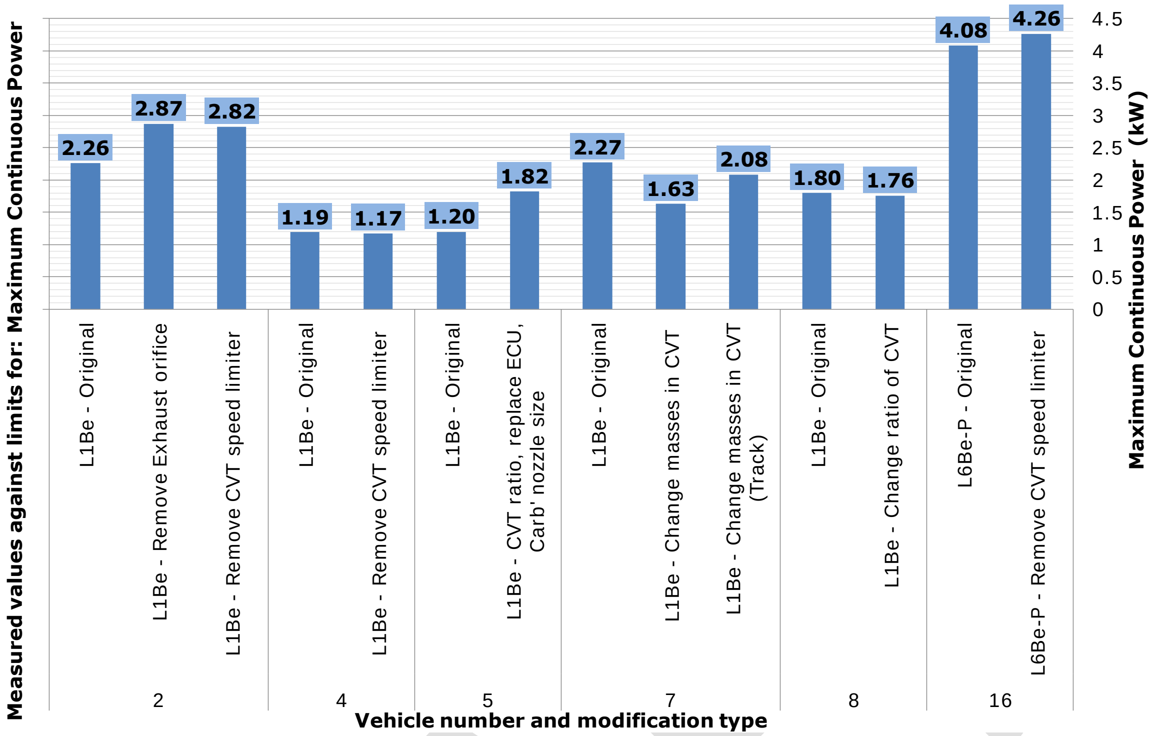


Figure 6-52: CVT modification: Maximum power [kW]

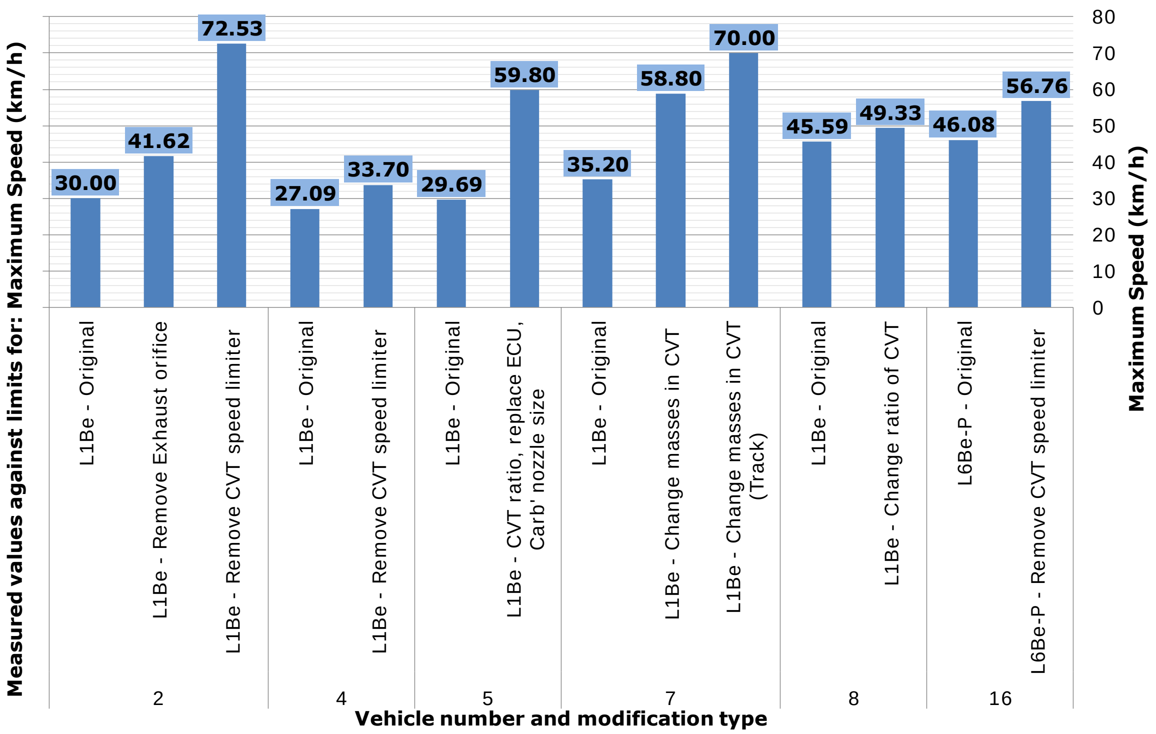


Figure 6-53: CVT modification: Maximum vehicle speed [km/h]

The effects of different modifications that can be performed on the CVT present in very different ways. Vehicle 2, 4 and 16 had their speed limiter removed and this had no effect on the power output of the vehicles. However, their vehicle speed was increased to 174%, 124% and 123% of the original value respectively.

Vehicle 5 had combined modifications on the CVT masses, ECU and Carburettor, increasing the power to 152% and speed to 201% (30 to 60 km/h) of the original values. Vehicle 8 had the CVT ratios modified; this had little or no effect on the power output, reducing it slightly to 98% of the original value, and increased the speed slightly to 108% of the original value.

Vehicle 7 had a reduction in power to 91% of the original value; however the speed increased 100%. Vehicle 8 showed small decreases in power and small increases in maximum speed. Vehicle 16 showed minor increases in both power and maximum speed.

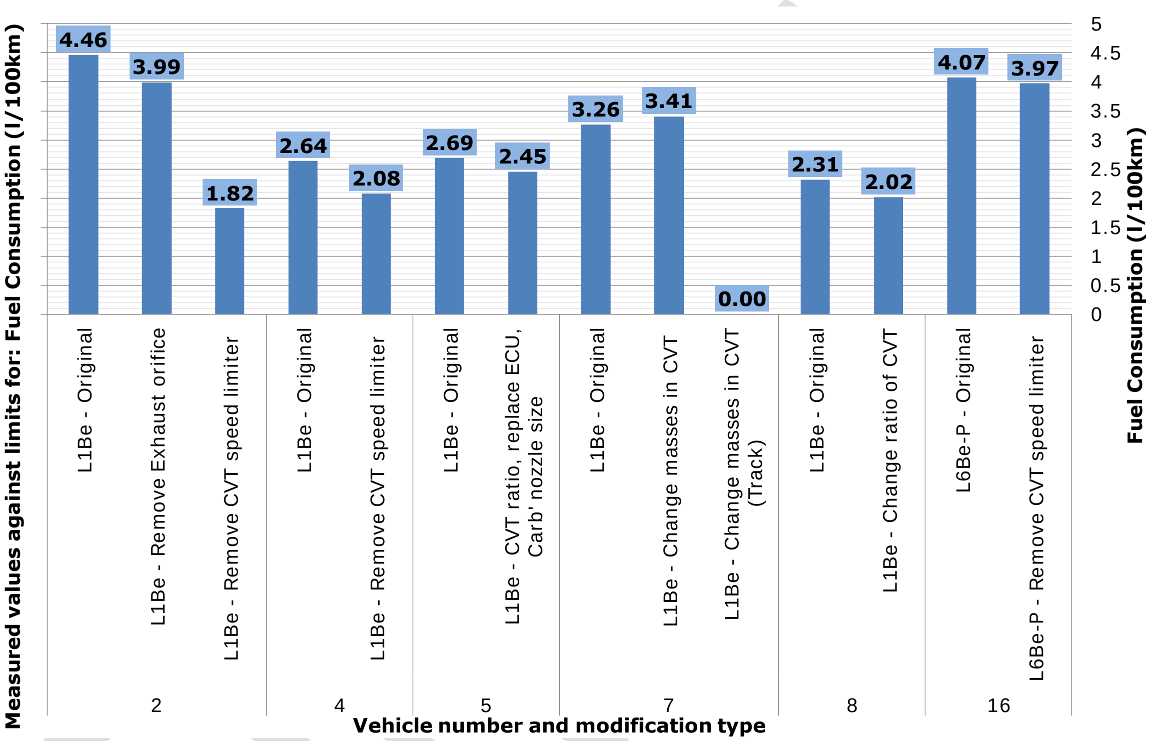


Figure 6-54: CVT modification: Fuel consumption [l/100km]

The preceding figure shows that fuel consumption of vehicles 4, 5, 8 and 16 reduced slightly by around 10%. The fuel consumption of vehicle 2 dropped to 46% from the original configuration (41% from the previous modification). The fuel consumption of vehicle 7 increased very slightly by 5%.

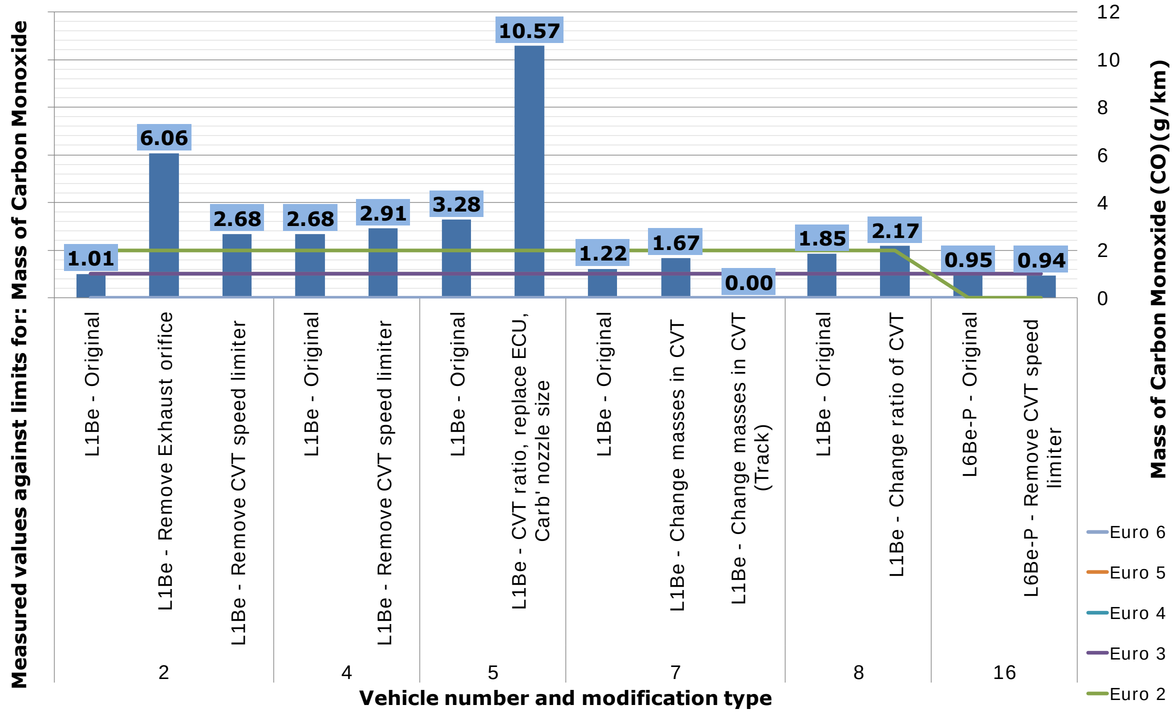


Figure 6-55: CVT modification: CO [g/km]

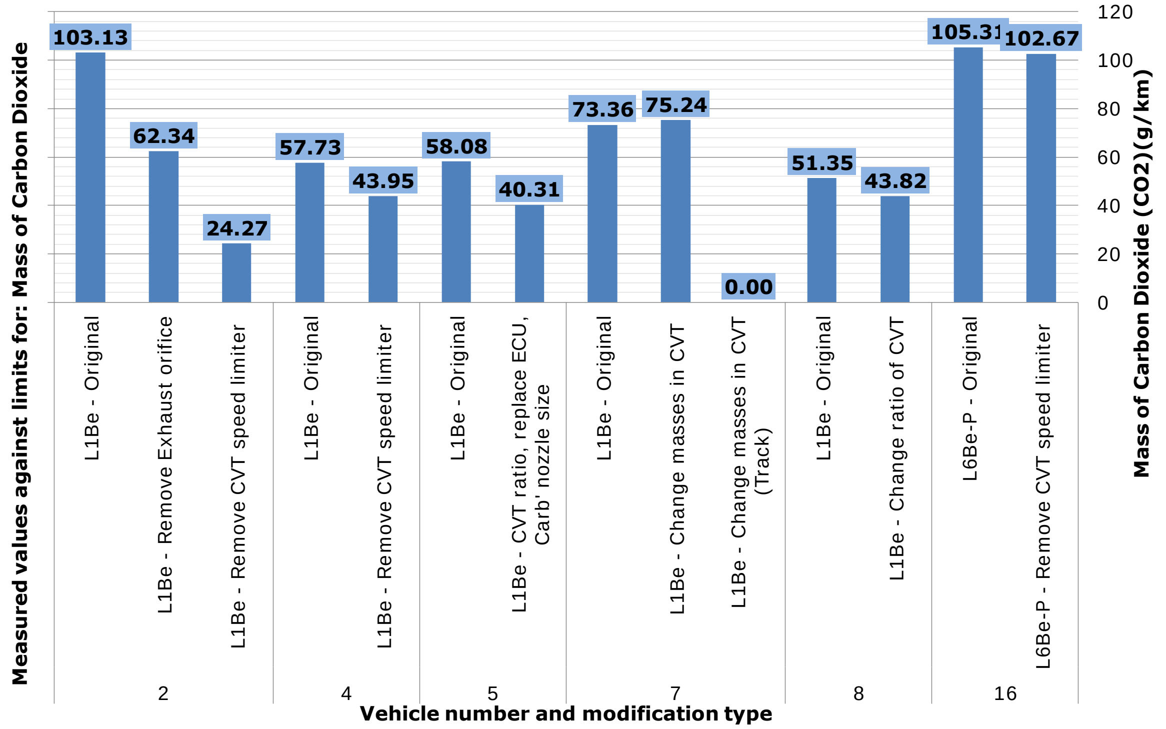


Figure 6-56: CVT modification: CO_2 g/km

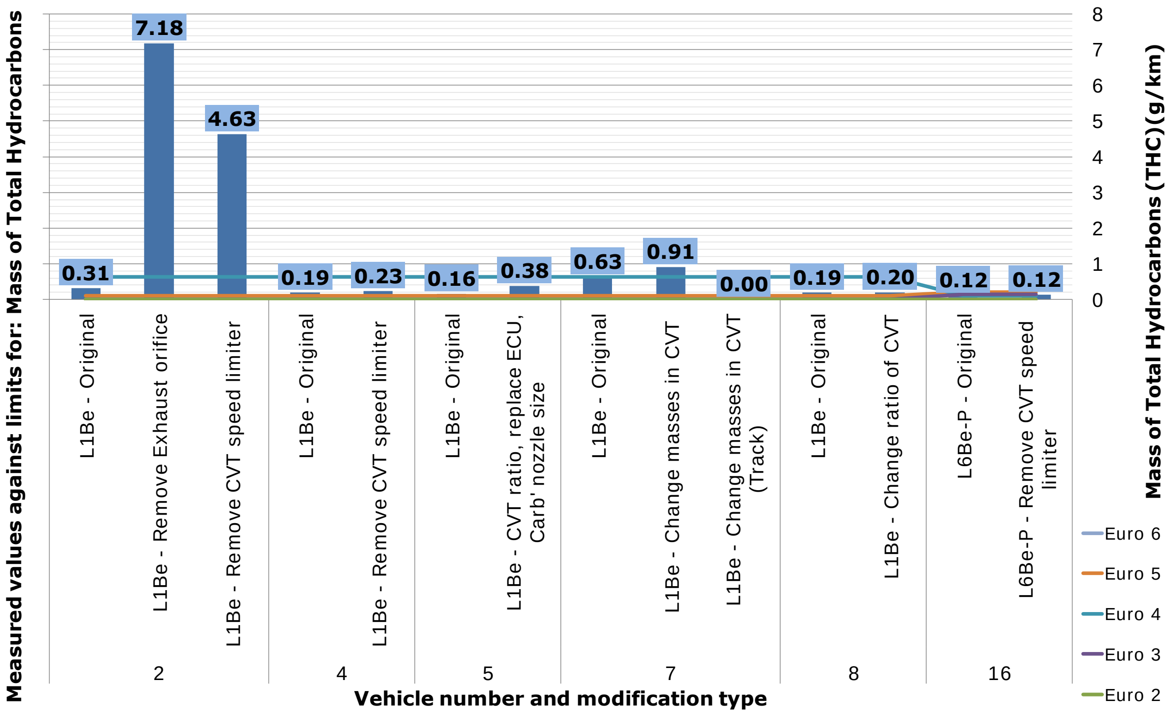


Figure 6-57: CVT modification: THC g/km

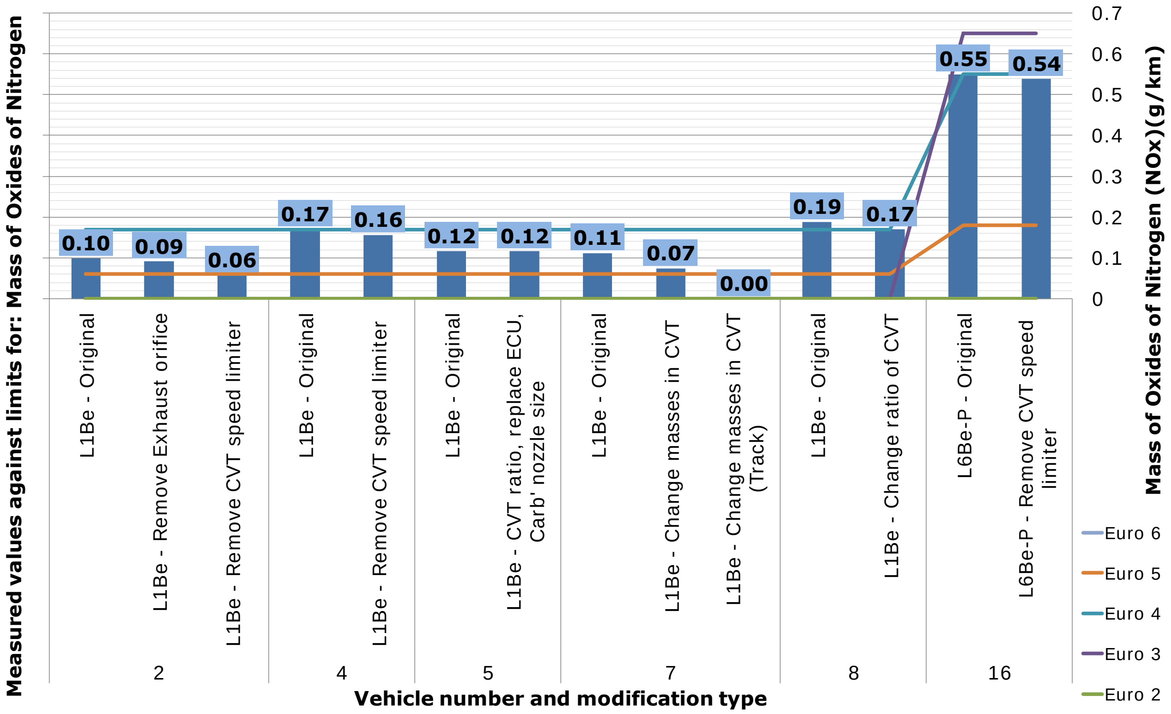


Figure 6-58: CVT modification: NOx g/km

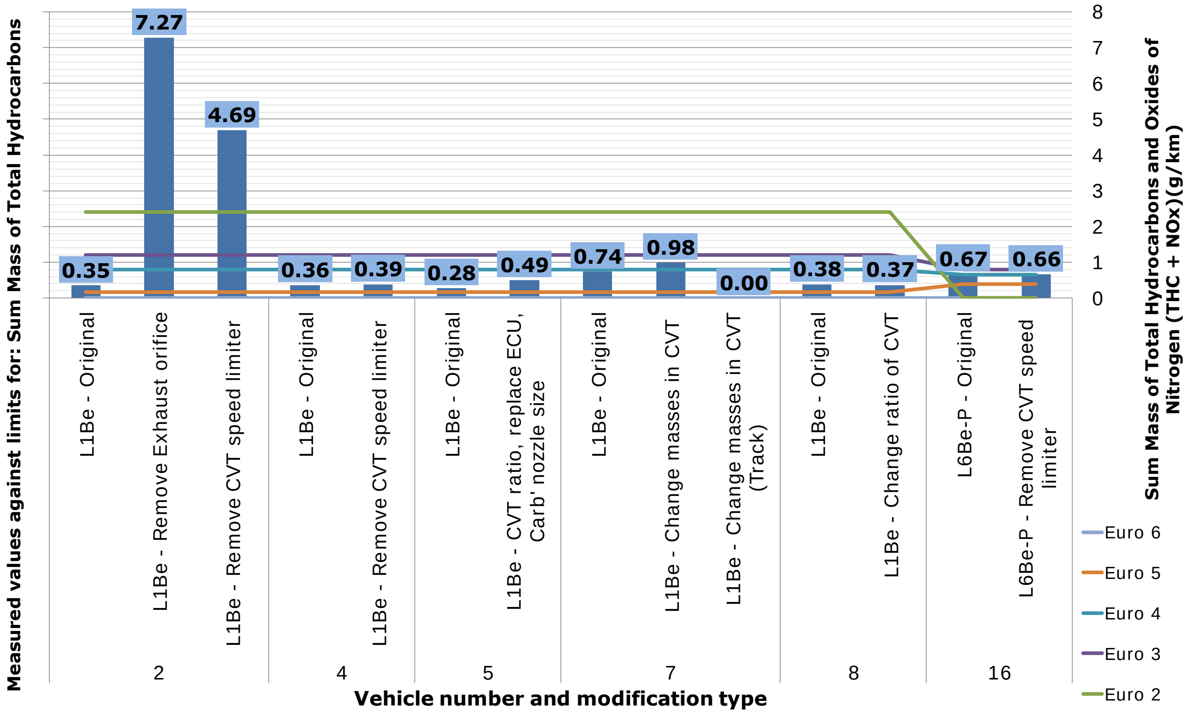


Figure 6-59: CVT modification: THC + NOx g/km

The emissions of CO and THC from Vehicle 2 both follow the same pattern, the emissions after modification of the air and exhaust systems increased significantly. After the removal of the speed limiter, these reduced, but to levels which were still 265% and 1,493% that of the original baseline settings. CO_2 and NOx emissions reduced from the original configuration in both cases. This step down in emissions after the removal of the vehicle speed limiter is a consequence of the emission cycle design as explained in section 6.3.

The CO and THC emissions of vehicle 4 increased by 8%, while its NOx and CO_2 both decreased slightly.

The CO emissions from vehicle 5 increased to 322% of the original value, THC to 236%, and NOx reduced slightly to 99.7% of the original value. By the change in emissions for this vehicle with the effect of this modification on the others, it can be shown that the additional modification performed on this vehicle is likely to be the primary cause and not the modification to the CVT.

Based on the data from the first set of emissions results from vehicle 7, the CO increased and NOx reduced slightly and the THC emissions increased to by 44%. The emissions from Vehicle 8 and 16 exhibited only marginal changes in emissions.

It can be seen that on their own, the modification to the CVT, be it a change to the ratio or removal of the speed limiter, does little or no change to the emissions. However, this tampering type raises the maximum vehicle speed to illegally high limits. When performed in conjunction with other modifications, it can more fully realise the potential effects created by the other modifications.

6.5 Engine

6.5.1 Crankcase ventilation

Several tampering modes were performed with the intention of changing blocking the flow of crankcase gasses into the air intake. These were as follows:

Table 6-9: Carburettor modification: Vehicles and modification

Vehicle	Category	Modification	Cumulative modification
5	L1Be (≤25 km/h)	Deactivate crankcase ventilation recirculation	no
15	L7Ae	Remove air filter, shut crankcase ventilation, adjust carburettor (lean)	no

It should be noted that for these modifications, the emission from the crank case were not measured and so perceived reductions in emissions and fuel consumption could be incorrect. Also, as stated previously, the fuel consumption is calculated from the emissions and so could be lower than the actual figure.

Crankcase ventilation channels gasses, which have built-up in the crankcase, to the air intake to be fed back into and burnt by the engine. This gas contains lubricating oil, fuel, air and exhaust gasses which have escaped past the piston rings.

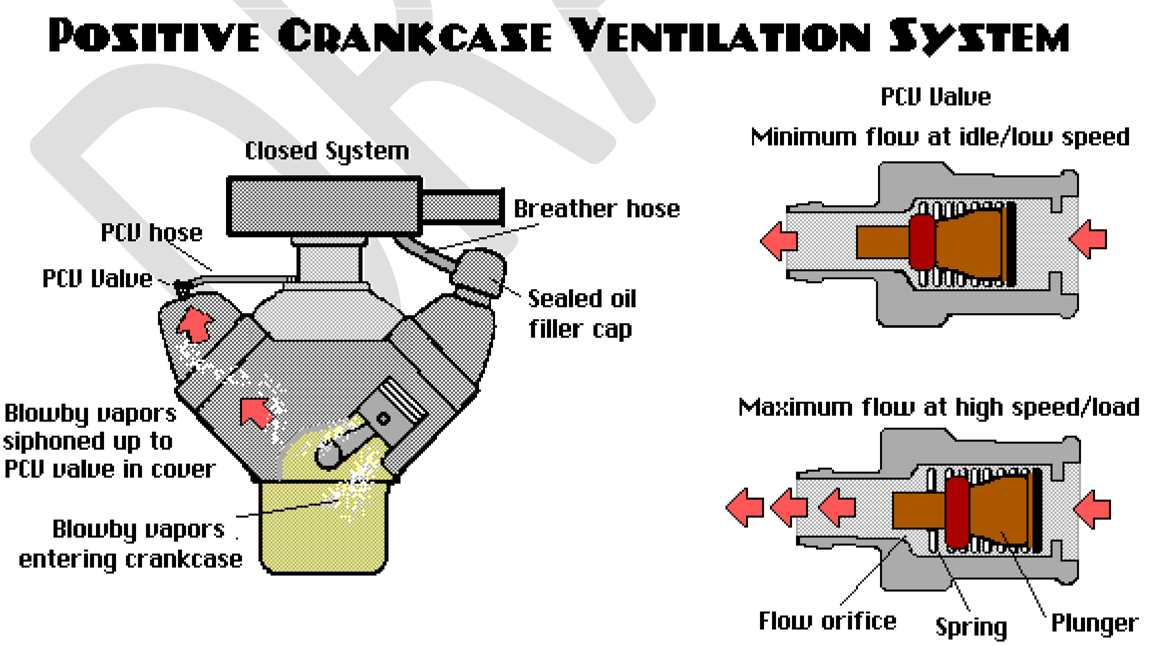


Figure 6-60: Crankcase ventilation system valve

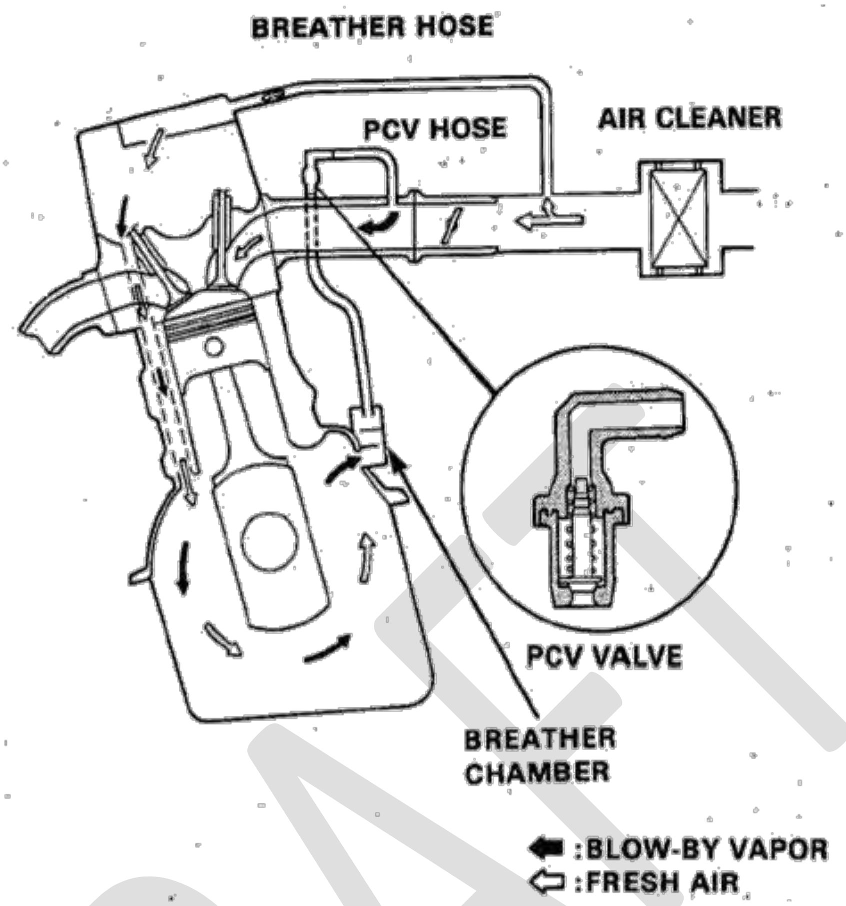


Figure 6-61: Crankcase ventilation system piping schematic for an average passenger car

Two possible modifications that could be performed in this area:

- Seal the ventilation so that the gasses cannot escape
- Disconnect the connection to the intake, thereby letting the gasses escape into the atmosphere

These modifications reduce performance in three ways: As these gases contain unused fuel if returned in the intake they can be used. If the crankcase is sealed there will be an increase of pressure on the underside of the piston resisting its movement. And if this pressure gets high enough the gasses will try to escape from the weakest point such as forcing past and damage gaskets. Therefore, performing either of these modifications will decrease the maximum vehicle speed and power and increase the fuel consumption. However, it could reduce the exhaust emissions in older types of vehicles but new ones with adaptive fuelling this change in terms of exhaust emissions is neutral.

It should be noted that performing the first of these modifications for an extended period will culminate in damage to the various seals and gaskets leading from the crankcase due to an increase in pressure with little route to escape.

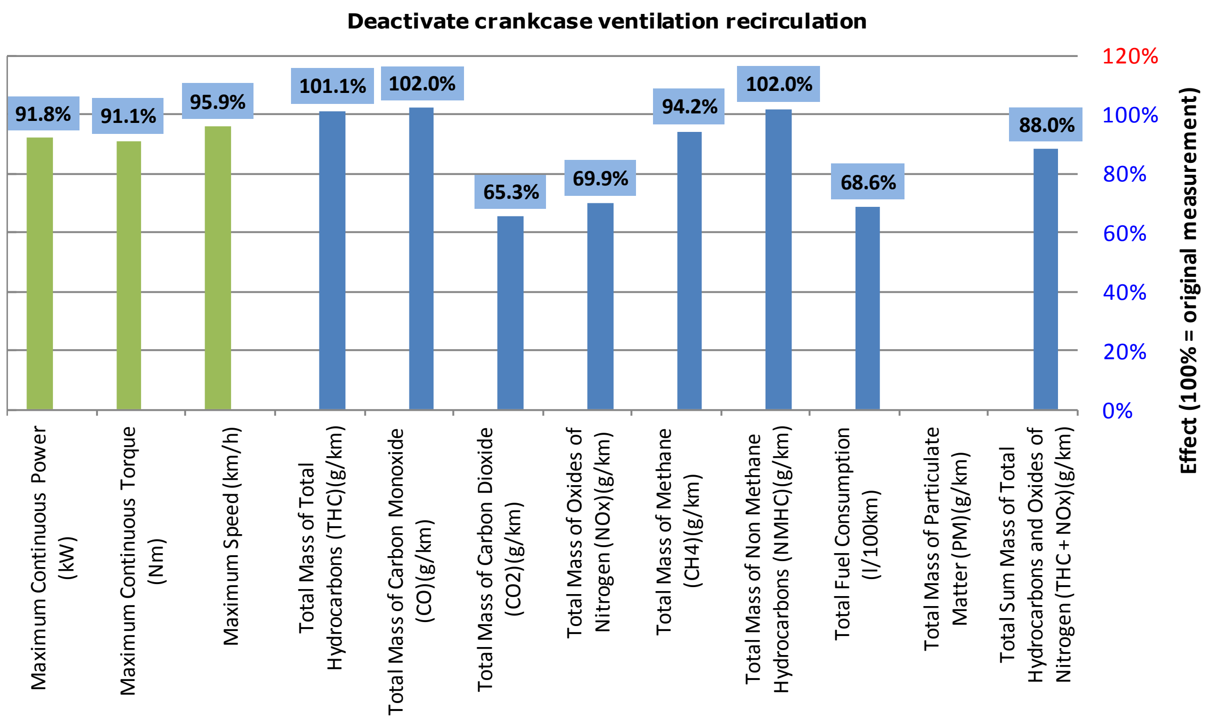


Figure 6-62: Crankcase ventilation modification: Vehicle 5

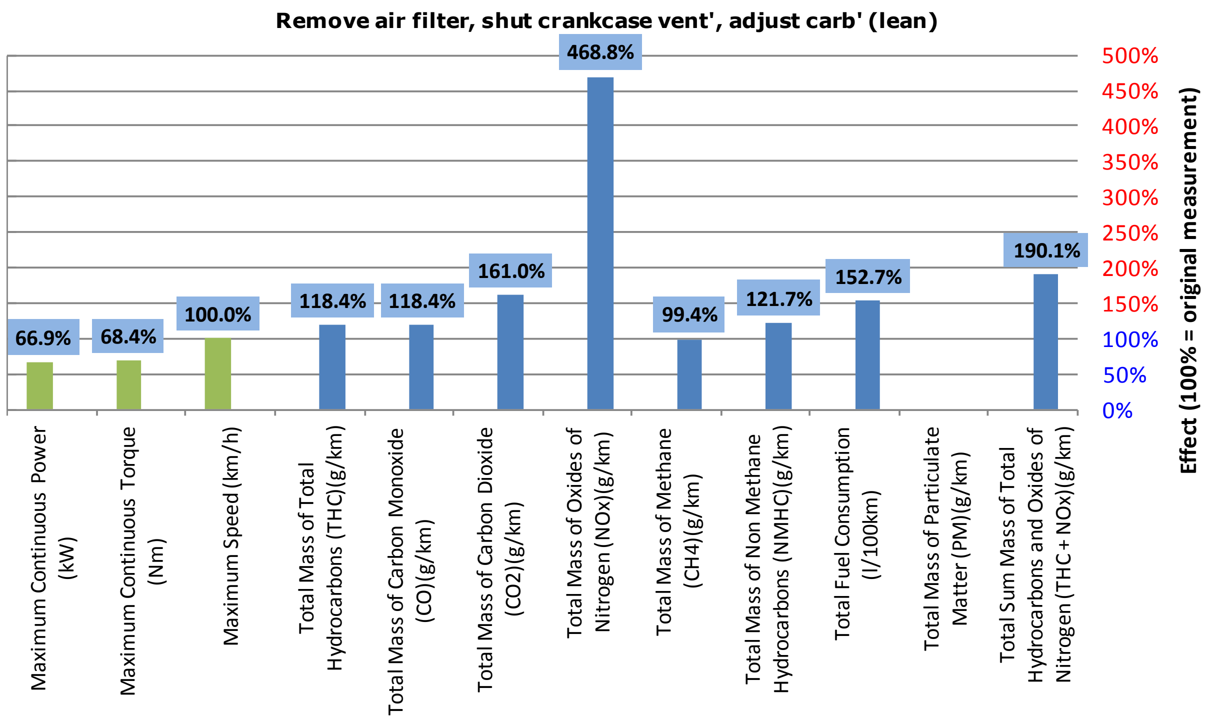


Figure 6-63: Crankcase ventilation modification: Vehicle 15

Note the maximum speed of vehicle 2 could not be measured because of safety concerns.

6.5.2 *Increase engine capacity modification*

A modification, which involves significant technical knowledge, is to change the overall engine capacity without replacing the engine. This is done to increase the power and speed capabilities of the vehicle. It can be done in a manner which allows the engine to keep its original appearance.

This can be done by:

- Change the compression ratio or squish
    - Replace the head gasket
    - Replacing the piston
    - Replace the connecting rod
- Re-bore the cylinder, increasing its diameter (a larger diameter piston will also be needed)
- Replace the cylinder and piston

This modification was performed on one vehicle:

Table 6-10: Increase engine capacity modification: Vehicle and modification

Vehicle	Category	Modification	Cumulative
1	L1Be (≤25 km/h)	Replaced piston and cylinder (50-80)[17]	No

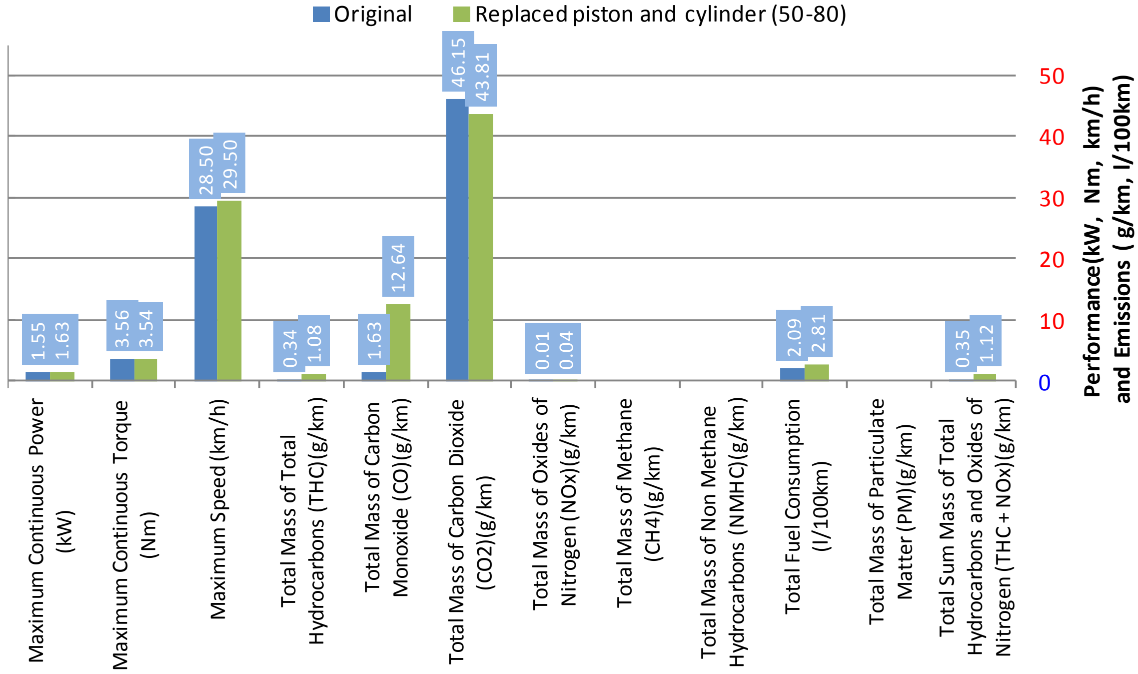


Figure 6-64: Increase engine capacity modification: Performance and Emissions

[17] Swept volume of the single cylinder engine, was changed from 50 cm^3 to 80 cm^3

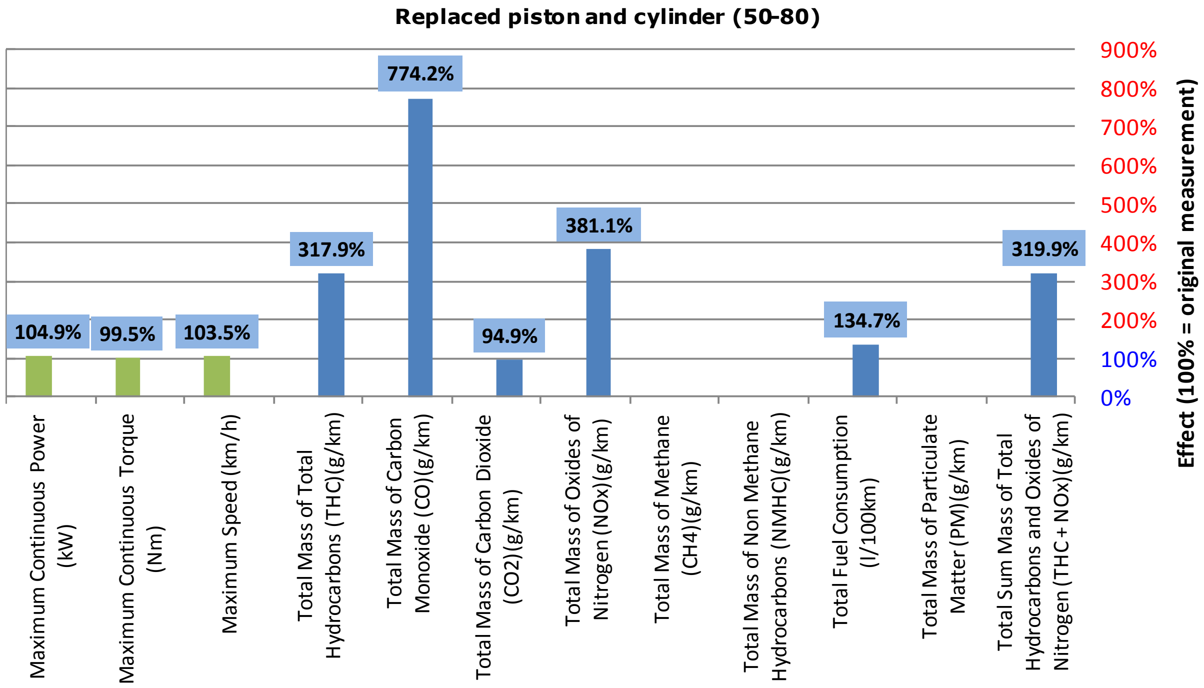


Figure 6-11: Increase engine capacity modification: Vehicle 1

This modification was performed on its own, therefore any additional vehicle speed produced is being limited by not removing the speed limiter from the CVT. Therefore, the effect on emissions can be observed without the change of driving cycle affecting them.

It can be seen that CO emissions show a large increase, increasing to 774% the initial value and exceeding both the Euro 2 and 1 limits by 532% and 110% respectively, see Table 6-12. The NOx also increased to 400% of the original value and the THC to 317%; this increase however did not exceed the Euro 1, 2 or 3 limits.

Table 6-12: Euro limits for an L1Be ≤25 km/h moped [18]

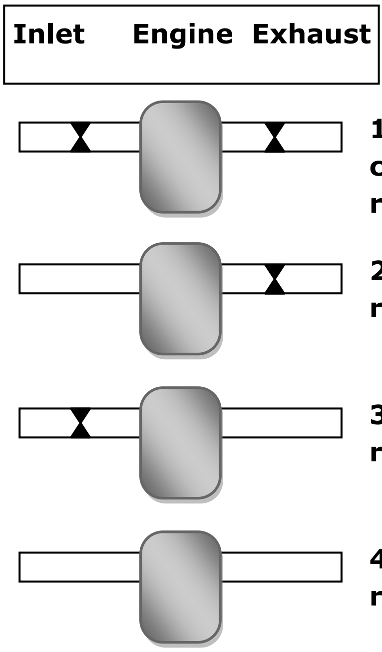
Euro level	Net Power (kW)	Engine displacement (cm^3)	Maximum Vehicle speed (km/h)	THC (g/km)	CO (g/km)	NOx (g/km)	NMHC (g/km)	THC + NOx (g/km)
1		$50cm^3$	25		6			3.0
2		$50cm^3$	25		2			2.4
3	4	$50cm^3$	25		1			1.2
4	4	$50cm^3$	25	0.63	1	0.17		0.8
5	4	$50cm^3$	25	0.10	1	0.06	0.068	0.16

By changing the engine so fundamentally, this modification is in effect creating a new engine with non-optimised intake airflow, fuelling and spark angle. Therefore considerable tuning is required to return the engine to an optimised configuration. This is feasible, but further modification or replacement of other systems both preceding and following the engine may be required.

6.6 Combined modifications

The performance of a vehicle, be it power, vehicle speed, fuel economy or emissions, is not all defined by one part, but rather by the interaction of all the parts in the powertrain. Therefore, when a vehicle is modified it makes engineering sense to adjust or modify other areas which will be affected by, or restrict, the intentions of the first modification. The following example shows what happens when the air flow is derestricted:

[18] Com(2010) 542 final, EC, 2010



1: Original configuration, with restricted orifices	Normal performance
2: Inlet orifice removed	Increased performance, more inlet air, but extra air on top of normal restricted outlet retards boost
3: Exhaust orifices removed	Increased performance, exhaust backpressure allows engine to run optimal for given airflow
4: Both orifices removed	Both flows opened combine to move limit to other vehicle parts. This may result in a better volumetric efficiency and more fresh air flow into the cylinder, but as the fuelling and spark angle are not optimised this change may lead to a power decrease rather than an anticipated increase.

Figure 6-65: Combined modification: Exhaust orifice example[19]

This takes the modification into a chain where one modification is only needed if another is performed. Once this is done, the limitation moves to another area which may be modified next depending on the funds and knowledge of the user. This is an example of a possible modification progression which focuses on increasing engine performance at the detriment of fuel consumption, emissions and engine durability:

1. CVT speed limiter removed, limit moves to exhaust back pressure:
2. Exhaust orifice plate remove, limit moves to air supply:
3. Air inlet orifice removed, power to engine speed relationship changes:
4. CVT ratio adjusted

The progression depends on the specific vehicle, such as which limiters it does or doesn't have. If it had automatic spark angle retard for instance increasing the fuel flow will just be wasted, so this would need to be modified in conjunction.

Getting good performance in all areas is a compromise and while the compromise can be shifted to favour one parameter over another, doing so without serious adverse consequences is very complex. Most modifiers either by limits to engineering knowledge or available money are not able to tailor their modifications in this way and so risk situations where they implement modifications that offer a modest improvement in their target parameter but at major cost to another parameter.

[19] Diagram from TRL

Five of the twenty vehicles under test had combined modifications performed on them, the following two were specific cases which follow the progression that a vehicle tuner is likely to do to a specific vehicle.

Vehicle 1 shows the likely progression of simple and inexpensive modifications performed to a 2 stroke 50cm3 L1Be vehicle after the initial replacement the exhaust, including removing the restriction orifice from the exhaust, replacing the air filter and removing the speed limiter from the CVT.

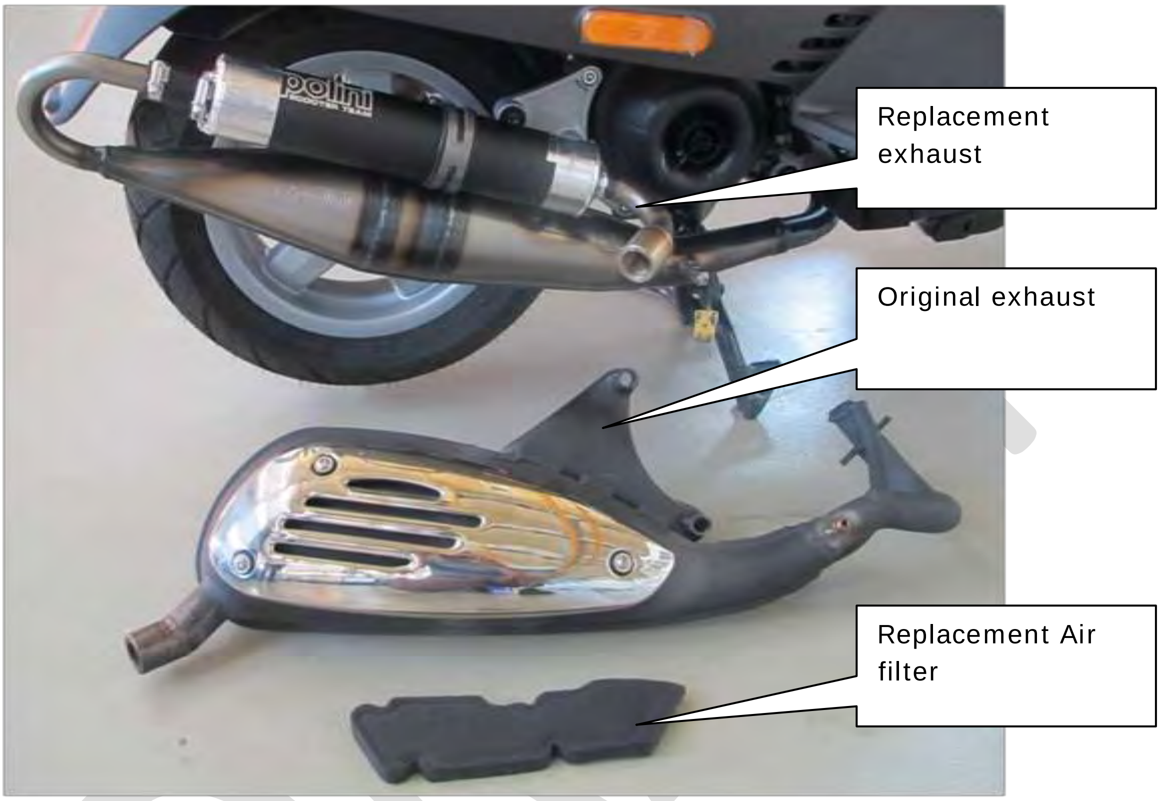


Figure 6-66: Combined modification: Exhaust and air filter[20]

The cost of the replacement exhaust was €172 and the air filter €5, additionally the original exhaust can currently be sold for €84; an approximate net cost of €93. It should be noted that these are the prices direct from the supplier and only a basic internet search for prices of second-hand goods. A more thorough search of the market could potentially reduce the overall cost even further.

[20] Photo from JRC

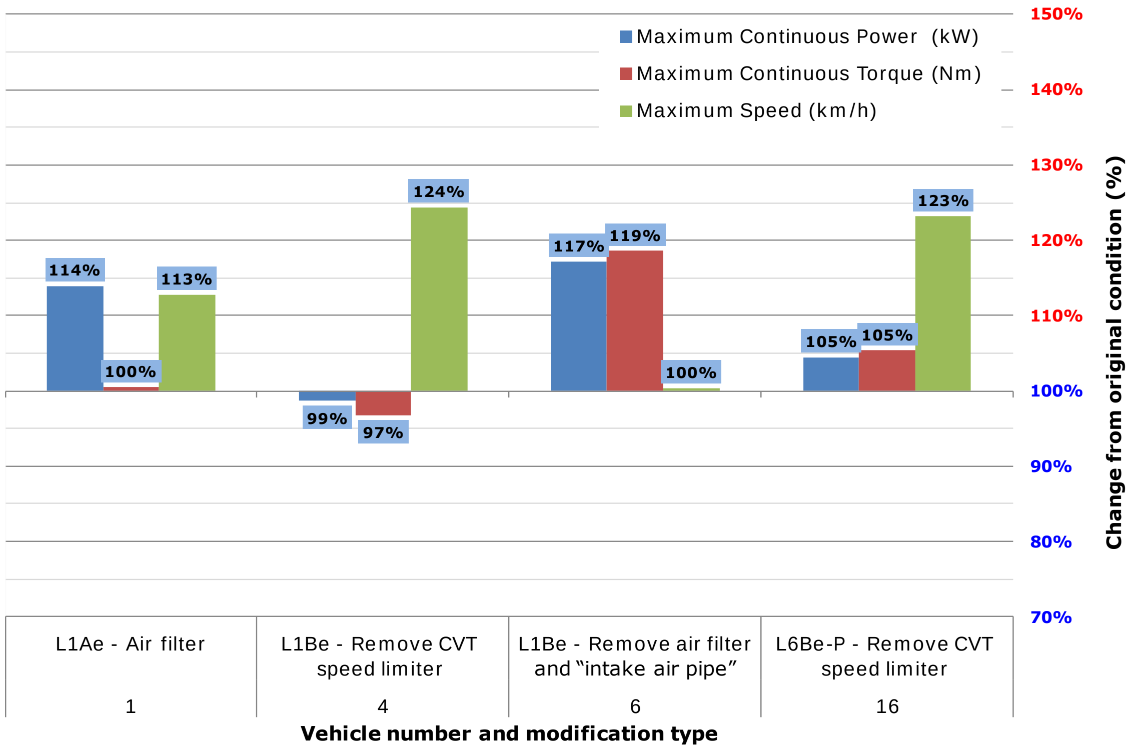


Figure 6-67: Individual modifications

When performed individually the modification of the air inlet (see section 6.1) and the CVT speed limiter (see section 6.4.1 above) have been shown to change the performance within a certain range. As can be seen in Figure 6-67, de-restricting the inlet of air, either by removing the air filter or the entire inlet assembly can increase power by 14-17% and increase vehicle speed by 0-13%. Removing the speed limiter in the CVT can change the power output by -1-5% and increase the maximum vehicle speed by 23-24%.

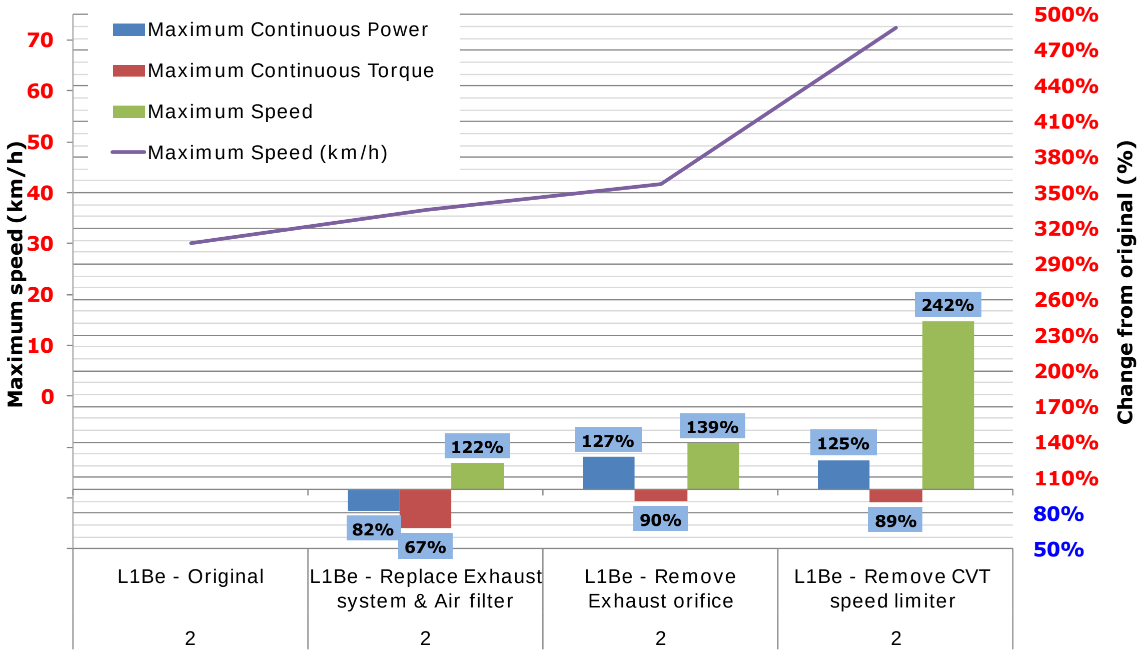


Figure 6-68: Combined modification: vehicle 1: change in performance

As can be seen in Figure 6-68, when performed in succession on this particular vehicle, the replacement of the exhaust and air filter initially reduces the peak continuous power, but increases the maximum vehicle speed (as mentioned before a reduction in the peak power may not actual represent an overall reduction in engine power across its whole speed range). The removal of the orifice in the exhaust then exceeds the original power output, an increase of 52% from the first modification and slightly increases the maximum vehicle speed again, an increase of 14% from the first modification. Finally, the removal of the speed limiter in the CVT releases the capabilities of all of these modifications and provides a final maximum vehicle speed of 72.5 km/h, from the original vehicle speed of 30 km/h.

Vehicle 2 is a slightly more complex 4 stroke 50cm3 L1Be vehicle with an electronically controlled carburettor. This combined modification shows the requirement for certain modifications to be performed on one package in order for them to function.

Figure 6-69: Combined modification: vehicle 2: Location of crankcase ventilation pipe

The first step was to shut the crankcase ventilation, this is intended to provide a performance boost but as can be seen from section 6.5, the modification provides no such benefit. Figure 6-72 shows a top down view of the engine with the location of the pipe leading to the crankcase indicated.

The cost of the ECU was €73 (Figure 6-70), the CVT kit €62 (Figure 6-71) and the carburettor jet €2. The used ECU can be resold for a close to equal price as the replacement and the CVT parts can be sold at around half of the replacement, this gives a total net price of approximately €50.

Figure 6-70: Combined modification: vehicle 2: Replacement ECU

Figure 6-71: Combined modification: vehicle 2: CVT kit

The results of these four modifications (shown in Figure 6-72), first show a decrease in power and speed, 8% and 4% respectively, and then an increase of 52% and 201%. This gave a maximum continuous power at the wheel of 1.8 kW, an increase of 0.6 kW from the original 1.2 kW, and a maximum speed of 59.8 km/h, increasing by 30.7 km/h from the original 29.7 km/h.

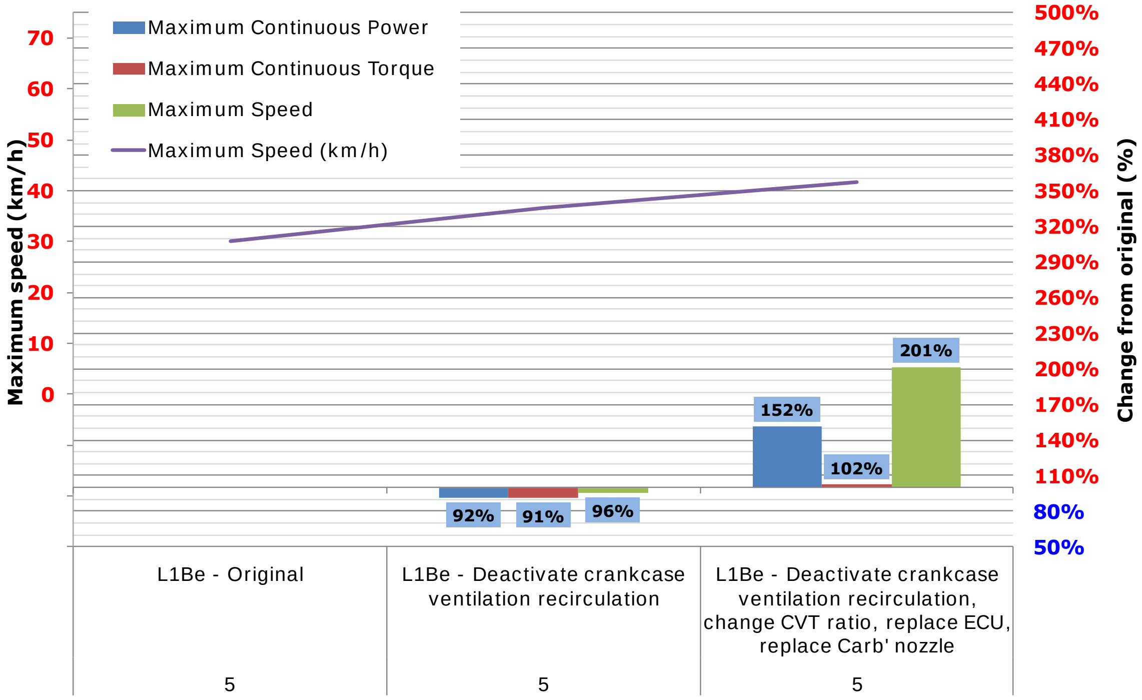


Figure 6-72: Combined modification: change in performance

6.7 Noise

When a vehicle is modified it can, intentionally or unintentionally, have an effect on the noise level emitted by the vehicle. This could be due to an adjusting to the configuration of the vehicle. However, it is most likely caused by a physical change to the air inlet and exhaust. Three vehicles were tested for the effect modifications have on sound:

Table 6-13: Noise: Vehicle and modification

Vehicle	Category	Modification	Cumulative
2	L1Be (≤25 km/h)	Replace Exhaust system & remove orifice, replace Air filter, remove CVT speed limiter	Yes
5	L1Be (≤25 km/h)	Deactivate crankcase ventilation recirculation, change CVT ratio, replace ECU, replace Carb' nozzle	Yes
12	L3e-A3	Replace Exhaust (throttle cat bypass)	No

Vehicles 2 and 5 had multiple modifications performed on them, while vehicle 12 only had one. Vehicles 2 and 12 had modifications to the exhaust.

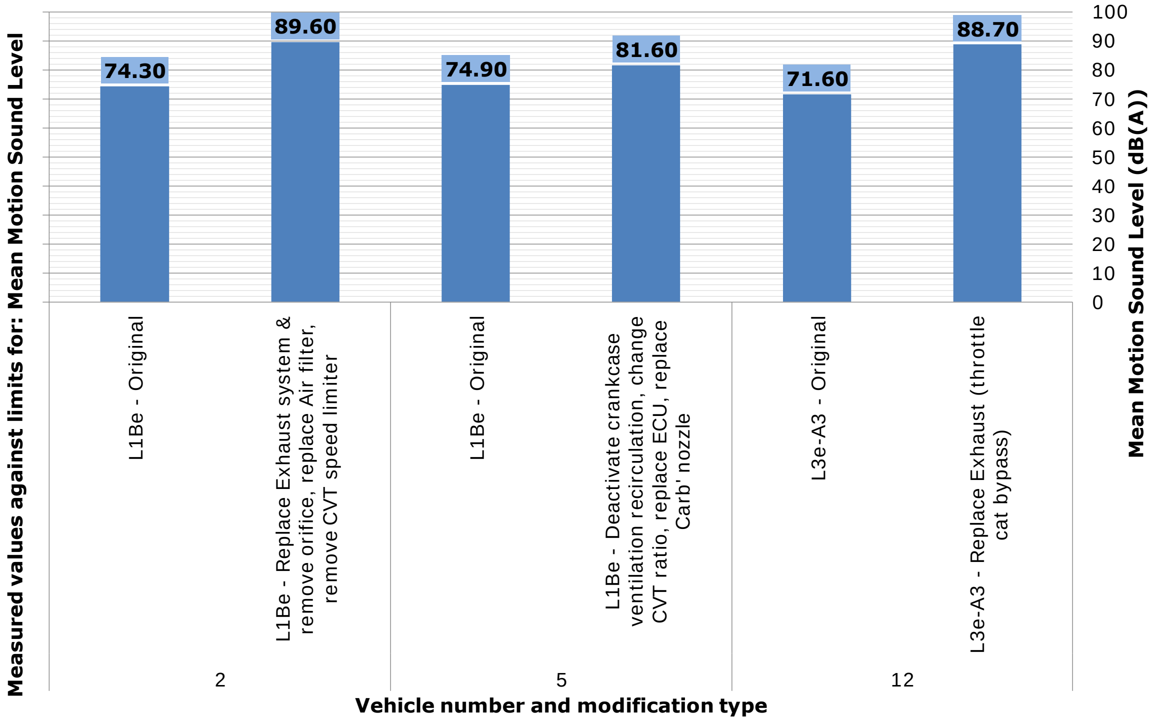


Figure 6-73: Noise: Mean motion sound level dB

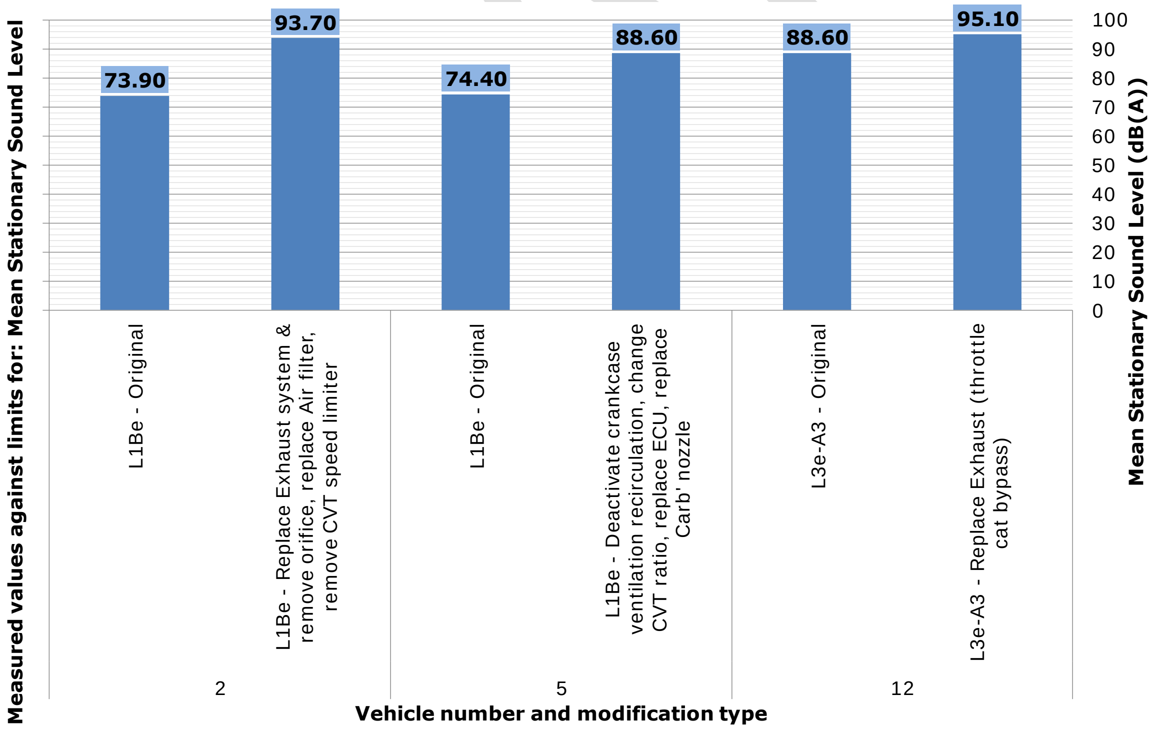


Figure 6-74: Noise: Mean stationary sound level dB

The modification performed on vehicle 2 is sometimes performed not only to increase power, but also to make the vehicle louder. The results from the motion test exceeded the Euro limit of 66 dB by 35% or 23 dB.

Vehicle 5 had had multiple modifications, none of which are specifically intended to increase vehicle noise, but the increase in power and speed brought about an increase in noise of 6.7 dB. Due to the logarithmic scale, this value would produce a noticeable change in noise, however the unmodified vehicle was already exceeding the legislated limit by 8.9 dB (likely due to vehicle age), so in total the modified vehicle exceeded the limit by 15.6 dB, which is a substantial change.

Vehicle 12 had a bypass system on the exhaust, intended to prevent damage to the catalyst at high loads, but this also reduced the noise deadening effects it produced. This modification caused a jump from 8.4 dB below the legislated limit (80dB) to 8.7 dB above it, i.e. an increase of 17.1 dB or 23%.

6.7.1 Analysis

For the pass-by test, noise levels increased by between 6.7 – 17.1 dB(A) while for the stationary test noise levels increased by between 6.5 – 19.8 dB(A). The smallest increases in noise level were not observed on the same vehicle in both tests; this was similarly the case for the largest increases in level. The results suggest that for the largest increase, the tampered vehicle would be perceived to be almost 4 times as loud as the untampered vehicle.

The type approval test is being modified to introduce a constant speed pass-by (revised UNECE Regulation 41, incomplete at the tame of testing).

6.8 Non mechanical effects on performance and emissions

One of the intentions of this report was to look at using test data from the type approved vehicle to determine if a modification has occurred. The original tests would be performed in laboratory conditions, on factory new or prototype vehicles, while the vehicle being compared to would be used, aged and tested in non-laboratory ambient conditions.

It is therefore important to build information on the scale with which these and other legal or environmental changes can affect the results, in order to decide on proper tolerances for these tests if used by enforcement authorities.

6.8.1 High octane fuel

Some users of high performance vehicles carefully select the fuel to use, when racing on track days for instance. Taking a simplistic overview there are five main groups of fuel:

- Test fuel
- Regular fuel
- High octane fuel
- Aviation fuel (avgas)
- Ethanol

Reference fuel (used for emission testing) is similar to regular fuel, however, to ensure that tests are repeatable and fair between vehicles, it has a specific mixture with

carefully defined parameters and tight tolerances. This was used for all testing performed in this test programme.

High octane fuel has either tight tolerances or has additives added such as ethanol to raise the knocking combustion limit. Reducing the chance of premature or uncontrolled ignition and knowing what conditions will cause it, allows for the vehicle to use higher compression ratios and/or advance the ignition angle earlier in the compression stroke. By doing this greater power can be obtained from the available engine capacity and fuel.

A highly refined form of high octane fuel is Aviation fuel or avgas. Due to taxation differences, it is not permitted to use this fuel on public highways. It is expensive, so although it is available and some people do purchase it, the fuel is generally only used for racing. To take advantage of high octane fuel, the vehicle must either be manually tuned or have an ECU which intelligently tunes itself using knock and/or pinking sensors.

Bio ethanol or pure ethanol has lower energy content by volume than petrol, but its predictable behaviour and high octane make it a desirable fuel for higher performance vehicles. Ethanol burns with an invisible flame so can be hazardous in accidents, combined with its low energy content it is usually mixed with petrol to gain its benefits while limiting the negative aspects. The mixes are designated by an "E" followed by the percentage of ethanol, i.e. E85, E20. Low percentage mixtures (~5-10%) are already widely available in Europe, although they are not marked as such, rather they are called high octane or premium fuels. Ethanol is a solvent and can dissolve seals within engines and their fuel systems so should not be used with vehicles not designed for it. It also hygroscopic and by nature binds condensed water vapour from the atmosphere, leading to natural degradation over time when stored.

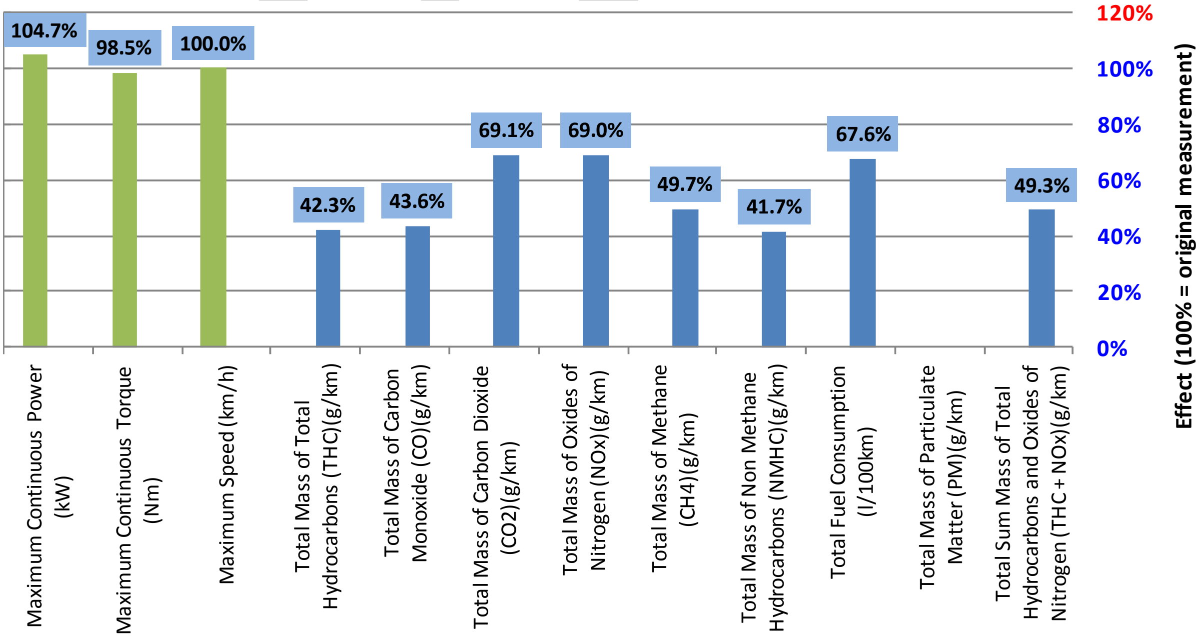


Figure 6-75: Non mechanical effects: High octane fuel (vehicle 5)

A single vehicle, with knock sensors and automatic spark angle advance was chosen to test the effects of commercially available high octane fuel. This had a dramatic effect on

the emissions and fuel consumption, all of which reduced by a not insignificant amount (see Figure 6-75). This vehicle is specifically designed to use high octane fuel and it is recommended by the manufacturer. Additionally the power increase by 4.7% or 1.7kW, the maximum speed of this vehicle was not tested as it was above 130 km/h.

Currently very few power/vehicle speed limited vehicles have the sophisticated ECU with spark angle advance/retard to take advantage of high octane fuel, however spark angle retard is used to limit power at high engine speeds in some. Therefore, it is not unfeasible to envisage this having an effect on the power output of these vehicles in the future, and so the fuel used should be considered when testing.

6.8.2 Temperature tests

The effect of ambient temperature on the emissions and performance of a vehicle was looked at from a modification point of view in section 0 on rich air/fuel ratios, here will be a short recap on the scale of the effect.

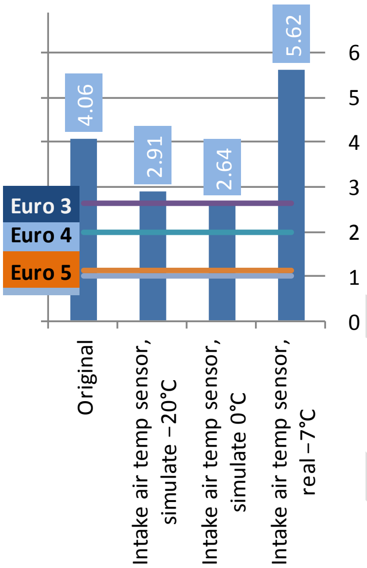


Figure 6-76: Non mechanical effects: Temperature: CO g/km

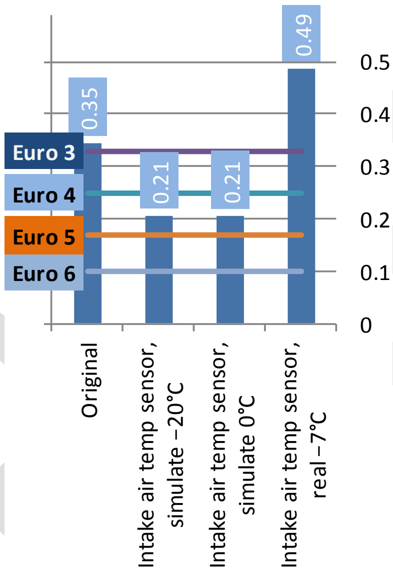


Figure 6-77: Non mechanical effects: Temperature: THC g/km

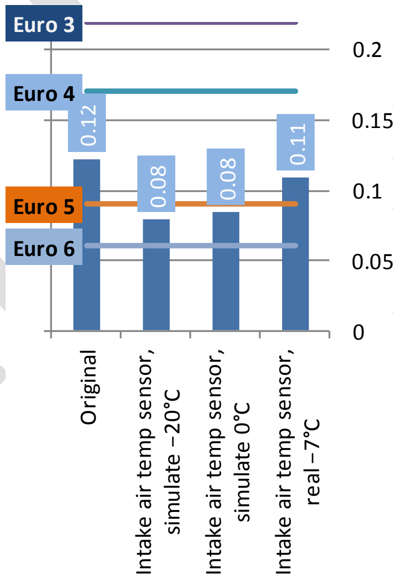


Figure 6-78: Non mechanical effects: Temperature: NOx g/km

An experiment to see the effect of ambient temperature was performed, where an L3e vehicle performed a modified Type VI test[21]. The test cell and vehicle were cooled to −7°C and the appropriate emission driving cycle performed. Where simulated, the actual ambient temperature was between 20 and 30°C.

Disregarding the effects of age, the low temperature causes this particular vehicle to increase its CO emissions by 38%, THC by 40% and decrease emissions of NOx by 9%.

[21] Type VI test, verifying the average low ambient temperature carbon monoxide and hydrocarbon tailpipe emissions after a cold start at -7 °C ambient temperature, 70/220/EEC as amended to 2006, section 5.3.5

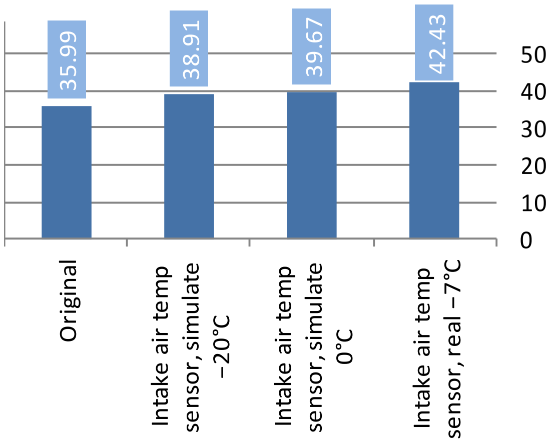


Figure 6-79: Ageing effects: Temperature: Power at the wheel (kW)

As the vehicle increased fuel flow to compensate for the cold and denser intake air, the power output of the vehicle increased by 17%.

6.8.3 Age of vehicles

As mentioned earlier, the vehicles used in the test programme were not new and were of a variety of ages and mileages. By looking at the emissions of the vehicles in their original configuration, the ageing effects of previous use can be seen.

For the following graphs only the current legislated emission limits are shown. These are the limits which these vehicles must meet at type approval.

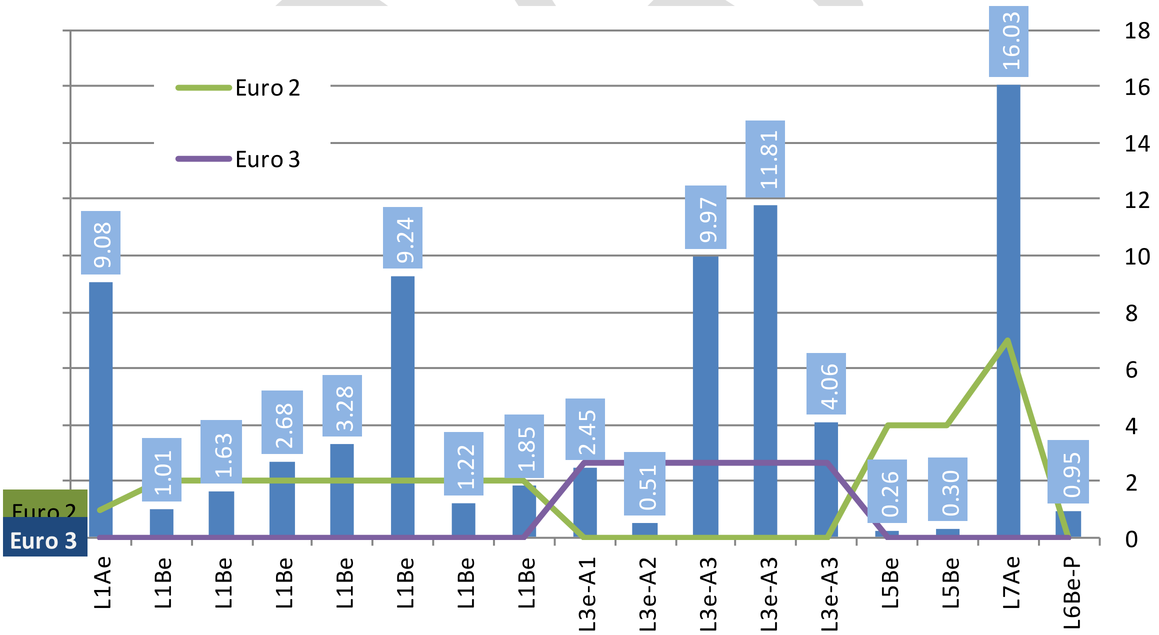


Figure 6-80: Ageing effects; emission test results of vehicles in original configurations CO [g/km]

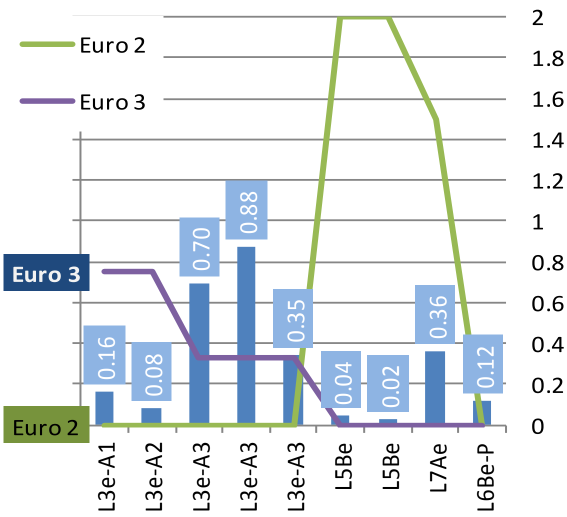


Figure 6-81: Ageing effects; emission test results of vehicles in original configurations THC [g/km]

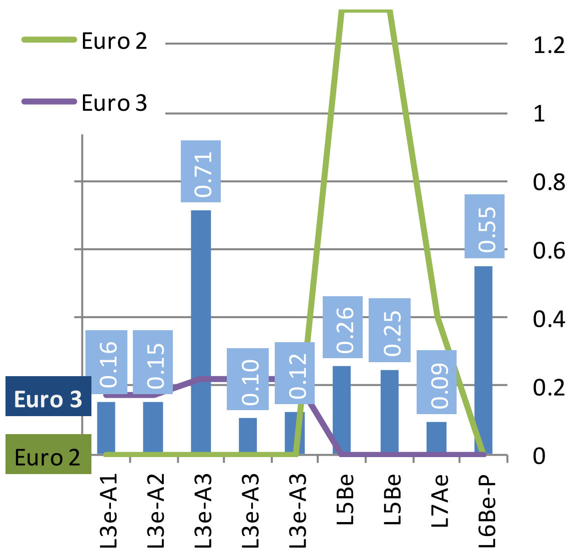


Figure 6-82: Ageing effects ; emission test results of vehicles in original configurations: NOx [g/km]

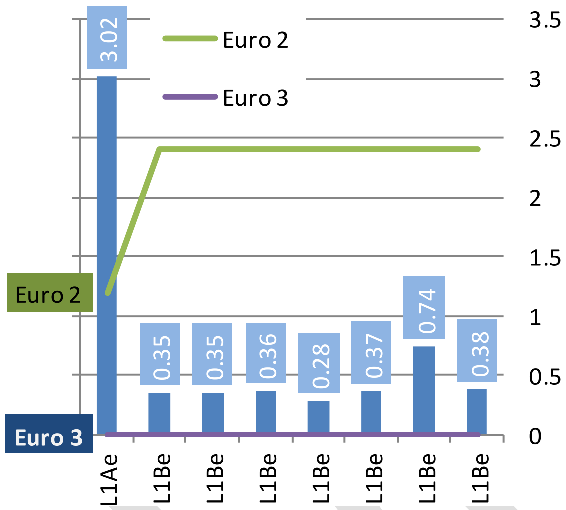


Figure 6-83: Ageing effects; emission test results of vehicles in original configurations: THC + NOx [g/km]

Of the 16 ICE vehicles tested as baseline (unmodified and 'as received'), eight exceeded their CO limits, two exceeded their THC limits, one exceeded the NOx limit and one exceeded the THC + NOx limit.

One vehicle, the L6Be-P, did not have any limits as the concept of a diesel moped is not covered by the current legislation. However, it was likely tested to meet the L1Be limits, which it still met.

6.8.4 Conclusion

Considering the maximum extremes of the results in the six legislated areas, ranges of results were obtained that were not a result of intentional or illegal modifications, see Table 6-14.

Table 6-14: Non-tampering effect: Ranges to define tolerances

	CO	THC	NO_x	Power	Speed[22]	Noise
Fuel	-56%	-58%	-31%	4.7%	n/a	n/a
Low ambient temperature	38%	40%	-9%	17%	n/a	n/a
Age	800%	156%	223%	n/a	n/a	13%
Range	**−56 to 800%**	**−58 to 156%**	**−31% to 223%**	**0 to 17%**	**n/a**	**0 to 13%**

From this limited analysis it can be seen that these unintentional consequences can have a large effect on propulsion performance, emissions and noise. Age (wear) causes the biggest increase and it would be important to monitor, design for and rectify this, e.g. by compliance with appropriate future durability requirements. Similarly, the way premium fuel artificially reduces emissions could be used to pass an emissions test that it might otherwise fail. Finally, if enforcement authorities use road side maximum vehicle speed or power tests, then the difference from laboratory temperatures must be considered, as a cold day could cause a vehicle to exceed increase its power beyond permitted limits.

[22] The effect of fuel and temperature was performed on non speed restricted vehicles, and the effect of age would need to compared to the new vehicles stated maximum speed not the legislated limit

7 Driveability and Braking

These tests (see Section 7.1) were carried out to assess the extent to which tampering affects 'driveability' and brake performance. The following graphs present the results for each of the tests.

7.1 Driveability assessment

Driveability is not easily to quantify objectively and in this research was assessed according to the subjective scale presented in Appendix M. The aim of the assessment was to put the vehicle in situations where: uncontrollable power, excessive power, unpredictable power, inconsistent power, or an unreliable engine would cause the vehicle to behave poorly and/or cause the rider difficulties. A series of test situations involving starting accelerating, cornering and stopping were therefore defined, based on the manoeuvres that riders are required to undertake as part of the UK's driving test[23]:

- T1 engine start and immediately idle
- T2 rev engine 1/2 throttle for 30", quickly return to idle
- T3 moving off slowly, 0-10 [km/h], straight line
- T4 moving off slowly, 0-10 [km/h], turning
- T5 figure of 8, 25 [km/h]
- T6 short drive (30 [m] straight, turn radius semi-circle, 30 [m] straight), 25 [km/h]
- T7 moving off fast, 0-45 [km/h], straight line
- T8 moving off fast, 0-45 [km/h], turn 5 [m] radius semi-circle
- T9 short drive (30 [m] straight, turn radius semi-circle, 30 [m] straight), 45 [km/h]
- T10 warm engine start, immediately idle, restart after forced stall
- T11 part-throttle steady-state (1/4, 1/3, 1/2), 60"
- T12 deceleration fuel cut-off (stalling test), from 45 [km/h]
- T13 deceleration fuel cut-off (stalling test), from 25 [km/h]
- T14 throttle linearity
- T15 part-throttle acceleration, 1/2 throttle, straight line
- T16 WOT, from idle to 45 [km/h]

[23] http://www.direct.gov.uk/en/Motoring/LearnerAndNewDrivers/PracticalTest/DG_178328

- T17 WOT, from idle to 75 [km/h]
- T18 WOT, from idle to 100 [km/h]
- T19 WOT, from idle to 120 [km/h]

Based on their overall impression from these tests, the assessors were also asked to give an overall rating for:

- Throttling – stall, ease of control, throttle linearity
- Vehicle to road – skidding, acceleration, wobbling, wheel spin, jumping
- Engine feeling - straining, knock, misfire, power or lack of, torque delivery
- Exhaust – smoke, opacity, smell
- Engine noise – overall magnitude, pitch, presence of unusual noises
- Vehicle damage – electronics, controls, overheating, brakes, loose parts

It should be noted that the tests and ratings were undertaken by a single, experienced test rider. In reality, the L-category vehicles tested will be ridden by a wide variety of individuals who will each perceive driveability in their own distinct manner. In the case of L1e vehicles it is also likely that these individuals tend to be less experienced in many cases. Thus, the use of a single experienced test rider will not necessarily represent the average perception of the populations of riders of the test vehicles.

7.1.1 Driveability Results

The results were analysed by summing each rating for the tampered vehicle and subtracting the sum of each rating for the equivalent vehicle in standard trim. Thus, a score of +1 means that the overall view of the assessors was that the modification had slightly improved the vehicle. It should be noted that the extent of change for each vehicle may be slightly masked by this approach i.e. an untampered vehicle achieving 5 out of 250 that, when tampered, achieved 4 out of 250 would be rated the same as a change from 250 out of 250 to 249 out of 250.

Overall Figure 7-1 shows that, for the seven vehicles that had 'before' and 'after' assessments (one L1Ae and six L1Be vehicles), the net score either remained unchanged or improved by 1 or 2 points. For two assessments, the rating decreased by one point: throttling with an air filter modification on an L1Ae vehicle and "vehicle to the road" for an L1Be vehicle which had a replaced piston and cylinder 50:80 (increasing the engine capacity from 50 cm^3 to 80 cm^3).

In addition to this, the results were considered in aggregate, summed across all tests where there was a direct comparison between tampered and untampered. The aggregate change in score, expressed as a percentage of the baseline score ranged from minus 1.02% to plus 11.43%.

The rating scheme defined a score of 5 in a safety relevant test as unsafe for inexperienced riders and a score of less than 4 as unsafe for any use. There were no

cases where the modifications undertaken changed the score in a safety relevant test from 6 or more to 5 or less. However, there were a small number of safety relevant tests, mainly on 25km/h mopeds, where the score was 5 in both original and modified conditions.

In combination, these suggests that in general, the tampering types undertaken in this research did not have any substantial adverse effects on their driveability, as perceived by an experienced test rider.

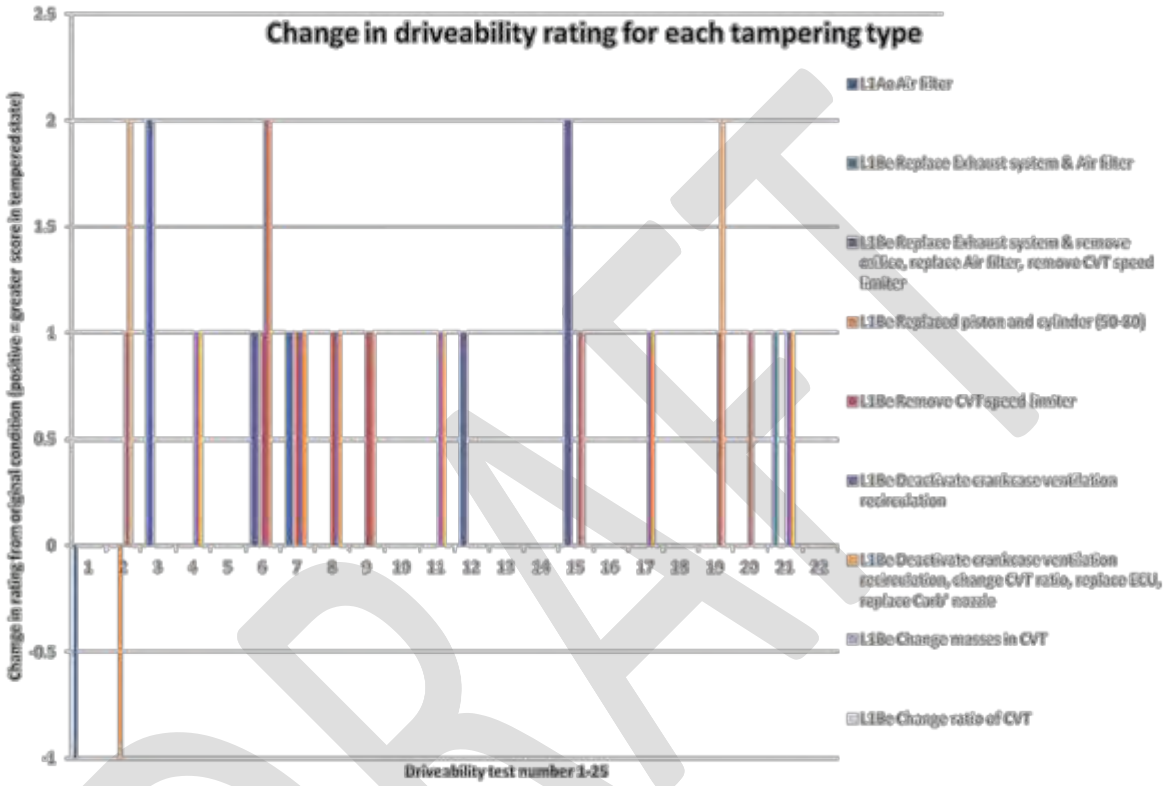


Figure 7-1: Driveability results

7.2 Braking assessment

7.2.1 Expectation and theory

Section 5 of this report identified a range of effects on vehicle performance that could be obtained by a variety of modifications to the vehicle and its components. The effects identified were those on fuel consumption, tailpipe emissions, noise, engine power and maximum speed. It is clear that changes to vehicle performance in terms of fuel consumption, tailpipe emissions, and noise will not have any consequential effects on the performance of the braking system. However, increases in engine power and/or speed may be considered likely to have some implications for the brake system.

In simple terms, the performance of a service brake system can be measured in terms of three main parameters, the stopping distance in emergency conditions, the stability of the vehicle under braking, and the ability to resist brake fade in instances of repeated or

prolonged harsh braking (e.g. maintaining a constant speed during a long descent, or repeatedly braking for corners on a twisting road).

The stability under emergency braking is fundamentally related to the potential to lock the wheels and can be affected by changes in the mass distribution, brake ratio (for combined brake systems) or rider braking strategy (for single controls) and the presence and effectiveness of ABS. None of the modifications identified in Section 5 would be likely to affect any of these and so braking stability has not been considered further.

Stopping distance considered in fundamental terms can be assessed according to the following equations:

Equation 2: Stopping distance

Equation 3: Mean acceleration

Equation 4: Maximum braking force

Where:

S	=	stopping distance (m)
U	=	initial velocity (m/s)
A	=	mean deceleration (m/s^2)
F	=	braking force (N)
M	=	mass of vehicle (including rider)
μ	=	Coefficient of friction between tyre and road
R	=	Instantaneous vertical load on the tyre

In ideal conditions where the amount of braking applied at each wheel is perfectly matched to the dynamic load carried by each wheel and is applied at a level that maintains the ideal amount of tyre slip at each wheel, then the deceleration (a) is equal to the peak coefficient of friction μ. Thus, as a minimum the brake system must be designed such that it produces sufficient torque at the brake to ensure that F_{Max} can be achieved in all conceivable conditions of friction, mass and mass distribution during braking. So, considering an extreme example where a vehicle is braking hard such that all of the mass is transferred onto the front wheel, then the torque (T_{Fmax}), measured in Nm, that the front brake must be capable of generating in order to achieve F_{max} is:

Equation 5: Torque at maximum braking force

Where:

R_t	=	Rolling radius of the front tyre (m)

Once the brake has been designed, the maximum torque it can produce can be considered to be fixed. Based on Equation 5, it can be seen that an increase in the coefficient of friction, the vehicle mass or the rolling radius of the tyre over and above the levels designed for would mean that the torque was no longer sufficient to generate the maximum possible deceleration and thus, for any given starting speed, the stopping distance would increase. It can be seen that vehicle speed is not a term that influences the design of the brake in terms of the torque that it must be capable of generating and thus, modifications that increase the maximum speed of the vehicle would not be expected to directly affect emergency stopping distance.

However, the torque that a typical friction brake is capable of generating is dependent on the force pressing the brake lining against the rotor (i.e. disc or drum) (F_{L-r}), the coefficient of friction between lining and rotor (μ_{L-r}) and the effective radius of the rotor (r_{rotor});

Equation 6: Torque

Thus, if vehicles were modified to increase the rolling radius, coefficient of friction or mass, such that there was a risk that the brakes could no longer produce sufficient torque to achieve the maximum possible deceleration, the brakes could potentially be modified to cope with this by increasing the lining to rotor friction, the force that pushes the lining against the rotor or by increasing the effective radius of the rotor itself.

For current friction brake linings and rotors, the coefficient of friction between the lining and rotor is temperature dependent. Typical linings for road vehicles are designed to have a relatively sFigure characteristic between ambient temperatures and the maximum temperature that the designer considers the brake is likely to reach in reasonably foreseeable road circumstances. However, in extremes, this temperature can be exceeded and the coefficient of friction between the lining and rotor can be substantially reduced such that for a fixed driver input, the deceleration will be substantially reduced and the stopping distance increased. This is known as brake fade.

The temperature of the brake is a function of the amount of kinetic energy it converts to heat, the thermal capacity of the brake, and the rate at which heat is dissipated to atmosphere (cooling). For a given design of brake, the thermal capacity (the relationship between heat energy and temperature) will remain constant. If the maximum speed of the vehicle (V) is increased then the kinetic energy (KE, measured in Joules) that the brake must convert to heat is increased in proportion to the square of the speed:

–

Equation 7: Kinetic energy

The square relationship means that if the speed at the start of braking is doubled then the energy that the brakes must convert to heat while stopping the vehicle is multiplied by a factor of 4. Thus, modifications to increase the maximum speed of the vehicle will greatly increase the energy that the brakes must dissipate when stopping from the higher speeds and thus increase the brake temperatures experienced and the risk of fade. If the increase in maximum speed is sufficient it is possible that fade could occur in a single stop from maximum speed to an extent sufficient to have a noticeable effect on

emergency stopping performance. However, brakes are usually designed with significant factors of safety, so it is more likely that the effects will be noticeable in situations where repeated heavy braking is required at short intervals (in traffic, on switchback roads etc), or if braking is required to control speed on long descents, for example in mountainous regions.

In theory the brakes can be modified to mitigate any fade effects caused by an increase in maximum speed, either by improving the cooling of the brakes (e.g. vented discs), increasing the thermal capacity of the brake (e.g. increasing the mass of material that the heat can soak into), or by changing the friction materials for ones with better friction coefficients at high temperature (e.g. specialist carbon brakes). In the latter case of different friction materials caution must be applied because sometimes materials with a better high temperature friction have a worse low temperature friction. As such, solutions that work well in racing, where the brakes will always be operating very hot, may not work well in ordinary road applications where the brakes will be cold for much of the time.

7.2.2 Test methods

Vehicles where the modifications reported in Section 0 resulted in substantial increases in maximum speed therefore underwent cold stopping tests and heat fade tests in accordance with ISO 8710:2010, as outlined in Table 7-1, below.

Table 7-1: Brake tests undertaken in accordance with ISO 8710:2010

Sub test	Notes
~~0. Burnishing procedure~~	Not performed as brakes used
1. Dry stop test (single brake control actuated) **F – Front** **R – Rear**	
2. Dry stop test (all service brake controls actuated)	
3. High speed test	Only performed if significantly faster test speed than test 2
~~4. Wet brake test~~	Not performed
5. Heat fade test **x10 tests**	Simplified procedure
~~6. Parking brake system test~~	Should not be affected by modification
~~7. Partial failure test~~	Should not be affected by modification
~~8. Power-assisted brake system failure test~~	Should not be affected by modification

The tests were the responsibility of the JRC and were sub-contracted to ETA Engine Technology in Italy.

It should be noted that the force applied to the braking control (lever and/or pedal) by the rider was not measured during the test because of practical difficulties. It was ensured that the maximum permitted was not exceeded by fitting a mechanical stop to the handlebar in a position relating to the maximum permitted force.

The fade test was not undertaken in accordance with the ISO standard but was simplified to simply be 10 emergency stops from an initial speed of 0.7 Vmax with the performance in the first stop compared with that in the last stop. Temperature was measured on the surface of the brake rotor, where available (principally for disk brakes rather than rim or drum brakes).

7.2.3 Test results

The results of the emergency stop tests are presented below. These are based on the use of both front and rear brakes (Test 2 in the matrix above).

Table 7-2: Emergency stop tests, application of front and rear brakes

Vehicle	Category	Condition	Max speed (km/h)	Initial speed (km/h)	Stopping distance (all brakes)(m)	Average decal (m/s/s)	MFDD (m/s/s)	Final temperature (°C)
1	L1Ae	OEM	19.5	17.6	5.8	2.1	2.7	X
		Tampered	22	19.8	6.5	2.3	5.0	X
		Change	**2.5**	**2.3**	**0.7**	**0.3**	**2.4**	**n/a**
2	L1Be	OEM	32.7	29.4	8.0	4.2	5.4	50
		Tampered	49	44.1	10.6	7.1	9.0	54
		Change	**16.3**	**14.7**	**2.6**	**2.9**	**3.6**	**4**
3	L1Be	OEM	28.5	25.7	8.8	2.9	4.3	X
		Tampered	29.5	26.6	9.1	3.0	3.7	X
		Change	**1**	**0.9**	**0.3**	**0.1**	**-0.6**	**n/a**
4	L1Be	OEM	30.4	27.4	9.1	3.2	4.3	53
		Tampered	29.2	26.3	9.0	3.0	4.0	54
		Change	**-1.2**	**-1.1**	**-0.1**	**-0.2**	**-0.3**	**1**
7	L1Be	OEM	47	42.3	8.9	7.8	10.0	75
		Tampered	56	50.4	14.6	6.7	11.3	75
		Change	**9**	**8.1**	**5.7**	**-1.0**	**1.3**	**0**
8	L1Be	OEM	45	40.511.5	5.5	8.6	57	n/a
		Tampered	52.5	47.3	13.2	6.5	11.1	68
		Change	**7.5**	**6.8**	**1.7**	**1.0**	**2.5**	**11**
E4	L3e-A1 <130 km/h	OEM	127	100.0	74.0	5.2	6.3	72
		Tampered	127	100.0	73.9	5.2	6.4	X
		Change	**0**	**0.0**	**-0.1**	**0.0**	**0.1**	**n/a**

Note that average deceleration is the average between the initial speed and the vehicle coming to a complete stop. Mean fully developed deceleration (MFDD) is defined as the average deceleration measured between 80% of the initial speed and 10% of the initial speed. It thus excludes the period of lower deceleration experienced during the finite amount of time taken for the rider to progress application of the brakes from first movement of the control(s) to reaching the full control force required for maximum braking and for the brake system to react to application of the control force and reach full brake torque. It also excludes the final part of the stop where oscillations of the vehicle as it comes to rest and low frequency effects can sometimes produce spurious measurements of distance in some measurement systems. The expectation is, therefore, that MFDD will produce higher and more consistent values than a simple average deceleration.

Type approval requirements are mainly based on tests of single brakes but figures are provided for tests using all brakes where tyre road friction is the factor that prevents the minimum being achieved. The results highlighted in red indicate tests where the vehicle would not have met the requirements for tests involving all brakes (MFDD of 2.8 m/s^2 for mopeds with a max vehicle speed of no more than 25 km/h, 4.4 m/s^2 for mopeds capable of more than 25 km/h and 5.8m/s^2 for motorcycles).

The theory described in section 7.2.1 would suggest that there should only be a significant difference in performance if the increased speed in tampered condition led to sufficient temperature increase to cause fade in a single stop. It can be seen that none of the temperatures recorded exceeded 100 degrees, which is typically the upper threshold used in braking regulation to identify a "cold" brake, so brake fade would not be expected. NoFigure differences between the tampered and OEM conditions were observed in most tests. However, most of these tests involved the tampered vehicle exhibiting improved deceleration rates, in stark contrast to expectations (e.g. MFDD almost doubled for tampered vehicle 1 [L1Ae] compared with OEM version).

Further analysis was undertaken to investigate this unexpected result. This included studying the effects of initial speed, different measures of deceleration and including the 1st and 10th fade stops as if they were emergency stops from a different speed. A summary is shown in Figure 7-2, below.

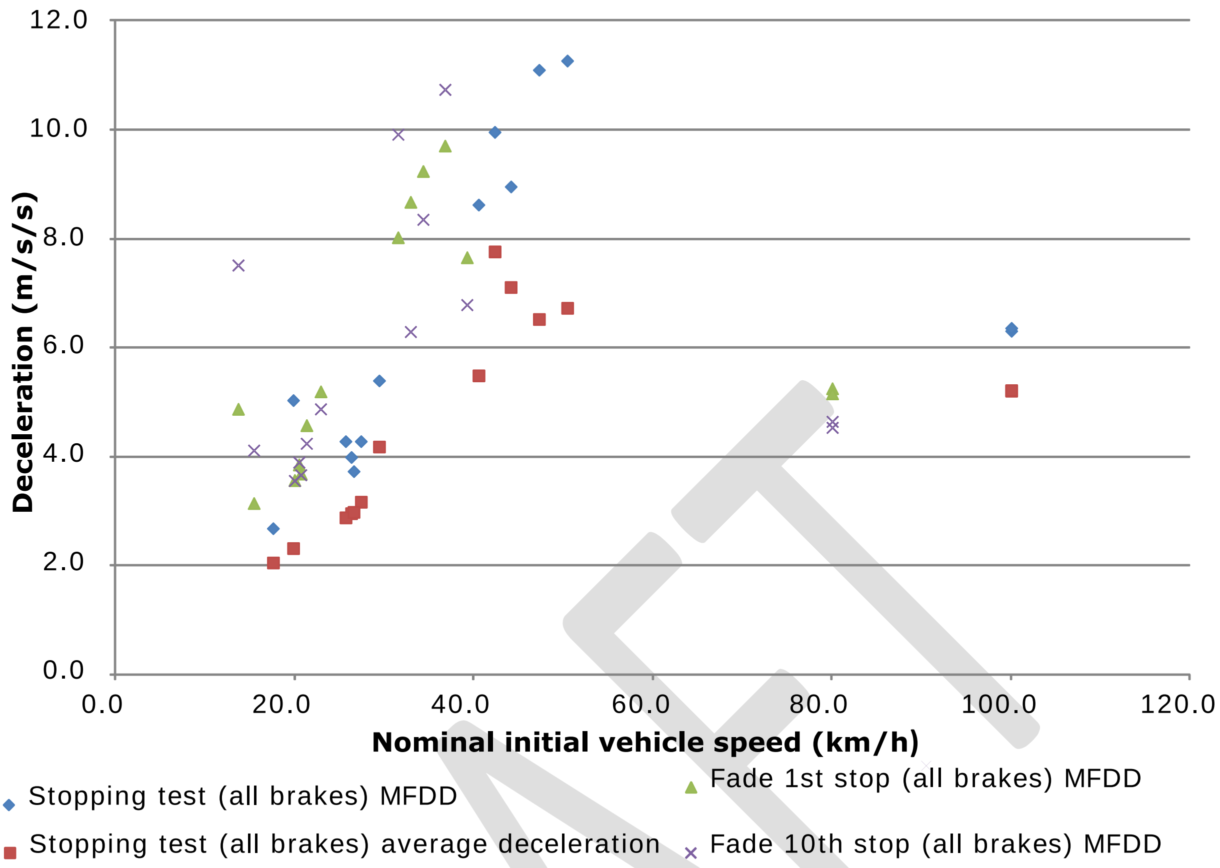


Figure 7-2: Analysis of the relationship between initial speed, deceleration measure and test type

It can be seen that when all series are considered there is quite a large degree of scatter in the results but at low speeds there seems to be a relatively strong correlation suggesting a substantial increase in recorded deceleration with increased initial test speed (regardless of tampering status, test type or vehicle make/model). The theory shows that vehicle speed should not be a direct factor in maximum deceleration capability. The maximum deceleration capability does depend strongly on the coefficient of friction between tyre and road. Tyre road friction is speed dependent in some circumstances but it is typically observed with locked wheels in wet conditions (these tests were in dry conditions) and the relationship is typically that available friction decreases with increasing vehicle speed.

The observed pattern of results cannot therefore be explained with the objective data available. However, one possible explanation might lie in a combination of two acknowledged difficulties with brake testing on motorcycles. The first is that the vehicles tested would not be equipped with ABS and thus wheels may lock under severe braking. On a motorcycle a locked wheel has much greater consequences for stability than for passenger cars and can quickly lead to a rider falling from the vehicle. There is thus a need for riders to be cautious when applying heavy braking in order to avoid locking the wheels. In any kind of brake testing the rate at which the control force is applied can have an important effect on the stopping distance, the faster the application is, the more the results are an objective measurement of vehicle performance rather than being

driver dependent. As previously explained, the use of MFDD is intended to reduce this influence. However, in very low speed testing such as that undertaken on some of the mopeds (e.g. 20km/h - 30km/h) 80% of the initial speed will only be around 4km/h-6km/h slower than the initial speed. In these circumstances it is possible that a cautious brake application to avoid wheel lock could mean that maximum braking is not actually developed for the whole speed range in which MFDD is measured. In effect it can be that by the time full braking is reached the vehicle is already at a virtual standstill. At higher initial speeds more time is available for the rider to reach maximum braking in the zone measured by MFDD.

This could possibly explain the initial trend whereby decelerations are very low at very low initial test speeds. However, one vehicle was tested from initial speeds of 80 km/h and 100 km/h where this should not be a problem. It is possible that in this case full braking was not reached because of the safety concerns associated with locked wheels. However, it must be emile/hasised that these possibilities cannot be proven because the control force actually applied was not measured during the test. There is, therefore, considerable uncertainty with respect to the effect, or otherwise of tampering on measures of stopping performance (distance, average deceleration and MFDD).

The theory suggests that an increased maximum vehicle speed would be more likely to be a problem with respect to brake fade. Although the uncertainty with respect to the deceleration achieved does remain, the temperature of the brakes was measured for some vehicles before the 1st and after the 10th test in the heat fade sequence. The full set of temperature measurements was available for only 4 vehicles (which did not involve the higher speed L3e category vehicle, which might be expected to have the greatest energy input into the brakes). For these 4 vehicles, the average brake temperature increase between the 1st and 10th brake stop when the vehicle was in OEM condition was 5.75°C. For the same vehicles in tampered condition the average rise was 6.25°C. Both of these temperature rises can be considered insignificant in respect of brake fade, which strongly suggests that in terms of thermal capacity, the brakes of these low speed vehicles tend to be substantially over-engineered in OEM form, such that increases to the maximum speed do not exceed their design limits for fade.

However, only a small sample of vehicles were tested and the results do not preclude the possibility of an existing moped not tested, or some future design, being equipped with brakes that are designed down to match the requirements of the low maximum speed of the vehicle to which they are fitted.

8 Cost benefit and break-even analyses

8.1 Introduction

The results of the test programme (see Section 0) have reported the effects of each tampering type by comparing the 'original state' with the 'tampered state'. Examination of these data shows the differences in absolute terms. However, in order to interpret these changes, it is necessary to value in monetary terms the differences that have been measured. This chapter describes the process used to evaluate of the test data so that estimates could be made with respect to the broad impacts from different tampering types.

This evaluation has used "best estimate" values to scope the potential magnitude of the effects from tampering. Assumptions have been necessary in this process and obtaining consensus, evidence-based values would require further research. In principle, the effects valued here assume that the results measured in the testing programme apply to all vehicles in the same L-category.

This study has considered the effects on the environment from tailpipe emissions and the effects on safety, largely from measurements of maximum vehicle speed with reference to results from power, driveability and braking effectiveness. The effect of tampering on noise has not been valued directly due to incompatibilities between the standard testing methodology (required for determining legislated limits) and the damage cost to society. Therefore, it is difficult to monetise the impacts of noise using a scale compatible with safety and emissions, even though it was found that substantial increases in noise level are easily obtained.

8.1.1 Values and assumptions used in the assessments

This section provides information on the values used for the assessment of all tested effects. Four scenarios were assumed to model the percentage of the fleet that are tampered in the ways that produce these effects. These are pragmatic values and were used in the absence of more robust data on this parameter:

- 10% (target value),
- 20% (19.6% found during site visit to The Netherlands, see Appendix C.4.2),
- 30% (26.5% found between October to December in 2004 by Dutch police, see Appendix 0, 35% used as default value in HARMONOISE software)
- 40% (38.7% found between June to October in 2004 by Dutch police, see Appendix 0, MAIDS data shows 40% of fatal accidents involving L1e vehicles occurred at greater than their design speed, see section 8.2.4)

The sizes of the fleets and estimates of the general split between sub-categories were derived from estimates provided by stakeholders (see Appendix B.2).

Table 8-1: Estimated annual vehicle kilometres for each L-category type

L-category type	Estimate for number of vehicles in the fleet (million)	Estimate for annual distance travelled (km)	Estimated annual million vehicle kilometres (M km)
L1Ae	0.5 M	1,500 km	750 M km
L1Be	12.6 M	3,000 km	37,800 M km
L3e-A1	5.4 M	4,500 km	24,075 M km
L3e-A2	8.8 M	7,500 km	65,959 M km
L3e-A3	8.8 M	7,500 km	65,959 M km
L5Be	0.1 M	4,500 km	450 M km
L7Ae	0.5 M	7,500 km	3,750 M km
L6Be-P	0.5 M	7,500 km	3,750 M km
Total	**37.4 M**	**43,500 km**	**202,493 M km**

Table 8-2: Example tampered and untampered division: L1Be

	Percentage of L1Be fleet tampered			
Number of vehicles:	10%	20%	30%	40%
- Tampered	1,260,000	2,520,000	3,780,000	5,040,000
- Untampered	11,340,000	10,080,000	8,820,000	7,560,000
- Total	12,600,000	12,600,000	12,600,000	12,600,000

8.2 Methodology for the assessment of safety effects

This section provides an evaluation of the test results by comparing the magnitude of absolute change in the results pertinent to safety measured in tampered condition compared to the original condition. Specifically, these examine the changes to maximum speed, maximum power, maximum torque, braking efficiency, and driveability. Although all of these factors are likely to influence safety risk, the maximum speed was the main factor used to estimate changes to safety risk in this analysis.

In terms of safety, the effects of tampering are generally difficult to quantify. As has been noted by other studies – for example, Robinson *et al.* (2009) - accident risk is related to multiple factors and therefore increases in speed or power are difficult to relate directly to changes in the number of casualties. Furthermore, many motorcycles are already capable of high speeds and have high power to weight ratios. Thus, for larger (higher engine capacity) machines, the effects of increased speed and power are likely to be negligible because any additional improvements cannot realistically be utilised on the road, and their effects cannot be accurately quantified. However, for certain types of vehicle, such as L1e vehicles, which are currently limited in speed and

appeal to novice riders, an increase in maximum speed or power can be considered to have a more realistic safety impact.

Studies on motorcycle accident risk did not isolate speed as a major factor; (Sexton, et al., 2004) found that other parameters such as annual mileage, age, experience, and driving style & behaviour were significant in explaining accident risk. Indeed, tampering types, which result in an increased maximum speed or power, may exaggerate accident risks because riders engaged in these activities may also be those prone to more risky driving styles and behaviours.

It is a premise of the analysis that, as the vehicles are both designed for the anti-tampering legislation and tested in use by enforcement agencies against legislated limits, the tests performed on the vehicles were for the most part done using the legislated tested methods. These testing methods look for maximum values and are not suited for identifying slight redistribution of effects across a wide engine speed or load range. The consequence of this became most evident in the measurement of power, where although the vehicle's maximum speed increased its maximum power and/or torque was either unaffected or decreased. This occurred because although the 'maximum' power had not changed, either the engine speed that the peak occurred at had changed or the power versus engine speed curve had changed shape, additionally the transmission ratio may have changed.

In order to provide initial quantification of the potential benefits, an analysis was performed on measures that would prevent the increase of maximum vehicle speed for L1e vehicles. Other L-category vehicles may also show benefits in preventing increases in maximum vehicle speed, but because many of these vehicles already have significant capabilities in this respect, any effect was considered negligible. Using a similar principle, the effects on braking and driveability were considered only important to safety when the vehicle speed or power was influenced such that the capabilities of the vehicle exceeded the component design limits. The results for these aspects suggested that this was not the case, or at least had not manifested in the limited time available for testing.

8.2.1 Accidents and vehicle speed

There is much published evidence that shows that increased vehicle speed is correlated with both increased injury severity and accident risk for passenger cars (e.g. Taylor *et al.* 2000). At greater speeds, drivers (and riders) have less time to react to situations on the road. Furthermore, when an accident does occur, the resulting severity is likely to be greater because of the increased impact energy. In relation to average traffic speed at a specific location, there is a robust general rule that an increase of 1 mile/h (1.6 km/h) results in an increase in injury accidents of 5% (e.g. Taylor *et al.* 2000). This means that an increase in the average traffic speed is associated with an increase in the number of accidents. If it is assumed that speed-tampered vehicles comprise a certain percentage of the fleet, then it is a reasonable starting point for the upper estimate to assume that this group have an increased contribution to injury accidents of 5% per 1.6 km/h maximum speed increase. However, because this relationship is between *average traffic* speed and the increase in injury accidents, the central estimate used was half this value. The rationale for this is that if the *maximum* speed is increased by 5%, the increase in *average* speed is perhaps more accurately represented by 2.5% increase in injury accidents per 1.6km/h maximum speed increase because the increased maximum speed

may not be realised all the time. For the lower estimate, the relationship between injury accidents and average vehicle speed was divided by four (i.e. 1.25% increase in injury accidents per 1.6km/h increase in maximum speed).

8.2.2 Road casualties and young riders

UK accident data (DfT, 2010) data shows that the modal group for those killed or seriously injured (KSI) on an L1e vehicle is aged 16-19, whereas for machines with an engine capacity greater than 50cc, the KSI modal group is aged 40-49. This clearly demonstrates that the casualty age distribution is different based on the size of the vehicle. One of the major reasons for this is that riding experience is a key factor in determining accident risk. It is well documented that younger riders have least experience and consequently a greater accident risk; one of the reasons for age restrictions for specific types of L-category vehicle.

8.2.3 Accidents and rider age and experience

New drivers, especially young new drivers, are over-represented in road collisions. The risk of involvement in a crash during the first year of driving decreases substantially, this is true for all ages of new and novice drivers, but the younger the driver the more pronounced the reduction in accident propensity as they acquire on road experience.

Maycock et al., (1991) included a study of self-reported accidents from a sample of 13,500 drivers. The programme found that mileage-adjusted accident liability decreased with respect to the age at which the driver passed their driving test. Male drivers have higher accident liabilities than females, but age and experience when combined produced very steep declines in accident propensity during the early period of unsupervised driving following gaining a driving a licence (Figure 94).

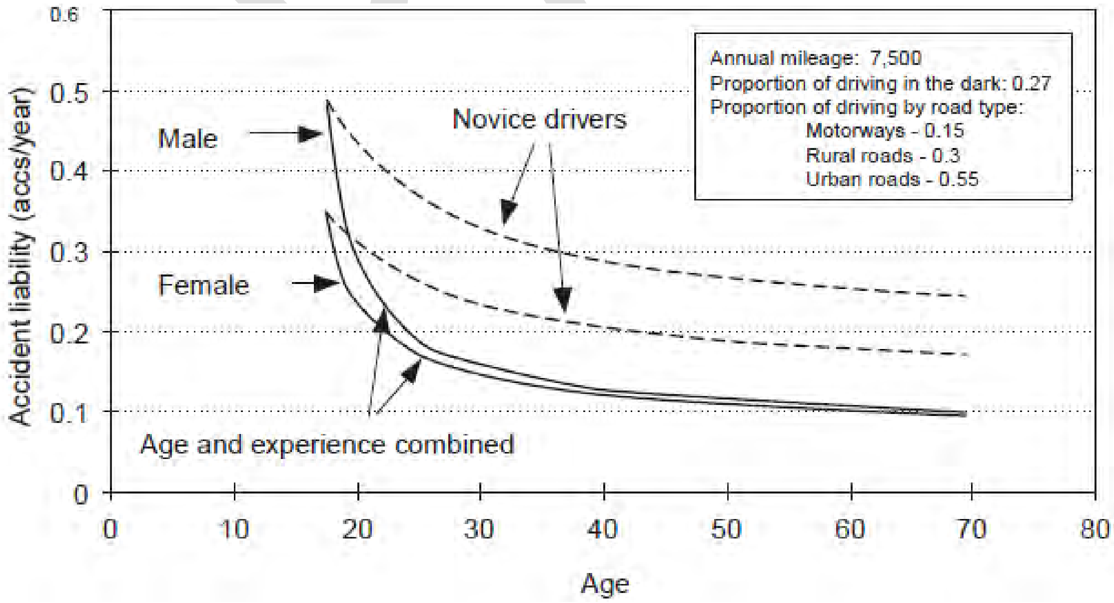


Figure 8-1 The effects of age and driving experience on collision risk (1991; reproduced from (Maycock, 1991), 2002).

Another British study (Forsyth, 1995)found similar results and these findings were summarised by Maycock, 2002 (Figure 8-2). Both show that once the effects of age and

experience are separated, the effect of experience is the dominant force behind the lowering of collision risk. The dotted line shows the initial collision rate of a new driver in their first year of driving, depending on the age they pass their test. The solid line shows the way in which collision rate drops with experience for drivers who pass their test at 17. The effect of experience is, as we can see, substantial in those early years of driving, and even the early months.

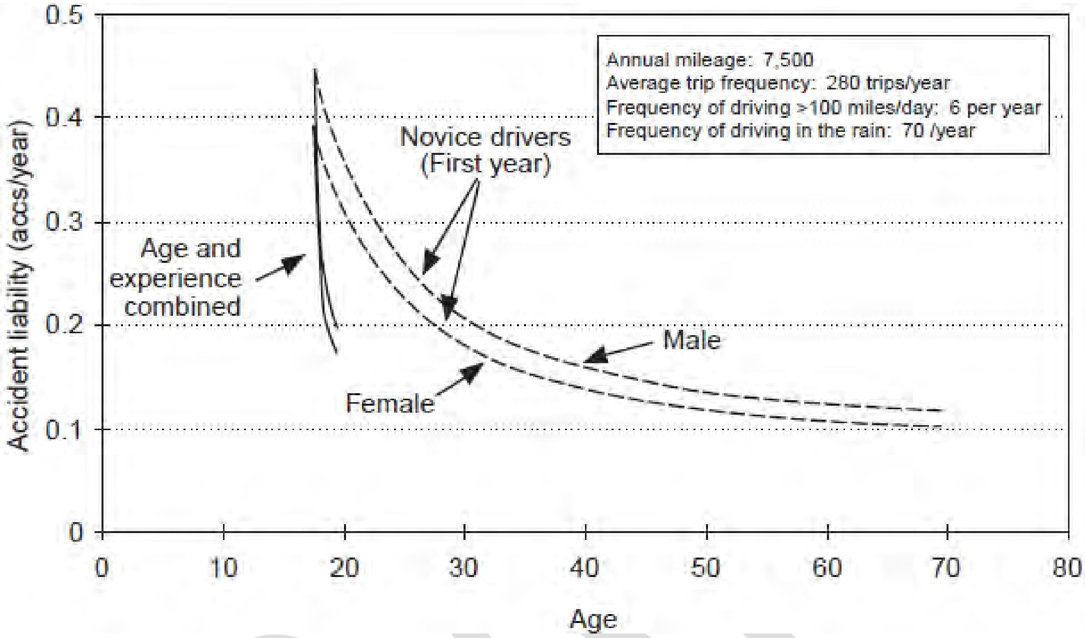


Figure 8-2: The effects of age and experience on collision risk, from Forsyth *et al.* (1995; figure reproduced from Maycock, 2002)

A third study specifically considering motorcycles was performed in 2004, this found similar results except that the male/female difference was less pronounced Figure 8-3.

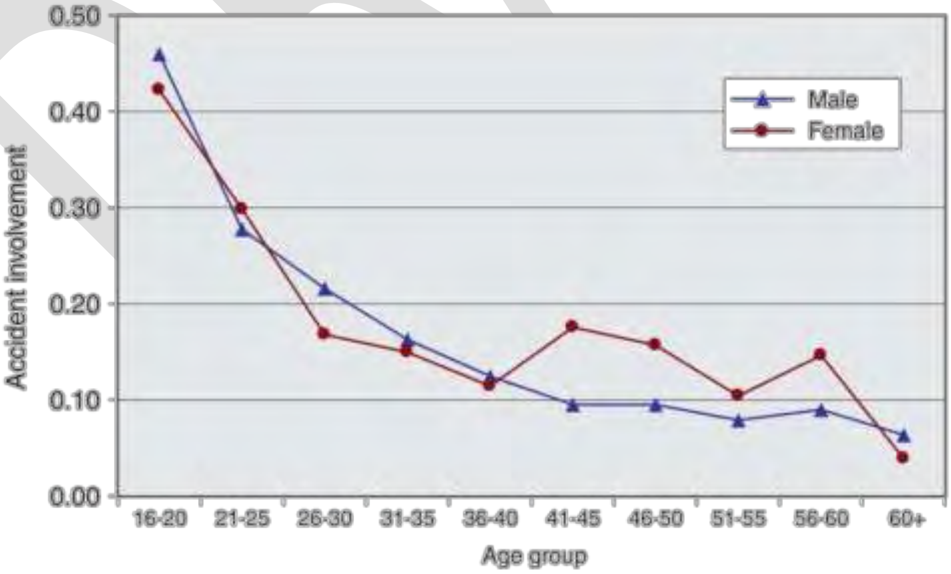


Figure 8-3: Age group, and probability of accident involvement (Sexton, et al., 2004)

This British research is substantiated by many other international studies that have all shown that initial very high crash involvement decreases rapidly during the first six months of driving (Mayhew *et al.*, 2000; McCartt *et al.*, 2003; Sagberg *et al.*, 1998).

8.2.4 Light two-wheel powered vehicle (L1) accident risk

The available evidence suggests that tampered vehicles have a greater accident risk than untampered vehicles. For example, the MAIDS[24] study found higher accident involvement of tampering vehicles: 71 of 398 (17.3%) compared with 46 of 373 (12.3%) in the exposure group:

From the MAIDS data, the relative risk for accident involvement for a tampered L1e can be calculated as 1.38 – an increase in risk of 38%. However, 95% confidence interval for relative risk can be estimated to be 0.97 to 1.95. This shows that there is a strong trend for increased accident risk to be associated with tampered bikes, but that the confidence interval includes 1 (no increased risk). This is broadly in line with the assumptions used in this study between speed and accident risk that there is an association between tampered L1e vehicles and increased accident risk. Rider behavioural factors other than speed will also contribute to accident risk and may also be significant contributors as well as being confounded with the likelihood of carrying out tampering with the aim of increasing maximum speed.

The MAIDS data also shows that 40% of fatal accidents involving L1e vehicles occurred at greater than the 45 km/h (28 mile/h) design speed. This suggests that a large group of L1s are tampered to travel faster because of the large proportion of these vehicles seen in the accident sample. However, the inherent difficulties with deriving accurate travel speeds from accident reconstructions means that uncertainty is associated with this result.

These data tend to support the strengthening of tampering prevention measures on L1e vehicles because they demonstrate an increased risk for L1e vehicles who are ridden by, on average, younger, more inexperienced riders, and a rider type that may show a propensity for tampering with the aim of increasing the maximum speed.

8.2.5 Assumptions and sensitivity analyses

Using these assumptions, the effects of the tampering types were compared. It was assumed that the increase in risk applied only to L1e vehicles and that 26% of the estimated annual fatalities result from these vehicles (see Table 8-3).

[24] Motorcycle Accident In-Depth Study - http://www.maids-study.eu/

Table 8-3: Assumptions and rationale for values used

Description	Value used	Comment or further information
Annual European L-category Fatalities	5,518[25]	Estimate of number of annual European PTW Fatals (Robinson, et al., 2009)
Number of fatalities in the L1e fleet	1,450	26.27% of motorcycle and moped fatalities (EC CARE Database 2008, 2006 values)
Number of serious casualties (relative to fatal casualties)	11.21 × fatals	Number of serious casualties is estimated to be 11.21 times greater than for fatal casualties. This estimate is derived from the ratio between fatal and serious GB PTW casualties (DfT, 2010)
Number of Slight casualties (relative to fatal casualties)	31.59 × fatals	Number of slight casualties is estimated to be 31.59 times greater than for fatal casualties. This estimate is derived from the ratio between fatal and slight GB PTW casualties (DfT, 2010)
Casualty valuations	Fatal: €1.744M Serious: €0.196M Slight: €0.015M	From UK values (DfT, 2010) converted to Euro using rate of 1.1

8.2.6 *Methodology for assessment of safety*

Using the test results, the safety effect for each tampering event (on L1e vehicles) was estimated. The following provides a worked example with reference to the steps indicated in Table 8-3.

1. For tampering with the air filter, the test results revealed an increase in vehicle speed of 2.5km/h. four estimates were used for the proportion of distance ridden at the vehicles new maximum vehicle speed: 0.25, 0.5, 0.75 and 1. Taking the mid estimate of 0.5 gave an average vehicle speed increase of 1.25 km/h.

2. Using the rule that every 1.6 km/h (1 mile/h) results in a 5% increase in injury accidents (which was assumed to be approximately equivalent to casualties), this equates to an increase in casualties of 3.9%.

[25] See Robinson *et al.* (2009) who used this value for the estimate of annual European PTW fatalities

Figure 8-4: Equation for estimating the increased proportion of casualties caused by the vehicle speed increase effect of the tampering mode

Where

I= Increase in percentage of injury accidents for tampered vehicles (based on test results for one vehicle). I is found by increasing the percentage of casualties by the percentage derived from step 1

$V\Delta_{average}$ = *Average vehicle speed difference between the tampered and untampered state*

3. Four estimates for the percentage of the fleet that are tampered (Tp) were used: 10%, 20%, 30% and 40%. The mid estimate for Tp of 20% has been used for the example.

4. If the tampered vehicles in the fleet already confer an increase in casualties, then the number of L1e fatalities (F_t) for each hypothetical scenario can be estimated as follows:

Figure 8-5: Equation for estimate of number of fatalities from tampered L1e vehicles

Where:

F_t = *Number of fatalities from tampered vehicles*

Tp = Proportion of population tampered

F_{tot} = *Total number of L1e fatalities per year*

5. Estimates for the number of serious and slight casualties affected were estimated by multiplying the number of fatal casualties.

6. The estimated casualty cost can be monetised by multiplying the target populations by their respective casualty valuation values (see Table 8-3). Assuming that the tampering mode could be completely prevented in the fleet, the entire tampered fleet used this single tampering mode, and the entire fleet was fitted with an appropriate anti-tampering device (i.e. retrofitted), then this cost equals the potential saving to the EU per year.

This calculation method has been performed in the following example:

Table 8-4: Example estimates for experiment "air filter"

	Mid Estimate	Notes and cacluations
Casualties in fleet	1,449	Annual PTW fatalities multiplied by percentage of category (L1e)
Speed difference	2.5 km/h	The maximum vehicle speed in the tampered state minus that of the untampered state
Average percentage of vehicle speed above original	50%	Vehicle speed difference multiplied by percentage
Percentage of fleet tampered	20%	Four percentages were calculated
Increase in number of casualties for tampered vehicles	3.9%	Using the rule that every 1.6km/h results in 5% increase in injury accidents (which was assumed to be approximately equivalent to casualties)
Increase in fatalities from tampered vehicles due to speed which could be potentially prevented	11.3	Proportion of fleet tampered multiplied by fatals and increased risk
Serious casualties which could be potentially prevented	127.7	For every fatal there are 11.21 serious injury casualties
Slight casualties which could be potentially prevented	357.2	For every fatal there are 31.59 slight injury casualties
Casualty valuation (€M) per annum	**€ 50.0 M**	

Additionally, the number of fatalities from untampered vehicles (F_u) is therefore:

Figure 8-6: Equation to estimate the number of fatalities from untampered L1e vehicles

The fatality rate per vehicle for tampered and untampered vehicles were estimated by taking the values for fatalities in the tampered and untampered fleet respectively and dividing them by the number of vehicles in their tampered or untampered fleet (see Table 8-2).

8.3 Methodology for the assessment of emission effects

This section provides an evaluation of the test results by comparing the magnitude of absolute change in the emission values measured in tampered condition compared to the original condition. For each emission parameter, the deviation between the two results was valued, and a high-level cost-benefit analysis carried out to attempt to quantify the effects of each tampering event.

The monetary values of emissions used in the evaluation are presented in Table 8-5, Table 8-6 and Table 8-7. The damage cost of emissions was used for HC and CO. For NOx emissions, it was assumed that approximately 33% of the emissions referred to abatement (i.e. emissions in urban areas) and 66% elsewhere (damage cost). This assumption has not been validated and is likely to vary between the different categories of vehicle and also between different Member States. For the purposes of this evaluation, a simple, pragmatic value was used. For CO_2 emissions, the Shadow Price of Carbon was used (see Table 8-7).

Methane and non-Methane Hydrocarbons were not included in the assessment because no appropriate valuation could be located.

The damage cost values used value only the effect of the emissions and do not include components which represent costs associated with the value society is willing to pay to prevent the emissions. This evaluation includes valuations for damage, abatement, and willingness to pay, meaning that the values used for the different emissions are not constructed in the same way. It is acknowledged that this is not ideal, and should additional data become available from other research, these should be updated. It is considered that, in line with conventional approach for casualty valuation, an approach should be taken which includes direct and indirect cost in addition to a component representing the societal willingness to pay. The result of using the available damage cost values is that the monetised estimate will be lower than if abatement values for all emissions are used. However, this analysis was not aiming to derive an accurate monetary valuation, but to determine an initial assessment of the effects.

Table 8-5: Damage cost values (TRL)

Damage cost values (€/t)			
	Low	**Central**	**High**
CO[26]	1.1	1.8	2.2
HC[27]	264	339	385
NO_x	749	961	1092

Table 8-6: Abatement cost values for NOx (Defra/DfT value, 2008)

Abatement costs (€/t)			
	Low	**Central**	**High**
NO_x	31,539	32,437	80,825

Table 8-7: Shadow price of carbon (DfT value[28])

WTP costs (€/t)			
	Low	**Central**	**High**
CO_2		28.6	

8.3.1 Valuation of tailpipe emissions

Using the test data recorded for each tampering type, a comparison of the measured emissions in the tampered condition with those in the original condition was made. The emission values (see Table 8-5 to Table 8-7) were applied to this difference in order to quantify the effects of tampering. The effects from those emissions that are currently regulated was estimated separately to those for CO_2.

It was necessary to estimate the distance travelled by each L-category vehicle type in order to estimate the annual effects. This was achieved by multiplying the Euro per kilometre above and the data on annual kilometres travelled (see Table 8-1 in section 8.1.1).

[26] AEA Technology report value

[27] Defra/DfT value (2008)

[28] http://www.decc.gov.uk/assets/decc/what%20we%20do/a%20low%20carbon%20uk/carbon%20valuation/shadow_price/background.pdf. Page 21.

8.4 Methodology for the assessment of noise effects

The HARMONOISE road traffic noise prediction model allows a limited evaluation of the potential impacts of tampered L-category vehicles under normal traffic conditions. Consider an urban road; with 30 mile/h (48 km/h), steady-flowing traffic, with 3% of the traffic being comprised of l-category vehicles. The software predicts that if 35% of those vehicles having been tampered with, then the increase in the equivalent continuous noise level $L_{Aeq,1h}$ (see Equation 8) is negligible compared to the same scenario where none of the motorbikes have been tampered with, being approximately 0.05 dB(A). Note that 35% of the fleet being modified is the default parameter in the software.

Equation 8: Noise level notation

Where:

L = Sound pressure level

 # = Percentage of the time that the sound exceeded the given level

eq = (equivalent) Average sound level over the time period

#h = Time in hours that the measurement was taken over

night = 8 hours from 11pm to 7am, assumes "Aeg" i.e. 'A' weighting and average value over the time period

Note: The design manual for road and bridges (DMRB) by the DfT (department for transport in the UK), classifies noise impacts of 0.1 – 0.9 dB(A) (based on $L_{A10,18h}$ levels) as negligible. Since almost all sounds vary or fluctuate with time it is helpful, instead of having an instantaneous value to describe the noise event, to have an average of the total acoustic energy experienced over its duration. This is the index commonly used when describing road traffic noise and can best be explained as the noise level in decibels (dBA) exceeded for 10% of the measurement period; in this case for the 18 hours between 06:00hrs and 00:00hrs. DMRB also includes noise nuisance curves based on $L_{A10,18h}$ levels. However as noted above, the effects of tampered motorcycles on 18-hour traffic noise levels is likely to be very small.

Motorcycle noise will be most significant at locations where traffic flows are low and the background noise levels are low. As such, it is the disturbance caused by the individual vehicle that is most significant to residents and is likely to be of greatest disturbance in the home. The 1979 report by Nelson reports on findings from the 1972 national noise survey – it is likely that whilst levels might have changed, current relative perceptions may not be greatly different.

For passenger cars, at speeds above 20 km/h tyre/road noise becomes the dominant noise source. However, this rule does not apply to motorcycles due to the differing number and type of wheel and the unenclosed engine.

The WHO website states that "According to a European Union (EU) publication, about 40% of the population in EU countries is exposed to road traffic noise at levels exceeding 55

db(A), 20% is exposed to levels exceeding 65 dB(A) during the daytime and more than 30% is exposed to levels exceeding 55 dB(A) at night."[29]

A report by the Cyclists' Public Affairs Group (Anon., 2003) quotes statistics from 2002 as published by Defra[30]. It stated that more people report hearing traffic noise than any other external noise and of those, 78% objected to motorcycle/scooter noise compared to 72% for heavy lorries and 64% for cars and vans. Even though there were relatively few PTWs, 69% of people reported being "annoyed" by PTW noise compared to 65% and 63% for heavy lorries and cars respectively. Obviously, this does not distinguish between tampered and untampered PTWs; these percentages relate to average traffic and not the less frequent tampered vehicles that may cause greater, more disturbing noise.

A report by TRL (Muirhead M, 2008) examined the monetised benefits of proposed changes to type approved noise limits for tyres. This used a baseline cost for noise reduction of €27/dB(A)/household per year, for a baseline year of 2006 (FEHRL, 2006), and a conservative estimate that in the UK there were approximately 23,910,000 houses where the closest source of noise was a road with a speed limit ≤ 50 km/h.

Ainge *et al.* (2007) proposed a method for assessing the disturbance caused by night-time traffic. This linked steady-speed pass-by noise levels (i.e. not type approval levels) to the percentage of people highly sleep-disturbed using established dose-response relationships. The equations could potentially be adapted to include motorcycles but only consider the change in noise due to traffic over an 8-hour period, i.e. L_{night}.

8.5 Summation of cost benefit analysis

Based on the valuation exercises described in the preceding sections, a cost was obtained for each experiment. However, before these figures can be used they need to be consolidated into the nine main areas of the vehicle, as used in section 5.

Two assumptions were made in performing this calculation:

- Each of the tampering modes performed on one vehicle in a single experiment caused an equal proportion of the effect, although in some of the test data the effect can be attributed to one specific modification this was not definite;
- Each of the tampering modes that covered one area of the vehicle caused an equal proportion of the effect on the fleet.

Therefore, the sum cost of emissions and safety was first divided by the number of modifications performed in that experiment, and then the mean was found for all of the costs attributed to a single vehicle area.

Using the approach described, estimates for the monetary value of the casualty and emission saving if tampering in each vehicle area could be prevented entirely (see Table

[29] http://www.euro.who.int/en/what-we-do/health-topics/environment-and-health/noise/facts-and-figures (No reference given at source)

[30] DEFRA (2002) Digest of Environmental Statistics, Noise, tables 6.4(a) and 6.4(b)

8-8Table 8-8 below) the full values found for legislated emissions, CO_2 and safety are presented in Appendix O.1. Although some areas show a negative damage cost, generally there is still damage caused, but this has been outweighed by other costs from another experiments or areas and should not therefore be considered a benefit.

Table 8-8: Tampering costs to the EU per year for each vehicle area, for all values see Appendix O.1

		Modification Cumulative modifications equally split amongst areas								
Proportion of time between tampered and untampered max speed	Proportion of fleet tampered	Air/fuel Rich	Air/fuel Lean	Fuel Pump (Diesel)	Carburettor	Air Intake	Exhaust	Transmission CVT	Engine Crankcase ventilation	Engine Capacity
1/4	10%	-€ 13.1 M	-€ 0.9 M	-€ 3.4 M	€ 2.8 M	€ 11.9 M	€ 68.5 M	€ 84.4 M	-€ 7.8 M	€ 7.4 M
	20%	-€ 27.1 M	-€ 1.4 M	-€ 6.8 M	€ 5.8 M	€ 24.4 M	€ 139.8 M	€ 168.9 M	-€ 15.6 M	€ 15.5 M
	30%	-€ 40.7 M	-€ 2.0 M	-€ 10.2 M	€ 8.6 M	€ 36.6 M	€ 209.8 M	€ 253.4 M	-€ 23.5 M	€ 23.2 M
	40%	-€ 138.8 M	€ 36.9 M	-€ 13.0 M	€ 24.1 M	€ 55.9 M	€ 317.8 M	€ 325.7 M	-€ 39.1 M	€ 43.1 M
1/2	10%	-€ 8.0 M	-€ 0.9 M	-€ 6.9 M	€ 2.8 M	€ 22.5 M	€ 128.9 M	€ 172.7 M	-€ 12.7 M	€ 12.4 M
	20%	-€ 16.9 M	-€ 1.4 M	-€ 13.8 M	€ 5.8 M	€ 45.7 M	€ 260.6 M	€ 345.4 M	-€ 25.4 M	€ 25.4 M
	30%	-€ 25.3 M	-€ 2.0 M	-€ 20.8 M	€ 8.6 M	€ 68.5 M	€ 391.0 M	€ 518.2 M	-€ 38.1 M	€ 38.1 M
	40%	-€ 118.2 M	€ 36.9 M	-€ 27.1 M	€ 24.1 M	€ 98.5 M	€ 559.4 M	€ 678.8 M	-€ 58.6 M	€ 63.0 M
3/4	10%	-€ 2.8 M	-€ 0.9 M	-€ 10.5 M	€ 2.8 M	€ 33.2 M	€ 189.3 M	€ 260.9 M	-€ 17.6 M	€ 17.4 M
	20%	-€ 6.6 M	-€ 1.4 M	-€ 20.9 M	€ 5.8 M	€ 67.0 M	€ 381.4 M	€ 522.0 M	-€ 35.2 M	€ 35.4 M
	30%	-€ 9.9 M	-€ 2.0 M	-€ 31.3 M	€ 8.6 M	€ 100.4 M	€ 572.2 M	€ 783.0 M	-€ 52.8 M	€ 53.0 M
	40%	-€ 97.7 M	€ 36.9 M	-€ 41.2 M	€ 24.1 M	€ 141.0 M	€ 801.0 M	€ 1,031.8 M	-€ 78.2 M	€ 82.9 M
1	10%	€ 2.3 M	-€ 0.9 M	-€ 14.0 M	€ 2.8 M	€ 43.8 M	€ 249.7 M	€ 349.2 M	-€ 22.5 M	€ 22.3 M
	20%	€ 3.7 M	-€ 1.4 M	-€ 28.0 M	€ 5.8 M	€ 88.2 M	€ 502.2 M	€ 698.5 M	-€ 45.0 M	€ 45.3 M
	30%	€ 5.5 M	-€ 2.0 M	-€ 41.9 M	€ 8.6 M	€ 132.4 M	€ 753.4 M	€ 1,047.8 M	-€ 67.5 M	€ 68.0 M
	40%	-€ 77.2 M	€ 36.9 M	-€ 55.4 M	€ 24.1 M	€ 183.6 M	€ 1,042.6 M	€ 1,384.9 M	-€ 97.8 M	€ 102.8 M

It is acknowledged that any tampering prevention measure is unlikely to prevent all tampering. Again, these values are presented in the context of scoping the magnitude of potential savings and in examining relative differences between tampering types. They are not intended to be definitive benefit estimates, because the actual cost-effectiveness of these measures will depend on a range of other factors such as;

- the extent to which the results from the test programme are more widely applicable to other models,
- the level of tampering in the current fleet, and
- the cost involved in developing and implementing any tampering prevention measure.

A possible way of interpreting the results is by taking the costs for differing tampered fleet sizes, choosing the appropriate probable change based on the confidence in the anti-tampering measure devised and finding the difference.

8.6 Break-even analysis for cost of tampering prevention measures

Analysing the specific cost of tampering prevention measures was beyond the scope of this project. However, initial tentative valuations for emissions and safety were used to estimate break-even costs for measures to address the harmful tampering. The purpose of this was to include an initial examination of likely cost, so that a tentative examination of the cost-effectiveness could be attempted. The results of this analysis are sensitive to the assumptions and are included here for relative comparison of those areas which might be worthy of further consideration. More detailed data, which was not collected or

available to this project, could be used in the future to validate the cost categorisations, or expand them to a more detailed level.

The break-even analysis for the cost of potential tampering prevention measures was performed based on the following assumptions:

- The results observed in this test programme can be applied more generally to the full range of L-category vehicles
- The estimates for fleet size used were as presented in Table 8-1
- The benefits from prevented emissions and improved safety are accrued for:
    - 5 years for motorcycles (L3e)
    - 3 years for all other L-category vehicles
- The costs are for fitment to:
    - The entire L-category fleet for emissions
    - L1e fleet for safety
- The values represent the cost at which measures which are 100% effective break-even (BCR =1), bearing in mind the assumptions used.

The estimated break-even cost for prevention measures are presented in Table 8-9 below:

Table 8-9. Initial estimates for break-even tampering prevention costs

		Modification Cumulative modifications equally split amongst areas								
Proportion of time between tampered and untampered max speed	Proportion of fleet tampered	Air/fuel Rich	Air/fuel Lean	Fuel Pump (Diesel)	Carburettor	Air Intake	Exhaust	Transmission CVT	Engine Crankcase ventilation	Engine Capacity
1/4	10%	-€ 6	€ 3	-€ 102	€ 17	€ 30	€ 19	€ 71	€ 1	€ 2
	20%	-€ 12	€ 5	-€ 203	€ 35	€ 61	€ 40	€ 142	€ 3	€ 4
	30%	-€ 18	€ 8	-€ 305	€ 52	€ 92	€ 60	€ 213	€ 4	€ 6
	40%	-€ 74	€ 47	-€ 390	€ 144	€ 131	€ 103	€ 281	€ 18	€ 10
1/2	10%	-€ 1	€ 3	-€ 208	€ 17	€ 59	€ 34	€ 143	€ 0	€ 3
	20%	-€ 2	€ 5	-€ 415	€ 35	€ 118	€ 69	€ 286	€ 1	€ 6
	30%	-€ 4	€ 8	-€ 623	€ 52	€ 178	€ 103	€ 429	€ 1	€ 9
	40%	-€ 54	€ 47	-€ 813	€ 144	€ 246	€ 161	€ 569	€ 14	€ 15
3/4	10%	€ 4	€ 3	-€ 314	€ 17	€ 88	€ 48	€ 215	-€ 1	€ 4
	20%	€ 7	€ 5	-€ 627	€ 35	€ 176	€ 98	€ 430	-€ 2	€ 8
	30%	€ 11	€ 8	-€ 940	€ 52	€ 263	€ 146	€ 645	-€ 3	€ 13
	40%	-€ 35	€ 47	-€ 1,237	€ 144	€ 360	€ 218	€ 857	€ 9	€ 20
1	10%	€ 9	€ 3	-€ 420	€ 17	€ 116	€ 63	€ 287	-€ 2	€ 5
	20%	€ 17	€ 5	-€ 839	€ 35	€ 233	€ 126	€ 574	-€ 4	€ 11
	30%	€ 25	€ 8	-€ 1,258	€ 52	€ 349	€ 189	€ 861	-€ 6	€ 16
	40%	-€ 16	€ 47	-€ 1,661	€ 144	€ 474	€ 276	€ 1,145	€ 4	€ 24

The costs shown above represent the maximum cost for the anti-tampering measure to break-even over the timeframe considered in the assumptions. Considering larger timeframes for the benefits means that the break even cost will be lower than the values presented here.

The costs used do not necessarily represent the total cost to the manufacturer. This is dependent on the types of vehicles made by the manufacturer, the number of vehicles they produce and the technologies they employ in their design. Initial values have been

used simply to allow an analysis which highlights areas that may be cost-effective to address.

Simplifying and combining the data shown in the previous Figures,

Table 8-10 shows the relative magnitude of costs for safety and emissions, and simply the dB increase for noise for each vehicle area. They have been ordered by the break-even value and the rounded values are based on assumptions that 20% of the fleet are tampered in each case and that they utilise the resulting maximum speed increase 50% of the time.

Table 8-10: Summary of results of cost benefit analysis

Tampering type	Safety	Emissions	Noise	Break-even
Transmission - CVT				€ 286
Air Intake				€ 118
Exhaust				€ 69
Carburettor				€ 35
Engine capacity				€ 6
Air/fuel lean				€ 5
Engine crankcase ventilation				€ 1
Air/fuel rich				-€ 2
Fuel pump (diesel)				-€ 415

Where:

(red)	**High**	**A significant negative effect**
(orange)	**Medium**	**A medium negative effect**
(green)	**Low**	**A negligible negative effect**
(white)	**None/Unknown**	**Unknown or no negative effect**

A limited analysis of which vehicle categories anti-tampering measures in each vehicle areas would effect is presented in

Table 8-11 below. The vehicle areas applicable to a specific category will depend greatly on the technologies employed by the manufacturers, and how this changes with time. Generally,

Table 8-10 shows which tampering control areas are applicable for the current fleet, but it also shows areas for the future.

Table 8-11. Vehicle category tested and estimate of how results can be generally applied to other l-category vehicles

Tampering type	L1Ae	L1Be	L3e-A1	L3e-A2	L3e-A3	L5e	L6e	L7e
Air/fuel Rich	✓	✓	✓	✓	✓	✓	✓	✓
Air/fuel Lean	✓	✓	✓	✓	✓	✓	✓	✓
Fuel Pump (diesel)						✓	✓	✓
Carburettor		■	■	■	■	■	■	■
Air Intake	✓	✓	✓				✓	✓
Exhaust	✓	✓	✓	✓	✓	✓	✓	✓
Transmission - CVT		✓	✓			✓	✓	
Engine Crankcase Ventilation		■					■	
Engine Capacity	✓	✓	✓				✓	

Where:

✓= tampering type currently applicable to a large proportion of this vehicle category

■ = tampering type either applicable to a small proportion of this category, or likely to be applicable in the future

Adjusting the air/fuel ratio, or replacing the exhaust effects every category because it influences emissions as well as performance, whereas restricted air intakes are only present in a fewer subcategories. A key area is the carburettor; this, by all accounts, obsolete technology is currently widely used, but is phasing out rapidly as the cheapest vehicles are equipped with electronic controlled fuelling and spark angle.

With reference to Table 8-9, measures to address a number of tampering types do not appear to be good prospects for cost-effectiveness. However, based on the assumptions made, areas to focus further research and attention can be identified.

9 Anti-tampering measures

Taking all of the information collected by the project, a full assessment has been performed to devise viable solutions that could, if selected by the European Commission, be implemented in the revised legislative text. Consideration has been made with regard to the stakeholders involved and the limitations noted in the testing methodology. In this sense some areas which have been previously considered not to be cost beneficial, or dropped from the testing programme, have nevertheless been assessed for possible measures. Potential new or amended legislative text has been proposed where appropriate.

9.1 Transmission – CVT

For L1e vehicles, CVT modifications (removal, changing the ratio etc.) can have large effects on maximum vehicle speed. The results from the test programme and subsequent analysis suggests that measures to prevent such modifications are amongst the most likely to achieve cost-effectiveness, if implemented successfully. However, it is likely that implementing requirements for the CVT would be the only area where an addition, rather than an amendment to the existing legislation would be required.

The emissions recorded for this area were lower than in the initial condition; this is because the tampered vehicle has increased performance, but is being driven according to an identical test cycle as was the untampered vehicle. In the real world, a vehicle with greater speed capabilities may be ridden faster (for the same journey) and therefore may not actually realise these emission benefits. These effects cannot be quantified without the inclusion of driver behavioural factors in the test.

The CVT and whole transmission assembly or "automatic gearbox" used in mopeds, quadrimobiles, and some motorcycles performs three functions:

- Controls the engine to wheel gear ratio
- Controls the power curve, i.e. the relationship between a given speed and gear ratio
- And may also contain an automatic clutch

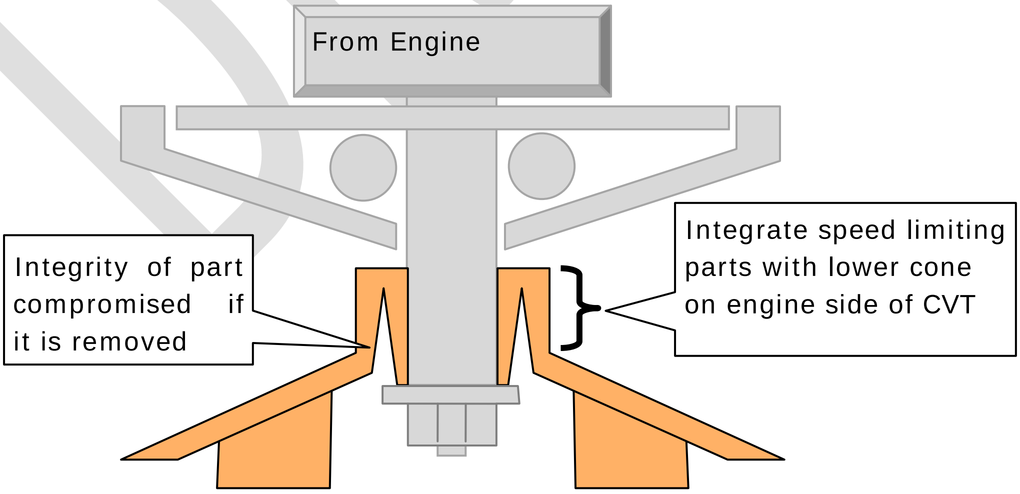
The second two have not been shown to affect a legislated limit, although they will change driveability and the performance characteristics. Only the first one was indicated as causing a change to the maximum vehicle speed under normal driving conditions. This is achieved by the removal of the rotation speed limiting rings, washers or plates. These are used to limit the highest transmission ratio to the appropriate level in a gearbox, which may be used on many different vehicle models. However, these parts can be easily removed and discarded with minimal technical knowledge or cost.

One way to prevent this would be to require that they are physically part of the cones, i.e. cast as one piece. This would make the removal of the limiter more difficult because it would require sawing the part off with some skill to prevent the high speed rotating part from becoming unstable, although a lathe could be used this is not a common tool for most people to poses. Nevertheless, it would make a currently free, simple and highly effective modification into a costly or high skilled one. On the other hand there

may also be potential cost increase, since requiring this may make it more difficult for manufacturers to use common parts in different models, thus increasing costs through reduced economies of scale.

Figure 9-1: CVT kit[31]

It is already common practice to replace one side of the cone (the side containing the rollers) amongst enthusiasts (see Figure 9-1). However, these kits are designed to change the engine speed to transmission ratio, changing the level of torque available at different rotation speeds, and not necessarily increase the vehicle speed. Therefore, rather than creating an anti-tampering method, which would be easily circumvented with commonly available aftermarket parts, the rotation speed limiting addition could be added to the other cone (i.e. the 'fan').



[31] Photo from product website

Figure 9-2: Anti-tampering method: CVT: limiter integration[32]

In addition, the cone could be so designed that the rotation speed limiting rings are fundamental to the structural integrity of the part and removing them would destroy it. In some vehicle the limiter is a plate at the back of the cones, the same principle could be applied here.

Another way could be to stop the vehicle from functioning if the limiting rings or plates were removed. The diameter of one or more cones could be such that, if the limiters where removed, the belt would slip out of position and lose traction. However this could be dangerous if it occurred at high speeds.

It can be seen that the cones could always be replaced or modified to allow the cone to get closer together, but the shrouding around the wheel side of the CVT could be so designed that if the cones came too far apart it would cause interference and so prevent it from occurring (see Figure 9-3). The design of this shrouding could be done in such a way as to be easily visible to enforcement authorities if it was replaced or adjusted. This option could be much more costly to the user to try to replace, effectively being the entire swing arm for the rear wheel, but this would also be true for the manufacturer.

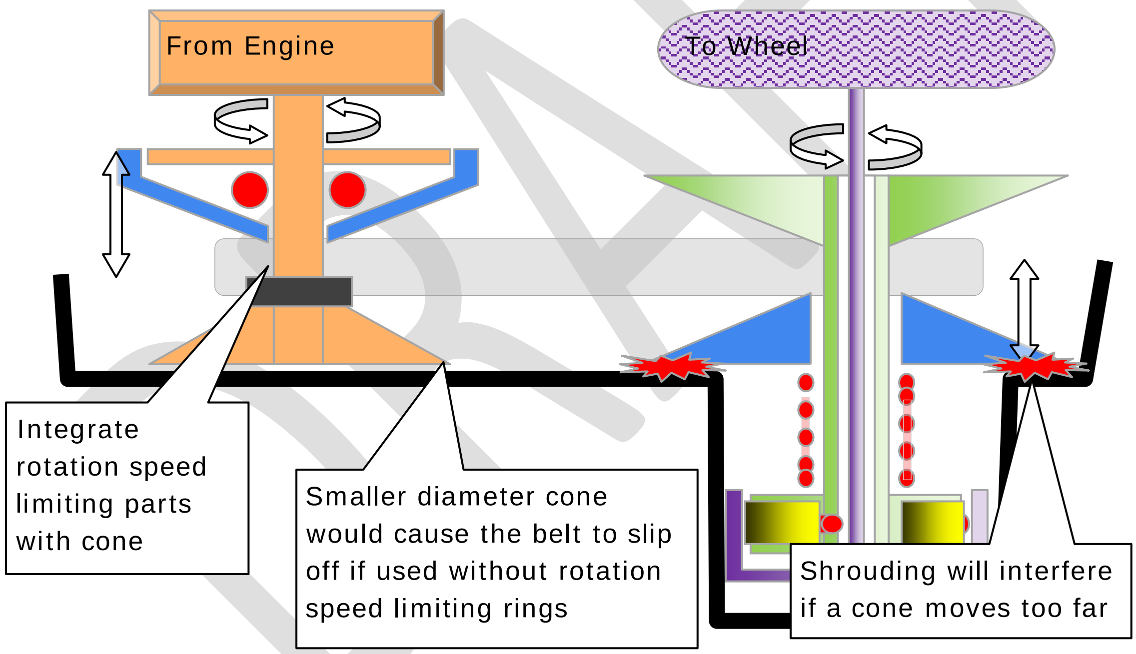


Figure 9-3: Anti-tampering methods: CVT[33]

As said previously the CVT performs many functions, and it also contains three parts which can be considered consumables. Firstly, the belt, these are generally made from reinforced rubber and over time sag and break. Additionally there are pads in the

[32] Diagram copyright TRL

[33] Diagram copyright TRL

automatic clutch which can wear over longer periods, and the rollers that control the engine to wheel speed which rub and eventually must be replaced.

A possible way of preventing the modification of the CVT would be to prevent access to the internal working with bolts accessible only with special tools. However, as this area is so full of consumables it is likely that doing so would necessitate all vehicle maintenance businesses to own these tools and enthusiasts would quickly duplicate and sell them openly. Doing so would also prevent users from performing the general maintenance of checking the belt, to allow its replacement before a catastrophic failure.

9.2 Air intake

There are two parts of the intake to investigate, the air filter and the intake system itself. Simple modifications, such as those involving removing (or replacing the air filter) return positive break-even estimates. The current legislation already has an article relating to mopeds, and this is looked at further in 9.7.1 below.

As for the intake system, there is currently an obligatory choice of three methods specified to restrict the air intake on learner motorcycles (L3e-A1 vehicles):

1. A removable sleeve fitted inside the air inlet,
2. a restricted section in the pipe (visible from the outside), or
3. a restriction in the air inlet to the engine itself.

The stakeholder study indicated that the first option is generally known to be easy to circumvent. There is a requirement that the object itself must be destroyed in the process of removal, to prevent it being reinstalled before an inspection. However power and speed restricted vehicles rarely last until any sort of roadworthiness inspection, as the user will have already progressed to the next licensing step and changed vehicles. In addition, without knowing how that specific vehicle is restricted they may not look for its removal.

Therefore to prevent this restriction being bypassed the option of a removable sleeve could be removed as a permissible design. The other two options are much harder to circumvent without damage to the vehicle. Although the third option is the most severe, it would prevent the engine being used for other purposes where the restriction is not needed and so option two of using a restriction as part of the intake pipe design should still be allowed.

This requirement for the design of an air restriction is only for applicable to learner motorcycles. There is no further rule, so Mopeds (L1e) may have a restriction at the manufacturers' discretion but it will not be tested and does not have to be difficult to remove. Without overriding the discretion of the manufacturer, the rules could be applied to Mopeds (L1e) as well, e.g.:

"If the manufacturer chooses to fit a restriction to the air-intake, it must adhere to the design rules for learner motorcycles (L13e-A1)"

9.3 Exhaust

The prevention of tampering to the exhaust is very complex. There are many parts to the design of the exhaust that effect emissions performance, and noise. It is also a part which is replaced on a vehicle as part of normal maintenance because high temperatures, combined with harsh chemicals and environmental conditions such as rain and salt cause it to corrode and fail. In addition, the replacement of the entire exhaust is commonly done by enthusiasts. Therefore, the problems cannot all be solved through type-approval for new vehicles and measures for aftermarket parts which are not approved for road use must be considered. These and other measures are discussed in the following sections.

9.3.1 Orifice

Removing the exhaust orifice(s) results in an increase in emissions and combined with other changes made to L1e vehicles, can also increase the maximum vehicle speed. The tentative break even analysis indicates that measures to prevent removal of the orifice (not just that the orifice cannot be replaced) have the potential to achieve positive cost benefit values. The current legislation already covers this area, and so any new measure here would simply represent a strengthening of existing requirements.

The stakeholder study indicated that the removal of a restriction orifice from the exhaust was common. However, unlike with the air inlet, this was generally performed on aftermarket exhausts.

Aftermarket exhausts are sometimes indicated as approved for use on the road, but by removing the orifice restriction, they can be converted to 'race' exhausts. This will be studied further in section 9.3.4 below.

Within the type approval process, and the anti-tampering legislation, the requirement for restrictions in exhausts is the opposite of the situation for other areas. It states that *"no artificial restriction is permitted in the exhaust system"*. Taken together with a preceding article, this means that if a vehicle has, in its original condition, a restriction orifice, the removal of it will not cause the vehicle to exceed its legislated speed and/or power limits. The removal of this could, however increase the noise level, but as mentioned previously, this legislation does not consider noise levels.

Figure 9-4: Exhaust orifice[34]

Information from stakeholders, the TUV report and the testing undertaken as part of this research all suggested that the orifice was easy to remove. Sometimes using the tool provided by the exhaust manufacture to 'tune' the exhaust once fitted. If there was a requirement that the exhaust orifice should not be a removable part, for example if it was integrated with another main part of the exhaust or welded into place, it would be likely to considerably reduce the incidence of tampering.

9.3.2 Effective length

A modification technique used in some European countries is to remove parts of the pipe internal to the exhaust. This allows for a power increase without leaving any externally visible signs.

The legislation indicates that this pipe must be affixed internally in *"such a way that they cannot be removed"*. In this case 'cannot remove', indicates the use of devices such as shear bolts rather than normal bolts, such that it is difficult to remove rather than impossible. Simply sawing it off or drilling out the bolts is still possible, and because it is hidden there is no need to do so in a skilful way.

One solution to this would be a requirement that, the exhausts should be designed so that all pipe that might affect power output is visible from outside. After market exhausts are sometimes designed to fold back on themselves to achieve the required length in the given space available, vehicle manufacturers could follow suit. Following on from this it could be stipulated that whatever pipe is hidden, its removal will not allow the vehicle to exceed its legislated limits.

Another solution could be a requirement that the design of this part be critical to the integrity of the exhaust such that removing it would cause damage it. However, it is unlikely that anything could be designed that couldn't be fixed with some basic wielding, which is likely to be within the abilities of those performing the current tampering method.

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[34] Photo from product documentation

9.3.3 Disrupter (Stubber) pipe

The disrupter pipe is a short length of pipe that is fitted perpendicular to the exhaust flow (See Figure 19-4 in appendix C.3.1). This provides the backpressure used in a two-stroke engine to return unburnt mixture into the cylinder, but also has the effect of slightly limiting the performance. This design feature is used at the discretion of the manufacturer, and even though it can limit performance it does so without the need for a reduced diameter section.

To perform this modification the pipe is removed and the hole welded over, or the pipe can simply be crimped to remove its effect without cutting it off.

If it is known that this feature is supposed to be part of the exhaust, then simply looking for the modification is possible. The key problem is knowing if it is supposed to be there and where if should be upon inspection. The concept is not mentioned within the anti-tampering legislation and therefore is not marked.

A possible solution might not be to require this feature or to try to make it more difficult to remove, but instead, to provide markings or information so that enforcement authorities can know if it should be fitted and where to look.

Arguably the disrupter pipe is supposed to just provide the backpressure required for the engine to operate, and should not be used as a restrictor. It was suggested in the stakeholder information that this should be specified in the legislation as a reversed anti-tampering measure, requiring that upon its removal a performance increase is not achievable.

9.3.4 Aftermarket parts

As mentioned above it is common practice to replace the exhaust entirely, for both enthusiasts and maintenance. Yet, the aftermarket exhausts tested, though technically permitted, showed design features that caused the vehicle to fail legislative type-approval tests. In addition, they were designed to be configurable, either to fit various vehicles or to be adjusted to the user's preference. This enabled them to be tampered with ease, allowing the vehicles to exceed emissions, performance and noise limits.

It is inappropriate to use the anti-tampering legislation to tackle the problems presented, as this only covers the design of whole vehicles. Instead, the rules covering the approval of after-market exhausts need to be improved and additionally any measures taken from the previous sections on the permitted design need to be taken across. The conformity of production or market surveillance methods used for the manufacturer to apply the current R or CE marking may need to be adapted to match any changes.

To counter the problems with adjustability of aftermarket exhausts, they need to be designed in such a way that it is not possible to bypass limits. This may necessitate that a replacement part has to be adjusted to the vehicle for which it is intended and these adjustable parts welded in place before the part can be shipped, specifically orifices or brackets that change the effective length. These anti-tampering methods would of course stop short of welding the entire exhaust together, which is unnecessary and, for some vehicles, would make installation impossible.

If a supplier wishes to make a road legal and a racing version of an exhaust these should not be convertible from one to the other easily. This would make the possibility of

converting a vehicle for a short term change in performance specifically for track days a more technically complex task, though not impossible. While it is likely that off road vehicles will be brought into line with road emission standards in the future similar measures are not anticipated for performance and noise limits.

The literature study also presented the issue of a non-road legal or 'race' exhaust being used on the road. These models or variants of other road legal models are designed for activities such as racing or cross-country riding. These are marked as such, but inconspicuously. Improving the conspicuity of the marking for the off-road exhausts (see Figure 9-5) and, in particular, requiring marking on multiple sections of the exhaust would be expected to offer benefits. Although this marking could still be covered, it should assist enforcement authorities in discovering a breach of legislation, and also discourage users from considering the option for risk of getting caught.

Figure 9-5: Example of conspicuous exhaust marking

One of the exhausts tested was a quite specialist aftermarket product, designed for high performance vehicles. Using a connection to the throttle, it bypassed the catalyst in an attempt to protect it. This not only increased the emissions but also the sound level significantly. The use of a bypass to protect the catalyst seems counter intuitive. If the emission abatement system is bypassed there can be no reason for having it except to pass an emissions test.

Figure 9-1: Catalyst bypass exhaust[35]

Emission abatement parts, such as catalytic converters do restrict the flow, and therefore some enthusiasts do remove them or replace the exhaust with one without it. One reason for this is the concept of a 'sacrificial catalyst' i.e. the catalyst is designed to only allow the vehicle to pass the type-approval test, after a insignificant amount of driving the catalyst stops functioning and is simply a burden on the exhaust flow and weight.

The problem of sacrificial catalysts would be solved with the introduction of a Type V durability test. In addition to this, to dissuade enthusiasts from removing it the issue of flow could be tackled. Article 3.5 Appendix P states that "no artificial restriction is permitted in the exhaust system" if its removal would allow a performance increase (≥10% power), and the catalytic converter could be considered as such a restriction.

9.4 Carburettor

As mentioned previously, modern types of carburettor which use electronic control loops to control the air/fuel mixture may continue to be used in the future. Therefore, it may not be advisable to remove or except them from any current controls. This should be re-examined in the future if carburettors do fall out of use, however as the legislation is designed, if the feature isn't used it presents no burden on the manufacturer or type approval authority.

Controlling their modification with anti-tampering designs is difficult; by their nature they are easily adjusted and modified. Three areas of the part present a route for modification: The adjustment of valves and vanes such as the throttle and choke, the replacement or modification of nozzles and jets, and the interference with control signals to the device.

To prevent adjustment is not possible, it is required for proper tuning and maintenance, however the extent to which they can be adjusted can be. Any adjustment screw should only be adjusted by the small amounts required for the proper maintenance of that vehicle. If the part is used in multiple vehicles, where this adjustment amount could change, any excess thread one way could be drilled out, and a non-removable stopper fitted to prevent over screwing the other.

One method to prevent the replacement of nozzles of different sizes is the use of special tools to install and replace them; however over time these tools become available on the open market and would only present an inconvenience of low monetary significance.

[35] Photo from product documentation

Alternatively, for all performance restricted vehicles there could be a special thread, this could be reversed of a certain pitch or diameter which is not currently used. This thread would have to be standard amongst all vehicle manufacturers and non-limited parts would be forbidden to use these threads. There may need to be a range of threads to cover the range of l-category vehicles without allowing 'interchangeability'. Additionally the material at needle inlet could be hardened or brittle, so that re-tapping the thread to add larger parts is difficult.

UN legislation related to a similar part has wording which could be applied here: "In the case of mechanical fuel-injection pumps fitted to compression-ignition engines, manufacturers shall take adequate steps to protect the maximum fuel delivery setting from tampering while a vehicle is in service." (UN Regulation 83, Section 5.1.5.3., page 14). Rewording it to state:

"In the case of mechanical fuel delivery system, manufacturers shall take adequate steps to protect the maximum fuel delivery setting from tampering while a vehicle is in service"

To prevent the consequence of modification of its control signals, firstly there could be a limit along the lines of that for the adjustment screws, so that no matter the signal the carburettor stays within an accepted adjustment range. Secondly the integrity of the signal could be queried and the vehicle react accordingly, such as go into limp home mode. Alternatively the signal from the ECU to the carburettor could be digital and/or encrypted.

To bypass all of the methods presented above, the entire carburettor could simply be replaced. Although a costly modification it may still be done if the gains were considered to be worth it. In this case the carburettor could be marked prominently as being a performance limiting one, which would be noticeable if the vehicle was inspected closely, such as painting it a standard colour.

9.5 Areas which may be beneficial in specific areas

Five vehicle areas in the testing programme showed either a low or negative benefit to cost ratio (BCR). The areas with a low benefit may still be implemented cost effectively if a low enough cost solution can be devised. Two of the three vehicle areas showing a negative overall BCR showed a positive BCR in one of the three harmful areas (safety, emissions, or noise). With this is mind the possible solutions to the five areas are presented below.

9.5.1 Engine capacity

One modification fundamentally changes the engine to that of a larger capacity (see Figure 9-6). In the tests performed this modification showed a small performance benefit, however as this modification is technically changing the engine into another it was felt that a greater performance could be gained following comprehensive configuration and tuning.

Figure 9-6: Increased engine capacity[36]

This advanced modification cannot be prevented through a change to the design of an engine because they are designed specifically for every engine design and replace major parts. However tools to detect it could be made available to the enforcement authorities. This would mean that instead of having to consider the cost to change the design per vehicle (€3), one would instead measure against the cost for enforcement authorities to purchase and use a tool at test centre or road-side inspections. If these tools are already used in testing station, the road-side inspectors could be made aware of their availability.

One method may be to remove the cylinder head and physically measure the sweep and diameter however this is time consuming and difficult, not likely to be performed at the road-side. Another method used by race scrutineers is the use of a Burette. This is used to measure the amount of liquid (such as alcohol or paraffin) that can fill the combustion chamber through the hole for the spark plug or glow plug, and taking the difference between top and bottom dead centre (TDC and BDC). The liquid then needs to be drained from the combustion chamber and either disposed of or recycled, and the engine cleaned and returned to a usable state. But even this seems excessive to consider performing unless there is evidence to suspect the test is required, such as a visible clue to the parts being changed.

Using some very rough estimates a new break even value can be calculated for the amount of vehicles which can be tested for it to be cost effective (see Table 9-2). This gives a value of 1.2 M vehicles.

[36] Photo from product website, need permission

Table 9-2: Increased engine capacity testing breakeven calculation

Description	Estimate values and calculations
Mid estimate[37] damage cost value	€ 25.4 M
Burette cost	€10
Number of burettes purchased by enforcement authorities and/or test stations	10,000
Paraffin cost	€5/litre
Vehicles tested per litre (Assuming a mixture of 50 cm^2 and 125 cm^2 vehicles tested)	10 vehicles per litre
A labour cost per test	€20
This gives a rough estimate of the break even of 0.25 M tests per year.	__________________

This process of measure the cylinder capacity is highly accurate, though the tampering method is usually intended to increase the volume by large amounts. Therefore a simpler and less untidy take on this could be to insert a bladder or balloon and fill this with a fluid, the accuracy would be dependent on the bladder's flexibility and the compressibility of the fluid used to fill it. This tool would still only be implemented if there was evident need, but would be easy to transport and use in these cases.

9.5.2 Engine crankcase ventilation

This modification, which was presented by stakeholders as being performed on some vehicles showed anomalous results. It would seem that the removal of crankcase ventilation reduces performance and increases emissions.

Therefore, a suitable method of preventing this being done would be education. If it was known that this harmed performance, users are not only more likely to not do it they may also keep the link from the crankcase to the air intake maintained. Manufacturers could, as part of their product manuals, indicate that if a reduction in performance is noticed that the crankcase ventilation should be checked for problems such as blockages.

9.5.3 Air/fuel ratio

In the work on the air/fuel ratio, the actual ECU was not modified, but instead, its signals were modified using a sophisticated bypass system. This methodology does not fully test its 'tamperability', but rather the effect of changes to the other components in the vehicle. It also took a very simplistic view on the change to the air/fuel ratio, sticking to a fixed value related to the maximum torque area at full load (see Figure 6-1), and not taking into account the possible deviation (see Figure 6-3) in maximum performance for differing throttle and engine speeds.

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[37] Mid estimate taken as 20% of the fleet tampered and tampered maximum speed ridden as 50% of the time

It is for these reasons, although the break-even costs showed no benefit, the stakeholder and literature information should be taken as being superior to the results obtained and air/fuel ratio should be kept in the anti-tampering legislation and manufacturers should continue to devise methods of protect the designed fuelling strategies. However, with the current evidence it is difficult to comment on cost-effectiveness.

Excluding mechanical adjustment methods, the air/fuel ratio can be tampered by: modifying the signals from sensors, changing the ECU's response to given signals, modifying the signals leaving the ECU or changing the fuel delivery systems response. This can be done by replacing parts, adding additional components to effect the signals, or reprogramming the electronic components.

Parts which can change the air/fuel ratio include the: lambda sensor, air flow sensor, air pressure sensor, air temperature sensor, engine speed sensor, vehicle speed sensor, throttle position sensor, and the ECU. To tamper with the air/fuel ratio the user is generally not required to perform any complex procedures or design anything themselves, instead modules, software or parts can be purchased online and simply plugged in.

One anti-tampering method could be to monitor the integrity of the signals two and from parts. If the signals are analogue they may either change in voltage or resistance to indicate a value, hidden signals could be overlaid and monitored for a difference, but it is not too complex to take this into account and the tampering module to be designed around it.

Instead of using simple methods with analogue data, the signal could be encrypted and/or digital, this would require the sensor to have some internal logic, however, this is simply moving the electronics from the ECU to the sensor and should not cause an overall increase in whole vehicle cost.

With this change the tampering method would either have to decrypt and duplicate an alternative signal or the sensor itself could be replaced or modified to again intercept the analogue signal within the device.

Replacing parts is an obvious way around any inbuilt blocks, however from the stakeholder consultation it was found that some manufacturers use a method of matching keys between significant components. In their model; the ECU, fuel injector and ignition key came as a set and one could not be changed without the other. If different parts were installed, the vehicle would simply refuse to start. This method could be used for other components if necessary.

The third method is to reprogram the ECU, to change what it outputs for a given input. This will be looked at further in section 9.6 below.

9.5.4 Fuel pump (diesel injector pump)

This part is very simple, using the engines rotation to provide both the pumping force and the timing of the stroke. The adjustment of a screw changes the amount of fuel injected per stroke.

As with the carburettor (see section 9.4), preventing adjustment is not viable, it is required for proper tuning and maintenance, however the extent to which they can be

adjusted can be. Any adjustment screw should only be adjustable by small amounts required in the proper maintenance of that vehicle. If the part is used in multiple vehicles, where this adjustment amount could change, any excess thread one way could be drilled out, and a non-removable stopper fitted to prevent over screwing the other.

Taking the general requirements of a modification not permitting a performance by ≥5 km/h or power by ≥10 %, or exceeding the legislated limits:

"The adjustment of the direct injection fuel pump must not increase engine performance."

And the reworded UN legislation (UN Regulation 83, Section 5.1.5.3., page 14) could apply to this technology just as well:

"In the case of mechanical fuel delivery system, manufacturers shall take adequate steps to protect the maximum fuel delivery setting from tampering while a vehicle is in service"

Additionally, although it seems unlikely that this antiquated technology will be used, some alternative fuel vehicles have been found to perform well using compression ignition and direct injection. Therefore, the word diesel should not be used thereby creating a loophole for future vehicles.

9.6 Powertrain/Engine Control Unit (PCU/ECU)

The ECU (or multiple ECUs) receive(s) the signals from various sensors around the propulsion system and based on a program, outputs the required signal to the actuators such as the air and fuel delivery systems or the ignition system. A PCU performs the functions of an ECU and in addition controls the automatic gearbox (CVT) and/or automatic clutch(es) (robotised manual gearbox). The program does not calculate values, but instead uses logic and lookup figures to choose the appropriate pre-calculated value. This simplicity allows the ECU to perform at the required high speeds without significant electrical power use or processor complexity.

Depending on the complexity of the vehicle, the ECU can perform many functions that affect the performance; for instance, it can change the air quantity (electric throttle control), injection timing, injection quantity, and spark timing, all of which will have differing effects. As such, treating the ECU as a single tampering area in the same way as the other testing was not possible.

Instead the intended effects were looked for, and the ECU used as necessary to achieve this. Taking the short list of actions the ECU could perform, the TRL SENOD tool showed only the air/fuel ratio as an area of possible concern, as discussed in section 9.5.3 above.

Although the ECU cannot be looked at as a single vehicle area in terms of tampering it can be in terms of anti-tampering measures, and a single anti-tampering measure for the device could limit some or all of the performance changes mentioned above.

Two articles in the current legislation cover areas which could be performed by the ECU, articles 3.7 and 3.8 (see Appendix P). These rules inversed in that they don't help prevent tampering but limit the use of certain performance restriction methods. Article 3.7 states that any component that limits full engine load is forbidden (if its removal would allow a performance increase), while article 3.8 forbids inhibiting the spark and

excessive spark advance/retard to prevent wastage of fuel and/or the release of excessive HC into the atmosphere or forbid spark advance to significantly boost propulsion output performance beyond type-approved limits.

Although articles 3.7 and 3.8 are sound in practice, they may seem ambiguous in how they are written, which may lead to misinterpretation. The rules on the inhibition of the spark events could be separated into its own article, and as it can be seen that this action could have detrimental effect on the environment, perhaps made compulsory.

In addition to the article mentioned above manufacturers already use a range of techniques to protect the ECU and the literature obtained from stakeholders contains a few methods. Measures used by some manufacturers already:

- Encrypted ECU data
- Protect ECU data to prevent extraction
- Lock ECU so that data cannot be downloaded
- Physically restrict the ability to exchange processor
- Communication between chipped key, ECU and injector so that neither can be replaced or modified independently
- Communicate with critical sensors digitally and perform input/output rationality diagnostics, therefore preventing the signals being easily modified

All of the options mentioned above could be used with varying degrees of success depending on the technologies used on the vehicle and the level of sophistication in the implementation of the measure.

Looking at the measures from an electronics point of view, not one of the options stated is impossible to circumvent, and neither is it likely that an infallible measure will ever be found. Although some may be difficult or expensive to bypass at the moment, if pushed and given enough time, a method will be found and market forces will make it become widely available.

So rather than specifying set criteria, a minimum level of protection and difficulty to tamper could be used. Type approval authorities and manufacturers could work together to keep an up to date minimum level of protection to attain these requirements for new vehicles.

The type approval authorities should monitor and adapt the acceptable level of protection based on market surveillance to find if methods to bypass anti-tampering measures have become widely available, The assessment and changes should be performed on a yearly basis, and implemented community wide, providing due time for manufacturers to implement any changes to design.

Whatever methods are used they should not prevent proper maintenance, updating of the software by the manufacturer, and when OBD systems are used, the transmission of error signals for both affiliated and independent garages and users wishing to perform checks.

With these locks and restrictions on the ECU it become increasingly difficult to test whether a modification had taken place, one easy method is to extract and compare the software either bit-by-bit or by comparing checksums with the original install at type

approval. But if the ECU prevents extraction it would be impossible to do so. Allowing the ECU to do the check could be programmed to always output that it is untampered whether it is or not.

To allow proper testing of the software under such situations we have devised a test method, involving the use of standard OBD to computer communication and a test file recorded from the original type approved vehicle. The ECU would need to be designed in such a way that it would assume that it was communicating with the vehicle. The software would then run the ECU through a simulated test cycle and monitor the ECU's responses. Given appropriate tolerances, any changes to the ECU's programming could be detected.

The test file could be made by the manufacturer or type approval authority and submitted to enforcement agencies and/or garages.

9.7 Removal of performance gain

Some areas, be it in the vehicles design or changes that can happen when in use, cannot or should not be prevented. One such area is already recognised and dealt with in the current legislation:

"Removing the air filter must not have the effect of increasing a moped's maximum design speed by more than 10%." (Directive 97/24/EC, Chapter 7, article 2.4.)

9.7.1 Air filter in mopeds

The removal of the air filter is not only simple, but has to be retained as the user's responsibility in order to undertake maintenance. Additionally, removing the air filter is liable to cause damage to the engine. By limiting the performance gain attained, the user is less likely to be motivated to attempt such a modification.

The effect of this rule is that the manufacturer will design the air intake and air filter more efficiently; this is a benefit to the user. During the research into tampering methods, the concept of using a "free-flow" air filter was mentioned as a possible tampering method on larger vehicles, it is therefore reasonable to expand the scope of this to all performance restricted vehicles. This expansion will complement article 2.3.5 which applies to learner motorcycles, that states that apart from the restriction in the air intake that there is no other section which, if modified, could increase vehicle performance by more than 10%.

However, it is unclear whether this article (2.3.5.), or a similar rule on the design of exhausts: "Without prejudice to the provisions of 2.3, no artificial restriction is permitted in the exhaust system..." (article 3.5.) is interpreted like this. For instance although no physical restriction such as a narrowing of the pipe is allowed, disrupter (stubber) pipes are, which restrict the flow using resonance. Similarly, a simple bend in a pipe will retard the flow even if the pipe's diameter does not narrow.

9.7.2 Fuel

Another change to the vehicle, which could cause a performance increase but which cannot be called tampering, is the use of different fuels. The use of high-octane fuel, was also put through the testing, cost benefit and break-even analysis (see Table 9-3). As

mentioned in section 6.8.1, this calculation is based on a single vehicle, which was designed for use with performance fuels, but it gives an indication of a possible future issue.

Table 9-3: High-octane fuel: Cost benefit and break even analysis, emissions only

Proportion of fleet tampered	**Cost benefit**	**Break even**
10%	*-€ 11.4 M*	*-€ 6*
20%	*-€ 23.3 M*	*-€ 13*
30%	*-€ 34.9 M*	*-€ 20*
40%	*-€ 71.0 M*	*-€ 40*

The cost calculations show a negative figure, because overall it generated a benefit for both the legislated emissions and CO_2, but as this was a high performance vehicle increases in maximum speed were not measured.

Control loop based fuel delivery systems have already progressed into the lower power L-category vehicles, and technologies such as knock and pinking sensors together with spark timing adjustment are following (see Figure 9-4). When combined with high octane fuels these systems can provide noticeable environmental and propulsion performance gains.

Figure 9-4: High-octane fuel: applicable categories

L1Ae	L1Be	L3e-A1	L3e-A2	L3e-A3	L5e	L6e	L7e
	■	■	✓	✓	■	■	■

Where: ✓ = currently applicable; ■ = likely to be applicable in the future.

Therefore, legislation similar to that for air filters could be used. However in this case, as it is almost definite that a performance gain will be achieved, and preventing this would be a detriment to the environment, only a limit up to the legislated values could be used, i.e.:

"For performance restricted vehicles, if the vehicle has the capability to adjust the spark timing of a propulsion engine, when used with high-octane fuels in no case may the maximum design speed or maximum net engine power of the relevant category be exceeded."

It may be necessary to define a standard high-octane fuel. However, due to the continued advances in fuel technology it is likely that this may create a misalignment in the future, so it may be best to choose an appropriate fuel on the market at the time.

This separation of performance between the test fuel and those available on the market may be happening to other fuels, such as diesel.

9.7.3 Ambient temperature

A third type of on unpreventable performance gain is the effect of atmospheric conditions on the vehicle. All testing on L-category vehicles is performed at fixed temperature and pressure range (with the exception of durability testing, which has no defined temperature or pressure limits). The standard is based on the average environmental conditions and not on optimal conditions for engines.

Therefore a cold day or high pressure weather could cause a performance boost, and a hot day or low pressure weather could cause a performance loss. In addition, an engine does not start easily when cold, so a choke is used to provide an especially rich mixture to aid in warming it, this may give a performance boost in itself.

It may be challenging but not impossible to prevent the effect of ambient conditions (temperature, pressure and humidity) on vehicles' environmental and propulsion performance. For example, the same rules as with the previous two sections could be applied.

"ambient temperatures from ## to ## °C and pressure between ## to ## mbar, shall not allow the vehicle to exceed the limits of its category. This may be verified by testing only the worst case scenario"

In addition, the Commission will perform an environmental effect study in 2016 in which the need for off-cycle environmental requirements will be assessed. If deemed feasible and cost-effective this could help L-category vehicles tested under real-world random ambient conditions to be better approximated as tested under narrowly defined, laboratory-type of testing conditions in terms of environmental performance.

10 Other options for changes to the legislation

In addition to the anti-tampering measures to specific vehicle areas, other changes to this and other legislation may help in improving the prevention of tampering. This includes clarifying, opening or limiting the scope and removing loopholes or caveats that may not be compatible with current technologies.

10.1 Introduction to the legislation

From the start of the project, there were some strong views from both riders and industry regarding the anti-tampering measures for L-category vehicles. This may partially stem from the complexity of the current legislation and the scale and scope of any proposed changes to the powertrain prevention Annex and the implications to vehicles currently in use.

Therefore in addition, in the delegated act for vehicle construction, it would be prudent to layout and clarify its purpose in the introduction to the Annex. i.e. that the revised anti-tampering legislation is not directed towards riders or vehicle owners regarding modifications of L-category vehicles already in use and on the market, but to manufacturers of new vehicles. Also any proposed changes to the powertrain tampering prevention measure will only be applicable once the new legislation comes into force for new types of vehicles (currently indicated to be 1st January 2016) and to new vehicles in production (currently indicated to be 1st January 2017). Some possible example text is as follows:

"The type approval process performed by manufacturers aims to ensure that a L-category vehicle will attain a high level of functional safety and environmental protection.

"The level of protection required by the type approval legislation may be linked to the capabilities or characteristics of one or more other parts, and tampering with them may harmful such as invalidating the protection afforded by the type approval process.

"'’modification' means the adaption, repair, replacement or the fitting of an additional part (or parts) to the vehicle.

"'’tampering' or 'harmful tampering' means a modification which has a detrimental impact on safety and/or the environment."

Although it is not related to the type approval process, reiterating the reasoning for performance restrictions and anti-tampering legislation of these restrictions could be used in other documentation (see Figure 10-1):

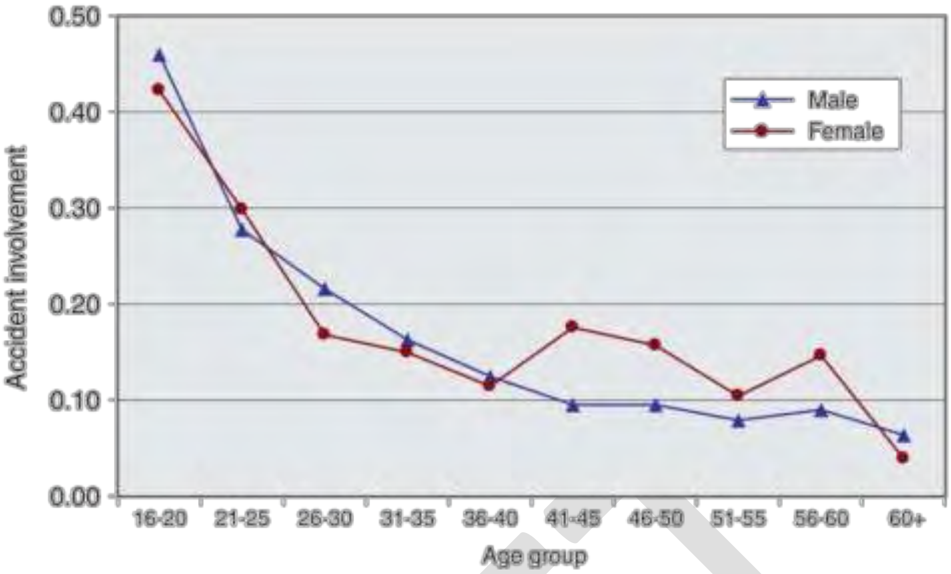

Figure 10-1: Age group, and probability of accident involvement (Sexton, et al., 2004)

"As a rider gains experience their likelihood to be involved in an accident decreases *Users attain the right to use vehicles of greater performance (speed and/or propulsive power) based on age and experience. e.g. Bicycles → Low speed powered Cycles → Mopeds → Learner Motorcycles → Higher performance Motorcycles.*

The precise progression varies between member states."

10.2 Scope

As with the introduction to the legislation the scope of the vehicles covered by the legislation could also be clarified, both in terms of which vehicle categories are included in terms of which of the measures cover each of the categories.

In deciding the scope there are two main areas of concern; functional safety (related to propulsion performance) and emissions (noise, gaseous and particulate emissions). When considering just measures which restrict performance the anti-tampering legislation should only cover propulsion performance restricted vehicles, which could be defined as:

"Propulsion performance restricted vehicle' - a vehicle in a category with an upper propulsive power or vehicle speed limit which is used by EU and/or national legislation for vehicle classification and licensing, including all L-vehicle categories"

Note: Propulsion performance restricted vehicles currently include: L1e, L2e, L3e-A1, L3e-A2, L6e and some L7e.

However, there are some aspects of the legislation which prevent environmentally damaging design features or easily bypassed propulsion performance restrictions, such as the prevention of restrictions in the air intake and exhaust and prohibiting the use of environmentally unfriendly spark retard and inhibiting strategies. It may be beneficial if these practices were applied to the entire L-category fleet.

Therefore the scope of the entire chapter would be all L-category vehicles, but certain articles could be applied only to the propulsion performance restricted vehicles.

10.3 L3e-A2 motorcycles which can be de-restricted

Some L3e-A2 motorcycles are specifically designed to be derestricted after the user has gained the required experience to progress to the next performance level. Currently the measures used to restrict the vehicle and the legal framework and responsibilities of the parties involved are not defined.

This has led to some measures being easily bypassed before the user has gained the experience necessary to protect the safety of them and others on the road.

Examples include the removal of a single screw using an easily obtained security bit, the removal of a sleeve in the air intake with a pair of pliers, the replacement of the ECU which is provided with the vehicle at the time of purchase.

A possible option would be to include a range of restriction measures within this legislation, defining certain design restrictions. However, due to the varying design of vehicles this may become overly complex. Instead a level of difficulty in de-restricting could be described but this may be difficult to define for the type-approval authorities.

A more important area is the assignment of responsibility for deciding when a de-restriction can be performed and by whom. One route could be through the manufacturer checking the user's documentation, but this would require them to understand the specifics of vehicle licensing legislation in each of the member states. Instead it may be necessary for the licensing authorities to issue the user with a permission document when the user has gained the required experience. This could then be submitted to whoever the manufacturer has permitted to perform the de-restriction or if the user themselves would do it, the manufacturer would only release the parts upon the receipt of the document.

It may be prudent for the manufacturer to hold the derestricted part, software update or special tools, this service could be included in the sale price to discourage users bypassing the legal requirement simply due to cost. All leftover parts would have to be returned to the manufacturer who could then inform the licensing authority that the de-restriction process has completed. Insurance companies could also be included in the process, requiring disclosure of the process taking place before it can be performed.

The majority of this process would be part of other legislation. The following are a few examples of text which could be used in the anti-tampering legislation:

"'De-restricted vehicle' - a performance restricted vehicle which is legally permitted to be converted from one category to another. These must pass all type-approval requirements for both categories.

"If a software update is used, it shall be serial number locked."

This would allow it to be sent to or downloaded to the user or their chosen garage, without fear of the file being further distributed.

"If a mechanical restriction is used, the part shall be fitted in such as way that a special tool is required to remove it, and externally visible evidence is left if the part has been removed."

Note, a de-restricted vehicle is likely to be an L3e-A2 motorcycle which can be converted into a L3e-A3.

10.4 Redundancy

As indicated by the results of the testing programme, some tampering methods do not cause an increase in performance unless performed together with other tampering methods. The anti-tampering legislation as it stands may not highlight these issues. Therefore it has been proposed by stakeholders and the EC that modifications should be tested in combination during the type-approval process.

Having requirements for specific types of performance restriction is contrary to the current design freedom afforded by the legislation. Some vehicles are able to stay within the legislated limits without any sort of restrictor, the manufacturer electing for the design route of right-sizing the vehicle technologies, i.e. for the vehicle to be naturally able to keep within the maximum power and maximum vehicle speeds of its category. This type of design should be encouraged.

However amongst all of the areas tested, one part showed an ability to increase the speed of even the most underpowered vehicles, that being the CVT. It could therefore be a requirement that the restriction of this part be removed while testing the other areas of the vehicle. If such a method is used, this should be written such that a CVT which is designed to not require a limiter (it cannot provide transmission ratios above those required by the vehicle’s category) is permitted and therefore encouraged.

10.5 Pollutant emissions

The anti-tampering measures for performance restricted vehicles are tested accordance with criteria relating to changes in maximum vehicle speed and propulsive power. It was suggested from the stakeholder consultation to consider also including a measure of pollutant emissions.

There is currently only one article in the legislation which specifically prohibits the increase of emissions. This article is not an anti-tampering measure but rather a design restriction to prevent bad practices concerning the use of adjusting the spark angle to limit propulsion performance. Article 3.8 states that no increase in HC is permitted, it does not give a tolerance band and does not specify which test would be used to verify this.

Due to the variability in testing, a criterion of no change is unworkable and therefore a margin (even if it is a very small one) should be specified.

If emissions are included in the criteria there are two choices for a test: Type I, emissions while performing a driving cycle or Type II, emissions at idle or high idle. Depending on the technologies used in the vehicle it may have to perform this test multiple times therefore it may be preferable to specify the lower cost test. However, the specific criteria required to activate an environmentally damaging restriction may not be activated in the type II test.

Reducing the performance using restriction measures for safety reasons can and does increase some emissions, therefore trying to balance the anti-tampering measure would be a complex process.

The performance criteria is based on not surpassing the categories limits in addition to a maximum difference, if emissions were included in the criteria only the categories limits need to be used as the increase of emissions are rarely an encouraging factor in tampering.

Overall it seems that the current practice of only specifying an emissions test when necessary is still reasonable. But the inclusion of some tolerance should be given and in principle, the Type I or II tests should be used as necessary to verify any change if there are any doubts whether a powertrain modification is harmful or not.

10.6 Noise

Three vehicles were tested: a moped tampered specifically to increase noise, a moped tampered in a way which was not specifically aimed at increasing noise, and a motorcycle with an aftermarket exhaust fitted. In all cases the sound levels, in dB(A), increased significantly.

However it has also been shown that the increase of noise is not limited to the modification of any one part or even just the exhaust and air intake, but also a general increase in propulsion performance. Therefore the anti-tampering measures for preventing increases in propulsion performance will also help prevent increases in sound levels.

Additionally the EU will accede to a range of revised UN regulations on sound for the various L-category vehicles (UN regulations R9, R41, R63 and R92). In these regulations a range of requirements have been put forward which dictate how the exhaust and air intake are designed (see Appendix Q). Some of which are similar to the provisions shown in section 9.3, therefore removing the need for some new measure to be specified in this legislation.

To aid in reading the legislation, a reference to the UN regulations could be added so that these additional anti-tampering requirements can be easily found.

"Restrictions on the design of anti-tampering measures on the air intake and exhausts with regard to sound performance of L-category vehicles will be those Additional Sound Emission Provisions (ASEP) prescribed by UN regulations R9, R41, R63 or R92"

10.7 Braking

The brake testing performed did not show that an increase in maximum vehicle speed caused significant heat fade (see section 7.2). The vehicle tested seemed to use off the shelf parts which were designed to be usable on larger heavier vehicles, but the testing was performed on a very small sample of mainstream vehicles. It is reasonable to assume that these manufacturers will be keeping costs down by reducing the range of parts produced or bought in by using them on a range of different models. On the other hand smaller and international manufacturers offering fewer different models may instead choose to use brake systems better matched to the specific vehicle's requirements.

There remains a risk that increased maximum vehicle speed could cause braking system problems where vehicles are equipped with brake systems designed to be just adequate

for the original specification of vehicle. The following measures would help to minimise this risk.

One method which can be seen is the requirement of vehicles to have improved brake systems, capable of working at much higher speeds then the vehicle's maximum design speed. However this is adding cost to all vehicles, even those which will never be modified, which means a cost burden for users that do not indulge in harmful tampering.

Instead, the issue could be considered from the viewpoint of enthusiasts and custom vehicle designers following the legal path as explained in section 2.

Markings could be used to assist in the customizer in understanding the capabilities of the braking system. The manufacturer could specify a maximum design speed for a given mass or masses of vehicle and mark this on the parts. Alternatively, this information could be provided in the vehicle manual.

To complement this information, the motorcycle single vehicle approval test could be adapted. If the vehicle had been designed to increase its maximum vehicle speed then a heat fade test (possibly simplified) could be undertaken to verify continued compliance.

In the current rules only a roller brake test is performed, which cannot be used to quantify fade. There is the option of performing a track test for some vehicles, however the track available may not be sufficient to allow the vehicle to reach the higher speed required for a heat fade test. On the other hand, testing stations may have a brake dynamometer, which could be used to perform the test.

10.8 'Interchangeability' of non-identical parts

Currently there are rules on what parts a manufacturer can make which could replace certain components on a propulsion performance restricted vehicle (see article 2.1.). They are not permitted to manufacture anything which would increase the restricted vehicles performance by the criteria (≤5 km/h or ≤10 % power).

There are two areas of these requirements that could be improved; the list of components does not include technological advances to the fuel delivery system, and it does not prevent the 'interchangeability' of non-identical parts between manufacturers and/or suppliers.

The current components included are: cylinder/piston combination, carburettor, intake pipe, and exhaust system for all L-category vehicles, and cylinder head and camshaft for four-strokes only. To keep with current technological advances, the PCU/ECU and powertrain management could be added since this area is also paramount for the appropriate environmental and propulsion performance levels of L-category vehicles. Due to the design of the ECU, it is not necessarily directly connected to any component, and so the term 'fitting' is not applicable. While adding the whole part (or parts) to the article would not be practical, the software could be added. This would prevent the manufacturer from making available PCU/ECU software which could increase propulsion performance beyond type approved criteria, even after it is on the market. The manufacturer should be able to provide improved software, but this should require re-approval.

The software would need to be checked to ensure that the same version is being used at all stages in the type approval process. This can be done by allowing it to be interrogated via the OBD connector to provide a checksum and an ID detailing pertinent information such as the hardware, software and/or vehicle manufacturer, the vehicle model and variant, the software's production date and version number as well as a way of indicating if it is considered alpha (unstable or in early stages of development), beta (stable but still in testing), final, or type-approved. Software which is considered Beta or final could be then upgraded to type-approved after testing. It should be noted that allowing software to be accessed in a way which would allow the checksum to be generated for checking would in effect provide a possible route for the software to be extracted so that it can be tampered with. It could therefore be permitted that this access is only possible during the type approval process, and an appropriate method is devised so that access to the data used in the final vehicle is prevented, while still able to provide the identification information.

The fuel injector is quickly becoming the standard, replacing carburettors as the method of supplying fuel to the engine. Therefore it is logical to include this part in this article. The difficulty with this is that the injector is not necessarily made by the vehicle manufacturer, but an off-the-shelf part bought in from a specialist supplier. Unless the part is of a custom design specified by the vehicle manufacturer, this legislation would not prevent suppliers or after-market suppliers from making interchangeable parts of differing capabilities. However, as this would be a replacement component key to the environmental and propulsion performance of a type-approved L-category vehicle, a manufacturer of such a component should first be required to prove to the approval authority that the approval requirements remain fulfilled prior to placing such a component on the market.

Due to this issue, the legislation may need to be expanded to include all manufacturers (including suppliers). This creates the problem that different manufacturers would need to know each other's designs prior to manufacture. To prevent this issue, certain sizes, shapes, threads and fittings could be reserved for performance restricted vehicles. See Table 10-1 for an example concept for fuel injectors. This classifies injectors by throughput and specifies a fitting type.

Table 10-1: Example restriction on injector fittings

Code	Fitting examples	Maximum fuel flow examples	Maximum pulse speed examples	Other measures…?
A	Left hand	1 cm^3/s	500 Hz	?
B	2 mm pitch	1 cm^3/s	750 Hz	?
C	3 starts	3 cm^3/s	750 Hz	?
D		3 cm^3/s	1000 Hz	?
Not restricted	Any others			

These are of course just examples to illustrate the point, the actual flow characteristics and metrics will have to be carefully designed to match the range of vehicles in the L-category fleet, and even those used in M, N and non-road vehicles. No new threads or fittings will need to be invented, as there have been many types and sizes designed over the years, but it would be important to ensure that whatever is chosen considers the designs of the past so that legacy parts cannot be used.

10.9 Throttle stop

Directive 97/24/EC, chapter 7 article 3.7 state "Any component (mechanical, electrical, structural, etc.) which limits full engine load (e.g. a throttle control stop or a twist-grip stop) is forbidden".

Therefore, the concept of a throttle stop as a way of limiting performance is already forbidden. However it is unclear as to what other limiters this includes:

1. Mechanical stop on the hand or foot control
2. Mechanical stop in the link to the throttle (carburettor or sensor)
3. Electrical stop limiting signals over range (i.e. electronics cap high voltages from sensor)
4. Electronic stop limiting signals over range (i.e. software round down high values)
5. Electronic stop reducing maximum fuel at high vehicle and/or engine speeds

According to the mainstream interpretation of this article, items 1 and 2 are forbidden. However, according to the strictest interpretation of the wording, with current technologies in mind, items 3 to 5 may also be forbidden. Further clarification of the scope of this article would be advantageous.

Item 5 is currently used as an effective performance restricting method and also has benefits for anti-tampering and emissions without endangering driveability if the limit is applied gradually by scaling down the increase in throttle towards the high end, rather than capping the last 20% of response at a fixed value. Item 5 could be permitted if the scope of the article is revised and if the feature is implemented such that the response becomes proportionately lower. Rather than changing current text, a following article could clarify that item 5 is permitted:

"An electronic or software-based scaling down of throttle output at high loads, vehicle speed and/or engine speed is permitted"

This would not be an anti-tampering requirement, but a mechanism of limiting vehicle or engine speed that could be used by a manufacturer. For the purposes of anti-tampering legislation there could be a restriction on the adjustment of any such control, so that it is appropriately protected from modification.

10.10 Markings

One of the requirements of the existing legislation is that certain components deemed critical to the performance of the vehicle must be marked in a way that allows the competent authorities to identify if the correct component is fitted. This approach has the advantage of relative simplicity and low cost but also has the disadvantage that

critical components can be positioned in places that are not very accessible without partial dismantling of the vehicle. In addition to this, the examiner needs to be knowledgeable about where to look for the components and what the markings on them mean which may be preparatory for a given manufacturer.

The current requirements aim to mitigate these disadvantages by requiring the vehicle to be fitted with a plate identifying the location of parts and the relevant codes that should be found on them. In addition a number of modern marking technologies have been considered (discussed in more detail in Appendix S), however it seems that none are able to greatly improve on the current system, they are high cost and open up new routes to bypass requirements.

In regards to any cost benefit calculations, it has been stated by some stakeholders that because the information is so difficult to use, they do not make it part of any checks. Only the exhaust, which is easily seen and considered a key indication of modification taking place, may be checked for driving offences, all the other parts' markings may only be used by police forces if the vehicle is suspected to be stolen. This creates a cyclic argument, because the data is not greatly utilised improving it would not provide a large benefit, while if the marking system is not improved it will not be utilised.

Rather than improving the markings themselves more assistance in locating the marking and recognising discrepancies could be made available. As the enforcement authorities have to deal with such a wide range of vehicles, they cannot easily know about the features of every vehicle they come across. Therefore, all environmental and propulsion performance critical components could be documented in a way that is easy for the authorities to access:

- A regularly updated book, such as that used to detail emissions and CO_2 from cars, or emissions at high idle for measurement when servicing
- A European or worldwide database
- Indication on the Anti-tampering control plate

The third option does have the risk of teaching people where to modify their vehicle, so the first two options may be preferable. These options would require no additional cost or work on the part of the manufacturers because it would simply use and consolidate data which is already collected at type-approval, although the forms used in the process could be updated to make it simpler to do so.

Currently only mopeds and learner motorcycles (L3e-A1, 125 cm^3) must have the anti-tampering control plate. This could mean that by removing the label an enforcement authority may be tricked into thinking it was not covered by the legislation. Therefore it may be useful to extend this to all performance restricted vehicles or even all L-category vehicles. As some of these vehicles are not covered by the anti-tampering measures and changing parts is not an issue, it could require a smaller set of data, such as simply the category and whether or not the vehicle is permitted to be derestricted.

The anti-tampering control plate will need to be updated to use the L-category system (see article 3.10.2.1.2.). This system is more complex and so may make it more difficult to identify whether a vehicle should be restricted, also the enforcement authorities will take time to learn the new system. It may be prudent to include both systems for a period of time (for 1 or 2 Euro emission steps for instance), a mark could be used to

indicate whether the vehicle is liable for a vehicle speed or power restriction with an (vs) or (p) following the category information and also show any additional national restrictions. Here is an example of how this could look:

Moped: *"L1Be (≤25km/h)(vs)(4kW)(p) | A"*

Motorcycle: *"L3e-A3" | D"*

This shows the: category, maximum allowable vehicle speed, maximum allowable Net power, followed by the legacy method for categorisation separated by a bar symbol.

In its current form it could take a lot of space and would be difficult for machine reading. Therefore superfluous spaces and brackets can be removed, hyphens show where a restriction isn't part of the category and values in fractions of a kW could use preceding zero to indicate the location of a decimal point e.g. 250W → 025P. Additionally, Power to weight (or mass) ratio used on L3e and L4e A1 and A2 subcategories could also be shown if thought necessary: e.g. 0.1 kW/kg → 01PW and 0.2 kW/kg → 02PW respectively. And for quadricycles the maximum mass could be indicated: e.g. 500M.

Therefore this alternative could be used:

Moped: L1Be25VS4P-PM-M | A

Motorcycle: L3eA1-VS11P01PM-M | B

Motorcycle: L3eA3-VS-P-PM-M | D

Quadricycle: L6Be45VS6P-PM425M | A

10.11 Anti-tampering type-approval test methods

The current legislation does not explain how the specific requirements are to be verified, it would be useful for both the manufacturers and type-approval authorities to have a standard and consistency across the various authorities in the EU.

As mentioned in section 10.4 above, if emissions are specified in an article, the vehicle could use the Type I and/or II test. For propulsion performance the tests are laid out in Directive 95/1/EC and will be set-out in the REPPR (Regulation for environmental and propulsion requirements) in the new legal package on measuring maximum vehicle speed and Net power. Maximum vehicle speed is measured on a test track or dynamometer and Net power is measured using an engine fitted to an engine dynamometer.

It can be seen however that some measures could be checked by simply inspecting design drawings. Article 3.4 for instance requires that rotating the piston does not increase performance, if it can be seen that the piston is symmetrical no test would be required. Also it may be feasible to use a simulation of gases flowing through vehicle parts to ascertain the locations of restrictions for instance.

"The manufacturer shall ensure that the vehicle complies with powertrain and noise abatement system tampering prevention measures. The type approval authority shall verify this manufacturer obligation by witnessing or conducting appropriate tests and in addition by performing documentary checks, such as inspecting design drawings, inspecting documents indicating the manufacturer has performed physical or simulated

testing, inspecting the vehicle, appropriate physical tests on vehicle parts, and performing legislative tests as laid out below:

"Maximum vehicle speed shall be tested in accordance with Regulation …

"Maximum Net and/or rated power shall be tested in accordance with Regulation …

"Emissions shall be tested using type I and/or II test, depending on which is most likely to expose the required information"

10.12 Flexibility in permitted vehicle configurations

Under the current EU and national level legislation when a part of the vehicles power train or noise abatement system is changed, it is considered a modification, and until it is checked and the vehicle's registration is updated by a technical service and the vehicle may be considered un-roadworthy.

In one of the MCWG meetings, an example was used where a vehicle that had the sprocket on the final drive changed in a routine manner (when used on differing road surfaces) would have to be taken for re-inspection by a national technical service station each and every time it was swapped. Users may be doing this to coincide with when the vehicle must change to winter tyres, which is a requirement in some Member States.

A solution to this predicament could be to extend the type approval process to not just cover a single fixed design of a vehicle model but, for selected parts, a range of allowable configurations.

This could be done as part of the initial type-approval process or supplement the vehicles permitted configurations if enough users are requesting the option. This could be done with the help of the manufacturers.

For example, a standard type approved vehicle has a final sprocket with 20 teeth; however, 10% of the users wish to fit a sprocket with 25 teeth. The manufacturer could modify the vehicle and have the Type I emission test performed again. If it passed, rather than this modified vehicle becoming a variant, it will become permissible for all of these models to have sprockets between 20 and 25 teeth.

The manufacturer could then produce and distribute the required parts and perform the replacement at approved garages if the vehicle is in warranty. Or even package the vehicle with additional parts to change at the users' discretion.

The sections of the type-approval legislation that need to be retested will be dependent on the discretion of the type-approval authority.

10.13 Structure, layout and clarity

On reading the legislation in its current layout, it was easy to become confused and to misread the intentions of certain sections. It would be beneficial to clarify and to separate out the different measures according to their objectives and to which L-category vehicles they apply. Table 10-2 shows one possible way of presenting the anti-tampering legislation in a clear and systematic way.

Table 10-2: Example layout of the legislation on tampering prevention

<table>
<tr><th></th><th>Section</th><th>Content</th></tr>
<tr><td>1</td><td>Introduction</td><td>Clearly layout the intentions of the legislation
See section 10.1</td></tr>
<tr><td>2</td><td>Scope</td><td>Indicate that it covers all L-category vehicles with a vehicle speed or maximum power restriction, but there level of restriction decides what parts of the legislation are applicable.
See section 10.2</td></tr>
<tr><td>3</td><td>Figure of (sub)categories for vehicles that can be power/vehicle speed/noise/’de-restrictable’</td><td>
<table>
<tr><th>(Sub) Category</th><th>Speed</th><th>Power</th><th>‘De-restricable’</th><th>Noise</th><th>Markings</th></tr>
<tr><td>L1e, L2e, L6e</td><td>✓</td><td>✓</td><td></td><td>✓</td><td>✓</td></tr>
<tr><td>L3e-A1, L7e</td><td></td><td>✓</td><td></td><td>✓</td><td>✓</td></tr>
<tr><td>L3e-A2</td><td></td><td>✓</td><td>✓</td><td>✓</td><td>✓</td></tr>
<tr><td>L3e-A3, L4e-A3, L5e,</td><td></td><td></td><td></td><td>✓</td><td>✓</td></tr>
</table>
</td></tr>
<tr><td>4</td><td>Definitions</td><td>Definitions of terminology relevant to powertrain and noise abatement system prevention measure section.</td></tr>
<tr><td>5</td><td>Propulsion and environmental performance requirements in terms of tampering preventing measures</td><td>The main criteria for measuring propulsion performance and pollutant emissions increases could be kept in one place.</td></tr>
<tr><td>6</td><td>Type-approval test methods</td><td>See section 10.11. This section could include information regarding tests for enforcement authorities (the reference for which should be populated through performing type-approval testing by the manufacturer).</td></tr>
<tr><td>8</td><td>‘Interchangeability’ of non-identical parts</td><td>See section 10.8</td></tr>
<tr><td>9</td><td>Measures for vehicles that can be derestricted
(L3e-A2)</td><td>This will contain the legal responsibilities and if necessary references to articles in the following sections.
See section 10.3.</td></tr>
<tr><td>10</td><td>Obligatory anti-tampering measures</td><td>Such as the air-intake restriction on learner motorcycles.
See section 9.2.</td></tr>
</table>

	Section	Content
	(L3e-A1)	
11	Technology dependent anti-tampering measures	The majority of the anti-tampering measures will fit in this section.

The following areas which are either not anti-tampering or applicable to all vehicles via UN regulations shall be transferred to other, more relevant legislation.

Table 10-3: Parts of legislation not within anti-tampering section

	Section	Content
#	Reference to additional Anti-tampering legislation	The reference to the UN regulations on sound emission provisions. See 9.5.4, 10.6.
#	Performance restriction measures that are forbidden. (All categories)	This section contains the only parts which are also applicable to completely unrestricted vehicles such as L3e-A3. It forbids designs which increase emissions for the sake of performance restrictions (even ones applied at the discretion of the manufacturer) such as increased emissions on spark adjust. It also details certain designs which cannot be allowed to cause a performance restriction as they are too easy to circumvent, encourage environmental harm (like drilling out the cat), or would be instantly exceeding performance limits upon use by using the another available fuel over test fuel. See section 9.3, 9.7, 10.4.

10.14 Tolerances

The testing results also showed that, in addition to vehicle age, some non-tampering modes could affect results. This would not be part of the anti-tampering legislation but should be noted by enforcement authorities when devising any tests. This is related to the issues discussed in sections 9.7.2 and 9.7.3; further testing is required to devise appropriate tolerances bearing in mind variation in factors such as ambient conditions and fuel types.

10.14.1 Fuel

Using high-octane fuel is not a preventable occurrence (but exceeding the limit of the category would be prevented; see 9.7.2). Therefore, enforcement authorities should take

this into account if the performance has increased beyond the vehicles stated capabilities, but not if exceeding any limit.

10.14.2 Ambient conditions

Changes in ambient temperate, air pressure or humidity could cause the vehicle to perform differently by using a richer mixture, using more fuel, emitting more toxic emissions and generating greater power as a result. Variation in ambient conditions should be taken into account when performing tests during maintenance or by the enforcement authorities. Test results should be considered with prudence and within certain tolerance bands, rather than comparing the test results to one single maximum limit value. See section 9.7.3.

It is possible that the effects on performance of ambient conditions may be exaggerated by engine control systems on low-cost power and vehicles restricted in vehicle speed. For example, the system may adjust fuel injection or spark timing in response to the prevailing ambient conditions. To provide information which could be used to define appropriate tolerances for use by enforcement authorities, additional testing could be required at the type approval stage. This could include the Type IV test (an emission test performed with the vehicle cooled to -7°C) or a similar 'cold ambient conditions' version of the powertrain net power test and maximum vehicle speed test.

10.14.3 Noise

If noise is tested it is important for the tester to understand the effect of the logarithmic scale (see 5.2.5). In addition the inverse square law means that slight changes in distances when positioning test equipment will change the measurements. Furthermore testers should be aware that that human hearing perceives high pitch frequencies as being louder than they actually are and the importance of background noise emissions and the driving conditions under which the test verification is performed.

11 Impact assessment for cost-effective tampering prevention measures

11.1 Introduction

This study did not set out with a set of specific options to evaluate as was the case in previous studies involving an impact assessment. Instead, the project aimed to primarily quantify the effects of the tampering types judged to be most harmful and to develop proposed tampering prevention measures to mitigate against these harmful effects. This section provides an initial impact assessment of the proposed measures; a more detailed assessment would require another iteration of in-depth consultation and analysis. This is because of the range of potential measures identified, and the lack of specific information on technical feasibility and cost for specific measures obtained from the consultation phase, mainly because the detailed measures were unknown at the time of the consultation.

Previous research by (Robinson, et al., 2009)considered three broad policy options proposed by the EC (essentially "do nothing", repeal the existing tampering prevention regulation, or implement new, unspecified tampering prevention measures). With the information available at that time, (Robinson, et al., 2009)concluded that implementing new measures for anti-tampering was the preferred option and because it had the potential to deliver positive impacts with respect to economic, societal and environmental affects. However the economic impact (not including quantified societal and environmental costs) could be negative, depending on the specific measures selected and the stakeholders affected; the overall net economic effect (including quantified environmental and societal benefits) had the potential to be positive.

11.2 Candidate options for tampering prevention

After the break-even analysis (see section 8) and the consideration of other aspects not specifically tested, but for which other evidence indicates that these areas should also be considered, the following options of tampering prevention have been identified:

a. No change. Legislation concerning measures for anti-tampering for some L-(sub) categories remains unchanged and no new tampering prevention measures are implemented (the "do nothing" option).

b. Inclusion of the CVT in powertrain and noise abatement system tampering prevention requirements and specific technical solutions as follows:

   i. the rotational speed limiting component could be required to be fitted to the other cone of CVT to which it is currently fitted (i.e. the 'fan').

   ii. A cone of the CVT could be designed so that the rotational speed limiting rings are fundamental to the structural integrity of the part and removing them would destroy the component.

   iii. The diameter of one or more cones could be such that, if the rotational speed limiters where removed, the belt would slip out of position and lose traction.

c. Prevent removal of the exhaust orifice(s) by integrating the orifice into the fundamental exhaust design, since current measures do not prevent its removal.

d. **Remove the option of a 'removable sleeve' on the air intake system of 'learner' motorcycles (L3e-A1) as a permissible design.**

e. **Technical measures to prevent tampering with the PCU/ECU and input/output signals.**

f. **Improvements to markings used on 'off-road' exhausts**, thus providing more effective information to enforcement authorities.

g. **Measures to prevent tampering to electric L-category vehicles to activate the motor at levels greater than permitted at type approval.**

11.3 Analysis of impacts

It should be noted that while option A is mutually exclusive form the other options, options B to G could be individually or collectively applied. The impacts associated with these options are mainly societal, with respect to their safety and environmental benefits. There are also likely to be some economic impacts, as a direct result of these measures or as a secondary outcome from the safety or environmental impacts. The impacts outlined above are discussed in the following section in relation to the costs and benefits for the stakeholders.

11.3.1 Economic impacts

There are potential economic impacts associated with options B to G. These will have a direct impact on the vehicle manufacturers and component manufacturers depending on the investment required to develop and/or implement the technical solution.

11.3.1.1 Option A: No change

For the "no change" option, the existing anti-tampering measures would remain in place. Therefore, the economic impact on all stakeholders is neutral.

11.3.1.2 Option B: Inclusion of the CVT in powertrain and noise abatement system tampering prevention requirements

Three technical solutions have been proposed. All of these are likely to increase costs to manufacturers and would be expected to have proportionately greater effects on SMEs. However, because the specific measures were not identified at the time of the consultation, no information has been obtained regarding technical feasibility or relative costs of these measures.

Therefore, although it cannot be quantified, the economic impact will be proportional to the costs of the design changes and/or additional components required above that currently used and are likely to be negative. These adverse economic impacts apply to OEMs. There may also be positive impacts for suppliers if new parts are required and these may be SMEs. The net economic impact is difficult to estimate with the information available.

11.3.1.3 Option C: Prevent removal of the exhaust orifice(s)

The economic impact associated with introducing this measure is considered to be negligible owing to the fact that only a minor alteration is required to current exhaust

systems. Although the additional cost to implement this measure is considered negligible, it is likely that the effect would be proportionately greater for SMEs.

11.3.1.4 Option D: Remove the option of a 'removable sleeve' on the air intake system of 'learner' motorcycles (L3e-A1) as a permissible design

The economic impact associated with introducing this measure is considered to be small because two other methods of restriction remain and this change will only result in additional cost to the manufacturer if they current employ this approach.

11.3.1.5 Option E: Technical measures to prevent tampering with the PCU/ECU and input/output signals

The economic impact associated with introducing this measure cannot be quantified because the specific measure has not been defined. Additional costs may accrue to the manufacturer in strengthening the protection they already provide.

11.3.1.6 Option F: Improvements to markings used on 'off-road' exhausts, thus providing more effective information to enforcement authorities.

The economic impact of this measure cannot be quantified because the specific measure has not been defined. Additional costs may accrue to the manufacturer in strengthening the protection they already provide in this area.

11.3.1.7 Option G: Measures to prevent tampering to electric L-category vehicles from activating the motor at levels greater than permitted at type approval

For this possible measure, the specific technical solution has not been identified, but is considered likely to result in increased costs to the manufacturer because additional as yet unspecified control systems would be required to prevent easy routes to access additional electric power.

11.3.2 Societal impact

It is anticipated that options B to G would have significant societal effects in terms of benefits to road safety, particularly for those L-(sub)categories which have speed restrictions.

11.3.2.1 Option A: No change

This option will retain the existing measures. It is expected that this will result in a negative effects on safety and is likely to represent an ever increasing negative safety impact as the existing anti-tampering measures become increasingly ineffective. It is not possible to quantify this impact robustly with data that is currently available because the incidence and combination of tampering types within the current vehicle fleet are largely unknown, at least at the level required to determine rates with statistical confidence.

Evidence collected during this study as part of the literature review and consultation with enforcement authorities highlighted that tampering is present in the L-category fleet and some data suggests that up to 40% of some categories exhibit tampering. Other data on the internet shows devices and components that can be used to tamper L-category

vehicles as well as detailed instructions and forum discussions on these topics. Based on this evidence it seems a logical conclusion that tampering does occur in the L-category fleet, with greater prevalence in certain sub-categories. Therefore, conserving the status quo will take no steps to address tampering. Furthermore, it is considered that the effect of tampering may increase over time as less-protected areas become a greater proportion of the L-category fleet and can be potentially exploited to a greater extent.

Table 11-1: Annual European safety prevention estimates by tampering type (+value = cost, -value = saving)

Proportion of time between tampered and Untampered max vehicle speed	Tampering type (Cumulative modifications equally split amongst areas)											
	Proportion of fleet tampered	Air/fuel Rich	Air/fuel Lean	Fuel Pump (Diesel)	Carburettor	Air Intake	Exhaust	Transmission - CVT	Engine Crankcase ventilation	Engine Capacity	High Octane	Temperature
1/4	10%	**€ 5.1 M**	€ 0.0 M	*-€ 3.5 M*	€ 0.0 M	**€ 10.6 M**	**€ 60.4 M**	**€ 88.3 M**	*-€ 4.9 M*	**€ 5.0 M**	€ 0.0 M	€ 0.0 M
	20%	**€ 10.3 M**	€ 0.0 M	*-€ 7.1 M*	€ 0.0 M	**€ 21.3 M**	**€ 120.8 M**	**€ 176.5 M**	*-€ 9.8 M*	**€ 9.9 M**	€ 0.0 M	€ 0.0 M
	30%	**€ 15.4 M**	€ 0.0 M	*-€ 10.6 M*	€ 0.0 M	**€ 31.9 M**	**€ 181.2 M**	**€ 264.8 M**	*-€ 14.7 M*	**€ 14.9 M**	€ 0.0 M	€ 0.0 M
	40%	**€ 20.5 M**	€ 0.0 M	*-€ 14.1 M*	€ 0.0 M	**€ 42.6 M**	**€ 241.6 M**	**€ 353.1 M**	*-€ 19.6 M*	**€ 19.9 M**	€ 0.0 M	€ 0.0 M
1/2	10%	**€ 10.3 M**	€ 0.0 M	*-€ 7.1 M*	€ 0.0 M	**€ 21.3 M**	**€ 120.8 M**	**€ 176.5 M**	*-€ 9.8 M*	**€ 9.9 M**	€ 0.0 M	€ 0.0 M
	20%	**€ 20.5 M**	€ 0.0 M	*-€ 14.1 M*	€ 0.0 M	**€ 42.6 M**	**€ 241.6 M**	**€ 353.1 M**	*-€ 19.6 M*	**€ 19.9 M**	€ 0.0 M	€ 0.0 M
	30%	**€ 30.8 M**	€ 0.0 M	*-€ 21.2 M*	€ 0.0 M	**€ 63.8 M**	**€ 362.4 M**	**€ 529.6 M**	*-€ 29.4 M*	**€ 29.8 M**	€ 0.0 M	€ 0.0 M
	40%	**€ 41.0 M**	€ 0.0 M	*-€ 28.2 M*	€ 0.0 M	**€ 85.1 M**	**€ 483.2 M**	**€ 706.1 M**	*-€ 39.1 M*	**€ 39.8 M**	€ 0.0 M	€ 0.0 M
3/4	10%	**€ 15.4 M**	€ 0.0 M	*-€ 10.6 M*	€ 0.0 M	**€ 31.9 M**	**€ 181.2 M**	**€ 264.8 M**	*-€ 14.7 M*	**€ 14.9 M**	€ 0.0 M	€ 0.0 M
	20%	**€ 30.8 M**	€ 0.0 M	*-€ 21.2 M*	€ 0.0 M	**€ 63.8 M**	**€ 362.4 M**	**€ 529.6 M**	*-€ 29.4 M*	**€ 29.8 M**	€ 0.0 M	€ 0.0 M
	30%	**€ 46.1 M**	€ 0.0 M	*-€ 31.8 M*	€ 0.0 M	**€ 95.8 M**	**€ 543.6 M**	**€ 794.4 M**	*-€ 44.0 M*	**€ 44.8 M**	€ 0.0 M	€ 0.0 M
	40%	**€ 61.5 M**	€ 0.0 M	*-€ 42.4 M*	€ 0.0 M	**€ 127.7 M**	**€ 724.8 M**	**€ 1,059.2 M**	*-€ 58.7 M*	**€ 59.7 M**	€ 0.0 M	€ 0.0 M
1	10%	**€ 20.5 M**	€ 0.0 M	*-€ 14.1 M*	€ 0.0 M	**€ 42.6 M**	**€ 241.6 M**	**€ 353.1 M**	*-€ 19.6 M*	**€ 19.9 M**	€ 0.0 M	€ 0.0 M
	20%	**€ 41.0 M**	€ 0.0 M	*-€ 28.2 M*	€ 0.0 M	**€ 85.1 M**	**€ 483.2 M**	**€ 706.1 M**	*-€ 39.1 M*	**€ 39.8 M**	€ 0.0 M	€ 0.0 M
	30%	**€ 61.5 M**	€ 0.0 M	*-€ 42.4 M*	€ 0.0 M	**€ 127.7 M**	**€ 724.8 M**	**€ 1,059.2 M**	*-€ 58.7 M*	**€ 59.7 M**	€ 0.0 M	€ 0.0 M
	40%	**€ 82.0 M**	€ 0.0 M	*-€ 56.5 M*	€ 0.0 M	**€ 170.2 M**	**€ 966.4 M**	**€ 1,412.3 M**	*-€ 78.3 M*	**€ 79.6 M**	€ 0.0 M	€ 0.0 M

11.3.2.2 Option B: Inclusion of the CVT in powertrain and noise abatement system tampering prevention requirements

Three technical solutions were proposed as options. The individual cost and effectiveness of each of these options is unknown with the level of information available. An initial assessment of the possible safety benefits of applying these solutions to the L1e and L6e fleet (where the link between increased maximum vehicle speed and safety is arguably strongest) showed that, if 100% effective, measures could prevent between €177M (if 10% fleet currently tampered) and €706M per year (if 40% fleet currently tampered) with a 'best estimate' of €353M per year assuming the 'best estimate' relationship between increase in maximum vehicle speed and safety. The lowest and highest estimates taking into account all assumptions on tampering rate and the effect of maximum vehicle speed increase on safety were between €88M and €1,412M per year.

11.3.2.3 Option C: Prevent removal of the exhaust orifice(s)

An initial assessment of the possible safety benefits of applying the technical solution for option C to the L1e and L6e fleet (where the link between increased maximum vehicle speed and safety is arguably strongest) showed that, if 100% effective, measures could prevent between €121M (if 10% fleet currently tampered) and €483M per year (if 40% fleet currently tampered). The 'best estimate' was predicted at €242M per year assuming the 'best estimate' relationship between increase in maximum vehicle speed and safety. The lowest and highest estimates taking into account all assumptions on tampering rate and the effect of maximum vehicle speed increase on safety were between €60M and €966M per year.

11.3.2.4 Option D: Remove the option of a 'removable sleeve' on the air intake system of 'learner' motorcycles (L3e-A1) as a permissible design

An initial assessment of the possible safety benefits of applying the technical solution for option D to the L1e and L6e fleet (where the link between increased maximum vehicle speed and safety is arguably strongest) showed that, if 100% effective, measures could prevent between €21M (if 10% fleet currently tampered) and €85M per year (if 40% fleet currently tampered). The 'best estimate' was predicted to be €43M per year assuming the 'best estimate' relationship between increase in maximum vehicle speed and safety. The lowest and highest estimates taking into account all assumptions on tampering rate and the effect of maximum vehicle speed increase on safety were between €11M and €170M per year.

11.3.2.5 Option E: Technical measures to prevent tampering with the PCU/ECU and input/output signals

The PCU/ECU has been identified as an important area because it controls the engine, the air/fuel ratio, engine timing etc. and many mechanical tampering types can be replicated by changing software or providing false signal information. Measures aimed at preventing access (encryption) and modification (checksums and systems to verify input and output signals) are important areas to ensure adequate controls exist in the future (when more L-category vehicles are likely to have electronic control). In this high level study, it was identified that the PCU/ECU was difficult to access and all attempts to do so

on one vehicle resulted in it entering 'safe mode'. While this is encouraging, it is not known whether all L-category vehicles are resistant to tampering of this type. The societal benefits of appropriate measures cannot be quantified with the information available but are likely to be positive and increasingly positive as more of the L-category fleet have PCU/ECU systems.

11.3.2.6 Option F: Improvements to markings used on 'off-road' exhausts, thus providing more effective information to enforcement authorities

In a societal context, Option F is likely to have most effect on the level of emissions (see assessment for environmental impacts). It is possible that more effective marking of 'off-road' exhausts would result in more effective enforcement, thereby reducing the maximum vehicle speed for those L-category vehicles using 'off-road' exhausts on public roads. However, the effect on safety is more difficult to assess away from the L1e and L6e categories. This is because although maximum vehicle speeds may increase, components and systems on larger capacity machines are considered likely to be able to cope with such increases and therefore the effect on safety is considered less sensitive to increases in maximum vehicle speed; rider behaviour is probably a greater contributor to safety risk.

11.3.2.7 Option G: Measures to prevent tampering to electric L-category vehicles from activating the motor at levels greater than permitted at type approval

The societal impacts of measures in Option G are judged to be positive, although the size of the effect is unknown. Increases in maximum vehicle speed were demonstrated in a supplemental test for some vehicles and internet information depicts examples of larger increases in maximum vehicle speed.

11.3.3 Environmental impact

It is anticipated that options B to G would have significant environmental effects in terms of exhaust emissions that could be prevented.

11.3.3.1 Option A: No change

Evidence gathered as part of this project confirmed that tampering which is known to result in increased emission levels (for example, changing the exhaust to an aftermarket type with no catalyst) does occur in the fleet. Furthermore, tampering modes undertaken with the intention of enhancing performance in one area will bring about detrimental effects on other parameters. The testing carried out as part of this project highlighted that tampering can bring about very significant increases in exhaust emissions to levels many times that of the type approval limits.

The current in-service testing regime across member states, for example the UK, only includes a cursory check on the noise level (generally, at the testers' discretion as to whether the noise is louder than the standard system). There is no in-service emissions test at present for 2-wheelers. Therefore the removal of the catalyst is not recorded within the in-service testing. In some cases, the ECU may also be modified (re-mapped) when changing the exhaust.

Table 11-2: Annual European environmental prevention value estimates (regulated emissions and CO2) by tampering type (+value = cost, -value = saving)

Modification Cumulative modifications equally split amongst areas											
Proportion of fleet tampered	**Air/fuel Rich**	**Air/fuel Lean**	**Fuel Pump (Diesel)**	**Carburettor**	**Air Intake**	**Exhaust**	**Transmission - CVT**	**Engine Crankcase ventilation**	**Engine Capacity**	**High Octane**	**Temperature**
10%	*-€ 18.2 M*	*-€ 0.9 M*	**€ 0.1 M**	**€ 2.8 M**	**€ 1.3 M**	**€ 8.1 M**	*-€ 3.9 M*	*-€ 2.9 M*	**€ 2.5 M**	*-€ 11.4 M*	*-€ 8.1 M*
20%	*-€ 37.4 M*	*-€ 1.4 M*	**€ 0.3 M**	**€ 5.8 M**	**€ 3.1 M**	**€ 19.1 M**	*-€ 7.6 M*	*-€ 5.9 M*	**€ 5.5 M**	*-€ 23.3 M*	*-€ 16.4 M*
30%	*-€ 56.1 M*	*-€ 2.0 M*	**€ 0.4 M**	**€ 8.6 M**	**€ 4.7 M**	**€ 28.6 M**	*-€ 11.4 M*	*-€ 8.8 M*	**€ 8.3 M**	*-€ 34.9 M*	*-€ 24.6 M*
40%	*-€ 159.3 M*	**€ 36.9 M**	**€ 1.1 M**	**€ 24.1 M**	**€ 13.3 M**	**€ 76.2 M**	*-€ 27.4 M*	*-€ 19.5 M*	**€ 23.2 M**	*-€ 71.0 M*	*-€ 53.0 M*

11.3.3.2 *Option B: Inclusion of the CVT in powertrain and noise abatement system tampering prevention requirements*

Three technical solutions were proposed as options for this measure. The individual cost and effectiveness of each of these options is unknown with the level of information available. An initial assessment of the possible environmental benefits of applying these solutions to L-category vehicle fleet showed that, if 100% effective, measures could provide an annual disbenefit of between €4M (if 10% fleet currently tampered) and €27M per year (if 40% fleet currently tampered) with a 'best estimate' of €8M per year. However these net emissions results from tests comparing tampered with untampered using an identical test cycle (speed profile). In reality, the additional vehicle speed resulting from the tampering might be expected to increase emissions for an identical real-world journey. Thus, tampering measures for this area might not result in any disbenefit. They are also likely to reduce noise levels because the vehicle speed will be reduced.

11.3.3.3 *Option C: Prevent removal of the exhaust orifice(s)*

An initial assessment of the possible environmental benefits of applying these solutions to L-category vehicle fleet showed that, if 100% effective, measures could provide an annual benefit of between €2M (if 10% fleet currently tampered) and €12M per year (if 40% fleet currently tampered) with a 'best estimate' of €2M per year. Bearing in mind the assumptions made in this assessment, it is considered that the effects predicted are negligible.

11.3.3.4 *Option D: Remove the option of a 'removable sleeve' on the air intake system of 'learner' motorcycles (L3e-A1) as a permissible design*

An initial assessment of the possible environmental benefits of applying this solution to the L-category vehicle fleet showed that, if 100% effective, measures would have an annual prevention value of between €1M (if 10% fleet currently tampered) and €13M per year (if 40% fleet currently tampered) with a 'best estimate' of €3M per year. Bearing in mind the assumptions made in this assessment, it is considered that the effects predicted are negligible.

11.3.3.5 *Option E: Technical measures to prevent tampering with the PCU/ECU and input/output signals*

It is considered that preventing access and manipulation of the signals to and from the PCU/ECU would have environmental benefits. However, there is not sufficient information to quantify them.

11.3.3.6 *Option F: Improvements to markings used on 'off-road' exhausts, thus providing more effective information to enforcement authorities*

Improving the requirements for marking at type approval are considered likely to have significant benefits. Although the ability of the user to switch exhausts will not be influenced (because to do so is not feasible bearing in mind the requirement for maintenance and legitimate changes that the user might wish to carry out), the ability of enforcement authorities to later detect tampering is likely to be improved. If 100% efficient than such a measure might be expected to result in a saving of between €24M (if 10% fleet currently tampered) and €208M per year (if 40% fleet currently tampered)

with a 'best estimate' of €51M per year. It should be noted that this is based on the result of single vehicle and so the value extrapolated to the fleet should be considered indicative; more testing would be required to verify whether or not the results for other vehicles and aftermarket exhaust types are similar.

11.3.3.7 Option G: Measures to prevent tampering to electric L-category vehicles from activating the motor at levels greater than permitted at type approval

This option has low direct environmental effects, although increasing the power delivered by the vehicle will use more energy and therefore require re-charging sooner. Depending on the source of the electricity used to recharge the battery, there could be indirect environmental impacts that would be prevented if effective measures were devised to prevent motors running at levels greater than that permitted. There is not sufficient evidence to estimate the effects at a more detailed level.

11.4 Comparing the options

Table 11-3 compares the economic, societal and environmental impacts for the options related to possible tampering prevention measures. In the Figure, arrows are used to represent the estimated magnitude of each impact, with the direction of the arrow denoting whether the impact is positive (the measure results in a *benefit* or *cost saving*) or negative (the measure results in a *cost*). Where the impact is considered to be neutral, no arrows are presented on the diagram. The "dotted" arrows are used where the magnitude of the impact is either uncertain, dependent on other factors, or differs for different stakeholder groups.

Table 11-3. Comparison of impacts for options relating to tampering prevention measures

Impact type	Option (see 11.2)	Negative impact	Neutral	Positive impact
Economic	A		●	
	B	←————	●	
	C		←⋯●	
	D		←⋯●	
	E	←⋯⋯⋯⋯⋯⋯	●	
	F		←⋯⋯●	
	G		←⋯⋯●	
Societal	A		●	
	B		●————	————→
	C		●⋯⋯→	
	D		●————	————→

	E	●·················▶
	F	●········▶
	G	●·················▶
Environmental	A	◀———●
	B	●————▶
	C	●——————————▶
	D	●·······▶
	E	●·················▶
	F	●·················▶
	G	●·······▶

11.5 Preferred option(s)

It should be reiterated here that while Option A is mutually exclusive, Options B to G can be applied individually or collectively. The test results and other information gathered in the project have identified Options B to G as having overall net societal and environmental benefits which appear to be reasonable candidates for cost-effective tampering prevention measures. On this basis, implementation of Options B to G would be the preferred option since this results in the greatest estimated saving. However, it is difficult to determine a preferred option with certainty because of a paucity of detailed information on the costs and economic impacts of potential measures, as well as the level of uncertainty with regard to the extent that the magnitude of effect observed in the test programme can be applied more generally to the L-category fleet. While the precise technical measures have not been subject to detailed consultation with stakeholders in terms of technical feasibility, cost implications and effectiveness, the full complement of impacts cannot be assessed with certainty. However, options B to G are considered very likely to bring about significant safety and environmental benefits that show promise in terms of cost-effectiveness.

11.6 Monitoring and evaluation

In order to monitor the effect of any option that might be selected by the EC, it is recommended that the following actions be taken:

- Identify baseline data, especially relating to the current levels of tampering in the L-category fleet so that this can be compared to a later survey to determine the effect of any options that have been implemented. This could be carried out in several ways:

  - via a co-ordinated survey of enforcement authorities and, where carried out, inclusion of unauthorised manipulations in periodical technical inspections;
  - a representative survey of in-use condition of vehicles, either using sampling at periodic inspection or in dedicated roadside surveys.
- The stakeholder consultation indicated that improved exchange of information between enforcement authorities, coupled with improved marking, could improve the efficiency of tampering detection and generate a better evidence base on which to determine and/or monitor the most effective countermeasures.
- Monitoring and documentation of costs incurred by manufacturers and stakeholders (particularly for SMEs) to comply with any new requirements and investigation of rider views on the effect of any measures on the ability of riders to carry out legitimate, 'harmless' modifications or vehicle customisation.

11.7 Impact on SMEs

Any type of regulatory change that requires changes to the technical requirements has the potential to involve investment to realise any benefits over the longer term. This may have a proportionately greater effect on these SMEs compared with larger companies, who may be able to absorb any additional capital or time costs more easily. Therefore, in general the effect on SMEs is considered to be greater, although this was not possible to quantify with the information gathered in this study. As recommended above, this aspect should be monitored as part of the implementation of any new requirements.

12 Conclusions

This project has identified a range of measures that could be implemented to reduce the prevalence of harmful tampering (those which result in adverse effects on the functional safety and/or the environmental performance) in the L-category vehicle fleet. These measures will not restrict other modifications to vehicles nor prevent custom tailoring when these activities have little or no performance effects on functional safety or environmental performance. Indeed, if there are no expected disbenefits to society then there can be no justification for measures aimed at harmless modification or custom tailoring.

In this study, L-category vehicle tampering types were identified and prioritised using a theoretical approach. The effects of these tampering types were then quantified in a test programme. This highlighted that:

- Some of the current type-approval measures in chapter 7 of Directive 97/24/EC are partly obsolete and should be amended to account for the technological advancements which have taken place in the L-category vehicle fleet over recent decades;
- Tampering using methods which are in use in the current L-category vehicle fleet can have adverse effects on safety (increasing maximum speeds in excess of design speeds), emissions and noise (increases above legislative limits).
- Some tampering types undertaken with the aim of achieving increased propulsion power or vehicle speed result in only minor increases with respect to these areas, but much larger increases in emissions to levels far in excess of regulatory limits.

With respect to the test results, the main findings of the test programme were:

- Removal of the CVT limiter(s) resulted in large increases in maximum vehicle speed. In conjunction with other modifications, increases of nearly one and a half times the original maximum vehicle speed were observed. The removal of the CVT limiter(s) was the single modification that had the most effect on maximum vehicle speed.
- Tampering with the exhaust orifice and air filter resulted in large increases in emission levels on some vehicles: up to more than 20 times the original levels of Hydrocarbons (HC), twice the level of Methane (CH_4) and a 50% increase in Carbon Dioxide (CO_2).
- Fitment of an aftermarket exhaust with a catalyst bypass resulted in increased maximum vehicle speed (7%) and propulsion power (24%), but even greater negative effects on emissions - approximately 170% increases in Hydrocarbons (HC) and 160% increases in Oxides of Nitrogen (NO_x) and Methane (CH_4). Fuel consumption also by increased (48%) and the mean motion sound level increased by 24%.
- Differences in the magnitude of effect on different L-category vehicles were noted for the same or similar tampering types. This highlights that the effect from tampering may vary between sub-categories and also perhaps between vehicle make, model and propulsion type, dependent on precise technical characteristics.

- Significant increases in noise levels were found for the three tampering modes which involved replacement of the exhaust. For combined tampering types on L1Be vehicles mean stationary sound levels rose up to 14 dB(A). On a single L3e-A3 vehicle, the same measure increased to 95.1 dB(A) from 88.6 dB(A).

- No substantive evidence could be found that L-category vehicles that are unlimited in power or maximum vehicle speed in the EC Co-decision proposal should be subject to anti-tampering measures related to performance.
- Significant evidence was found to suggest all vehicles should be covered by legislation preventing increases in noise and gaseous emissions, however not to the detriment of safety. It is anticipated that the control of noise will be improved as soon as the latest amended UN Regulations 9, 41, 63 and 92 are fully implemented in the EU, thereby replacing the proposed requirements originating from Chapter 9 of Directive 97/24/EC in the proposed Regulation for environmental and propulsion performance requirements.
- The test programme was successful at quantifying the effects of a range of prioritised tampering types on L-category vehicles. However, the limited amount of vehicles tested in each area has implications for how generally applicable the results are. To expand on these results a significantly larger test programme would be required.

A benefit estimate used the test results to value the effects and a basic break-even analysis was conducted with aim of scoping the likely break-even value. This analysis identified three areas for tampering measures which, based on the information from the test programme and the assumptions made are the most likely to prove cost-effective. These are measures aimed at preventing tampering of:

- The CVT on speed restricted vehicles (i.e. L1e and L6e vehicles)
- Air intake (specifically for L3e-A1 learner motorcycles)
- Exhaust
- ECU/PCU[38]

Evidence collected from the literature review and roadside enforcement in The Netherlands supported the view that CVT tampering is present in the L1e fleet. It should also be noted that the techniques used to tamper with those category L-vehicles can also be applied to any other speed restricted L-category vehicle equipped with similar automatic transmission.

In addition, measures to prevent tampering on the PCU/ECU should be considered important. These were not detected in the particular sample of vehicles used in this study, but wider project information supports the view that measures to address this area should also be given high priority.

The potential measures that this study has identified that could be used to help prevent harmful L-category vehicle tampering are as follows:

[38] Although not identified in the benefit assessment, ECU/PCU tampering is considered to have similar effects to other forms of tampering which were quantified.

- The CVT could be specifically included in powertrain the anti-tampering legislative requirements. Furthermore, technical measures have been discussed which, if implemented, could reduce the extent of tampering in this area:
  - The cone of the CVT could be so designed that the rotational speed limiting rings are fundamental to the structural integrity of the part and removing them would destroy the component. In some vehicle the rotation speed limiter is a plate at the back of the cones; the same principle could be applied.
  - The rotational speed limiting addition could be required to be fitted to the other cone of CVT to which it is currently fitted (i.e. the 'fan').
  - The diameter of one or more cones could be such that, if the limiters where removed, the belt would slip out of position and loose traction, thereby preventing the operation of the vehicle if the limiting rings or plates were removed. This could be dangerous if this occurred while riding, therefore appropriate warnings should be placed within the transmission.
- Removing the exhaust orifice(s) resulted in an increase in emissions and, when combined with other changes made to L1Be vehicles, can also increase the maximum vehicle speed. Measures have been proposed here to prevent the removal of the orifice by integrating the orifice into the fundamental exhaust design, since current measures do not prevent its removal (only that if it is removed that the orifice is destroyed). The current legislation already covers this area, and so any measure here would simply represent a strengthening of existing requirements (note will be covered by the changes to the UN regulations on noise).
- For the air intake system, there is currently an obligatory choice of three methods specified to restrict the air intake on learner motorcycles (L3e-A1 vehicles): A removable sleeve fitted inside the air inlet, a restricted section in the pipe (visible from the outside), or a restriction in the air inlet to the engine itself. The stakeholder study indicated that the first option is generally known to be easy to circumvent and the requirement that the object itself must be destroyed in the process of removal to prevent it being reinstalled before an inspection does not prevent its removal. Therefore, the option of a removable sleeve could be removed as a permissible design.
- Some evidence from electric cycles (which were tested in this test programme, but the results arrived too late to be included in this report) suggested that simple tampering to activate the motor at levels greater than intended should be prevented. Steps taken by manufacturers would have the effect of restricting the possibility of this occurring. The addition of this area to the powertrain and noise abatement system tampering prevention requirements would also have the effect of requiring manufacturers to address this issue.

In addition to measures aimed at specific tampering or modification types, a range of further issues have been identified which could be considered to improve the effectiveness of anti-tampering regulation. These can be summarised as follows:

- Proposed changes to the structure of the legislation with the intended effect of allowing greater clarity and understanding of the legislation, which was identified

as a concern by manufacturers, testing authorities, enforcement authorities, and end users.

- Specific inclusion of all powertrain propulsion systems under the powertrain and noise abatement system tampering prevention requirements to include other technologies (e.g. pure electric and hybrid electric propulsion) note, due to the format of the anti-tampering legislation this would require a very small change to the manufacturers current practices, help clarify the rules for all manufacturers and prevent loopholes for future technologies.

- Suggestions for changes to the anti-tampering legislation have been made regarding specific areas of the powertrain and noise abatement system. These cover the CVT and other areas found to be important.

- It was identified that compliance could potentially be improved if improvements were made in the markings used on components, thus providing more effective information to enforcement authorities. In particular:

    - Exhausts for off-road, racing or multi-functional use on all L-category vehicle categories could be required to have prominent markings to aid detection on the road, where their consequences both for noise and emissions have been found to be great.

    - The stakeholder consultation also indicated other issues which could be improved, such as how the data, in terms of test results, anti-tampering methods used, and marking locations, could be better utilised. With the exchange of information enforcement authorities could better detect tampering and generate a better evidence base on which to determine effective countermeasures.

- With respect to the scope of anti-tampering legislation, measures which restrict performance should only apply to performance restricted vehicles. These could be defined as: *'Performance restricted vehicle' - a vehicle in a category with an upper propulsive power or vehicle speed limit which is used by EU and/or national legislation for vehicle classification and licensing.* However, there are some aspects of the legislation which prevent environmentally damaging design features or easily bypassed propulsion performance restrictions, such as the prevention of restrictions in the air intake and exhaust and prohibiting the use of environmentally unfriendly spark retard and inhibiting strategies. It may be beneficial if these practices were applied to the entire L-category fleet, therefore these parts which are not performance limiting or anti-tampering related, could be moved to another more suitable section of the type-approval legislation.

- The testing results also showed that in addition to vehicle age, other factors (e.g. ambient temperature, fuel octane grade) affected the environmental and propulsion performance. To allow roadside enforcement to account for this, suitable tolerances should be defined with respect to the limits achieved at type approval. Alternatively if future studies find that this has become a significant issue for performance restricted vehicles, then further tests may be required as part of the type-approval process.

- To enable users to make modifications that may have an effect on propulsion performance and/or emissions, but are part of existing seasonal or normal use, the requirement for re-approval of the modified vehicle would not be needed if the original type approval took account of common modifications. Thus type approval evidence could be used to approve the vehicle with a range of specific components, thereby negating the need for re-approval if the part is changed in use.
- Changes could be made to the current rules on the compatibility of replacement parts. Adding requirements for the PCU/ECU and their sensors and actuators relevant to the environmental and propulsion performance would keep pace with technological developments. Additionally, a common standard specifying certain fittings for speed/power limiting parts would mean that it was more difficult to tamper with these areas.
- Any type of regulatory change that requires changes to the technical requirements has the potential to involve investment to realise any benefits over the longer term. This may have a proportionately greater effect on these SMEs compared with larger companies, who may be able to absorb any additional capital or time costs more easily. Therefore, in general the effect on SMEs is considered to be greater, although this was not quantifiable with the information gathered in this study. This aspect should be monitored as part of the implementation of any new requirements.

13 Considerations for further work

As described in the preceding sections, uncertainty in some of the baseline information affected the accuracy of the benefit estimate and meant that a high-level approach was considered appropriate. This was considered important, especially since a range of proposed options and measures have been identified that have not been the subject of detailed consultation.

13.1 Further in depth study

There are a range of reasons why further research and testing would improve the robustness of the results. For example, the results for each tampering type are based on a very small sample, often a single vehicle, since it was not deemed feasible to test a larger number of vehicles given the timing and resource constraints of the project. This clearly has limitations regarding how confidently this result can be applied to other vehicles, including (but perhaps to a lesser extent) those of the same make and model. For example, it is not known how applicable a single result on a single vehicle is to other vehicles or how representative the results from the vehicles tested are of vehicles in the same L-category, or other L-(sub) categories. This is a fundamental problem with extrapolating results from a small sample to the general population. In this case, we took steps to select and test a wide range of L-category vehicles at the experimental design stage and tried to select vehicles that were popular models.

This analysis is also limited because of information that was not available to the project. Information, which is currently missing that would allow a more accurate assessment of the relative costs and benefits of these potential tempering prevention measures are:

- Current fleet size for the detailed vehicle sub-categories specified in COM(2010) 542 final;
- Tampering rates for the fleet (by category, or if possible, by tampering type). Other studies (e.g. Robinson et al (2009) proposed recording schemes to monitor the tampering rate in the fleet);
- The number of European fatal, serious and slight casualties by vehicle categories;
- Effect on fatal, serious, slight casualties related to increase in:
    - Maximum vehicle speed
    - Maximum power
    - Maximum torque
    - Acceleration rate

It is acknowledged that this is very difficult to determine because of the complex relationships surrounding accident risk. Improved engagement from stakeholders may result in consensus values that may be more appropriate than the initial values used. The main assumptions made are presented in Table 8-3, along with an explanation of why these numbers were used.

The analysis employed in the benefit assessment is tentative because it relies on a range of assumptions that are not in every case robustly supported with evidence, primarily

because the required information is unavailable. Therefore, the test results and benefit assessment should be interpreted with these inherent limitations in mind.

Further work could reduce the effect of the limitations identified earlier in this section to improve the statistical robustness. Specifically these could repeat tests on a greater number of vehicles in each L-category to increase the statistical robustness of the results. These should also include vehicles from a range of manufacturers to find how variable the effects of tampering are within L-category subcategories and between different makes within the same subcategory.

Improved data on the occurrence of tampering in the L-category fleet would enable easier identification and targeting of measures, as well as improved estimates for cost effectiveness of anti-tampering measures. This data is difficult to collect across the whole fleet, but initiatives involving the recording of data by enforcement agencies would allow a database to be constructed that could be used to determine the occurrence in the fleet. Mechanisms to encourage the sharing of information on how to identify modifications and what to look for could be developed between enforcement agencies in Europe. This would have the likely effect of improving the detection rate of different tampering types, as well as improving the effectiveness of the enforcement authorities, potentially reducing the incidence of tampering in the fleet. However, it is recognised that this topic has a circular dilemma. If enforcement authorities are not put in the position that tampering with the environmental and functional safety performance can easily be identified, then it is difficult to determine whether a vehicle has been tampered with or not. A solution to this issue is to make iterative steps and to begin the process of strengthening the applicable legislation.

13.2 Significance of ambient conditions

It was noted in the testing that certain ambient conditions can both increase toxic emissions and also increase vehicle performance.

In cold weather the vehicle will enrich the mixture to allow it to warm up in order to function correctly. This increased fuel not only warms the engine, but also increases the emission of HC and CO. This could poison a catalytic converter, increase the motive power output, and increase the maximum vehicle speed.

When there is high air pressure or cold weather, the air is denser and therefore more oxygen can be taken into the engine. Both a carburettor and fuel injection system will compensate this by increasing the amount fuel. This shouldn't affect the emissions directly; however it will increase the motive power output and increase the maximum vehicle speed. This, in turn, may cause the engine to run at higher temperatures than intended, causing increased aging to the emission abatement system.

However, the extent to which this affects the European fleet is unknown. A large change in performance was seen on a high performance motorcycle with advanced fuelling systems which was also designed to be used with higher performance fuels, but it is now known whether this can be applied more generally to low-powered learner motorcycles and speed limited mopeds.

Before any additional testing is imposed at the type-approval stage, further testing and/or research should be performed on these classes of vehicle to determine whether or not this issue poses a significant problem.

14 Glossary

Term	Meaning
£ (GBP)	GBP= £ pounds sterling. €1.1 per £. All references to GBP has been converted using this exchange rate
ABS	Anti-lock brakes, system which monitors wheel rotation speed and rapidly modulates the brake pressure when imminent wheel lock is detected
ATV	All-terrain-vehicle, a quad bike
Carb	Abbreviation of carburettor, an apparatus for mixing air and fuel in PI engines
CBS	Combined Braking System, a system which distributes braking effort between front and rear wheels irrespective of the brake level applied
Checksums	A value generated by an algorithm to reduce the data to a arbitrary block of digital data, which can then be compared
CI	Compression ignition, used in Diesel engines, where the pressure and temperatures caused by compression starts the combustion process
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CVT	Constantly Variable Transmission
dB	Decibel, a measure of sound pressure
DfT	Department for Transport, UK
DMRB	Design manual for roads and bridges
DSA	Driving Standards Agency
EC	European Commission, The EU's executive body
ECU	Electronic Control Unit, electronic control unit that manages an the operation of an engine
EPA	Environmental Protection Agency
EU	European Union
FMEA	Failure mode and effects analysis
HARMONOISE	Road traffic noise prediction model software

HC	Hydrocarbon, such as vaporised petrol or diesel
ICE	Internal Combustion Engine - an engine in which the combustion of a fuel occurs with air in a combustion chamber
MFDD	Mean Fully Developed Deceleration, defined as the average deceleration from the point where the vehicle is travelling at 80% of its initial speed to the point where it is travelling at 10% of its initial speed. This is intended to exclude the parts of a full brake stop where the rider has initiated movement of the brake control but has not yet reached full pressure, the time taken for the brake system to fully respond to the riders brake demand and some unusual phenomenon experienced by speed measurement systems as a vehicle comes to a stop.
NO_x	Nitrogen oxides, i.e. NO and/or NO_2 (nitric oxide and nitrogen dioxide)
O_2	Oxygen, in its most common naturally occurring molecule
OBD	On Board Diagnostics, an electronics self diagnostic system
PCU	Powertrain Control Unit, as ECU (which see) but also receives additional inputs from sensors to actuate the gearbox, clutch and/or torque converter.
PI	Positive ignition, i.e. Spark ignition, used in petrol engines where a 'positive' addition of energy is used to start the combustion process
PID	Proportional Integral Derivative (controller) - a generic control loop feedback mechanism
PM	Particulate matter, in extreme cases this is visible a soot or an off colour haze from exhaust gases
RFID	Radio-frequency identification - a wireless non-contact system that uses radio-frequency electromagnetic fields to transfer data from a tag attached to an object
RPN	Risk Priority Number – Product of severity, occurrence and ‘detectability’ (RPN = S × O × D) in FMEA analysis
RPM	Revolutions per minute, a measure of engine speed
SbS	Side-by-side, a quadricycle were the driver and passengers can sit next to each other as with a car
SENOD	Safety, Emissions, Noise, Occurrence, Detection. A type of FMEA developed by TRL

Spark angle	The spark angle is the angle before/after Top Dead Centre at the point when the spark is delivered
TDC	Top Dead Centre. The position of a piston when it is furthest from the crankshaft
UNECE	UNECE United Nations Economic Commission for Europe, a body of the UN of which its Working Party 29 (WP.29) is tasked with world-harmonising international vehicle legislation
Washcoat	The coating of the catalytic converter monolith which hold the catalyst in place
WHO	World Health Organisation
WoT	Wide Open Throttle, i.e. full throttle, the maximum throttle control position. This is not necessarily the highest fuel flow
WTP	Willingness to pay, measure used in cost benefit studies which includes valuation for pain and suffering as well as direct and indirect costs

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Appendix A Website

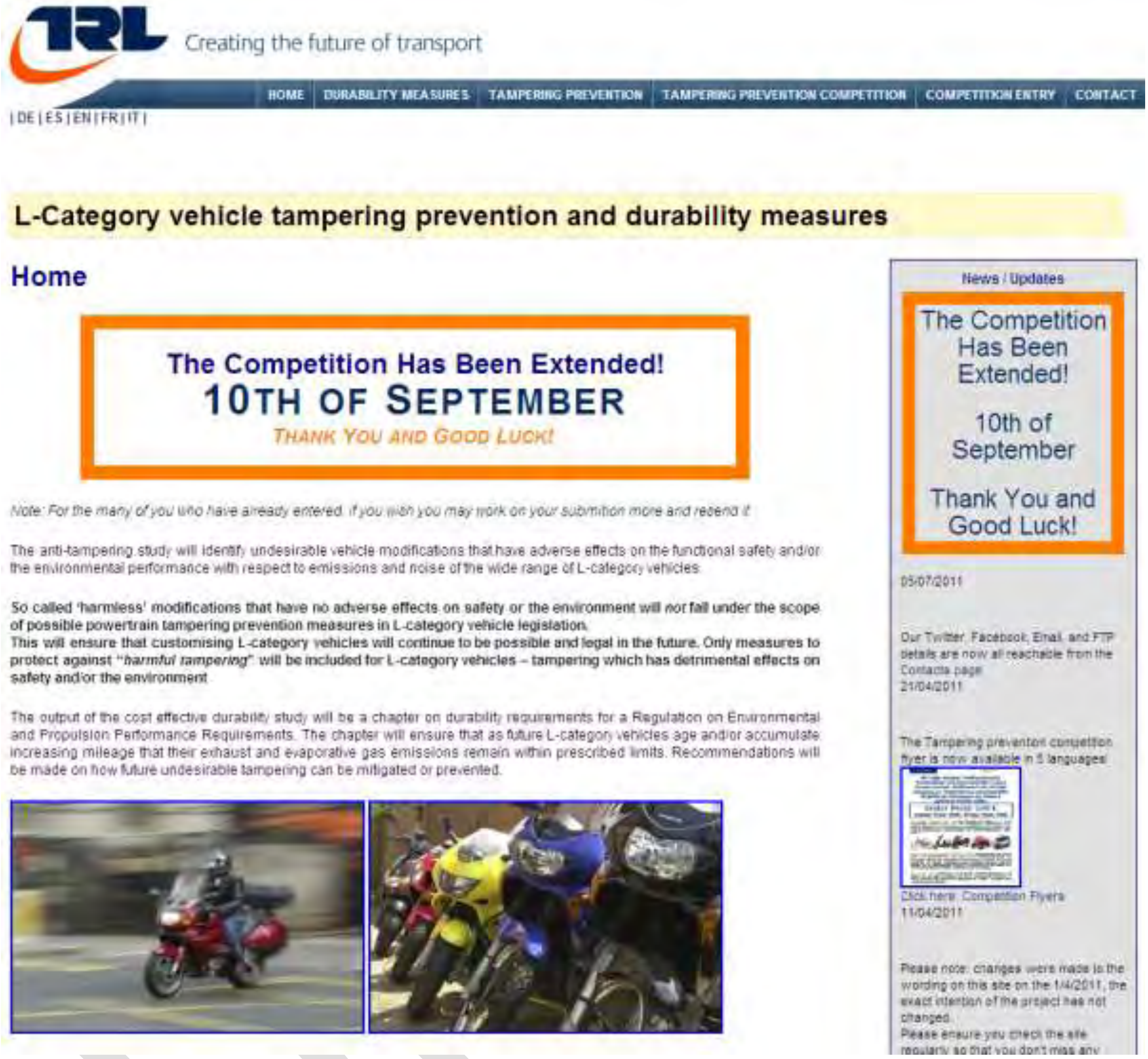


Figure 19-1: Stakeholder consultation website screen grab

A.1 Tampering Prevention Competition Flyer

Appendix B Stakeholder questionnaire

B.1 Email

Dear <insert name>,

Information request for L-Category vehicle modification

The European Commission have, in conjunction with JRC, contracted TRL to undertake research in order to:

- Identify cost-effective durability testing measures which could be applied to a range of L-category vehicles to minimise unwanted emissions.
- Identify and prioritise 'harmful' tampering and recommend prevention measures for a range of L-category vehicles

Further information regarding the project can be found on our website at: <URL>

As part of this research programme, TRL is seeking the views and advice of a wide range of stakeholders to gather the views of the industry and the wider L-category vehicle community.
A short on-line questionnaire on L-Category vehicle durability can be found at the following address and we would be very grateful if you could spend a few minutes answering these 12 questions.

URL: <URL>
Password: <Password> (case sensitive)

Furthermore, if you have data or other documentation which you feel would assist us in our project, please email this to the research team (<email address>) or request a password to our FTP site so that the relevant information can be uploaded. Please be assured that any information provided not in the public domain will be treated confidentially.

We appreciate your time in completing the questionnaire and would like to thank you in advance for your helpful participation **and please keep a close eye on your inbox for notification of the on-line questionnaire for L-Category vehicle tampering!**

Yours sincerely,

TRL L-Category project team

TRL supports the Decade of Action for Road Safety 2011-2020

Figure 19-1: Template of email request to stakeholders

B.2 Questionnaire responses

Questions:	Manufacturers (OEMs)	Riders/Rider groups and associations (response A)	Riders/Rider groups and associations (response B)
Stakeholder information request questions common to all stakeholder groups			
Please, by completing the Figure below, provide us with objective data on: **a. The number of vehicles on European roads** **b. The average annual distances covered by "typical" vehicles** **c. The average lifetime distances covered by "typical" vehicles**			
L1Ae: Fleet Size			
L1Ae: Average lifetime distances (km)	5500		
L1Ae: Average lifetime (years)			
L1Ae: Comments	category does not exist today		

Questions:	Manufacturers (OEMs)	Riders/Rider groups and associations (response A)	Riders/Rider groups and associations (response B)
L1Be: Fleet Size	12,6 Million		
L1Be: Average lifetime distances (km)	10000		
L1Be: Average lifetime (years)			
L1Be: Comments	90% of the fleet size are L1Be 45 km/h, the rest split between L1Be 25 km/h and L2e.		
L3e< 130 km/h: Fleet Size	22,3 Million	2	
L3e< 130 km/h: Average lifetime distances (km)	<150cc=12000, >150cc=20000. Enduro & Trial 5000, 8000 respectively	200,000	
L3e< 130 km/h: Average lifetime (years)		40	
L3e< 130 km/h: Comments	Fleet size for all L3e+L4e (distinction <130 Km/h and >130 Km/h not relevant for vehicle categorisation)	[Personal vehicles]	
L3e≥130 km/h: Fleet Size			
L3e≥130 km/h: Average lifetime distances (km)	35000, enduro & trial 13000		

Questions:	Manufacturers (OEMs)	Riders/Rider groups and associations (response A)	Riders/Rider groups and associations (response B)
L3e≥130 km/h: Average lifetime (years)			
L3e≥130 km/h: Comments	see comment above		
Which "harmful" tampering events do you believe, with objective evidence or supporting rationale wherever possible:			
Occur most frequently in the European L-category vehicle fleet? (Please also state what type of engine this applies to)	Exhaust systems (L1Be and L3e, ICE) Drive train (L1Be, ICE) Engine management (L1Be, ICE)	None	No Tampering is harmful if a Bike is ridden within its and its riders capabilities and the law as it currently stands in each member state.
Which L-category vehicles are affected by these tampering events?	See comment above	None	No Tampering is harmful if a Bike is ridden within its and its riders capabilities and the law as it currently stands in each member state.

Questions:	Manufacturers (OEMs)	Riders/Rider groups and associations (response A)	Riders/Rider groups and associations (response B)
Can the consequences for safety or the environment (emissions/noise) of these tampering events be quantified either objectively or subjectively? e.g. do you have any measurement data or number of complaints etc.	Yes they can. Tampered vehicles breach Type Approval limits in terms of pollutant limit values and noise. In the circulating park, it is estimated that 65% of L1Be and 35% of L3e vehicles are fitted with a road illegal exhaust system (source: Striving against traffic noise, ACEM http://www.acem.eu/media/d_StrivingagainstTrafficNoise_04469.pdf) From a safety perspective, tampered L1Be vehicles travelling >50 Km/h (legal limit is 45 Km/h)are overrepresented in accidents (source: MAIDS http://www.maids-study.eu/)	No	No Tampering is harmful if a Bike is ridden within its and its riders capabilities and the law as it currently stands in each member state.

Questions:	Manufacturers (OEMs)	Riders/Rider groups and associations (response A)	Riders/Rider groups and associations (response B)
Which measures would you propose or support to restrict the occurrence and/or impact of these tampering events?	See ACEM proposals on EC CIRCA website http://circa.europa.eu/Public/irc/enterprise/automotive/library?l=/mcwg_motorcycle/meeting_december/antitampering_2009pdf/_EN_1.0_&a=d http://circa.europa.eu/Public/irc/enterprise/automotive/library?l=/mcwg_motorcycle/meeting_december/requirementspdf/_EN_1.0_&a=d	None	I do not support the introduction of anti-tampering legislation

Questions:	Manufacturers (OEMs)	Riders/Rider groups and associations (response A)	Riders/Rider groups and associations (response B)
Do you have any concerns regarding potential measures to restrict harmful tampering on L-category vehicles? If so, please could you describe and explain them?	Any measures taken to prevent tampering would result in cost increases as a result of engineering changes to the product. Unreasonable requirements such as internal engine component marking or electronic safeguards may have the effect of increasing the cost of the vehicle in terms of documentation, manufacture, service and maintenance. Too much design restrictions for manufacturers may reduce the possibilities for essential maintenance or repair and will increase the costs to consumers.	What measures do you have to distinguish between harmful and non-harmful tampering? Example, How will I be able to make my motorcycle more efficient by raising the gearing to reduce the revs and therefore increase the fuel consumption.	I do not support the introduction of anti-tampering legislation

Questions:	Manufacturers (OEMs)	Riders/Rider groups and associations (response A)	Riders/Rider groups and associations (response B)
How easy is it to inform the authorities of any changes to L-category vehicles? (e.g. licensing authorities, insurance, tax)	A clear difference needs to be made between illegal modifications (tampering) and legal modifications. Legitimate changes of license category of a vehicle are important for owners and manufacturers (in particular, changing a vehicle from category L3e unlimited to L3e limited -currently 25 kW, in COM(2010)542 35 kW - and vice-versa). These changes can easily be notified to authorities and are subsequently reflected in registration documents.	Very	It is easy to do through the current processes there is no need for increased legislation.
Please provide any other comments or points that you feel are important	A mix of technical measures and enforcement measures is necessary in order to reduce the occurrence and the impact of tampering events. The main measure remains checks through periodic inspections and road side inspections to identify and deter tampering by consumers. Design technical measures without proper	Please explain why you want to do this. Is there a problem or is this just driven by the manufactures lobbying the EU. Cost. Example, pattern exhausts and air filters that can be cleaned and re-used instead of the throw away and buy a new paper air filter.	Anti-Tampering legislation would restrict the ability of riders to modify and improve bikes both functionally and aesthetically and would therefore reduce the current second stage manufacture and promotion of motorcycles. This legislation will only harm both riders and the biking related

Questions:	Manufacturers (OEMs)	Riders/Rider groups and associations (response A)	Riders/Rider groups and associations (response B)
	enforcement may just be a waste of material and cost.		industries.
Stakeholder information request for OEM - Anti-Tampering			
Please could you provide your annual sales/ number of vehicle models figures by each L-category class			
L1Ae:Annual Sales			
L1Ae:Number of vehicle models			
L1Ae:Comments	Category does not currently exist		
L1Be:Annual Sales	All brands on EU market 564851/ out of which ACEM members 262011		
L1Be:Number of vehicle models	AB 1933/ACEM 335		
L1Be:Comments	All data refers to 2010, all brands/out of which ACEM members		

Questions:	Manufacturers (OEMs)	Riders/Rider groups and associations (response A)	Riders/Rider groups and associations (response B)
L2e:Annual Sales	AB 3032/ACEM 2759		
L2e:Number of vehicle models	AB 10/ACEM 4		
L2e:Comments			
L3e-Al:Annual Sales	AB 413024/ACEM 229790		
L3e-Al:Number of vehicle models	AB 1595/ACEM 324		
L3e-Al:Comments			
L3e-A2:Annual Sales	L3e-A2+L3e-A3 AB 678861/ACEM 594181		
L3e-A2:Number of vehicle models	L3e-A2+L3e-A3 AB 2381/ACEM 1367		
L3e-A2:Comments			
L3e-A3:Annual Sales	L3e-A2+L3e-A3 AB 678861/ACEM 594181		
L3e-A3:Number of vehicle models	L3e-A2+L3e-A3 AB 2381/ACEM 1367		
L3e-A3:Comments			

Questions:	Manufacturers (OEMs)	Riders/Rider groups and associations (response A)	Riders/Rider groups and associations (response B)
L4e:Annual Sales	AB 94/ACEM 0		
L4e:Number of vehicle models	AB 15/ACEM 0		
L4e:Comments			
L5Ae:Annual Sales	AB 6833/ACEM 5707		
L5Ae:Number of vehicle models	AB 99/ACEM 17		
L5Ae:Comments			
L5Be:Annual Sales			
L5Be:Number of vehicle models			
L5Be:Comments			
L5Be-P:Annual Sales			
L5Be-P:Number of vehicle models			
L5Be-P:Comments			
L5Be-U:Annual Sales			

Questions:	Manufacturers (OEMs)	Riders/Rider groups and associations (response A)	Riders/Rider groups and associations (response B)
L5Be-U:Number of vehicle models			
L5Be-U:Comments			
L6Ae:Annual Sales	All L6 and L7 AB 54767/ACEM 4658		
L6Ae:Number of vehicle models	ALL L6 and L7 AB 1276/ACEM 81		
L6Ae:Comments			
L6Be:Annual Sales			
L6Be:Number of vehicle models			
L6Be:Comments			
L6Be-P:Annual Sales			
L6Be-P:Number of vehicle models			
L6Be-P:Comments			
L6Be-U:Annual Sales			
L6Be-U:Number of vehicle			

Questions:	Manufacturers (OEMs)	Riders/Rider groups and associations (response A)	Riders/Rider groups and associations (response B)
models			
L6Be-U:Comments			
L7Ae:Annual Sales			
L7Ae:Number of vehicle models			
L7Ae:Comments			
L7Be:Annual Sales			
L7Be:Number of vehicle models			
L7Be:Comments			
L7Be-P:Annual Sales			
L7Be-P:Number of vehicle models			
L7Be-P:Comments			
L7Be-U:Annual Sales			
L7Be-U:Number of vehicle models			

Questions:	Manufacturers (OEMs)	Riders/Rider groups and associations (response A)	Riders/Rider groups and associations (response B)
L7Be-U:Comments			
What measures do you currently take to prevent tampering to your vehicles and how effective do you consider these to be? Please provide any relevant evidence you have to support your response.	- ECU: The ECU can be protected from unauthorized writes with a complex seed and key algorithm. This ensures a read only status for critical software files within The operating system of The ECU. - throttle stops: special bolt for throttle sensor - critical components: assembly with special bolt requiring special tool - using different parts for each model, ensuring non interchangeability - sealing some electronic components with special resin, The opening of The seal causes The ECU breakdown - applying design thickness in some part of The engine not to allow any modification without engine breakdown		
Are any of the current anti-tampering requirements obsolete (97/24/EC chapter	See ACEM proposals on EC CIRCA website http://circa.europa.eu/Public/irc		

Questions:	Manufacturers (OEMs)	Riders/Rider groups and associations (response A)	Riders/Rider groups and associations (response B)
7)? If so, can you provide evidence or rationale for this?	/enterprise/automotive/library?l =/mcwg_motorcycle/meeting_d ecember/antitampering_2009pdf /_EN_1.0_&a=d http://circa.europa.eu/Public/irc /enterprise/automotive/library?l =/mcwg_motorcycle/meeting_d ecember/requirementspdf/_EN_ 1.0_&a=d		
How many in each L-category class have limited engines? (Power or speed)			

Questions:	Manufacturers (OEMs)	Riders/Rider groups and associations (response A)	Riders/Rider groups and associations (response B)
What type of limiting is used (e.g. speed, rpm, airflow) and how this is achieved (i.e. exhaust, throttle stop, ECU: spark advance (PI engine), fuel injection quantity and/or airflow restriction or combination, mechanically / electronically?)	Air filter housing, throttle body, inlet, cylinder, cylinder head, crankcase, exhaust pipe, muffler, transmission (sprockets), ECU. The components have the following impact: Air flow --- Air filter housing/throttle body/inlet Power and Engine speed (r.p.m) --- throttle body/inlet/cylinder/cylinder head/crankcase/exhaust pipe/muffler/ECU Speed(Km/h) --- transmission(sprockets or limited CVT ratio)/ECU.		
Bearing in mind the proposed changes to technical requirements, can you estimate how the sales figures will change in the future for each power source? (i.e. 2-stroke, 4-stroke, electric, hybrid)	No answer possible at the moment given that the detailed prescriptions from the Delegated Acts are still unknown.		

Questions:	Manufacturers (OEMs)	Riders/Rider groups and associations (response A)	Riders/Rider groups and associations (response B)
For each limited engine that you use in L-category vehicles, what is the maximum continuous rated power (kW) with and without the limiter?	This is always determined by external influences including license regulation, national regulations, insurance bands or purchase tax bands.For L1Be, different categories exist, and they are limited in maximum speed (25km/h and 45km/h). Tampering of mopeds often has a marginal effect on peak power itself, but rather seeks to move the peak power point in order to increase maximum speed. This tampering changes the profile of the vehicle\'s power curve, generally not affecting maximum power itself.L3A1 vehicles are limited to maximum 11 kW. Even thought this category is required to fulfil anti tampering measures, it should be underlined that the majority of these vehicles are unable to reach this 11 kW maximum power due to their 125cc engine. Generally speaking, other L3e vehicles are produced with both limited (A2 category)		

Questions:	Manufacturers (OEMs)	Riders/Rider groups and associations (response A)	Riders/Rider groups and associations (response B)
	and unlimited power (A3 category), all meeting the prescriptions for their specific category. Most common currently is to have vehicles with a maximum power of 25 kW (in COM(2010)542 35 kW) for the restricted version as well as an unrestricted version. Currently, special 74 kW versions are also necessary for the French market.		
How would you/do you measure "maximum continuous rated power" for various L-category vehicles and engine types? This value is a prerequisite for measured at type approval, but the method should also be appropriate for verification by enforcement authorities at the roadside.	In type approval, engine power is measured according to Directive 95/1/EC (maximum torque and maximum net power) on the engine bench after thermal setting. It is not possible to replicate the above mentioned procedure on the roadside because of the complexity of the engine bench and of the necessary equipment. Moreover, the bench measures the engine power without taking into consideration other power loss (for instance the transmission).		

Questions:	Manufacturers (OEMs)	Riders/Rider groups and associations (response A)	Riders/Rider groups and associations (response B)
	In order to inspect illegal mopeds on the road a maximum speed test method is under construction in ISO/TC22/SC23/WG1.		
Can you estimate the costs (or percentage of total engine cost) involved in restricting each engine in terms of:			
Parts?	N/A		
Development costs?	N/A		
How could the ECU be best protected from tampering?	The ECU has the structure to prevent access and re-write programming. It is usually protected by access keys, check-sums and encryption of the code itself. Sealing electronic devices with resin, plastic mold inside ECU, access password for ECU signal, signal protection etc. to avoid intentional access to ROM.		
What are the implications of:			

Questions:	Manufacturers (OEMs)	Riders/Rider groups and associations (response A)	Riders/Rider groups and associations (response B)
Making it more difficult to access and replace the ECU and peripheral components (e.g. DI)	Cost and practicality must also be considered, as well as logistics flexibility (diversification of products, such as L3-A2 and L3-A3, should be allowed as much as possible downstream, at importer/dealer level, to simplify production) . Costs of fitting would be increased both for manufacturers and customers, maintenance and repair would become more complicated. Customers should still be able to legally upgrade from 25kW (in COM(2010)542 35 kW) to full power according to license and registration requirements.		
Protecting the signals to and from the ECU	Not realistically achievable, from cost/practical/packaging perspectives.		

Questions:	Manufacturers (OEMs)	Riders/Rider groups and associations (response A)	Riders/Rider groups and associations (response B)
Reprogramming the ECU or altering its electronics	Re-programming is necessary for the service activity, but this activity should be limited to dealers. This should be already impossible outside factory control, however reprogramming the ECU must be feasible with the due precautions (see point 2.2 of ACEM proposal for amending Directive 97/24/EC Chapter 7, dated 09.12.2009).		
Can you estimate the costs associated with each of the following?			
Restricted access to ECU	The ECU is protected by access keys, check-sums and encryption of the code itself. Authorized access to the ECU is necessary for its fine adjustment and calibration during the life of the vehicle. The more sophisticated the vehicle is, the more often the ECU software must be updated.		

Questions:	Manufacturers (OEMs)	Riders/Rider groups and associations (response A)	Riders/Rider groups and associations (response B)
Detecting/protecting altered signals from sensors	Boundary ranges for sensors exist, which, if exceeded, flag an OBD fault code.		
Working with encrypted ECU data	ECUs have encrypted data. Who doesn't have the key/device to access the control unit, can only remove and replace the ECU. This is done to protect vehicles from tampering which could cause safety issues and abnormal warranty claims. The various methods above must be considered in the context of anti-tampering requirements as well as RMI obligations. A proper balance must be found between the anti tampering goals and access to RMI.		
Stakeholder information request for Riders/Rider groups and associations			
What incentives would be required to make harmful tampering less attractive?		Free parking, Free road tax.	No Tampering is harmful if a Bike is ridden within its and its riders' capabilities and the law

Questions:	Manufacturers (OEMs)	Riders/Rider groups and associations (response A)	Riders/Rider groups and associations (response B)
			as it currently stands in each member state.
Which anti-tampering methods do you see most restrictive for personal maintenance of the vehicle?		Air filters, exhausts, gearing, tyres.	All and any
In a pragmatic way, how would you ensure/enforce that a vehicle meets specified emissions limits?		I would not. I would spend the time and money encouraging more people onto fuel efficient bikes and out of their cars.	The current MOT requirements are more than effective enough.

B.3 Additional questions sent to other stakeholders, but which did not receive a response

Stakeholder information request for Suppliers	Stakeholder information request for Governments, local authorities and enforcement agencies	Stakeholder information request for Insurers
Please could you provide data on the range of vehicles your engines/drivetrain parts cover?	What, in your opinion, is the current likelihood of identifying a modified vehicle via PTI (Periodic Technical Inspections)/ roadside inspection?	What are your views/policy on insuring modified vehicles?
Approximately what proportion of parts sold is for non-public road use? (i.e. race track or off-road use only)	Are there some modifications which are harder to identify then others?	Which types of modifications do you allow / don't allow? (please indicate which in you answer)
Do you foresee any issues regarding additional requirements for markings on components, vehicles, or separate technical units?	Please state what these are.	What actions do you take upon the discovery of a customer's vehicle being modified before a claim
If RFID marking was introduced?	Do you foresee any issues with the improved marking of components or separate technical units for roadside enforcement?	What actions do you take upon the discovery of a customer's vehicle being modified after a claim
If stickers and/or other markings were required?	Are there any other measures that you would support? (e.g. electronic marking of components)	What expertise do you use to identify modifications on vehicles?
In terms of where and how markings could be positioned?	What is the budget available (either in money or a proportion of total) for market surveillance programme and/or road side inspections?	Can you provide us with objective data on the number of:

For the marking of aftermarket OEM and non-OEM parts?	How many police units already have roadside dynamometers?	L-category vehicles insured
	Regarding roadside inspections and with objective evidence or supporting rationale, what are your views on the following tests and techniques? (e.g. Speed, Power, Emissions (gas), Emissions (Noise), Road worthiness)	Modified vehicles involved in a claim
	Increasing the range of technical roadside tests?	Unmodified vehicles in a claim
	How would you like to see these tests performed?	Modifications which you were informed of by the owner prior to the claim
		What are the implications to the claim cost for vehicles fitted with anti-tampering devices (such as shear nuts, encrypted ECUs) compared to those without?

Appendix C Stakeholder responses

C.1 EC type-approval authority

Message received in response to request for stakeholder input:

Dear Ladies and Gentlemen

I'm head of the xxxx EC type-approval authority. In former times I did roadside inspections of all vehicles. Sometimes I am faced with problems of police and technical inspectors making roadside and periodical technical inspections of vehicles.

Outside of this competition I want you bring your attention to some of these problems and where no adequate anti tampering measures are in force today.

- Anti tampering measures are not only for safety of the vehicles themselves or for their environmental impact; they are related to the drivers licenses and the education of the drivers too.

- on two stroke engines the effective resonance length of the exhaust manifold has a big impact on maximum power and maximum speed. In much cases the exhaust manifold protrudes into the silencer and the correct length of the exhaust manifold can't be checked without demounting some parts. A solution might be that the end of the exhaust manifold shall not protrude into the silencer / resonance chamber / catalyst housing.

- much two stroke engines are throttled by a resonance tube inside the air filter box. This resonance tube is often an additional tube with a dedicated length and a orifice. This tube is placed into the plastic housing of the air filter box and can be removed easily. A solution might be that such resonance tubes shall be a fixed part of the air filter housing which cannot be removed without destruction of the housing.

- sometimes the original silencer/catalyst assembly is constructed in a manner that they are blocked by disposals from the exhaust gases in short time. If the owners of these vehicles come to the dealer he sells a replacement silencer (often without the required catalyst - who knows about the need of the catalyst?) having more sound level and sometimes resulting in higher engine power/max speed which doesn't have the problem with the disposals. A solution might be to stipulate a test run with the durability mileage as proposed in Annex VII of the Commission's proposal (without maintenance of the exhaust system and without the possibility of using deterioration factors only) .

- intentionally high tolerances in the variator belt drive of the continuous variable transmission leading to gear ratios outside the allowed range and therefore leading to higher speeds.

- No anti tampering measures for Quads with 15 kW (only lock screw without any prevention of advance, stop sleeve in the carburettor, ...)

- is some cases the electronic speed signal isn't adequate protected against tampering.

- some vehicles may run much faster furthermore if the go beyond a specific speed (for example after a downhill trip or in the slipstream of another vehicle); this might be an effect of throttling by resonance throttles. Therefore such properties of the vehicles should be tested.

I hope this input is useful for you. Don't hesitate to contact me for further questions.

Kind Regards

Reply

Could you expand on the problems you see with the electronic speed signal? Do you think the system should have some sort of automatic break when over-speeding?

Reply

Concerning electronic speed signal:

Some Mopeds are well known as for their high speed if the speed signal is interrupted (as I remember XXXXX). A solution might be to limit the engine speed (e.g. to the speed on which the stationary sound level is measured) if no speed signal is detected. This would not avoid higher speeds than 45 km/h but I think the speed reached by these vehicles should be observable lower than without this measure. Another solution might be to limit the reachable speed to a fixed number if the speed signal is missing - but this might be more complicated for the manufacturer. This measure also doesn't avoid the impact of "tuned control boxes" - I'm sure that they are available in short time on the market like today. Automatic braking might be dangerous.

C.2 EC custom motorcycle manufacturer

Message received in response to request for stakeholder input:

Thank you for your email

I represent myself, I am a Motorcycle Modification Engineer (customizer), I build chops. I am a welder/fabricator, engineer/machinist, I am also a VOSA approved vehicle tester, I hold qualifications in Engineering (EMTRA) Welding (EMFEC) Mechanical Engineering (NVQ) and Motor Vehicle Engineering (City & Guilds). I Used to manufacture valves for Nuclear Reactors/Submarines. I have also been employed as a Quality Control Inspector (Braking Systems) within the rail industry.

My concerns are on several levels, the first is that the over restrictive legislation on tampering with the power train will see the demise of motor cycle customising (or drive it underground) resulting in the loss of thousands of jobs!

Secondly It will be impossible to lower the chassis if the standard exhaust cannot be modified to fit the new frame, similar difficulties will be experienced regarding the induction system once the engine is fitted in the confines of a well constructed frame there simply is not space to facilitate the incorporation of all the chambers required to allow the engine to breath in its standard format, this results in the need for a system wide reset of the standard fuelling parameters. Sufficient thought therefore must be placed on the availability and exempted use

of non standard parts replacement. Most of the components required will be of a unique specification and will not comply with type approval or OE specification.

My final point is that most motorcyclists cherish the sense of freedom that motorcycling affords them and resent the introduction of "nanny state" interference the ability to go into the garage and tinker with one's own possessions should be a basic human right, We buy them we tax them we insure them we spend MILLIONS OF POUNDS on them. But most of all it is a sad day when over intrusive legislation is drafted for the sole purpose of reducing a small section of societies enjoyment. None of the proposals will increase the consumer protection they just erode our rights.

Yours sincerely

Further emails were received from this stakeholder detailing discussion with their MEP, these have not been reproduced.

Thank you for your response, as I manufacture all of my own components for each of my projects for me to attempt to provide accurate figures for you would be very difficult. I can however tell you that the software required to reprogram/remap industry standard OBD 1&2 is freely available. I personally have found copies of OBD 1/2 for as little as £6.99, this means that with the purchase of an interface lead absolutely anybody with a laptop will be able to totally remap their fuel management. This will result in emissions that are completely unmeasured until first MOT some 3 years after purchase. The only way this will be detectable is with an exhaust gas analyser, which just as with the MOT test equipment will need to be calibrated and carefully maintained. The users of the equipment will also need to be trained in its correct use as any deviation from strict operating parameters will result in invalid or even inaccurate exhaust gas analysis. Vehicles must also be of the correct operating temperature before any emissions test can carried out, this will result in the need for further calibrated equipment being utilised. Just as important during the exhaust gas analysis is knowing at which point to abandon the test to prevent damage to a vehicle that may have other faults that prevent correct engine cooling, Who will be liable for engine damage as a result of overheating because the operator of the equipment is not an experienced mechanical engineer? The time required to obtain an exhaust gas analysis that states the emissions of a vehicle are outside of the specified parameters can be up to 30-40 minutes allowing for calibration and warm up time.

C.3 UK Police

A meeting was made with a representative of a police a UK police force. We were provided with data, photographs and documents detailing some of the schemes they are involved with and the problems they experience.

The police officer was also a coordinator for one region in a scheme which educates novice riders on such things as road safety and vehicle maintenance. This scheme operates in regions where police forces have indicated a high instance of L-category vehicle accidents and/or have a large road population of moped and 125 cm^3 vehicles.

The following is a selection of the data provided.

C.3.1 Roadside checks

Various police forces around the UK perform road side checks which specifically target speed and power restricted vehicles. These are set-up at known areas frequented by these vehicle users. Vehicles/riders considered to be suspicious are pulled over, on closer inspection those where the vehicle looks to be modified are speed tested on a portable dynamometer (see Figure 19-2). Table 19-2 to Table 19-4 shows the results of these tests at one location on three dates.

Figure 19-2: Portable dynamometer used by police

Data on the total traffic flow of l-category vehicles was not taken and therefore this data cannot be used to calculate the proportion of modified vehicles.

For the UK roads the speed limit for L1Be and L6e vehicles has been converted to imperial and rounded to the nearest road speed limit. Therefore the speed restriction of ≤45 km/h is considered to be ≤30 mile/h (45km/h * 0.62 = 27.9 mile/h, a speed limit of 30 mile/h is enforced for built up areas), this is further simplified to mean < 31 mile/h. The police force then use the following rule to determine whether a vehicle can be seized: "Conditions of seizure are set in line with ACPO Speed Prosecution Policy of 10% + 2 mile/h therefore 36 mile/h" or ≥57 km/h. Combined this gives a tolerance of +12 km/h from the type-approval limit before a vehicle is considered liable to be seized.

Table 19-2: UK roadside moped testing data (2008)

Exhaust modification	Maximum vehicle speed (mile/h)	Recorded vehicle speed (km/h)
Aftermarket exhaust	45	**72**
Aftermarket exhaust	45	**72**
Aftermarket exhaust	45	**72**
Aftermarket exhaust	45	**72**
Aftermarket exhaust	47	**76**
Aftermarket exhaust	49	**79**
Unknown	44	**71**
Unknown	45	**72**
Unknown	46	**74**
Aftermarket exhaust	34	55
Unknown	43	**69**
Unknown	31	50
Aftermarket exhaust	52	**84**

Exhaust modification	Maximum vehicle speed (mile/h)	Recorded vehicle speed (km/h)
Aftermarket exhaust	45	**72**
Aftermarket exhaust	44	**71**
Aftermarket exhaust	42	**68**
No	30	48
Disruptor pipe cut off	39	**63**
Unknown	32	51
Unknown	34	55
Unknown	30	48
Unknown	41	**66**
Unknown	37	**60**
Unknown	35	56
Unknown	38	**61**
Unknown	43	**69**
Disruptor pipe cut off	38	**61**
	40	**64**
Tested: 28	**Exceed limit: 21**	**Seized: 10**

Table 19-3: UK roadside moped testing data (2009)

Exhaust modification	Maximum vehicle speed (mile/h)	Recorded vehicle speed (km/h)
Unknown	28	45
Unknown	40	**64**
Disruptor pipe cut off	39	**63**
Disruptor pipe cut off	44	**71**
Aftermarket exhaust	43	**69**
Aftermarket exhaust	41	**66**
Aftermarket exhaust	36	**58**
Aftermarket exhaust	37	**60**
Aftermarket exhaust	37	**60**

Exhaust modification	Maximum vehicle speed (mile/h)	Recorded vehicle speed (km/h)
Aftermarket exhaust	33	53
Aftermarket exhaust	39	**63**
Aftermarket exhaust	40	**64**
Unknown	31	50
Unknown	31	50
Aftermarket exhaust	42	**68**
Aftermarket exhaust	43	**69**
Disruptor pipe cut off	36	**58**
Aftermarket exhaust	41	**66**
Unknown	43	**69**
Unknown	28	45
Unknown	28	45
Unknown	29	47
Unknown	29	47
Aftermarket exhaust	46	**74**
Aftermarket exhaust	41	**66**
Aftermarket exhaust	38	**61**
Aftermarket exhaust	40	**64**
Aftermarket exhaust	44	**71**
Aftermarket exhaust	39	**63**
Unknown	27	43
Unknown	24	39
Unknown	28	45
Unknown	28	45
Unknown	32	51
Yes	53	**85**
Tested: 35	**Exceed limit: 22**	**Seized: Unknown**

Table 19-4: UK road side testing data 2010

Exhaust modification	Maximum vehicle speed (mile/h)	Recorded vehicle speed (km/h)
Aftermarket exhaust	43	**69**
Unknown	43	**69**
Disruptor pipe cut off	48	**77**
Unknown	44	**71**
Aftermarket exhaust	58	**93**
Aftermarket exhaust	56	**90**
Aftermarket exhaust	46	**74**
Aftermarket exhaust	45	**72**
Unknown	44	**71**
Unknown	33	53
Unknown	38	**61**
Aftermarket exhaust	39	**63**
Disruptor pipe cut off	35	56
States 40+ mile/h	38	**61**
Aftermarket exhaust	31	50
Disruptor pipe cut off	43	**69**
Aftermarket exhaust	33	53
Aftermarket exhaust	38	**61**
Aftermarket exhaust	34	55
Aftermarket exhaust	30	48
Aftermarket exhaust	40	**64**
Aftermarket exhaust	43	**69**
Unknown	48	**77**
Unknown	37	**60**
Disruptor pipe cut off	37	**60**
Tested: 25	**Exceed limit: 19**	**Seized: 20**[39]

[39] Note: The extra vehicle may have been seized for a non speed related offence

C.3.2 UK modified vehicles

The following images show two examples of derestricted vehicles being caught by speed cameras, as well as an example of the exhaust disrupter pipe being removed.

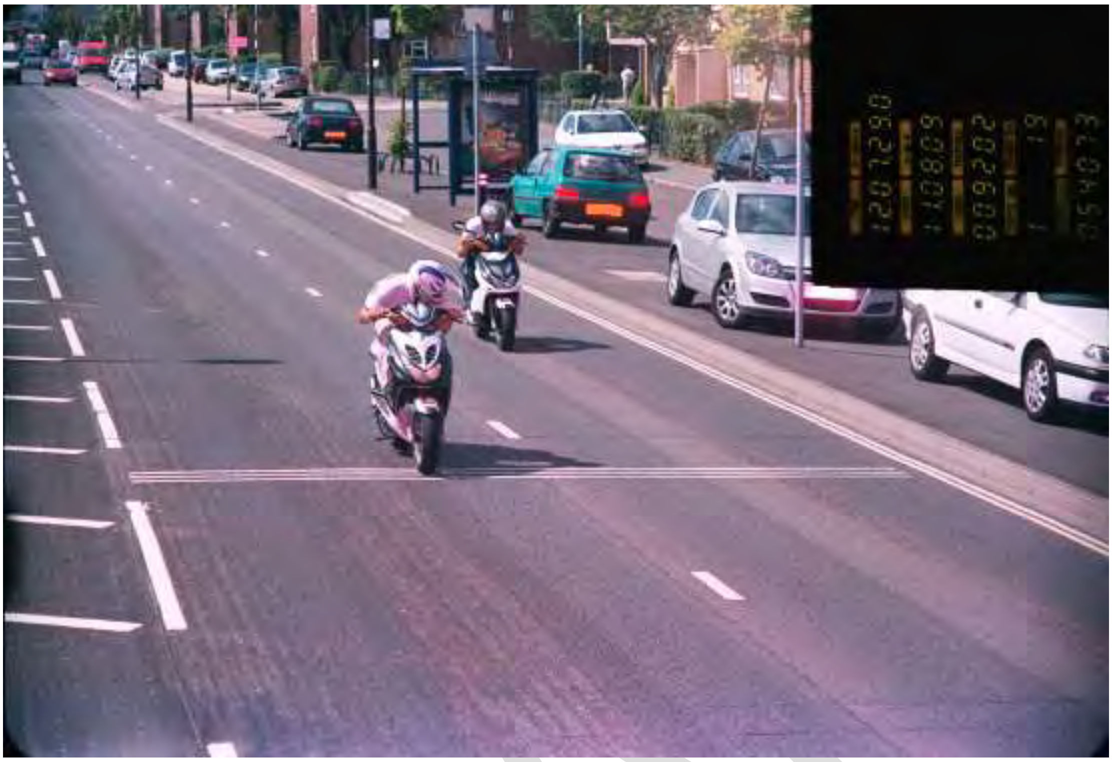


Figure 19-3: Photograph from a fixed speed camera in Portsmouth (UK) showing the leading rider to be travelling at 54 mile/h (87 km/h). 11/08/2009

Figure 19-4: Exhaust with disruptor pipe (stubber pipe) in place

Figure 19-5: Inspected vehicle with exhaust disruptor pipe (stubber pipe) removed and hole welded over

Figure 19-6: Photograph from a fixed speed camera in Portsmouth (UK) showing the rider to be travelling at 48 mile/h (77 km/h). 28/08/2010

C.4 Attended roadside check in the Netherlands

In the Netherlands a large proportion of the traffic consists of L1e users. Under their national law, there are 3 levels of power two-wheelers, differentiated by licence plate markings and style, these all have various legal requirements see Table 19-5 below.

Table 19-5: Overview of L-category legislation in the Netherlands

Category	Number plate	Maximum speed	Tolerance	Helmet
L1Be	Blue plate	$\leq$25km/h max speed	$\leq$30km/h allowance	no helmet required
L1Be	Yellow plate	$\leq$45km/h max speed	$\leq$50km/h allowance	helmet required
L3e	Bigger yellow plate with EC flag	no limit		helmet required

Table 19-6 shows the three levels of possible punishments:

Table 19-6: Punishment criteria in the Netherlands

Measured value	Punishment	After test
10% allowance (max 5 km/h)	nothing	
>5 km/h $\leq$ 15km/h	Fine	allowed to ride home
>15km/h	Court appearance	allowed to push home
3 illegal stops over 2 years and the bike will be confiscated and scrapped		

C.4.1 Road-side check total department statistics in the Netherlands

The police provided statistics which they had complied on a previous year's road-side inspection programme (see Table 19-7 to 19-9):

Table 19-7: Road-side inspection statistics for 2004 (Netherlands). Number of vehicle offenses

	Phase 1 21th Jun - 8th Oct		Phase 2 10th Oct - 17th Dec		Improvement Phase 2 to 1
	Total	%	Total	%	%
Driver or passenger without helmet	199	6.6%	103	5.8%	12.2%
Could not show driving license at first request	468	15.5%	187	10.5%	32.2%
No driving license	234	7.7%	117	6.6%	15.2%
No scooter / moped marking	130	4.3%	49	2.7%	36.1%
Illegal use of moped marking	144	4.8%	66	3.7%	22.2%
(*) In 2004 there was no mandatory registration plate, but a marking					
Breaking defect	86	2.8%	71	4.0%	-40.1%
Steering defect	22	0.7%	34	1.9%	-162.2%
Without or with incorrect approval number	2	0.1%	1	0.1%	15.2%
Without insurance	73	2.4%	32	1.8%	25.6%
Younger than minimum age	15	0.5%	14	0.8%	-58.3%
Could not show insurance policy at first request	501	16.6%	314	17.6%	-6.3%
Exceeded max design speed	**1172**	**38.7%**	**472**	**26.5%**	**31.7%**
Exceeded max design speed by more than 30 km/h	**104**	**3.4%**	**44**	**2.5%**	**28.2%**
Exceeded the noise limit	**9**	**0.3%**	**8**	**0.4%**	**-50.8%**
(*) Note: low numbers of noise offences is partially due to the lack of an adequate road side testing method. Only excessively obvious problems were sent for further testing					
Other	219	7.2%	289	16.2%	-123.9%
Number of drivers checked	3025	100.0%	1783	100.0%	
Total number of offenses	3378	111.7%	1801	101.0%	9.5%

Table 19-8: Road-side inspection statistics for 2004 (Netherlands). Number of criminal offenses

	Phase 1 21th Jun - 8th Oct		Phase 2 10th Oct - 17th Dec		Improvement Phase 2 to 1
	Total	%	Total	%	%
Theft	8	0.3%	142	8.0%	-2,911%
Fraud	43	1.4%	8	0.4%	68.4%
Other	72	2.4%	10	0.6%	76.4%
Total Crimes	123	4.1%	160	9.0%	-120.7%

Table 19-9: Road-side inspection statistics for 2004 (Netherlands). Total confiscations and vehicle + criminal offenses

	Phase 1 21th Jun - 8th Oct		Phase 2 10th Oct - 17th Dec		Improvement Phase 2 to 1
	Total	%	Total	%	%
Confiscation	55	1.8%	18	1.0%	44.5%
Total offences + crimes	3501		1961		

C.4.2 Road-side checks in The Netherlands

The plan for the study was to target areas where potential illegal bikes frequently pass and set-up a roadblock. The location would be changed twice during the day (3 locations in total), this was done to counter the effect of the news spreading (via services such as twitter) across the moped modification community of the road block causing people to avoiding the area.

The porFigure dynamometer was be setup at a natural bottle neck or trunk road, then 2 motorcycle police would patrol the area to draw in and pull over as many L1e category vehicles as possible.

All L1e category bikes will be stopped unless it got too busy. This happened at the third location a great deal, however this was less at the first two stops. Also the third location had substantially less moped enthusiasts i.e. 'boy racers' as the news had already spread of the police presence in the area.

In addition to the speed testing, all vehicles were given a visual check for safety concerns and certain vehicles had their identification checked. All Vespers had their VIN number checked as that brand had a high likelihood of being stolen. They used acetone to clean any paint off the marking as it was common for criminals to coat over and forge the numbers.

All vehicles are speed tested, the speed was only noted if the their categories' design speed was exceeded by more than 5 km/h. Only the speed beyond the 5 km/h allowance was used in determining the level of punishment (see Table 19-6 above).

Table 19-10: Results of road side check, location A (all measurements in km/h)

Max. design speed	Limit for in use (design speed + 5 km)	Measured speed	Speed after allowance correction	Difference	Description of violation(s)
25	30				
25	30				
25	30				
25	30				
25	30				
25	30				
25	30				
25	30				
25	30	40	35	5	Exceeding max. design speed
25	30	42	37	7	Exceeding max. design speed
25	30	46	41	11	Exceeding max. design speed
25	30	40	35	5	Exceeding max. design speed
25	30	43	38	8	Exceeding max. design speed
25	30				No mirror
25	30	42	37	7	Exceeding max. design speed
25	30	40	35	5	Exceeding max. design speed
25	30				Could not show registration documents
25	30				Could not show registration documents Could not show driving license
25	30				Could not show registration documents
25	30	41	36	6	Exceeding max. design speed
25	30	51	45	15	Exceeding max. design speed
45	50				
45	50				
45	50				

45	50				
45	50				
45	50				
45	50				
45	50				
45	50				
45	50				
45	50				
45	50				
45	50				
45	50				
45	50				Helmet not (correctly) fastened
45	50				Inadequate brakes
45	50	62	55	5	Exceeding max. design speed
45	50				No insurance
45	50				Could not show registration documents
45	50	70	63	13	Exceeding max. design speed
45	50	61	54	4	Exceeding max. design speed
Total					**42**
Exceeded design speed					**12**
Exceeded design speed by 30km/h					**1**
Number of offences					**20**

Table 19-11: Results of road side check, location B (all measurements in km/h)

Max. design speed	Limit for in use (design speed + 5 km)	Measured speed	Speed after allowance correction	Difference	Description of violation(s)
25	30				
25	30				
25	30				
25	30				
25	30				
25	30				
25	30				
25	30				
25	30				
25	30	52	46	16	Exceeding max. design speed
25	30				Could not show ID
25	30				Inadequate brakes
25	30	42	37	7	Exceeding max. design speed Could not show registration documents Could not show driving license
25	30	40	35	5	Exceeding max. design speed
45	50				
45	50				
45	50				
45	50				
45	50				
45	50				
45	50				
45	50				
45	50				
45	50				

45	50				
45	50				
45	50				Inadequate brakes
45	50	71	63	13	Exceeding max. design speed
45	50	68	61	11	Exceeding max. design speed No mirror
45	50				No mirror
45	50	69	61	11	Exceeding max. design speed Inadequate brakes
45	50				Could not show registration documents
Total					**32**
Exceeded design speed					**6**
Exceeded design speed by 30km/h					**3**
Number of offences					**11**

Table 19-12: Results of road side check, location C (all measurements in km/h)

Max. design speed	Limit for in use (design speed + 5 km)	Measured speed	Speed after allowance correction	Difference	Kind of violation(s)
25	30				
25	30				
25	30				
25	30				
25	30				
25	30				
25	30				
25	30				
25	30	42	37	7	Exceeding max. design speed
25	30	46	41	11	Exceeding max. design speed
25	30				Could not show registration documents
45	50				
45	50				
45	50				
45	50				
45	50				
45	50				
45	50				
45	50				
45	50				
45	50				
45	50				
45	50				
45	50				
45	50				

Max. design speed	Limit for in use (design speed + 5 km)	Measured speed	Speed after allowance correction	Difference	Kind of violation(s)
45	50				
45	50				Helmet not (correctly) fastened
45	50				No mirror
Total					**28**
Exceeded design speed					**2**
Exceeded design speed by 30km/h					**0**
Number of offences					**5**

This data covers only one date and three locations in the Netherlands, but nevertheless, it can be used in a limited degree to see the scale of the issue of harmful tampering is this country. 19.6% of the vehicle were tampered, 3.9% of the vehicles in the sample exceeded their design speed by over 30 km/h.

A specific danger in the Netherlands is that ≤25 km/h mopeds are allowed to be ridden on cycle lanes, some of which are also used by pedestrians, and riders are not required to wear helmets on these vehicles. 30.4% of the ≤25 km/h L1Be vehicles tested were modified, with an average maximum vehicle speed of 43.3 km/h.

C.4.3 Results of the road-side tests

Of the vehicles exceeding the limit there was not one specific brand or model which was more prone to tampering of this type although the sample was not large enough to draw definitive conclusions. However, it was noted that one particular manufacturer made de-restricting particularly difficult. Of the three examples of this make tested, only one showed excessive speed; however this was not because of the removal of a limiter, but instead due to mis-registration upon import. The vehicle in question had been tested by the authorities and shown to be borderline with respect to exceedance of maximum vehicle speed. The user had subsequently carried out maintenance to the vehicle, specifically the replacement of the spark plug, which increased the maximum vehicle speed from just under 30 km/h to 43 km/h.

The types of riders stopped appeared to represent a broad cross-section. The illegal bikes were also ridden by users of different types. Supposedly some had just purchased their vehicle second hand with no knowledge of the restriction or how to perform the de-restriction themselves; these people also tended to have poorly maintained machines.

Among the 102 vehicles pulled over and tested, only one was an electric moped (see Figure 19-7). This completed the speed test with negligible noise and attained the precise design speed.

Figure 19-7: Electric moped being tested at the roadside in the Netherlands

Appendix D Literature review

D.1 Previous research on tampering

Low performance motorcycles (<125cc) and mopeds are currently required to meet the ant-tampering requirements of Chapter 7 of Directive 97/24/EC. There are currently no mandatory anti-tampering requirements for any other L category vehicle.

At the request of text contained within Directive 97/24/EC, a study by TÜV Nord ((Dittmar, et al., 2003)) examined the effectiveness of the Chapter 7 requirements, including the occurrence of tampering events, recommended potential countermeasures and further research. Due to the lack of vehicles type-approved according to Directive 97/24/EEC at the time the TÜV study, it was not possible to assess conclusively the effectiveness of the legislation, nor was it possible to quantify the frequency and effects of tampering in the L category fleet. However (Dittmar, et al.), identified a range of tampering mechanisms and proposed some new measures concerning anti-tampering.

The study also conducted a questionnaire survey, and although the responses did not cover all stakeholder groups and were limited in number, they did allow identification of the main aims for tampering L-category vehicles. These aims were summarised as being to attain:

- Greater engine power output;
- Greater engine torque;
- Alteration of torque/power characteristic;
- Greater top speed; and
- Alteration of the sound signature.

The TÜV study also summarised motivations for L-category vehicle tampering; these included:

- By-passing driver licensing restrictions
- Saving on road tax
- Saving on insurance premium
- By-passing recurring technical inspections for special categories of vehicle
- General interest in customising and vehicle modification

Robinson *et al.* (2009) reviewed the research reported by Dittmar *et al.* (2003) and confirmed the main conclusions made by TÜV Nord. It was also recommended by TRL that to provide more definitive guidance on the effect of future policy options, the effects of tampering on safety and the environment should be objectively quantified. Robinson *et al.* (2009) recommended that if quantified effects are identified which cause concern, a data collection scheme could be instigated to identify and monitor the types and rates of tampering in the fleet. As part of this activity, mechanisms of data collection were proposed, including periodic technical inspections and roadside surveys.

Robinson *et al.* (2009) also conducted an initial impact assessment for anti-tampering measures. Three options were devised and assessed: a "do nothing" option (i.e. no action is taken and the status quo is maintained), repealing the Chapter 7 (Directive

97/24/EEC) requirements, and new anti-tampering measures. Robinson *et al.* (2009) found that the scale of the safety and environmental problem brought about by tampering is largely unrecorded, with evidence being largely anecdotal and specific to certain vehicle types. The effectiveness of the Chapter 7 regulation could not be assessed for this reason; the scale of the problem before and after the introduction of the regulation is unknown. Robinson *et al.* (2009) considered that the "do nothing" option had neutral economic and societal impact, although the potential for negative environmental impact was noted since some vehicles could continue to be modified in such a way that increases noise and perhaps also emissions. In addition, as vehicles become more electronically controlled, existing regulatory controls on anti-tampering were considered to become less effective or obsolete, although the effectiveness of existing measures are currently unclear. Repealing Chapter 7, i.e. taking away the requirements for anti-tampering, was considered a "backward step", with potential negative effects on safety, as well as negative economic and environmental impacts, although the magnitudes of these impacts were unknown because of the lack of information to quantify the effects of tampering before and after the introduction of Chapter 7. Robinson *et al.* (2009) stated that implementing new measures for anti-tampering has the potential to deliver positive societal, economic and environmental impacts. However, there was insufficient information to quantify these, and it was also noted that the economic impact (not including quantified societal and environmental costs) could be negative, depending on the specific measures selected and the scale of the problem the measures address.

The TÜV Nord report also concluded that regulatory changes are required to, among other things, address the changes in vehicle propulsion away from conventional engines towards electric and hybrid types, improved marking of components and tests to quantify the effect of electronic tuning on emissions, noise and top speed (safety).

D.2 Safety and tampering

Accident data consistently reveals that L-category vehicle users have a higher risk of fatal or serious accidents than other vehicle users. The fatality rate per million kilometres travelled is, on average, approximately twenty times greater than for passenger cars (Robinson, et al., 2009). Furthermore, L category vehicles account for approximately 2-3% of the distance travelled, but approximately 16% of road deaths in the EU-25 (ETSC, 2007). While casualties associated with other vehicle types have demonstrated significant decreases in terms of fatalities and serious injuries over recent years, corresponding figures for L-category vehicles have not shown the same rate of improvements and have remained approximately static over recent years.

The effect of tampering on safety (i.e. the size of the current 'problem' in the European fleet) is difficult to quantify, primarily because there is no sufficiently detailed systematic recording scheme for tampering data, and it is known that some types of tampering may be difficult to detect without a detailed mechanical inspection or specific testing. However, there is a body of evidence that supports the view that tampering is taking place on certain types of L-category vehicle, and that this has a detrimental effect on safety.

For example, if tampering were to have no influence on accident risk, the proportion of accident involved vehicles exhibiting tampering would be expected to be the same as that in the general population. Analysis presented in the MAIDS final report ((ACEM,

2004)) indicates that tampered mopeds (L1e) are over-involved in accidents; i.e. the proportion of tampered vehicles in the accident sample was greater than that in the exposure sample. MAIDS data suggests that 17.8% of the L1e vehicles involved in accidents had been tampered with, compared with only 12.3% in the exposure sample. This suggests that vehicles that have been tampered with are more likely to become involved in an accident. However, this relationship is subject to a number of caveats:

- The MAIDS data shows an associative relationship between accident frequency and vehicle tampering and does not necessarily mean that the tampering is the *cause* of increased risk. Greater involvement in accidents may result from other differences between the tampered and untampered groups, for example differences in rider type, attitude and behaviours;
- The accident data from the MAIDS study pre-dates the implementation of the chapter 7 anti-tampering measures, so it is possible that tampering may have already reduced due to existing regulatory measures;
- In the MAIDS sample, if it was unknown whether a vehicle had been tampered with or not, MAIDS studies classified it as a non-tampered vehicle. If, in fact some of those unknowns had been tampered with, then tampering in general may have been underestimated. However, assuming vehicles in the accident and exposure group were subject to an equal number of inaccuracies in this respect, the over-representation of tampered vehicles would be expected to remain unchanged.

Currently, L1e vehicles (as they are categorised in the current regulation) are restricted to a maximum speed of 45km/h. Analysis of fatal accidents in the MAIDS database (ACEM, 2004) showed that up to 40% of fatal accidents involved L1e vehicles travelling at speeds greater than 50km/h, implying that:

- tampered vehicles are much more over-represented in fatal accidents than the comparison between the accident and exposure samples reveals, since in 40% of the cases they were travelling 5km/h or more in excess of their maximum speed; and
- a much higher proportion of vehicles are tampered with than the accident investigators were able to identify during their visual inspection.

However, this does not necessarily mean that preventing tampering could reduce L1e fatalities by 40%, because the vehicle speed is likely to have contributed to the cause of the accident or injury severity in only a proportion of the cases identified. Furthermore, the topography at the accident scene and the reconstruction assumptions may influence the vehicle speeds. Other factors that would have contributed to the cause of the accidents or injuries, for example rider behaviour/experience or the actions of the other road users involved, were not identified in conjunction with speed in the MAIDS analysis.

Many studies have identified a proportional relationship between speed and injury outcome e.g. (Robinson, et al., 2009) because of a fundamental relationship between speed and crash energy. On this basis, it could be argued that a vehicle adjusted to travel faster has a greater accident risk because the consequences of a greater speed mean that the risk of accident involvement are increased due to less time for critical decision-making and the accident outcome is made more severe because of the increased crash energy. However, this relationship is affected by rider behavioural

factors to the extent that it is difficult to conclude that just because a vehicle travels faster, or is more powerful, it automatically has a detrimental effect on safety.

The extent to which tampering negatively influences safety is more prominent when a tampering event results in a shift of a vehicle to a different legal category. This may mean that the vehicle has avoided compliance with certain technical requirements, or that its capabilities are beyond the original design limits and that of safety critical components (e.g. brake systems). This may mean that these components are insufficient for the intended function and prone to premature failure. Increased acceleration or top speed may also have implications for driveability and stability characteristics such that rider control of the vehicle is impaired. Although difficult to quantify, this may also affect safety as it may increase the rate of rider control errors.

D.3 Emissions and tampering

The effects of tampering may also have implications for tailpipe and evaporative emissions. Emissions (from the exhaust system and evaporative emissions from the fuel system) have both negative environmental and health impacts. Improved standards for passenger cars (Euro 5 and 6) and Euro VI heavy-duty emission standards mean that in future, L-category vehicles are predicted to account for an increasing proportion of total emissions. The EC's impact assessment predicted that the proportion of total evaporative and exhaust hydrocarbons (THC) emitted by L-category vehicles will increase from 38% of those emitted by all road vehicles to 62% by 2021 if no additional measures are implemented (Leonidas Ntziachristos, 2009). In particular, mopeds (L1) have been identified as one of the most significant contributors to hydrocarbon emissions and are expected to account for 38% of total road transport hydrocarbon emissions by 2020 (Leonidas Ntziachristos, 2009). L-category vehicles are responsible for a very small proportion (less than 3%) of total European road transport mileage, so their pollutant emissions are disproportionately high.

Appendix E Light vehicle categories

Category & Category Name	Sub category & Sub category name	Example		Number of wheels	Propulsion: Internal Combustion Engine (ICE): Gasoline & Gasoline blends	Propulsion: Internal Combustion Engine (ICE): Diesel & Diesel blends	Propulsion: Internal Combustion Engine (ICE): Gaseous (CNG / LPG)	Propulsion: Hybrid Engine	Propulsion: Electric Engine	Max. vehicle Speed	Internal Combustion Engine (ICE) max. displ. (cm3)	ICE Max. Power (kW)	Hybrid Max. Power (kW)	Electric Motor Max. Power (kW)	Max mass (kg)
L1e, light two-wheel vehicle	L1e-A powered cycles			2	x	x	x	x	x	25	50 (PI)	max. 1.0			
	L1e-B Moped			2	x	x	x	x	x	45		max. 4.0			
L2e Three-wheel moped				3	x	x	x	x	x	45	50 (PI) or 500 (CI)				
L3e, motorcycle	A1, A2, A3			2	x	x	x	x	x			A1 max 11 kW A2 max 35 kW A3: n.a.			
L4e, motorcycle with side car	-			3	x	x	x	x	x			A1 max 11 kW A2 max 35 kW A3: n.a.			
L5e, tricycles	L5e-A Tricycles			3	x	x	x	x	x						
	L5e-B Commercial tricycles			3	x	x	x	x	x						
L6e, Light quadricycle	L6e-A Light quad			4	x	x	x	x	x	45	50 (PI)	max. 4			425 kg
	L6e-B Light mini car			4	x	x	x	x	x	45	50 (PI) or 500 (CI)	max. 6			
L7e, Heavy quadricycle	L7e-A On-road quad	L7e-A1		4	x	x	x	x	x			15 kW			Transport of passengers: 450 kg goods: 600 kg
		L7e-A2		4	x	x	x	x	x						
	L7e-B Heavy all terrain quad	L7e-B1 all terrain quad		4	x	x	x	x	x	90					
		L7e-B2 side-by-side buggy		4	x	x	x	x	x			max.15 kW			
	L7e-C Heavy Quadri-mobile			4	x	x	x	x	x	90		max.15 kW			

Figure 19-8: L-category vehicle classification criteria

Table 19-13: L-category vehicle classification criteria

Category	Sub category	Classification criteria
L1e Light two-wheel powered vehicle	L1Ae powered cycle	Engine aids pedalling of vehicle Engine Vd ≤ 50 cm^3 Vmax ≤ 25 km/h No aux. propulsion above Vmax

Category	Sub category	Classification criteria
		250 W< Pmax.cont ≤ 1kW
	L1Be two-wheel moped	Engine Vd ≤ 50 cm^3 Vmax ≤ 45 km/h Pmax.cont ≤ 4 kW
L2e Three-wheeled moped	-	Engine Vd ≤ 50 cm^3 Vmax ≤ 45 km/h Pmax.cont ≤ 4 kW
L3e Two-wheel motorcycle	A1 2-wheel motorcycle low performance	Engine 50 < Vd ≤ 125 cm^3 Vmax > 45 km/h 4< Pmax.cont ≤ 11 kW power/weight ≤ 0.1 kW/kg
	A2 2-wheel motorcycle medium performance	Engine Vd > 50 cm^3 Vmax > 45 km/h 11 < Pmax.cont ≤ 35 kW power/weight ≤ 0.2 kW/kg
	A3 2-wheel motorcycle high performance	Any other L3e category motorcycle
L4e Motorcycle with side car	A1, A2, A3 (follows same subcategory as L3e)	-
L5e Tricycles	L5Ae Tricycles	Engine Vd > 50 cm^3 Vmax > 45 km/h Pmax.cont > 4 kW
	L5Be Commercial tricycles	Engine Vd > 50 cm^3 Vmax > 45 km/h Pmax.cont > 4 kW Open and Enclosed driver and passenger (2 people including driver) Carriage of goods (bed area > 30% of vehicle length times width)
L6e	L6Ae Light on-road quad	Engine Vd ≤ 50 cm^3 Vmax ≤ 45 km/h

Category	Sub category	Classification criteria
Light quadricycle		Pmax.cont ≤ 4 kW Mass ≤ 425 kg
	L6Be Light quadri-mobiles	Engine Vd ≤ 50 cm^3 Vmax ≤ 45 km/h Pmax.cont ≤ 6 kW Mass ≤ 425 kg (not including weight of gaseous fuel tanks) Enclosed driver and passenger Carriage of goods (bed area > 30% of vehicle length times width)
L7e Heavy quadricycle	L7Ae Heavy on-road quad	Vmax > 45 km/h Pmax.cont ≤ 15 kW Mass ≤ 450 kg for passengers, 600 kg for transport of goods 2 people max (Includes passenger)
	L7Be Heavy all terrain quads	45 < Vmax ≤ 90 km/h (all terrain quads) or Pmax.cont ≤ 15 kW (all terrain buggies) ground clearance ≥180 mm; wheelbase to ground clearance ratio ≤ 6
	L7Ce Heavy quadri-mobiles	45 < Vmax ≤ 90 km/h Pmax.cont ≤ 15 kW Mass ≤ 450 kg for passengers Mass ≤ 600 kg for goods

Appendix F Tampering modes from literature

Table 19-14: Tampering modes: Web and stakeholder

Action	Hypothetical reasoning
removal of throttle stop	Increase power
de-tuning of the silencer	Alteration of noise emissions
Alteration of the transient response of the carburettor	Increase performance
Alteration of the engine control unit by manipulation of the gear sensor	Increase performance
Alteration of the engine control unit by adding electronic components	Increase performance
Alteration of the engine control by replacement or manipulation of the ECU	Increase performance

Table 19-15: Tampering modes: TÜV report

Action	Hypothetical reasoning
Reduce cylinder head gasket width	Increase squish/compression ratio and therefore performance
Rotate piston 180°	Increase performance
Shorten pipe length to silencer	Reduce return pressure
Remove throttle stop	Increase maximum engine power, engine speed and vehicle speed
Change reed valves	Increase performance
Remove ECU speed limiter	Increase performance
Piston cover inlet at TDC	Increase performance

Table 19-16: Tampering modes: Directive 97/24/EC, chapter 7

Action	Hypothetical reasoning
Modify signals from lambda sensor to ECU	Trick the vehicle into changing air/fuel ratio
Remove limiter form CVT	Increase maximum speed
Remove stubber pipe on exhaust	Increase performance
Replace exhaust	Increase performance and noise
Change sprocket	By changing this Move the peak power
Install boost/doppler bottle	Increase performance
Remove air filter or replace with "free-flow" air filter	Increase performance
Shorten pipes inside exhaust	Increase performance
Remove catalytic converter	Increase performance, allow a change to air/fuel ratio without causing a catastrophic failure while riding
Reprogram the ECU	Remove limits, change air/fuel ratio
High octane fuel/Aviation fuel	Increase performance

Appendix G Tampering mode from vehicle analysis

Table 19-17. Tampering modes: Full vehicle analysis

Area		
Controls		
	Throttle stop	Remove
	Quick action throttle	Add
	Switches to de-/activate systems	Add/Modify
Signals		
	Change lights	Smaller indicators
		Head lights
	Change Horn	Louder
		Different tune
Electronics		
	ECU	Replace
		Remove
	Reprogram ECU	Speed limit
		RPM limit
		Power curve
		Fuel/Air mix
	Interrupt signals	Lambda (oxygen) sensor
		Crank shaft position
		Throttle position
		Manifold Absolute Pressure sensor (MAP)
		Mass Air Flow (MAF)
		Injector
		Vehicle speed sensor
		Wheel speed sensor
	Change sensors	

Area		
Fuel		
Fuel : Petroleum		
	Dose	Add thinner
	Replace	High Octane
		Aviation fuel
		Bio ethanol
		Bio diesel
	Change fuel tank (weight distribution)	
	Choke	Add automatic/modify behaviour
Fuel: Battery (Auxiliary)		
	Change battery (starter)	Weight
Fuel: Battery (Traction)		
	Change battery	Power output rate
		Voltage
		Weight
	Remove	Power-weight ratio
		Weight distribution
Air		
	Air filter	Change
		Remove
		Add "Free-flow" air filter
	Nitrous Oxide System (NOS)	Add
	Forced induction	supercharger
		turbocharger
		Intercooler

Area	
Before Engine	
Carburettor	Replace Carb (bigger)
	Replace jet
	Adjust throttle
	Remover throttle limit
Direct injection	Replace injector
Boost Bottle (Doppler)	Fit between intake and carburettor
Reed valve	Tune / adjust
	Replace
	Add
	Remove
Radiator	Add Blanking
	Add/change behaviour of Electric Fan
Engine: internal combustion	
Cylinder	Re-bore
	Replace head/piston (change diameter)
	Replace liner
	Replace barrel
Head	Machine to change squish (increase compression)
Gasket	To raise ports
	To change squish
Crank Shaft	Replace for higher quality (balance weight)
	Replace and/or piston for increased sweep
	Polish to reduce drag
Engine: internal combustion (spark ignition)	
Spark plugs	Change
Engine: internal combustion (compression ignition)	
Fuel pump	Modify stroke length

Area		
Engine: electric		
	Remove / bypass limits	
	Change power curve in ECU	Power release to throttle, RPM, speed
	Remove voltage/current limiter	
Engine: fly wheel		
	Add	Increase power
		Change stability/controllability
Engine: Hybrid		
	Changes "mix" of engines	ECU
		Transmission
	Change overall power curve	ECU
		Transmission
	Change characteristics of mode switching	
Engine: external combustion		
	Used as generator in series hybrid, therefore changes to this will not directly affect the power or speed output	
After Engine		
	Exhaust	Replace with Road Legal
		Replace with Race
		Adjust opening/plate
		Add a cutout
	Catalytic converter	Replace catalytic converter
		Remove catalytic converter

Area		
Transmission		
	CVT / Variomatic	Replace rollers
		Replace belt
		Replace main spring
		Remove speed limiter rings
	Gear Box	Unlock hidden gears
		Replace gears
	Sprocket	Replace to change final drive ratio
	Clutch	Replace automatic clutch arm springs
Wheels		
	Change wheel size	Changes ratio, bypass speed based electronic limiter, inaccurate speedometer
Suspension		
	Replace	
	Lower height	
	Strengthen	
Brakes		
	Replace	
	Change drum to disk	
	Change hoses	
	Change pads	
	Remove/deactivate ABS/CBS	
Chassis		
	Modify	strengthen
		lower weight
	Add Pillion seat	
	Swing arm	replace
	Number of wheels	2 to 3, or sidecar
	foot rest position	move

Area		
Bodywork		
	Paint	
	Aero kits	changing the aerodynamics, pedestrian safety
	Badges	

Appendix H Test matrix

Vehicle number	Subcategory	Modification type
1	L1Ae	Air filter
2	L1Be	Replace Exhaust system & Air filter
2	L1Be	Remove Exhaust orifice
2	L1Be	Remove CVT speed limiter
2	L1Be	Replace Exhaust system & remove orifice, replace Air filter, remove CVT speed limiter
3	L1Be	Replaced piston and cylinder (50-80)
4	L1Be	Remove CVT speed limiter
5	L1Be	Deactivate crankcase ventilation recirculation
5	L1Be	CVT ratio, replace ECU, carburettor nozzle size
5	L1Be	Deactivate crankcase ventilation recirculation, change CVT ratio, replace ECU, replace Carb' nozzle
6	L1Be	Remove air filter and "intake air pipe"
7	L1Be	Change masses in CVT
8	L1Be	Change masses in CVT (Track)
9	L1Be	Change ratio of CVT
10	L3e-A1	Change engine map (Rich)
11	L3e-A2	Change engine map (Rich)
11	L3e-A3	Install RB2 ECU. Remove RPM limiter, A/F target: 13.2 (Rich)

Vehicle number	Subcategory	Modification type
12	L3e-A3	Replace Exhaust (throttle cat bypass)
13	L3e-A3	Modify ECU - Change Injection (Lean)
13	L3e-A3	Intake air temp sensor, simulate −20°C
13	L3e-A3	Intake air temp sensor, simulate 0°C
13	L3e-A3	High Octane fuel
13	L3e-A3	Intake air temp sensor, real −7°C
14	L5Be	Increase fuel pump stroke length
15	L7Ae	Remove air filter, shut crankcase vent', adjust carb' (Lean)
16	L6Be-P	Remove CVT speed limiter

Appendix I Results of the TRL SENOD analysis before testing

TRL SENOD RPN Ranking System: Before testing

Fill 3 severities, occurrence, and detection for each moddification type with a value from 1 to 10.
Values are based on the table in the "Scales" worksheet.
Analysis of top RPN numbers is performed in the "ParetoPivChart" worksheet.

Y = Yes to all,
No = No to all,
S = Safety,

Σ (Severity - Safety + Severity - Emissions + Severity - Noise) × Occurrence × Detection = Overall Result

Severity - Safety: Relative weight 1
Severity - Emissions: Relative weight 1
Severity - Noise: Relative weight 1

Detection: Type Approval: Detectable = (1); Road-Side/PI: Undetectable = (-1); To turn off = (0). 1=Bad, -1=Good, 0=Off: 0

Overall Result: Individual RPN, Individual Rank

Main area	Area	Mechanism	Notes	#	Equivilant	Done	Possibly Harmful	Applicable Categories	Severity - Safety: Low - s - s	Centre - s - s	High - s - s	Severity - Emissions: Low - s - e	Centre - s - e	High - s - e	Severity - Noise: Low - s - n	Centre - s - n	High - s - n	Occurrence: Low - o	Centre - o	High - o	Detection: Low - d	Centre - d	High - d	Individual RPN: Low - RPN	Centre - RPN	High - RPN	Individual Rank: Low - Rank	Centre - Rank	High - Rank
Air intake	Inlet Flow Rate	Air filter - remove entirely		01		1	Y	All	5	6	10	5	6	10	5	8	10	5	5	10	4	5	8	25.0	33.3	100.0	6.0	21.0	1.0
Air intake	Inlet Flow Rate	Air filter change to "free-flow"		02		1	Y	All	5	6	10	5	6	10	5	8	10	5	5	10	4	5	8	25.0	33.3	100.0	6.0	21.0	1.0
Air intake	Inlet Flow Rate	Carburettor - replace with larger		03			Y	Old	5	6	10	5	6	10	5	6	10	2	4	6	2	4	5	10.0	24.0	60.0	27.0	39.0	20.0
Air intake	Inlet Flow Rate	Remove sleeve	97/24/EC	04		1	Y	L1 - L3-A1	5	6	10	5	6	10	5	6	10	5	8	10	2	4	5	25.0	48.0	100.0	6.0	9.0	1.0
Air intake	Inlet Flow Rate	Open up section in inlet pipe	97/24/EC	05	1		Y	L1 - L3-A1	5	6	10	5	6	10	5	6	10	2	4	8	2	2	5	10.0	24.0	80.0	27.0	39.0	8.0
Air intake	Inlet Flow Rate	Open up section in cylinder head	97/24/EC	06	1		Y	L1 - L3-A1	5	6	10	5	6	10	5	6	10	2	4	8	2	2	5	10.0	24.0	80.0	27.0	39.0	8.0
Air intake	Change Inlet Air	Nitrous Oxide system (nos)		07			Y	L1 - L3-A1	6	8	10	6	6	10	5	6	10	1	1	2	5	6	8	5.7	6.7	20.0	51.0	64.0	60.0
Air intake	Increase Air Density	Forced induction (supercharger, turbo, intercooler)		08			S	L3 - L5	5	6	8	2	5	8	4	6	10	2	2	5	5	6	10	7.3	11.3	43.3	50.0	58.0	43.0
Fuel	Flow	Remove throttle stop (ECU)	97/24/EC	09		1	Y	All	5	6	10	4	5	8	5	8	10	2	4	8	1	2	2	9.3	25.3	74.7	40.0	33.0	14.0
Fuel	Flow	Remove throttle stop (mechanical)	97/24/EC / TÜV report	10			Y	All	5	6	10	4	5	8	5	8	10	2	5	6	4	5	5	9.3	31.7	56.0	40.0	25.0	32.0
Fuel	Flow	Replace carburettor jet		11		1	Y	Old	5	6	8	5	6	10	5	8	10	2	4	6	1	4	4	10.0	26.7	56.0	27.0	30.0	32.0
Fuel	Flow	Remove speed dependant flow reduction in	TÜV report	12			Y	L1 - L2 - L6	5	6	10	5	5	8	5	8	10	2	4	4	2	4	5	10.0	25.3	37.3	27.0	33.0	51.0
Fuel	Flow	Replace injector		13			Y	L1	5	6	10	5	5	8	5	8	10	2	4	4	1	4	4	10.0	25.3	37.3	27.0	33.0	51.0
Air/fuel ratio	Fuel/Air Mix	Manifold absolute pressure (MAP) sensor signal		14	1		Y	L3	5	8	10	4	8	10	4	8	10	5	6	6	2	4	5	21.7	48.0	60.0	12.0	9.0	20.0
Air/fuel ratio	Fuel/Air Mix	Mass air flow sensor (MAF) sensor signal		15	1		Y	L3	5	8	10	4	8	10	4	8	10	5	6	6	2	4	5	21.7	48.0	60.0	12.0	9.0	20.0
Air/fuel ratio	Fuel/Air Mix	Air temperature sensor signal		16		1	Y	L3	5	5	6	5	6	8	5	5	6	5	6	6	2	4	5	25.0	32.0	40.0	6.0	23.0	44.0
Air/fuel ratio	Fuel/Air Mix	Lambda sensor signal		17	1		Y	All	5	8	10	4	8	10	4	8	10	5	6	6	2	4	5	21.7	48.0	60.0	12.0	9.0	20.0
Air/fuel ratio	Fuel/Air Mix	Adjust carburettor		18		1	Y	L1 - L6 - L7	5	8	10	4	8	10	4	8	10	4	8	10	2	3	4	17.3	64.0	100.0	22.0	1.0	1.0
Air/fuel ratio	Fuel/Air Mix	Adjust fuel pump	Diesel	19		1	Y	L5+	5	8	10	4	8	10	4	8	10	4	8	10	2	3	4	17.3	64.0	100.0	22.0	1.0	1.0
Engine	Crankcase Ventilation	Shut crankcase ventilation valve		20		1	Y	All	5	8	10	5	6	10	5	5	8	2	4	5	1	3	6	10.0	25.3	46.7	27.0	33.0	40.0
Engine	Increase Engine Capacity	Re-bore cylinder		21	1		Y	All	5	8	10	5	6	10	5	8	10	1	2	2	1	2	3	5.0	14.7	20.0	52.0	47.0	60.0
Engine	Increase Engine Capacity	Replace cylinder head/piston (change capacity)		22		1	Y	All	5	8	10	5	6	10	5	8	10	2	2	4	1	3	6	10.0	14.7	40.0	27.0	47.0	44.0
Engine	Increase Engine Capacity	Replace cylinder liner/piston		23	1		Y	All	5	8	10	5	6	10	5	8	10	1	2	2	1	2	3	5.0	14.7	20.0	52.0	47.0	60.0
Engine	Increase Engine Capacity	Replace cylinder barrel		24		1	Y	All	5	8	10	5	6	10	5	8	10	2	2	4	1	3	3	10.0	14.7	40.0	27.0	47.0	44.0
Engine	Increase Compression (squish	Reduce thickness of cylinder head		25			Y	L1 - 3	5	8	10	4	5	10	5	8	10	1	2	4	1	2	3	4.7	14.0	40.0	54.0	52.0	44.0
Engine	Increase Compression (squish	Change to thinner gasket head	97/24/EC	26			Y	L1 - 3	5	8	10	4	5	10	5	8	10	1	2	6	1	4	5	4.7	14.0	60.0	54.0	52.0	20.0
Engine	Increase Compression (squish	Replace crank shaft (balance weight)		27			Y	L1 - 3	5	5	6	4	5	6	4	5	6	1	2	4	2	2	2	4.3	10.0	24.0	57.0	60.0	56.0
Engine	Increase Compression (squish	Polish crank shaft to reduce drag		28			Y	L1 - 3	5	5	6	4	5	6	4	5	6	1	2	4	2	2	2	4.3	10.0	24.0	57.0	60.0	56.0
Engine	Timings	Spark advance/retard	TÜV report	29			Y	L1	5	6	8	4	6	8	4	8	10	2	4	8	1	3	5	8.7	26.7	69.3	45.0	30.0	15.0
Engine	Tune	Boost bottle/doppler		30			S + E	2 - Stroke	4	5	6	4	5	6	4	5	6	1	2	2	3	5	5	4.0	10.0	12.0	60.0	60.0	64.0
Engine	Tune	Replace spark plugs		31			S	all	5	6	8	4	5	6	4	5	6	5	8	10	2	2	4	21.7	42.7	66.7	12.0	14.0	18.0
Engine	Tune	Change read valves	97/24/EC	32			S + E	2 - Stroke	4	5	6	4	5	6	4	5	6	1	2	4	1	2	5	4.0	10.0	24.0	60.0	60.0	56.0
Engine	Tune	Piston cover inlet at TDC	97/24/EC	33			All	2 - Stroke	4	6	10	4	6	10	4	6	10	2	2	4	1	2	5	8.0	12.0	40.0	48.0	55.0	44.0
Engine	Tune	Rotate piston 180°	97/24/EC	34			S	L3	4	6	10	4	6	10	4	6	10	2	2	4	1	2	5	8.0	12.0	40.0	48.0	55.0	44.0
Engine	Cooling	Add blanking to radiator		35			S	L3	5	5	6	5	5	6	5	5	6	4	6	10	8	10	10	20.0	30.0	60.0	17.0	26.0	20.0
Engine	Cooling	Add/change behaviour of electric fan for radiator		36			S	L3	5	5	6	5	5	6	5	5	6	4	6	10	1	3	5	20.0	30.0	60.0	17.0	26.0	20.0
Engine	Hybrid	Change ICE to E-motor bias		37			S + E	L3 - 7	4	6	8	4	6	10	4	5	6	1	4	10	1	2	2	4.0	22.7	80.0	60.0	43.0	8.0
Engine	Hybrid	Change overall power curve		38			S + E	L3 - 8	4	6	8	4	6	10	4	5	6	1	4	10	1	2	2	4.0	22.7	80.0	60.0	43.0	8.0
ECU	ECU	Replace ECU	TÜV report	39		1	Yes	All	5	8	10	4	8	10	4	8	10	4	6	8	1	4	5	17.3	48.0	80.0	22.0	9.0	8.0
ECU	ECU	Remove ECU		40			Yes	All	5	8	10	4	8	10	4	8	10	1	2	4	1	5	5	4.3	16.0	40.0	57.0	46.0	44.0
ECU	ECU	Reprogram ECU spark timing	TÜV report	41			Yes	L1 - L6	5	6	8	4	6	8	4	8	10	2	4	8	1	2	3	8.7	26.7	69.3	45.0	30.0	15.0
ECU	ECU	Reprogram ECU engine map	TÜV report	42	1		Yes	L1 - L6	6	8	10	5	8	10	4	8	10	5	8	10	1	2	2	25.0	64.0	100.0	6.0	1.0	1.0
ECU	ECU	Vehicle/wheel speed sensor		43		1	Yes	L1 - L6	6	8	10	5	5	8	4	8	10	2	4	6	1	3	5	10.0	28.0	56.0	27.0	29.0	32.0
ECU	ECU	Modify gear sensor signals	TÜV report	44			Yes	L3	5	6	10	5	5	8	5	8	10	2	4	6	1	3	5	10.0	25.3	56.0	27.0	33.0	32.0
ECU	ECU	Crank shaft position sensor		45			Yes	L1	4	6	8	4	6	8	4	8	10	1	2	4	1	3	5	4.0	13.3	34.7	60.0	54.0	53.0
Exhaust	Exhaust	Replace with road legal	TÜV report	46		1	All	All	4	5	6	4	5	6	5	5	5	6	8	10	5	8	10	26.0	40.0	56.7	5.0	15.0	31.0
Exhaust	Exhaust	Replace with race		47		1	All	All	5	8	8	4	6	8	6	6	8	4	8	8	5	8	10	20.0	53.3	64.0	17.0	6.0	19.0
Exhaust	Exhaust	Remove orifice plate	TÜV report	48		1	All	L1 - L6	5	8	8	5	6	6	6	8	8	4	8	8	2	4	5	21.3	58.7	58.7	16.0	5.0	29.0
Exhaust	Exhaust	Remove baffle		49			All	All	5	6	6	5	5	6	6	8	10	2	4	6	2	4	5	10.7	25.3	44.0	26.0	33.0	41.0
Exhaust	Exhaust	Add a cut-out		50		1	All	L3	5	6	8	5	8	10	8	8	10	2	2	2	4	5	8	12.0	14.7	18.7	25.0	47.0	63.0
Exhaust	Exhaust	Shorten pipe length to silencer	97/24/EC	51			All	L1	5	8	8	5	6	8	4	6	6	2	6	6	2	2	5	9.3	40.0	44.0	40.0	15.0	41.0
Exhaust	Catalytic Converter	Remove catalytic converter		52		1	All	L3	5	6	8	8	8	10	5	6	6	5	6	10	2	4	5	30.0	40.0	80.0	3.0	15.0	8.0
Exhaust	EGR	Deactivate EGR		53			S + E	All	4	5	6	5	8	10	4	5	6	2	5	8	2	5	5	8.7	30.0	58.7	45.0	26.0	29.0
Transmission	CVT	Replace rollers		54		1	S	L1 - L6	5	8	10	5	6	8	4	5	8	6	8	8	4	4	5	28.0	50.7	69.3	4.0	7.0	15.0
Transmission	CVT	Replace cone		55		1	S	L1 - L6	5	8	10	5	6	8	4	5	8	4	6	6	4	4	5	18.7	38.0	52.0	20.0	18.0	37.0
Transmission	CVT	Replace spring		56		1	S	L1 - L6	5	8	10	5	6	8	4	5	8	4	6	6	4	4	5	18.7	38.0	52.0	20.0	18.0	37.0
Transmission	CVT	Remove limiter		57		1	S	L1 - L6	5	8	10	5	6	8	4	5	8	8	10	10	4	4	5	37.3	63.3	86.7	2.0	4.0	7.0
Transmission	CVT	Replace belt		58			S	L1 - L6	4	5	6	4	5	6	4	5	6	10	10	10	4	5	5	40.0	50.0	60.0	1.0	8.0	20.0
Transmission	Gearbox	Unlock hidden gears		59			S	L3	6	8	8	4	5	6	4	5	6	1	4	4	1	2	5	4.7	24.0	26.7	54.0	39.0	54.0
Transmission	Gearbox	Replace gears		60			S	L3	6	8	8	4	5	6	4	5	6	2	2	4	1	2	5	9.3	12.0	26.7	40.0	55.0	54.0
Transmission	Final Drive	Replace sprocket		61			S	L3	6	8	8	4	5	6	4	5	6	2	6	8	6	8	8	9.3	36.0	53.3	40.0	20.0	36.0
Transmission	Final Drive	Change wheel size		62			S	All	5	6	6	5	5	6	5	5	6	2	2	4	5	6	8	10.0	10.7	24.0	27.0	59.0	56.0
Transmission	Clutch	Replace clutch arm springs		63		1	S	L1 - L6	5	6	8	5	5	5	5	5	5	5	6	10	2	4	5	25.0	32.0	60.0	6.0	23.0	20.0
Transmission	Clutch	Replace clutch bell		64			S	L1 - L6	5	6	8	5	5	5	5	5	5	2	4	8	2	5	5	10.0	21.3	48.0	27.0	45.0	39.0
Other / Out of Scope																													
Fuel	Dose Fuel with Additives	Additive - upper cylinder lubricant																											
Fuel	Dose Fuel with Additives	Additive - lead replacement																											
Fuel	Dose Fuel with Additives	Additive - octane boost / methanol																											
Fuel	Fuel Choice	High octane				1																							
Fuel	Fuel Choice	Aviation fuel																											
Fuel	Fuel Choice	Bio ethanol																											
Fuel	Fuel Choice	Bio diesel																											
Structure	Increase Power-Weight ratio	Change battery (auxiliary)				1																							
Structure	Increase Power-Weight ratio	Reduce size of battery (traction)																											
Structure	Increase Power-Weight ratio	Lower chassis weight																											
Structure	Change Weight Distribution	Change fuel tank (weight distribution)																											
***Engine** (exotic alternative power sources) i.e. gas turbine, stirling engine, flywheel*																													
Engine (exotic alte	Use in "Series Hybrid", not directly connected to the driven wheels																												
***Engine** (electric)*																													
Engine (electric)	This area is being looked at separately																												
Controls	Controls	Quick action throttle																											
Controls	Controls	Deactivate abs																											

Figure 19-9: SENOD Figure: before testing

Appendix J Pareto analysis of the results before testing

J.1 Risk Priority Number (RPN) prioritised using 'best estimate' and considering severity and occurrence

This chart represents the ranking of the vehicle modifications based on the best estimate (intersection between red and green on each bar), followed by the high estimate (top of each red bar), and finally the low estimate (bottom of each green bar). It indicates the modifications that are most likely to cause harm with safety, emission and noise based on theoretical estimates for severity and occurrence.

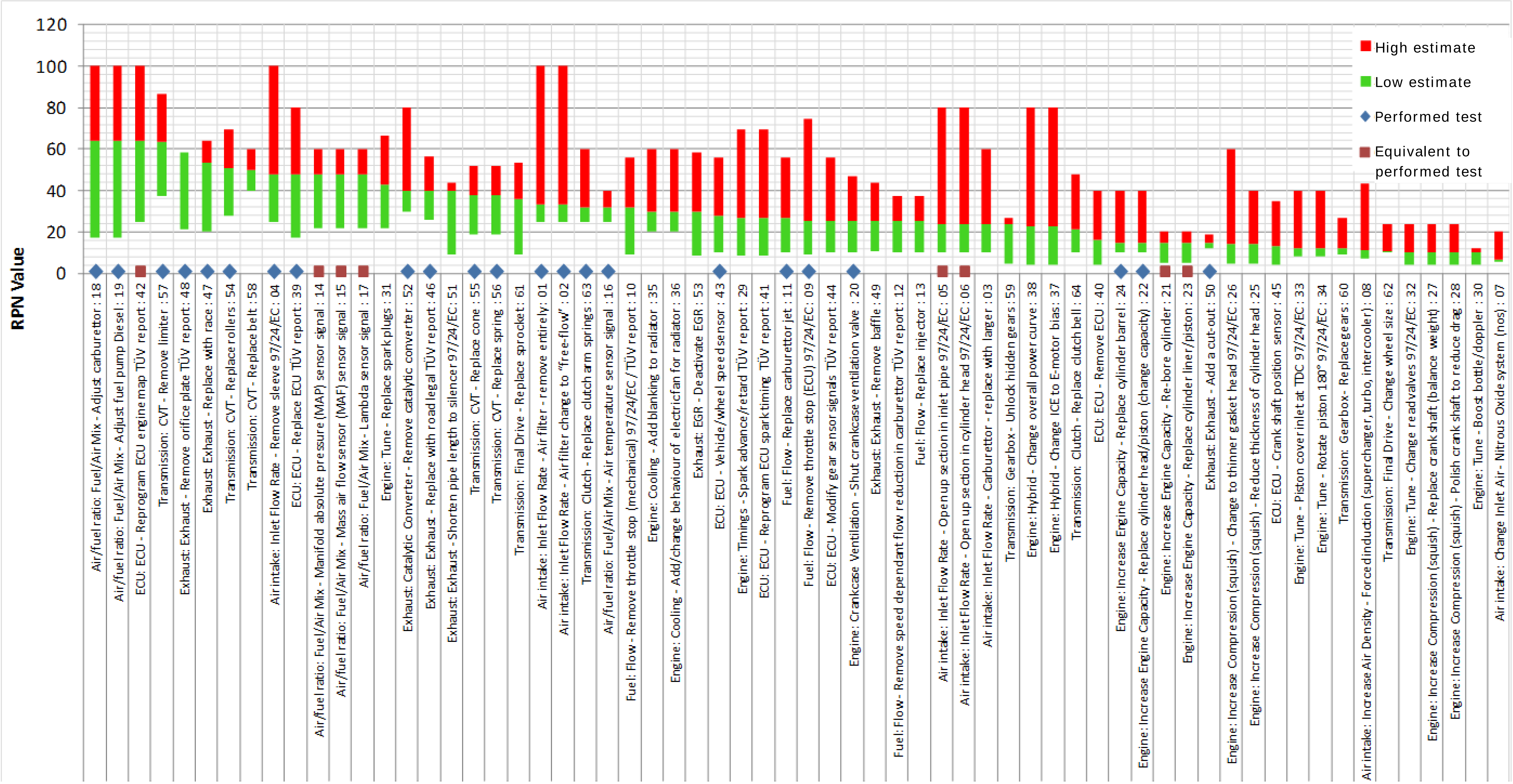


Figure 19-10: TRL SENOD Pareto analysis before testing: Excluding detection: Centre → High → Low – Order: High to Low

J.2 Risk Priority Number (RPN) prioritised using 'best estimate' and considering severity, occurrence detection (difficult detection given high rating)

This chart is the same as J.1, except that detection is taken into account in the RPN. Tampering that was judged more difficult to detect was given a greater detection rating. As with the previous graph, the best estimate is indicated by the intersection between red and green on each bar, the high estimate by the top of each red bar, and the low estimate by the bottom of each green bar.

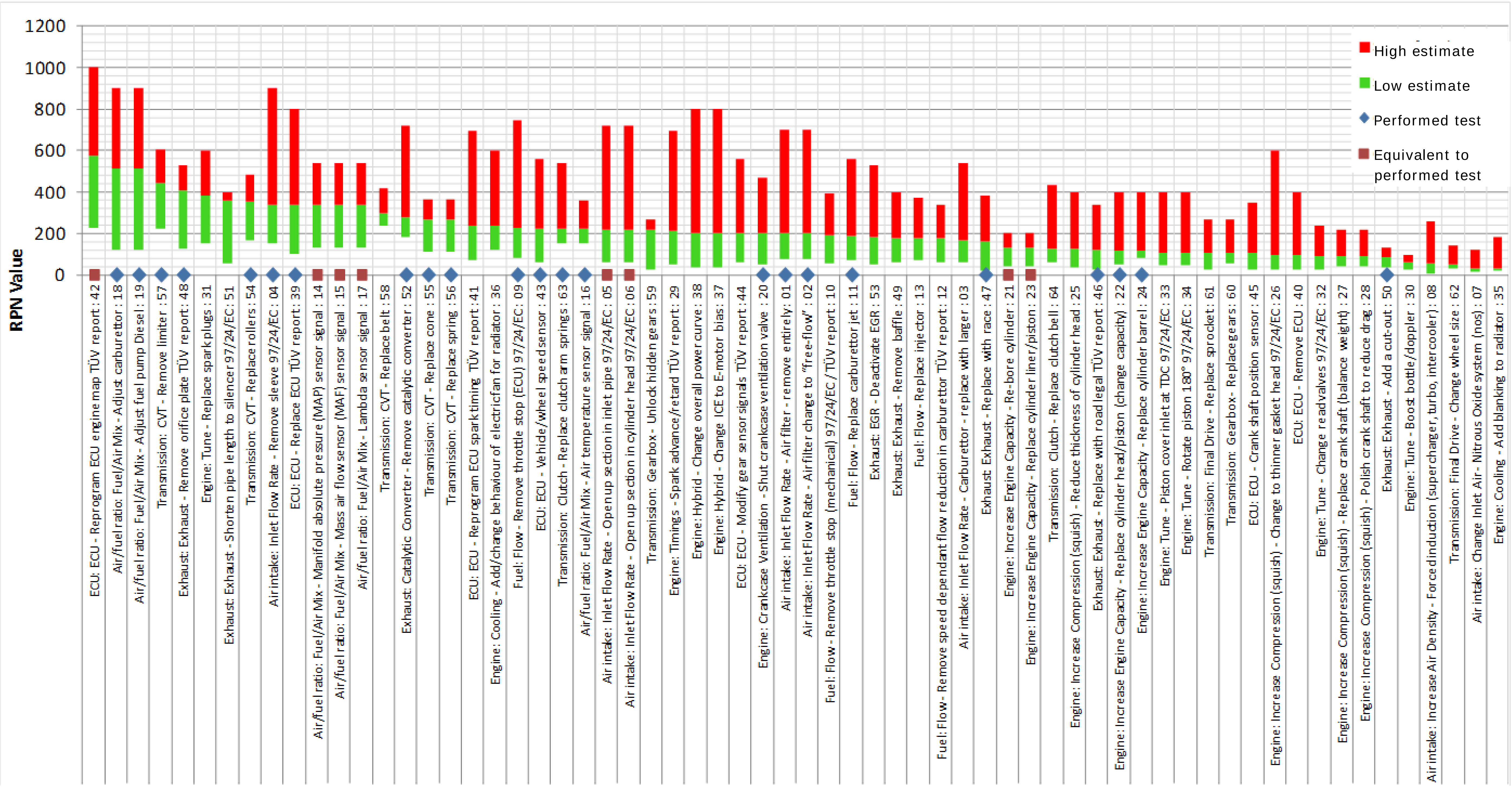


Figure 19-11: TRL SENOD Pareto analysis before testing: Hard to detect: Centre → High → Low – Order: High to Low

This represents those modifications which are difficult to detect and should therefore provide an analysis of those areas which would be preferable to try to prevent them at the type approval stage.

J.3 Risk Priority Number (RPN) prioritised using ‘best estimate’ and considering severity, occurrence detection (difficult detection given low rating)

This chart is the same as J.1 except that detection is taken into account with easy detection taking priority over those areas judged difficult to detect. As with the previous graph, the best estimate is indicated by the intersection between red and green on each bar, the high estimate by the top of each red bar, and the low estimate by the bottom of each green bar.

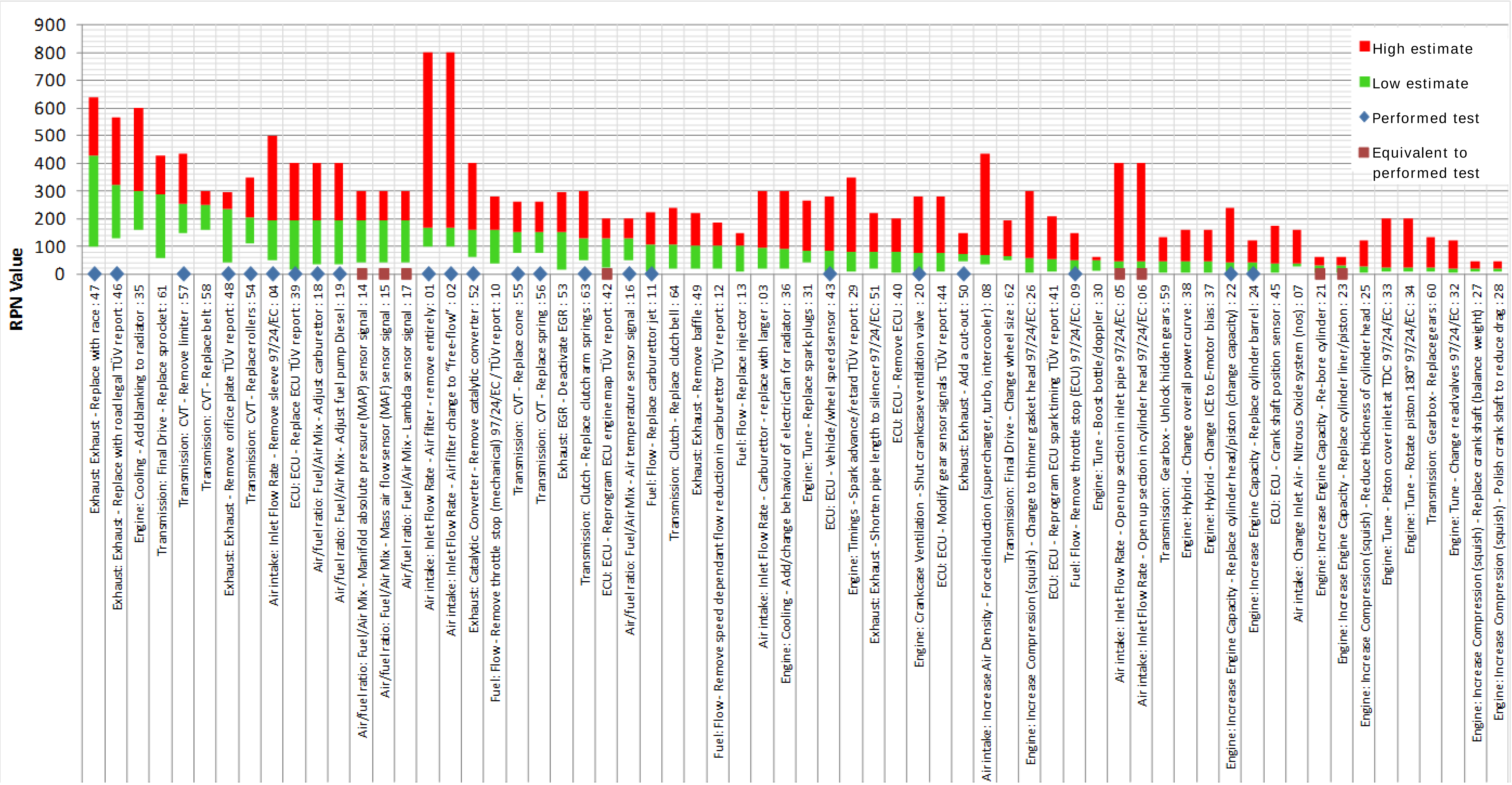


Figure 19-12: TRL SENOD Pareto analysis before testing: Easy to detect: Centre → High → Low – Order: High to Low

J.4 Risk Priority Number (RPN) prioritised using 'high estimate' and considering severity, occurrence and detection detection (difficult detection given low rating)

This chart orders the RPN numbers by the highest estimate in each of the areas.

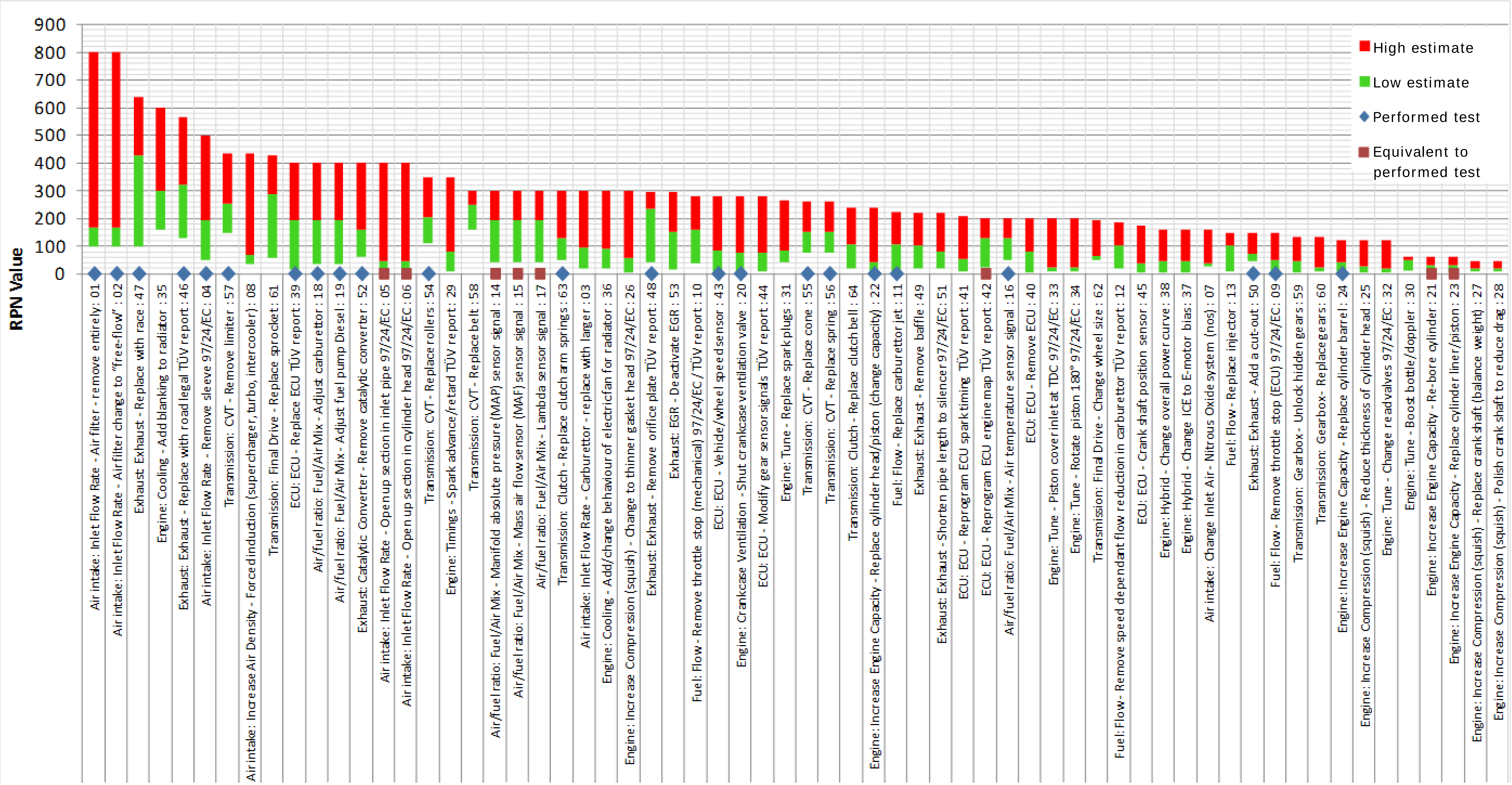


Figure 19-13: TRL SENOD Pareto analysis before testing: Easy to detect: High → Centre → Low – Order: High to Low

J.5 Risk Priority Number (RPN) prioritised by range between highest and lowest RPN and considering severity and occurrence

This chart ranks the modifications by the magnitude of the difference between low and high RPN values for each tampering area. This can be used to see those modifications for which there is a large range (and therefore greater uncertainty) in the analysis, either because of uncertainty in the estimate or because there are different values dependent on the specific type and characteristic of the L-category vehicle being considered in the theoretical assessment.

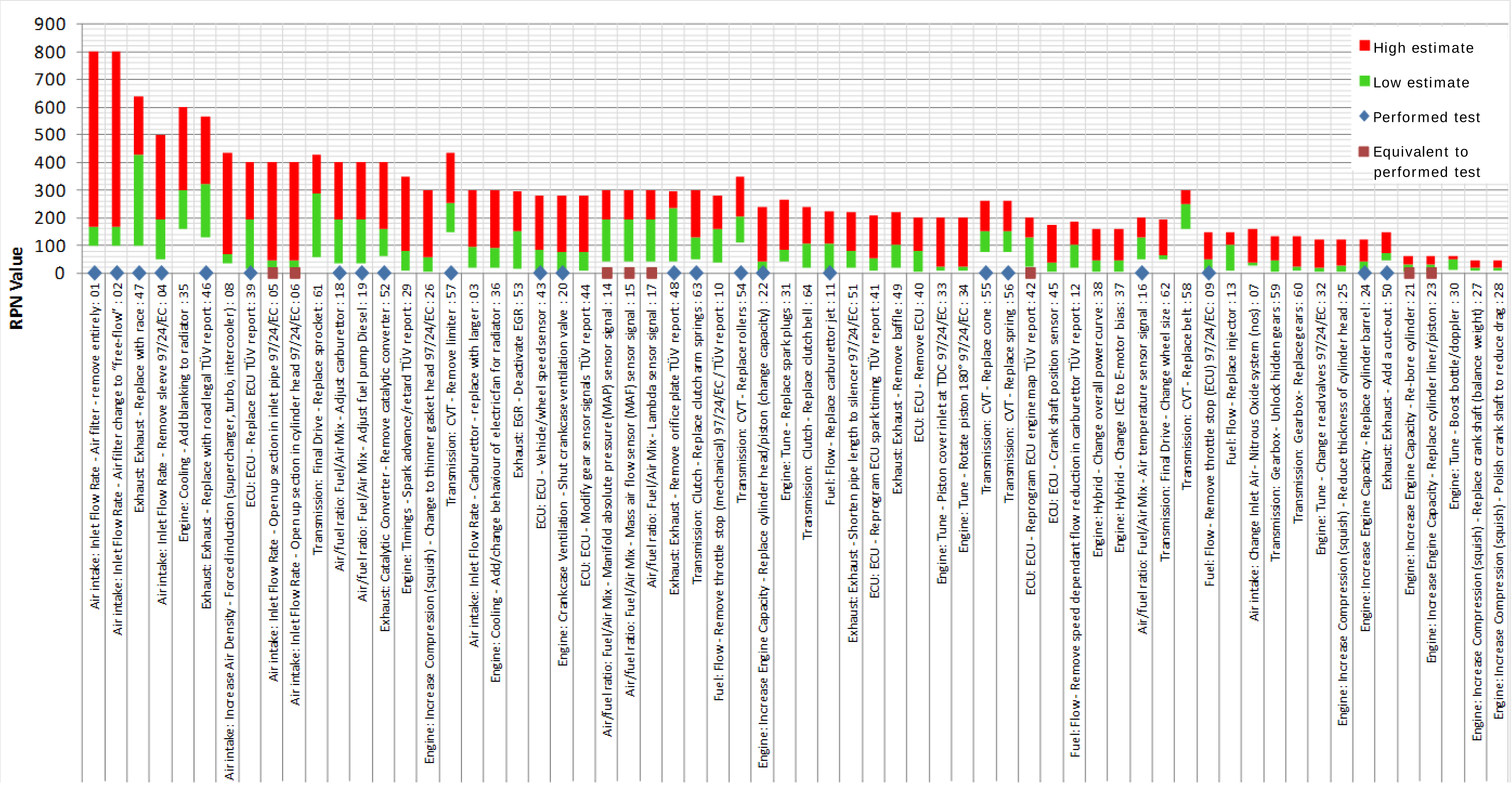


Figure 19-14: TRL SENOD Pareto analysis before testing: Difference between RPN: High-Low → High → Centre → Low – Order: High to Low

J.6 Mean rank of relevant ordering schemes

Modification	Best estimate, excluding detection	Best estimate, difficult to detection	Best estimate, easy to detect	High estimate, excluding detection	Difference, excluding detection	Mean Rank	Disregarded	Equivalent	Done	Pareto
Air/fuel ratio: Fuel/Air Mix - Adjust carburettor : 18	2	2	1	1	12	3.6			1	1.6 %
Air/fuel ratio: Fuel/Air Mix - Adjust fuel pump Diesel : 19	3	3	2	2	13	4.6			1	3.1 %
Air intake: Inlet Flow Rate - Remove sleeve 97/24/EC : 04	9	9	6	4	4	6.4			1	4.7 %
Transmission: CVT - Remove limiter : 57	4	4	4	7	17	7.2			1	6.3 %
ECU: ECU - Replace ECU TÜV report : 39	10	10	13	8	8	9.8			1	7.8 %
ECU: ECU - Reprogram ECU engine map TÜV report : 42	1	1	3	3	43	10.2		1		
Exhaust: Catalytic Converter - Remove catalytic converter : 52	15	15	12	9	14	13			1	9.4 %
Transmission: CVT - Replace rollers : 54	7	8	10	15	30	14			1	10.9 %
Exhaust: Exhaust - Remove orifice plate TÜV report : 48	5	5	7	29	27	14.6			1	12.5 %
Air intake: Inlet Flow Rate - Air filter change to "free-flow" : 02	22	33	14	6	2	15.4			1	14.1 %
Exhaust: Exhaust - Replace with race : 47	6	41	8	19	3	15.4			1	15.6 %
Engine: Tune - Replace spark plugs : 31	14	6	9	18	32	15.8	1			
Air/fuel ratio: Fuel/Air Mix - Manifold absolute pressure (MAP) sensor signal : 14	11	11	19	21	24	17.2		1		
Air/fuel ratio: Fuel/Air Mix - Mass air flow sensor (MAF) sensor signal : 15	12	12	20	22	25	18.2		1		
Air intake: Inlet Flow Rate - Air filter - remove entirely : 01	21	32	37	5	1	19.2			1	17.2 %
Air/fuel ratio: Fuel/Air Mix - Lambda sensor signal : 17	13	13	21	23	26	19.2		1		
Transmission: CVT - Replace belt : 58	8	14	5	20	50	19.4	1			
Engine: Cooling - Add/change behaviour of electric fan for radiator : 36	27	19	17	26	19	21.6	1			
Exhaust: Exhaust - Replace with road legal TÜV report : 46	16	46	11	31	6	22			1	18.8 %
Transmission: Clutch - Replace clutch arm springs : 63	23	22	15	24	28	22.4			1	20.3 %
Air intake: Inlet Flow Rate - Open up section in inlet pipe 97/24/EC : 05	39	24	31	10	9	22.6		1		
Engine: Timings - Spark advance/retard TÜV report : 29	30	27	28	16	15	23.2				
Air intake: Inlet Flow Rate - Open up section in cylinder head 97/24/EC : 06	40	25	32	11	10	23.6		1		
Exhaust: Exhaust - Shorten pipe length to silencer 97/24/EC : 51	17	7	23	41	35	24.6				
ECU: ECU - Reprogram ECU spark timing TÜV report : 41	31	18	29	17	36	26.2				
Engine: Cooling - Add blanking to radiator : 35	26	64	16	25	5	27.2	1			
Exhaust: EGR - Deactivate EGR : 53	28	36	22	30	20	27.2				
Transmission: CVT - Replace cone : 55	18	16	24	37	41	27.2			1	
Transmission: Final Drive - Replace sprocket : 61	20	52	18	36	11	27.4				
ECU: ECU - Vehicle/wheel speed sensor : 43	29	21	36	33	21	28			1	
Transmission: CVT - Replace spring : 56	19	17	25	38	42	28.2			1	
Fuel: Flow - Remove throttle stop (ECU) 97/24/EC : 09	33	20	30	14	51	29.6			1	
Fuel: Flow - Remove throttle stop (mechanical) 97/24/EC / TÜV report : 10	25	34	34	32	29	30.8				
Engine: Hybrid - Change overall power curve : 38	43	28	26	12	46	31				
Engine: Hybrid - Change ICE to E-motor bias : 37	44	29	27	13	47	32				
ECU: ECU - Modify gear sensor signals TÜV report : 44	34	30	39	35	23	32.2				
Air intake: Inlet Flow Rate - Carburettor - replace with larger : 03	41	40	41	27	18	33.4				
Engine: Crankcase Ventilation - Shut crankcase ventilation valve : 20	35	31	42	40	22	34			1	
Air/fuel ratio: Fuel/Air Mix - Air temperature sensor signal : 16	24	23	33	44	48	34.4			1	
Fuel: Flow - Replace carburettor jet : 11	32	35	38	34	34	34.6			1	
Exhaust: Exhaust - Remove baffle : 49	36	37	40	42	37	38.4				
jine: Increase Compression (squish) - Change to thinner gasket head 97/24/EC : 26	52	54	46	28	16	39.2				
Transmission: Clutch - Replace clutch bell : 64	45	44	35	39	33	39.2				
uel: Flow - Remove speed dependant flow reduction in carburettor TÜV report : 12	37	39	43	51	45	43				
ake: Increase Air Density - Forced induction (supercharger, turbo, intercooler) : 08	58	61	50	43	7	43.8				
e: Increase Engine Capacity - Replace cylinder head/piston (change capacity) : 22	48	47	48	47	31	44.2			1	
Transmission: Gearbox - Unlock hidden gears : 59	42	26	45	54	54	44.2				
Fuel: Flow - Replace injector : 13	38	38	44	52	52	44.8				
ECU: ECU - Remove ECU : 40	46	55	47	45	38	46.2				
Engine: Tune - Piston cover inlet at TDC 97/24/EC : 33	55	49	53	49	39	49				
Engine: Increase Engine Capacity - Replace cylinder barrel : 24	47	48	49	46	58	49.6			1	
Engine: Tune - Rotate piston 180° 97/24/EC : 34	56	50	54	50	40	50				
Engine: Increase Compression (squish) - Reduce thickness of cylinder head : 25	53	45	51	48	57	50.8				
ECU: ECU - Crank shaft position sensor : 45	54	53	52	53	44	51.2				
Engine: Increase Engine Capacity - Re-bore cylinder : 21	49	42	61	60	60	54.4		1		
Transmission: Gearbox - Replace gears : 60	57	51	55	55	55	54.6				
Engine: Increase Engine Capacity - Replace cylinder liner/piston : 23	50	43	62	61	61	55.4		1		
Transmission: Final Drive - Change wheel size : 62	59	62	56	56	49	56.4				
Engine: Tune - Change read valves 97/24/EC : 32	62	56	57	57	56	57.6				
Exhaust: Exhaust - Add a cut-out : 50	51	59	60	63	59	58.4			1	
Engine: Increase Compression (squish) - Replace crank shaft (balance weight) : 27	60	57	58	58	63	59.2				
Engine: Increase Compression (squish) - Polish crank shaft to reduce drag : 28	61	58	59	59	64	60.2				
Air intake: Change Inlet Air - Nitrous Oxide system (nos) : 07	64	63	64	62	53	61.2				
Engine: Tune - Boost bottle/doppler : 30	63	60	63	64	62	62.4				

Figure 19-15: TRL SENOD analysis mean ranking

Appendix K Sound levels

The following were the current limits in force at the time of the noise testing. Since that time, proposals for updating the legislation in this area has reached the final stage.

The EU will accede to the updated UN regulations (Numbers 9, 41, 63 and 92), which contain not only new limits, but a new test and a new definition of vehicle classes based on power to weight. Due to the major differences in the new and old testing they have not been presented to prevent miss interpretation.

K.1 Directive 97/24/EC, Chapter 9

ANNEX I	
SOUND LEVEL LIMITS IN dB(A) AND DATES OF ENTRY INTO FORCE FOR COMPONENT TYPE-APPROVAL REGARDING THE PERMISSIBLE SOUND LEVEL OF A TYPE OF TWO OR THREE-	
Vehicles	Sound level limits with effect from 24 months from the date of adoption of this Directive
1. Two-wheel mopeds	
≤ 25 km/h	66
> 25 km/h	71
three-wheel mopeds	76
2. Motorcycles	
≤ 80 cm 3	75
> 80 ≤ 175 cm 3	77
> 175 cm 3	80
3. Tricycles	80

Figure 19-16: Noise limits in EU

Note: Levels effective since 1999.

K.2 UNECE Regulation 41 (motorcycles)

1. SCOPE

This Regulation contains provisions relating to the noise made by two-wheeled motor cycles other than those having a maximum design speed not exceeding 50 km/h.

Figure 19-17: UNECE Regulation 41, relevant text: 1958 [40]

Category of motor cycle	Engine cylinder capacity (cc)	Values expressed in dB(A)	Dates of enforcement
First category	cc ≤ 80 cm^3	75	1 October 1995
Second category	80 cm^3 < cc ≤ 175 cm^3	77	31 December 1996
Third category	cc > 175 cm^3	80	1 October 1995

Figure 19-18: Noise limits for motorcycles under UNECE regulation 41

[40] 40 Uniform provisions concerning the approval of motor cycles with regard to noise. 1958. UNECE. URL http://live.unece.org/trans/main/wp29/wp29regs41-60.html

K.3 UNECE Regulation 63 (mopeds)

1. SCOPE

This Regulation applies to the noise made by two-wheeled mopeds.

Figure 19-19: UNECE Regulation 63, relevant text: 1958 [41]

Annex 4	
MAXIMUM SOUND LIMITS (NEW MOPEDS)	
Category of moped	dB(A)
Vehicles whose maximum speed is below or equal to 30 km/h.	70
Vehicles whose maximum speed is above 30 km/h.	73

Figure 19-18: Noise limits for mopeds under UNECE regulation 64: 1958

Annex 4, table, amend to read:	
Category of two-wheeled mopeds	Maximum noise-level values in dB(A)
< 25 km/h	66
> 25 km/h	71

Figure 19-20: Noise limits for mopeds under UNECE regulation 64: 1999

K.4 UNECE Regulation 9 (light three- and four-wheelers)

1. SCOPE

This Regulation contains provisions relating to the noise emitted by three-wheeled power-driven vehicles.

6.2.1.3. The sound level measured by the method described in annex 3, paragraph 3.1. to this Regulation when the vehicle is in motion shall not exceed (for new vehicles and new silencing systems) 82 dB(A).

Figure 19-21: UNECE Regulation 9, relevant text: 1958 [42]

Paragraph 6.2.1.3., amend the value of "82 dB(A)" to read "80 dB(A) for categories L4 and L5 and 76 dB(A) for category L2".

Figure 19-19: UNECE Regulation 9, amendment: 1999

[41] Uniform provisions concerning the approval of motor cycles with regard to noise. 1958. UNECE. URL http://live.unece.org/trans/main/wp29/wp29regs61-80.html

[42] Uniform provisions concerning the approval of category l2, l4 and l5 vehicles with regard to noise. 1958. UNECE. URL http://live.unece.org/trans/main/wp29/wp29regs1-20.html

Appendix L Emission driving cycles

L.1 UNECE R47 emissions driving cycle

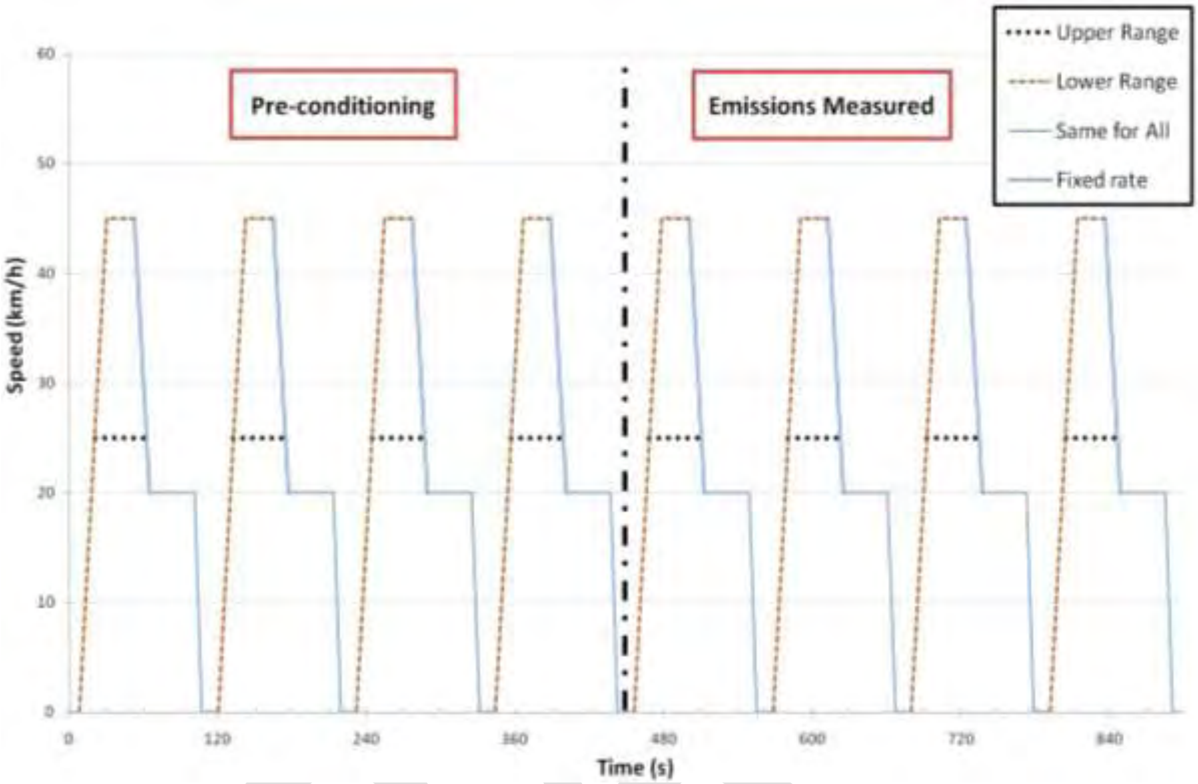


Figure 19-22: Graphical plot of R47 driving cycle

Table 19-20: General characteristics of the UNECE R47 driving cycle

	Example Low speed moped	Example High speed moped
Average speed during test	est. 18 km/h	est. 24 km/h
Effective running time	**112 s per part (448 s for 4 measured parts, 896 s total driving time)**	
Theoretical distance covered per cycle	est. 567 m (4,540 m for the eight cycles)	est. 746 m (5,972 m for the eight cycles)
Maximum speed (±5 km/h or 10%)	**25 km/h**	**45 km/h**
Maximum acceleration	Unknown, example based on 0.56 m/s2	
Maximum deceleration	-0.93 m/s2	

The vehicle is cooled to room temperature for 6 hours and then placed on an inertia dynamometer; the vehicle is then started and the cycle performed. The first 4 parts are ignored to allow the vehicle up get up to temperature, in the second set of 4 parts a

proportion of the gasses are stored in a bag, these gasses are then measured to find the average emissions over the cycle and compared with the legislated emission limits.

L.2 WMTC emissions driving cycle (Stage 1 & 2, Normal & Reduced Speed, Cycles 1, 2 & 3)

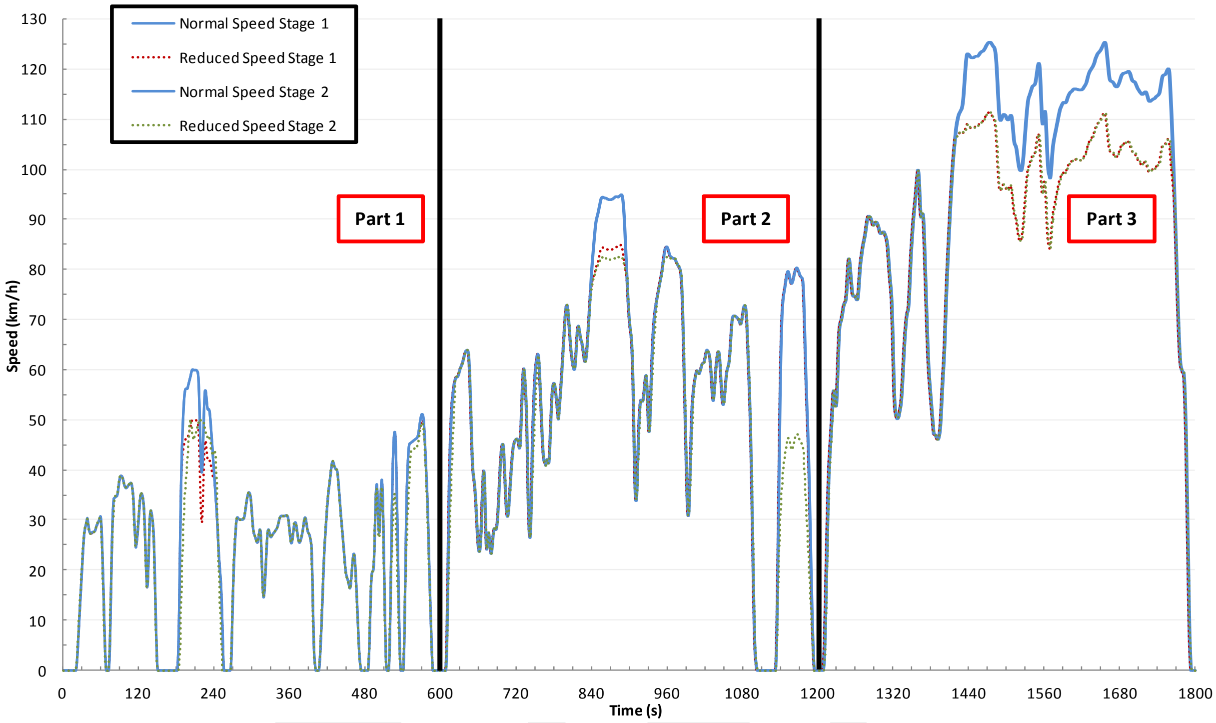


Figure 19-23: Graphical plot of WMTC driving cycle, normal speed trace

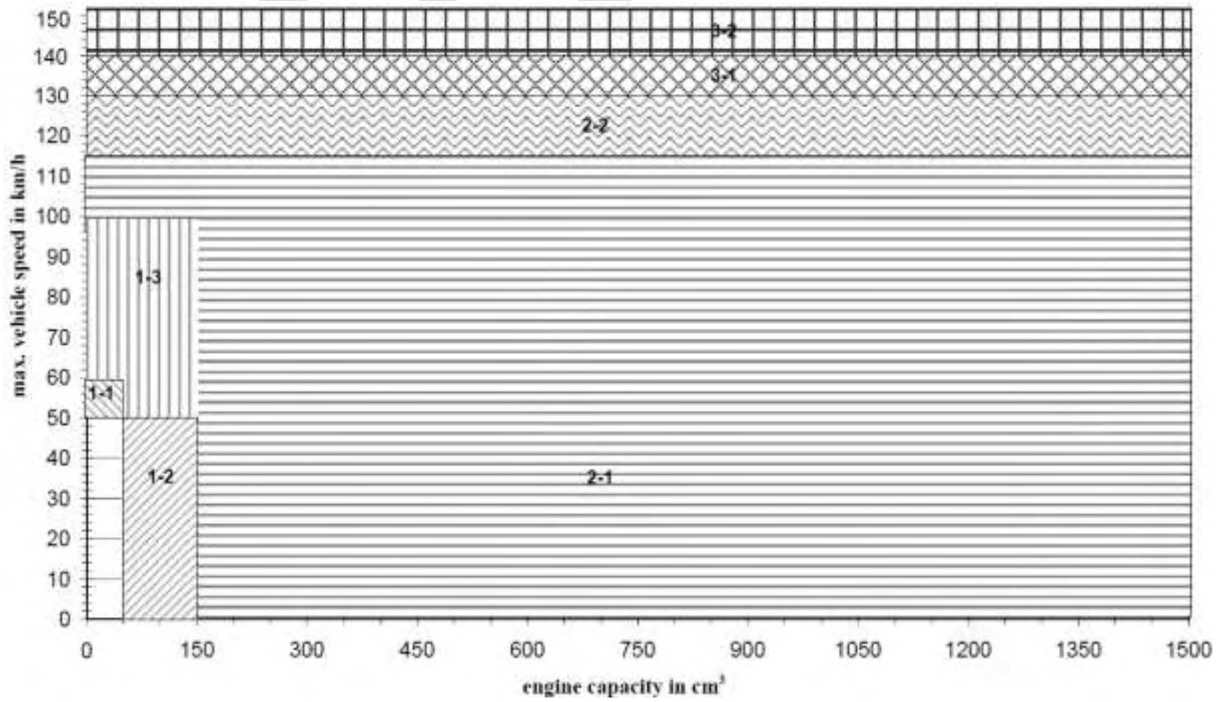


Figure 19-24: Class identification for the UNECE GTR No 2 (WMTC) driving cycle (stage 1)

6.5.4.1. Test cycles (vehicle speed patterns), for the Type I test consists of up to three parts that are shown in annex 5. Depending on the vehicle class (see paragraph 6.3.) the following test cycle parts have to be run:

Table 19-21: Cycle parts to be run depending on class for the UNECE GTR No 2 (WMTC) driving cycle, stage 1

Class 1:

Subclasses 1-1 and 1-2: part 1, reduced speed in cold condition, followed by part 1 reduced speed in hot condition.

Subclass 1-3: part 1 in cold condition, followed by part 1 in hot condition.

Class 2:

Subclass 2-1: part 1 in cold condition, followed by part 2 reduced speed in hot condition.

Subclass 2-2: part 1 in cold condition, followed by part 2 in hot condition.

Class 3:

Subclass 3-1: part 1 in cold condition, followed by part 2 in hot condition, followed by part 3 reduced speed in hot condition.

Subclass 3-2: part 1 in cold condition, followed by part 2 in hot condition, followed by part 3 in hot condition.

Table 19-22: Cycle parts to be run depending on class for the UNECE GTR No 2 (WMTC) driving cycle, stage 2

Class 1:

(No sub-classes) part 1, reduced speed in cold condition, followed by part 1 reduced speed in hot condition.

Class 2:

Subclass 2-1: part 1, reduced speed in cold condition, followed by part 2, reduced speed in hot condition.

Subclass 2-2: part 1 in cold condition, followed by part 2 in hot condition.

Class 3:

Subclass 3-1: part 1 in cold condition, followed by part 2 in hot condition, followed by part 3 reduced speed in hot condition.

Subclass 3-2: part 1 in cold condition, followed by part 2 in hot condition, followed by part 3 in hot condition.

Table 19-23: General characteristics of the UNECE GTR No 2 (WMTC) driving cycle

	Part 1 and 2 (subclass 2-2)	Part 1, 2 and 3 (subclass 3-2)
Average speed during test	39.5 km/h	58 km/h
Effective running time (±0.5 s)	1,200 s (20”)	1,800 s (30”)
Distance covered (±2 %)	13,176.7 m	28,913.2 m
Maximum speed (±1 km/h)	94.9 km/h	125.3 km/h
Maximum acceleration	9.7 ms^{-2}	9.7 ms^{-2}
Maximum deceleration	-7.2 ms^{-2}	-7.2 ms^{-2}

The WMTC cycle is designed to be used by a wide range of vehicles, to accomplish this the engine capacity and maximum vehicle speed are used to define its class (see Figure 19-24) and this is then used to select which parts of the cycle are used (see Table 19-22).

The vehicle is cooled to room temperature for 6 hours, then placed on an inertia dynamometer the appropriate cycle is performed.

For each of the parts a proportion of the gasses are stored in a bag, these gasses are then measured to find the average emissions over the entire cycle and compared with the legislated emission limits.

L.3 UNECE R40 - Elementary Urban Cycle (EUC) +Extra Urban Driving Cycle (EUDC) emissions driving cycle

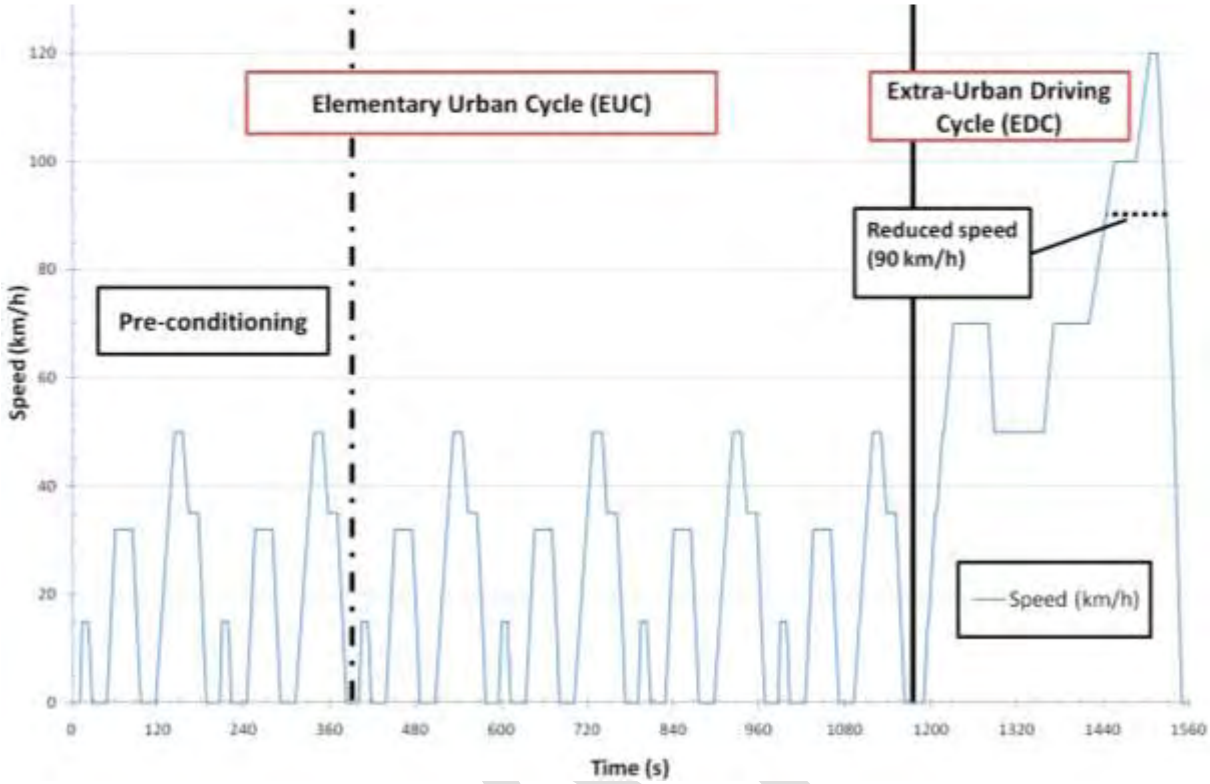


Figure 19-25: Graphical plot of UNECE R40 driving cycle

Table 19-24: General characteristics of the UNECE R40 driving cycle

	EUC	EUC + EDC	EUC + EDC reduced speed
Average speed during test	13.9 km/h	19.7 km/h	19.1 km/h
Effective running time (±0.5 s)	1,170 s (19.5")	1,570 s (26.2")	1,570 s (26.2")
Distance covered (±2 %)	5,964 m	12,947 m	12,554 m
Maximum speed (±1 km/h)	50 km/h	120 km/h	90 km/h
Maximum acceleration	1.04 ms-2	1.04 ms-2	1.04 ms-2
Maximum deceleration	-0.92 ms-2	-1.39 ms-2	-1.39 ms-2

The vehicle is cooled to room temperature for six hours, then placed on an inertia dynamometer, the vehicle is started and the cycle performed. The first two parts are ignored to allow the vehicle up get up to temperature, in the second set of four parts a

proportion of the gasses are stored in a bag, these gasses are then measured to find the average emissions over the cycle and compared with the legislated emission limits.

L3e with an engine <150 cm^3 also perform the third EDC part, this is capped at 90 km/h if the vehicle's maximum speed is below 110 km/h. However in practice, most manufacturers opt to use the WMTC cycle (above) instead.

Appendix M Driveability assessment

Table 19-25: Driveability assessment rating guide

Rating	1	2	3	4	5	6	7	8	9	10
Performance	very bad	bad	very poor	poor	medium	fair	satisfactory	good	very good	excellent
Disturbance	severe		annoying		light		trace		none	
Subjective rating - scale of weak points	not operational	limited operation	rated as bad failure	rated as failure	rated disturbing in all tests	rated disturbing in some tests	noticeable in all tests	noticeable in same tests	noticeable by trained testers	not noticeable even by trained testers
safety	Unsafe for use			unsafe for average rider	unsafe for inexperience rider	noticeable but not a serious impact on safety			ok	

Table 19-26: Driveability assessment tests

Test in Laboratory (controlled ambient conditions)
Start
Perform from cold, do test 1 and 2 quickly so engine stays cold
1: Engine start and immediately idle
2: rev engine to 1/2 throttle for 30", quickly return to idle

Test on track at low speed
procedure: from idle reach steady-state with part throttle and stay for 120 seconds for evaluation, then stop
3: Moving off slowly (0-10 km/h) straight line
4: Moving off slowly (0-10 km/h) turning
Low Speed Manoeuvres (25 km/h)
procedure: from idling, perform each at 25 km/h

5: Figure of 8: 2 cones 6 m spacing, 5 times around
6: Short drive; straight 30m, turn Xm (depending on the width of the track) radius semi-circle, straight 30m, stop (as performing a U-turn)
Medium speed (0-45km/h)
procedure: reach steady-state with 1/2 throttle and stay 120" for evaluation, then stop
7: Moving off fast (0-45 km/h) in a straight line,
8: Moving off fast (0-45 km/h) turn 5m radius semi-circle, (as if pulling out from a junction after a stop at a traffic light)
9: Short drive; straight 30m, turn Xm (depending on the width of the track) radius semi-circle, straight 30m, stop (as performing a U-turn)
Engine behaviour
procedure: fully warmed up engine
10: (Warm engine start and immediately idle) Restart after forced stall
11: Part-throttle steady-state: 1/4, 1/3, 1/2. reach steady engine rpm, stay 60" for evaluation
12: Deceleration fuel cut-off (stalling test): from 45 km/h stop applying throttle, roll to stop
13: Fuel reinstatement (stalling test): repeat test 12, at 25 km/h reinstate WOT

Test on track at low speed
Throttle / Gears
procedure: Accelerate with 1/4 throttle (more only as necessary), slowly proceed through all gears (CVT: all ratios) to top, proceed down all gears, and stop.
14: Throttle linearity (from idle - high speed) Go up and down all gears
Wide Open Throttle (max 120 km/h)
procedure: accelerate up to stated speed or Vmax if lower
15: Part-throttle acceleration: 1/2 throttle, straight line
16: WOT idle to 45km/h,
18: idle to 75km/h
19: idle to 100km/h
20: idle to 120km/h

Appendix N Test results

N.1 Results: THC all vehicle

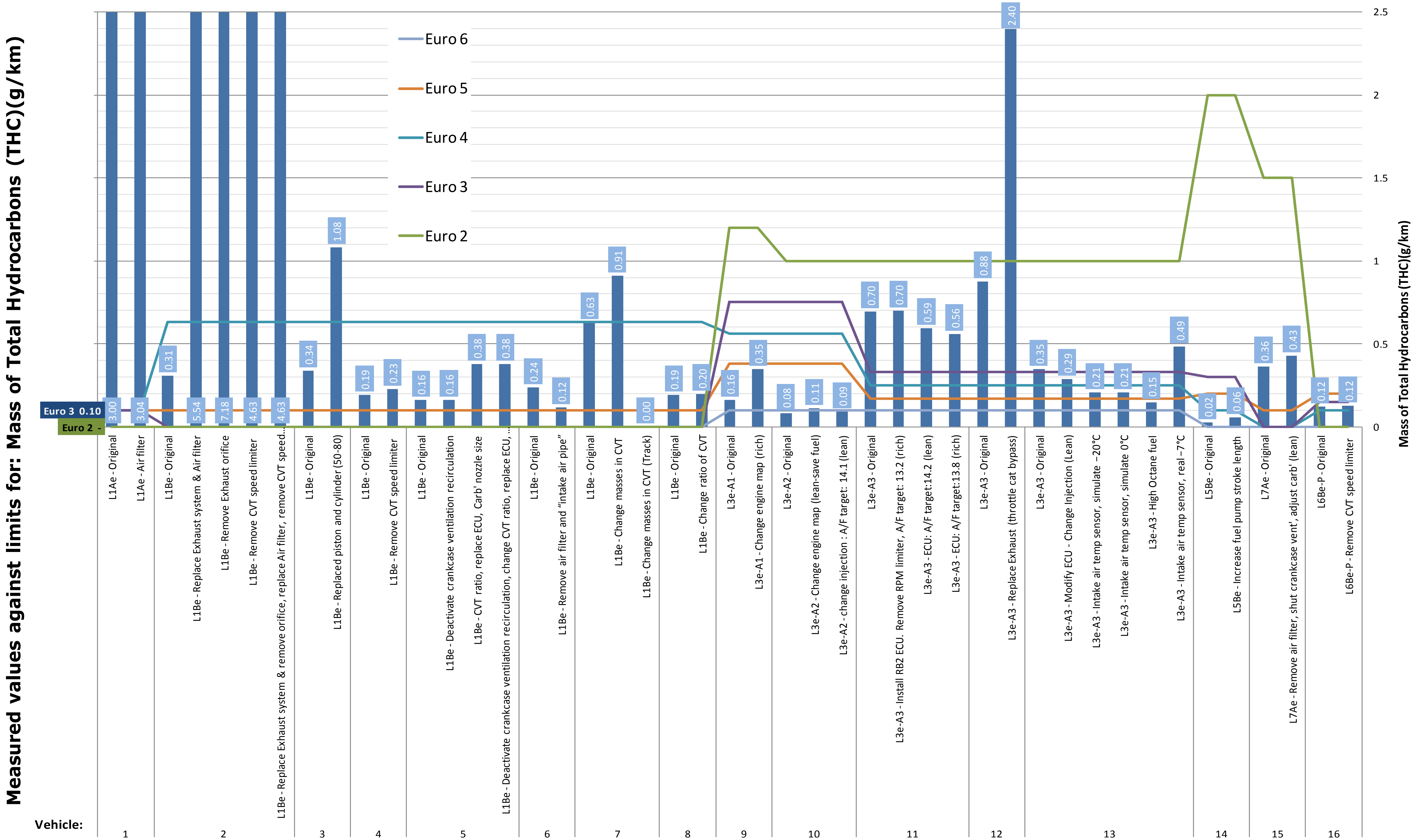


Figure 19-26: THC emissions for all vehicles in g/km

N.2 Results: CO_2 all vehicle

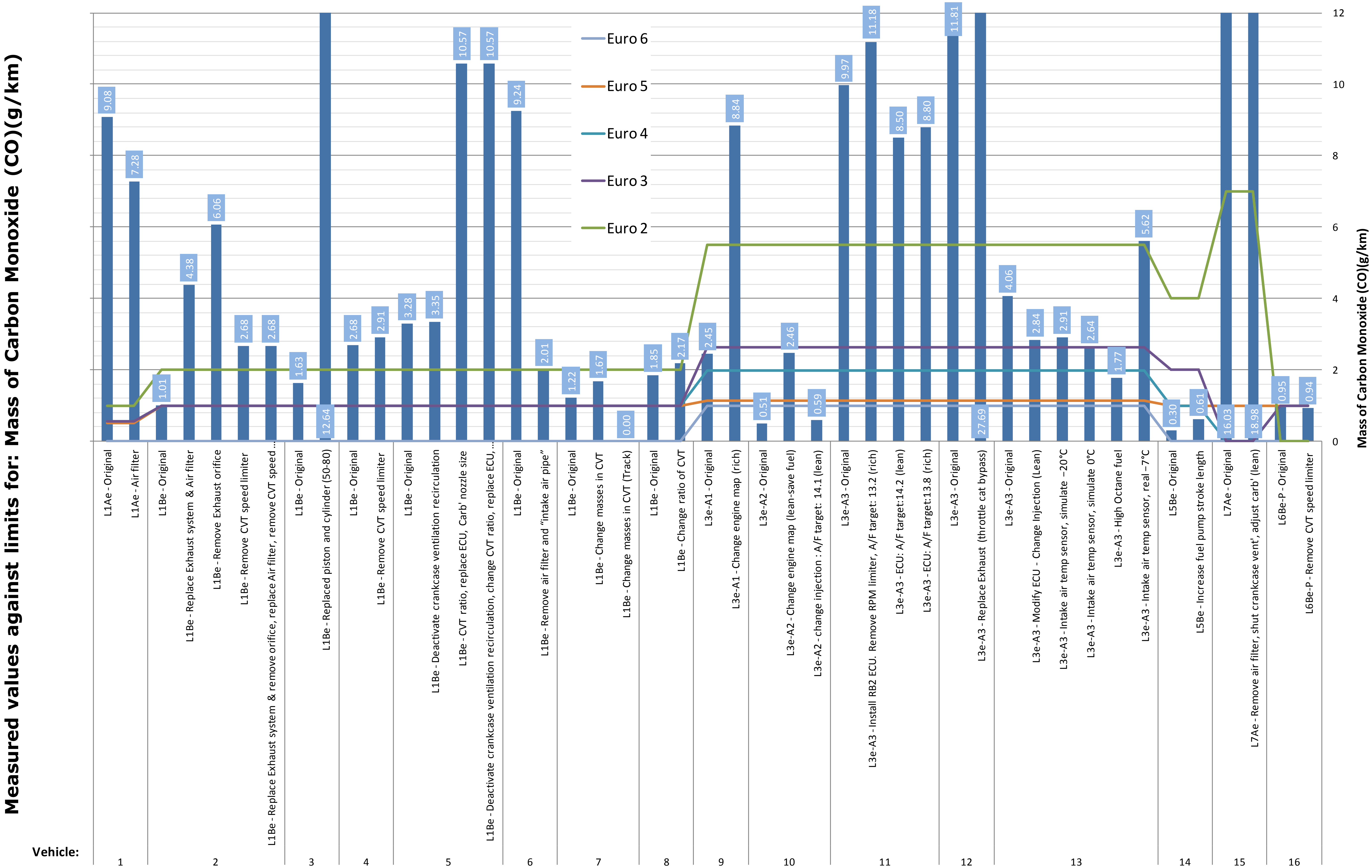


Figure 19-27: CO_2 emissions for all vehicles in g/km

N.3 Results: NOx all vehicles

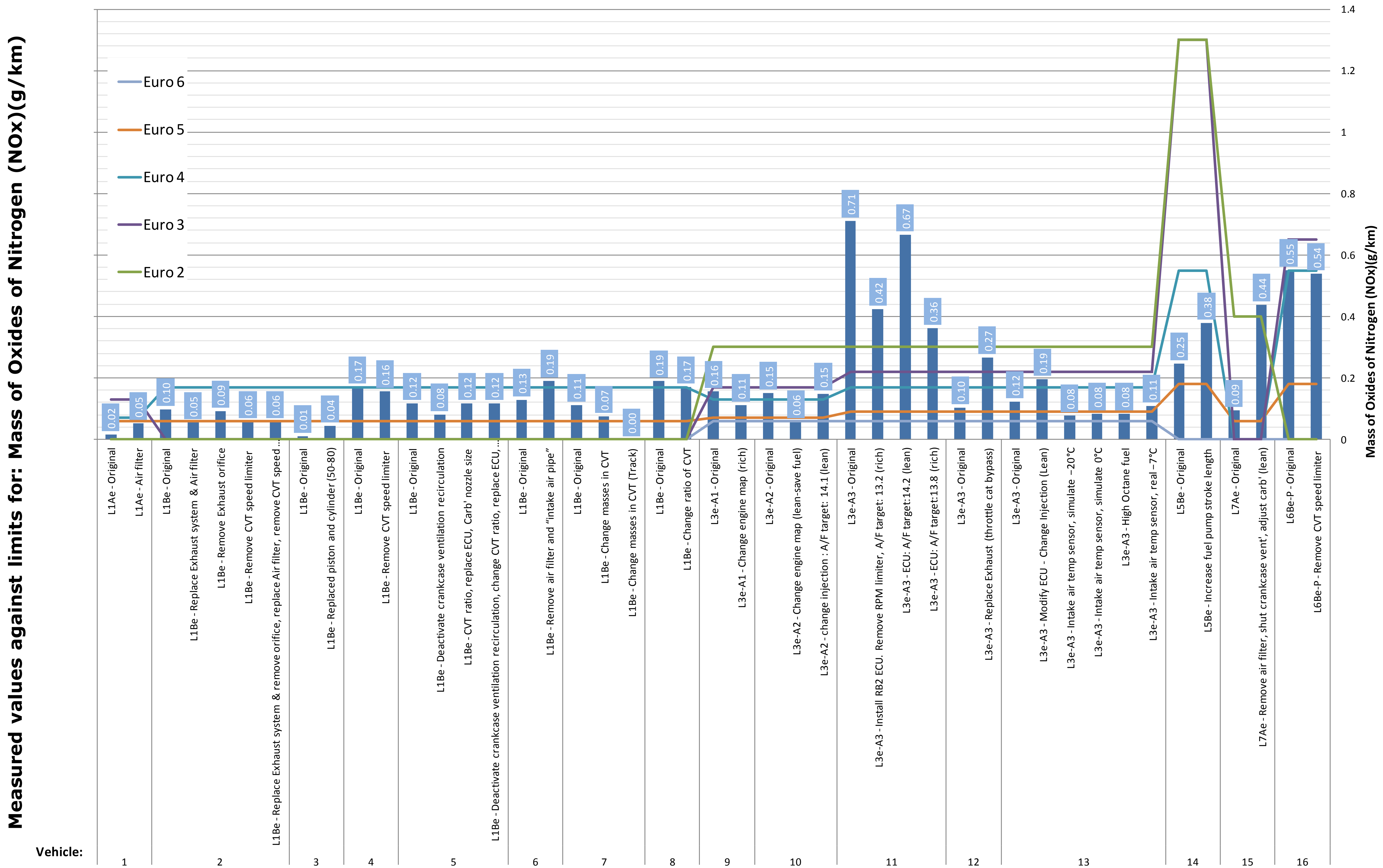


Figure 19-28: NO_x emissions for all vehicles in g/km

N.4 Results: THC+NOX all vehicles

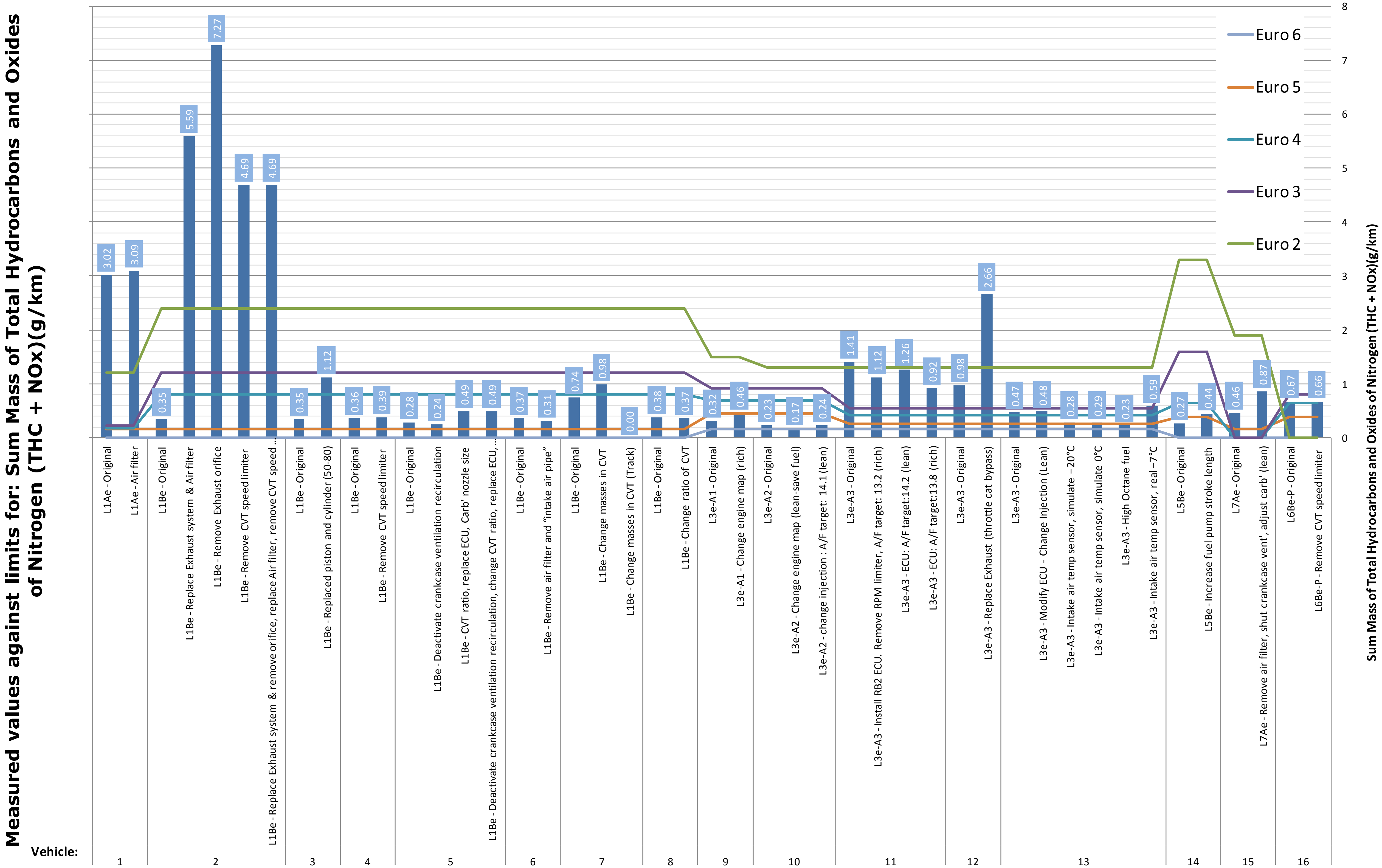


Figure 19-29: THC + NO$_x$ emissions for all vehicles in g/km

N.5 Results: CO2 all vehicles

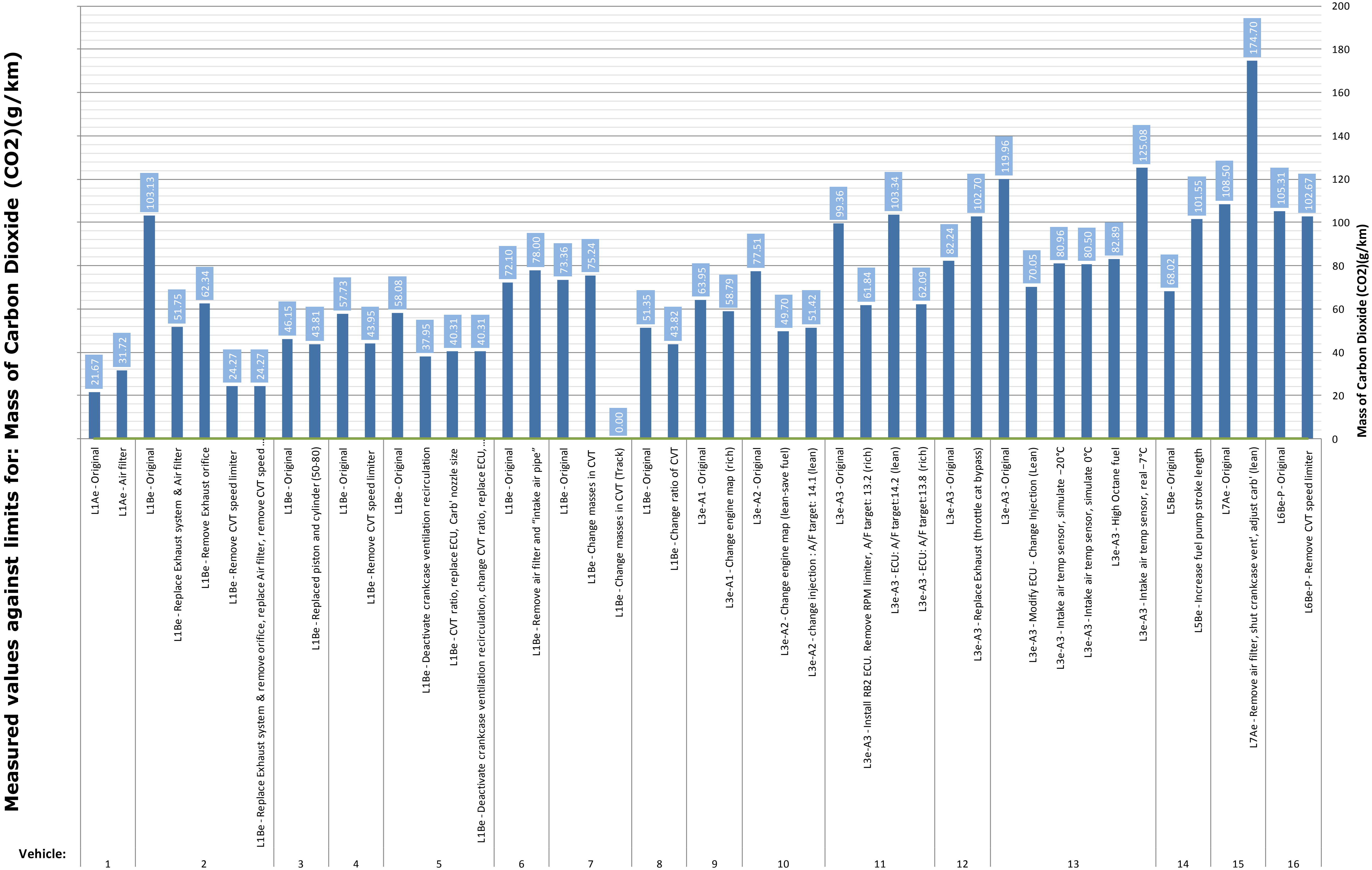


Figure 19-30: CO_2 emissions for all vehicles in g/km

N.6 Fuel economy all vehicles (metric)

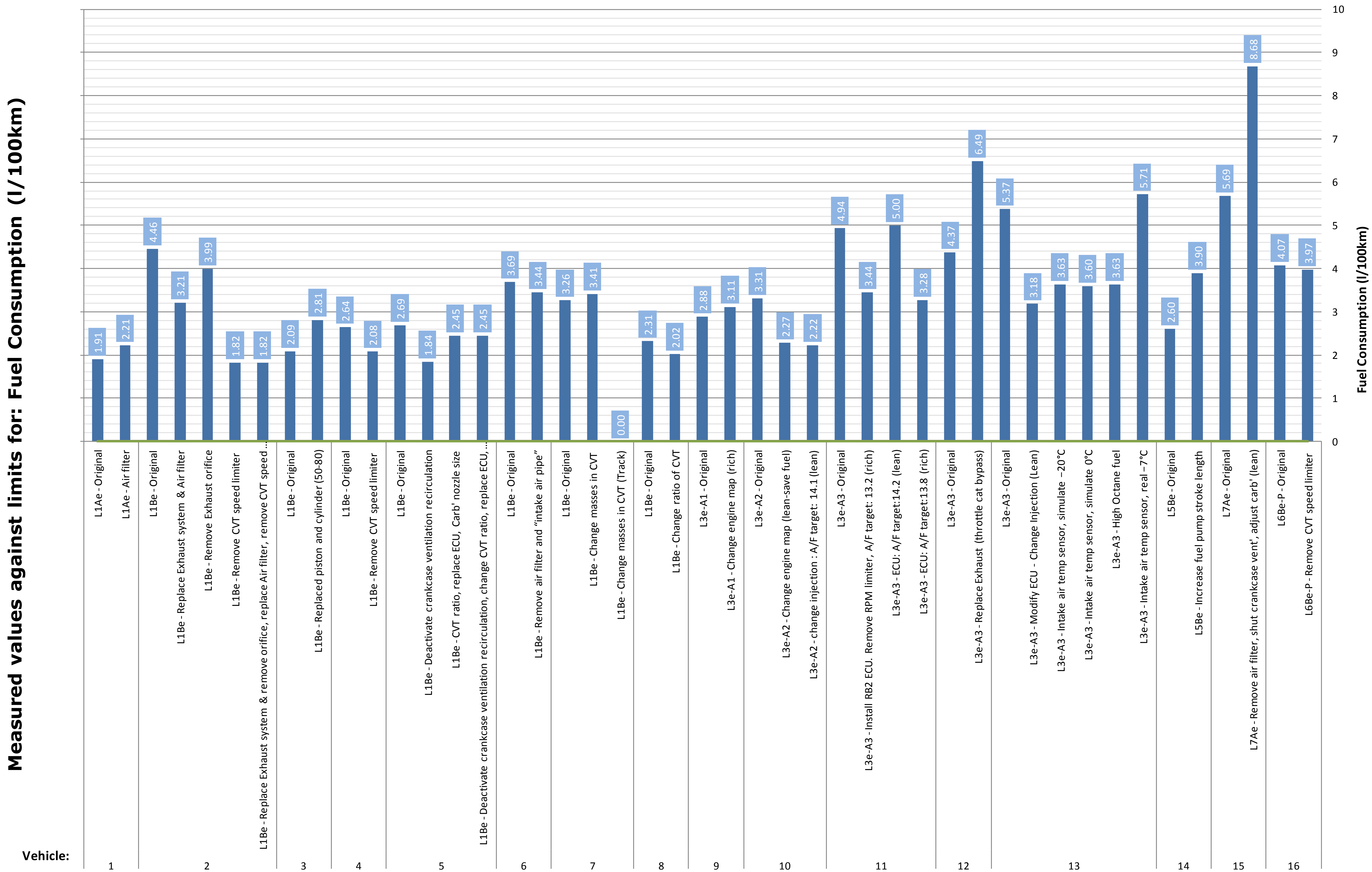


Figure 19-31: Fuel consumption for all vehicles in l/100km

N.7 Fuel economy all vehicles (imperial)

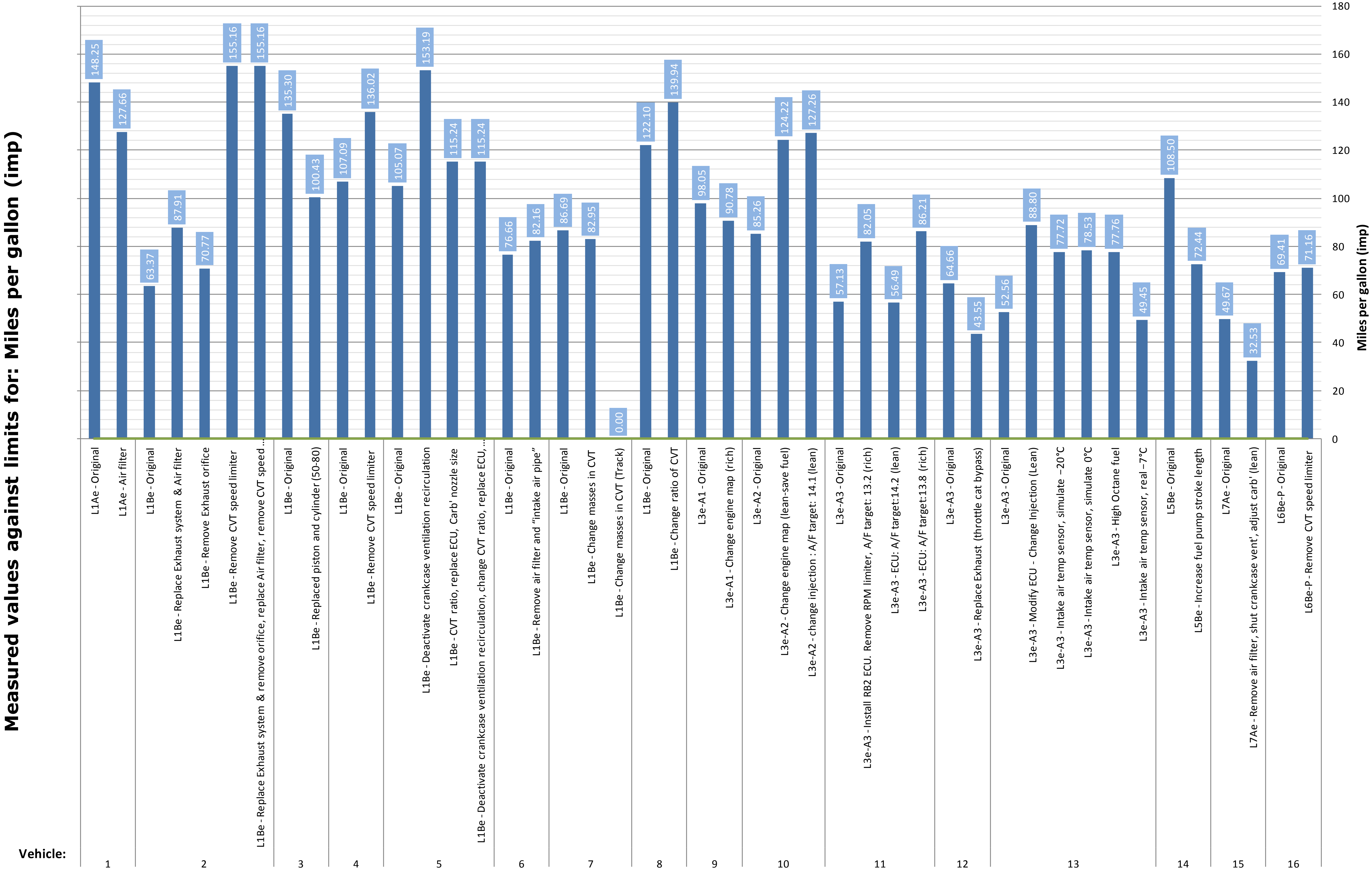


Figure 19-32: Fuel consumption for all vehicles and modifications in imperial miles per gallon

Appendix O Cost benefit

O.1 Monetised costs per experiment consolidated by vehicle area

Sum of all damages			Emissions				CO2				Safety				Sub total			
Vehicle Number	Vehicle category	Modification	10% modified	20% modified	30% modified	40% modified	10% modified	20% modified	30% modified	40% modified	10% modified	20% modified	30% modified	40% modified	10% modified	20% modified	30% modified	40% modified
1	L1Ae	Air filter	€ 0.0 M	€ 0.1 M	€ 0.1 M	€ 0.5 M	€ 0.0 M	€ 0.0 M	€ 0.1 M	€ 0.1 M	€ 49.7 M	€ 99.5 M	€ 149.2 M	€ 198.9 M	€ 49.8 M	€ 99.6 M	€ 149.4 M	€ 199.4 M
2	L1Be	Replace Exhaust system & Air filter	€ 2.5 M	€ 7.8 M	€ 11.7 M	€ 2.8 M	-€ 5.6 M	-€ 11.1 M	-€ 16.7 M	-€ 22.2 M	€ 130.9 M	€ 261.8 M	€ 392.6 M	€ 523.5 M	€ 127.8 M	€ 258.4 M	€ 387.7 M	€ 504.1 M
2	L1Be	Remove Exhaust orifice	€ 6.4 M	€ 16.7 M	€ 25.1 M	€ 35.6 M	-€ 4.4 M	-€ 8.8 M	-€ 13.2 M	-€ 17.6 M	€ 231.1 M	€ 462.3 M	€ 693.4 M	€ 924.5 M	€ 233.1 M	€ 470.2 M	€ 705.3 M	€ 942.4 M
2	L1Be	Remove CVT speed limiter	€ 1.8 M	€ 5.9 M	€ 8.9 M	-€ 0.2 M	-€ 8.5 M	-€ 17.1 M	-€ 25.6 M	-€ 34.1 M	€ 846.0 M	€ 1,691.9 M	€ 2,537.9 M	€ 3,383.8 M	€ 839.2 M	€ 1,680.8 M	€ 2,521.1 M	€ 3,349.5 M
3	L1Be	Replaced piston and cylinder (50-80)	€ 2.7 M	€ 6.0 M	€ 9.0 M	€ 24.2 M	-€ 0.3 M	-€ 0.5 M	-€ 0.8 M	-€ 1.0 M	€ 19.9 M	€ 39.8 M	€ 59.7 M	€ 79.6 M	€ 22.3 M	€ 45.3 M	€ 68.0 M	€ 102.8 M
4	L1Be	Remove CVT speed limiter		-€ 1.6 M	-€ 2.4 M	-€ 8.1 M	-€ 1.5 M	-€ 3.0 M	-€ 4.5 M	-€ 6.0 M	€ 131.5 M	€ 263.0 M	€ 394.4 M	€ 525.9 M	€ 130.0 M	€ 258.4 M	€ 387.6 M	€ 511.9 M
5	L1Be	Deactivate crankcase ventilation recirculation	-€ 2.1 M	-€ 4.4 M	-€ 6.6 M	-€ 21.7 M	-€ 2.2 M	-€ 4.4 M	-€ 6.5 M	-€ 8.7 M	-€ 24.5 M	-€ 48.9 M	-€ 73.4 M	-€ 97.9 M	-€ 28.8 M	-€ 57.7 M	-€ 86.5 M	-€ 128.2 M
6	L1Be	Remove air filter and "intake air pipe"	€ 3.6 M	€ 7.4 M	€ 11.1 M	€ 37.3 M	€ 0.6 M	€ 1.3 M	€ 1.9 M	€ 2.6 M	€ 1.9 M	€ 3.7 M	€ 5.6 M	€ 7.5 M	€ 6.1 M	€ 12.4 M	€ 18.6 M	€ 47.3 M
7	L1Be	Change masses in CVT	-€ 2.1 M	-€ 4.1 M	-€ 6.2 M	-€ 22.1 M	€ 0.2 M	€ 0.4 M	€ 0.6 M	€ 0.8 M	€ 469.4 M	€ 938.8 M	€ 1,408.3 M	€ 1,877.7 M	€ 467.6 M	€ 935.1 M	€ 1,402.7 M	€ 1,856.4 M
7	L1Be	Change masses in CVT (Track)	-€ 7.5 M	-€ 15.8 M	-€ 23.7 M	-€ 73.2 M	-€ 7.9 M	-€ 15.9 M	-€ 23.8 M	-€ 31.7 M	€ 692.2 M	€ 1,384.4 M	€ 2,076.6 M	€ 2,768.8 M	€ 676.8 M	€ 1,352.7 M	€ 2,029.1 M	€ 2,663.8 M
8	L1Be	Change ratio of CVT	-€ 1.1 M	-€ 2.4 M	-€ 3.5 M	-€ 11.6 M	-€ 0.8 M	-€ 1.6 M	-€ 2.4 M	-€ 3.3 M	€ 74.3 M	€ 148.7 M	€ 223.0 M	€ 297.3 M	€ 72.4 M	€ 144.7 M	€ 217.0 M	€ 282.4 M
9	L3e-A1	Change engine map (Rich)	-€ 1.6 M	-€ 3.1 M	-€ 4.7 M	-€ 16.3 M	-€ 0.4 M	-€ 0.7 M	-€ 1.1 M	-€ 1.4 M	€ 62.1 M	€ 124.1 M	€ 186.2 M	€ 248.2 M	€ 60.2 M	€ 120.3 M	€ 180.4 M	€ 230.5 M
10	L3e-A2	Change engine map (Rich)	-€ 9.9 M	-€ 20.3 M	-€ 30.5 M	-€ 100.3 M	-€ 5.2 M	-€ 10.5 M	-€ 15.7 M	-€ 21.0 M	-€ 0.5 M	-€ 1.1 M	-€ 1.6 M	-€ 2.1 M	-€ 15.6 M	-€ 31.9 M	-€ 47.8 M	-€ 123.3 M
11	L3e-A3	Install RB2 ECU. Remove RPM limiter, A/F target: 13.2 (Rich)	-€ 30.6 M	-€ 63.3 M	-€ 94.9 M	-€ 310.5 M	-€ 7.1 M	-€ 14.2 M	-€ 21.2 M	-€ 28.3 M	€ 0.0 M	€ 0.0 M	€ 0.0 M	€ 0.0 M	-€ 37.7 M	-€ 77.4 M	-€ 116.2 M	-€ 338.8 M
12	L3e-A3	Replace Exhaust (throttle cat bypass)	€ 20.2 M	€ 43.2 M	€ 64.8 M	€ 193.0 M	€ 3.9 M	€ 7.7 M	€ 11.6 M	€ 15.4 M	€ 0.0 M	€ 0.0 M	€ 0.0 M	€ 0.0 M	€ 24.0 M	€ 50.9 M	€ 76.4 M	€ 208.5 M
13	L3e-A3	Modify ECU - Change Injection (Lean)	€ 7.6 M	€ 15.7 M	€ 23.6 M	€ 77.8 M	-€ 9.4 M	-€ 18.8 M	-€ 28.2 M	-€ 37.7 M	€ 0.0 M	€ 0.0 M	€ 0.0 M	€ 0.0 M	-€ 1.8 M	-€ 3.1 M	-€ 4.7 M	€ 40.1 M
13	L3e-A3	Intake air temp sensor, simulate –20°C	-€ 4.9 M	-€ 10.2 M	-€ 15.3 M	-€ 48.3 M	-€ 7.4 M	-€ 14.7 M	-€ 22.1 M	-€ 29.4 M	€ 0.0 M	€ 0.0 M	€ 0.0 M	€ 0.0 M	-€ 12.2 M	-€ 24.9 M	-€ 37.4 M	-€ 77.7 M
13	L3e-A3	Intake air temp sensor, simulate 0°C	-€ 4.3 M	-€ 9.1 M	-€ 13.6 M	-€ 42.7 M	-€ 7.4 M	-€ 14.9 M	-€ 22.3 M	-€ 29.8 M	€ 0.0 M	€ 0.0 M	€ 0.0 M	€ 0.0 M	-€ 11.8 M	-€ 23.9 M	-€ 35.9 M	-€ 72.5 M
13	L3e-A3	High Octane fuel	-€ 4.4 M	-€ 9.3 M	-€ 13.9 M	-€ 43.0 M	-€ 7.0 M	-€ 14.0 M	-€ 21.0 M	-€ 28.0 M	€ 0.0 M	€ 0.0 M	€ 0.0 M	€ 0.0 M	-€ 11.4 M	-€ 23.3 M	-€ 34.9 M	-€ 71.0 M
13	L3e-A3	Intake air temp sensor, real –7°C	-€ 1.2 M	-€ 2.3 M	-€ 3.4 M	-€ 12.8 M	€ 1.0 M	€ 1.9 M	€ 2.9 M	€ 3.9 M	€ 0.0 M	€ 0.0 M	€ 0.0 M	€ 0.0 M	-€ 0.2 M	-€ 0.3 M	-€ 0.5 M	-€ 8.9 M
14	L5Be	Increase fuel pump stroke length	€ 0.1 M	€ 0.2 M	€ 0.3 M	€ 1.0 M	€ 0.0 M	€ 0.1 M	€ 0.1 M	€ 0.2 M	-€ 14.1 M	-€ 28.2 M	-€ 42.4 M	-€ 56.5 M	-€ 14.0 M	-€ 28.0 M	-€ 41.9 M	-€ 55.4 M
15	L7Ae	Remove air filter, shut crankcase vent', adjust carb' (Lean)	€ 2.1 M	€ 4.3 M	€ 6.5 M	€ 21.2 M	€ 0.7 M	€ 1.4 M	€ 2.1 M	€ 2.8 M	€ 0.0 M	€ 0.0 M	€ 0.0 M	€ 0.0 M	€ 2.8 M	€ 5.8 M	€ 8.6 M	€ 24.1 M
16	L6Be	Remove CVT speed limiter	-€ 0.1 M	-€ 0.1 M	-€ 0.2 M	-€ 0.7 M	€ 0.0 M	-€ 0.1 M	-€ 0.1 M	-€ 0.1 M	€ 212.4 M	€ 424.9 M	€ 637.3 M	€ 849.7 M	€ 212.3 M	€ 424.7 M	€ 637.0 M	€ 848.9 M

Figure 19-33: R.3 Monetised costs per experiment: emissions and safety

Continued on the following page:

Sum of all damages

Vehicle Number	Vehicle category	Modification	Sub total: 10% modified	Sub total: 20% modified	Sub total: 30% modified	Sub total: 40% modified	Modification (Cumulative modifications equally split amongst areas): Air/fuel Rich	Air/fuel Lean	Fuel Pump (Diesel)	Carburettor	Air Intake	Exhaust	Transmission CVT	Engine Crankcase ventilation	Engine Capacity	High Octane	Temperature
1	L1Ae	Air filter	**€ 49.8 M**	**€ 99.6 M**	**€ 149.4 M**	**€ 199.4 M**					1.00						
2	L1Be	Replace Exhaust system & Air filter	**€ 127.8 M**	**€ 258.4 M**	**€ 387.7 M**	**€ 504.1 M**					0.50	0.50					
2	L1Be	Remove Exhaust orifice	**€ 233.1 M**	**€ 470.2 M**	**€ 705.3 M**	**€ 942.4 M**						0.50	0.50				
2	L1Be	Remove CVT speed limiter	**€ 839.2 M**	**€ 1,680.8 M**	**€ 2,521.1 M**	**€ 3,349.5 M**						0.50	0.50				
3	L1Be	Replaced piston and cylinder (50-80)	**€ 22.3 M**	**€ 45.3 M**	**€ 68.0 M**	**€ 102.8 M**									1.00		
4	L1Be	Remove CVT speed limiter	**€ 130.0 M**	**€ 258.4 M**	**€ 387.6 M**	**€ 511.9 M**							1.00				
5	L1Be	Deactivate crankcase ventilation recirculation	*-€ 28.8 M*	*-€ 57.7 M*	*-€ 86.5 M*	*-€ 128.2 M*								1.00			
6	L1Be	Remove air filter and "intake air pipe"	**€ 6.1 M**	**€ 12.4 M**	**€ 18.6 M**	**€ 47.3 M**					1.00						
7	L1Be	Change masses in CVT	**€ 467.6 M**	**€ 935.1 M**	**€ 1,402.7 M**	**€ 1,856.4 M**							1.00				
7	L1Be	Change masses in CVT (Track)	**€ 676.8 M**	**€ 1,352.7 M**	**€ 2,029.1 M**	**€ 2,663.8 M**							1.00				
8	L1Be	Change ratio of CVT	**€ 72.4 M**	**€ 144.7 M**	**€ 217.0 M**	**€ 282.4 M**							1.00				
9	L3e-A1	Change engine map (Rich)	**€ 60.2 M**	**€ 120.3 M**	**€ 180.4 M**	**€ 230.5 M**	1.00										
10	L3e-A2	Change engine map (Rich)	*-€ 15.6 M*	*-€ 31.9 M*	*-€ 47.8 M*	*-€ 123.3 M*	1.00										
11	L3e-A3	Install RB2 ECU. Remove RPM limiter, A/F target: 13.2 (Rich)	*-€ 37.7 M*	*-€ 77.4 M*	*-€ 116.2 M*	*-€ 338.8 M*	1.00										
12	L3e-A3	Replace Exhaust (throttle cat bypass)	**€ 24.0 M**	**€ 50.9 M**	**€ 76.4 M**	**€ 208.5 M**						1.00					
13	L3e-A3	Modify ECU - Change Injection (Lean)	*-€ 1.8 M*	*-€ 3.1 M*	*-€ 4.7 M*	**€ 40.1 M**		1.00									
13	L3e-A3	Intake air temp sensor, simulate –20°C	*-€ 12.2 M*	*-€ 24.9 M*	*-€ 37.4 M*	*-€ 77.7 M*											1.00
13	L3e-A3	Intake air temp sensor, simulate 0°C	*-€ 11.8 M*	*-€ 23.9 M*	*-€ 35.9 M*	*-€ 72.5 M*											1.00
13	L3e-A3	High Octane fuel	*-€ 11.4 M*	*-€ 23.3 M*	*-€ 34.9 M*	*-€ 71.0 M*										1.00	
13	L3e-A3	Intake air temp sensor, real –7°C	*-€ 0.2 M*	*-€ 0.3 M*	*-€ 0.5 M*	*-€ 8.9 M*											1.00
14	L5Be	Increase fuel pump stroke length	*-€ 14.0 M*	*-€ 28.0 M*	*-€ 41.9 M*	*-€ 55.4 M*			1.00								
15	L7Ae	Remove air filter, shut crankcase vent', adjust carb' (Lean)	**€ 2.8 M**	**€ 5.8 M**	**€ 8.6 M**	**€ 24.1 M**		0.25		0.25	0.25			0.25			
16	L6Be	Remove CVT speed limiter	**€ 212.3 M**	**€ 424.7 M**	**€ 637.0 M**	**€ 848.9 M**							1.00				

Proportion of time between tampered and untampered max speed	Proportion of fleet tampered	Air/fuel Rich	Air/fuel Lean	Fuel Pump (Diesel)	Carburettor	Air Intake	Exhaust	Transmission CVT	Engine Crankcase ventilation	Engine Capacity	High Octane	Temperature
Number of modification performed		3.00	1.25	1	0.25	2.75	2.50	6	1.25	1	1	3
1/4	10%	*-€ 13.1 M*	*-€ 0.9 M*	*-€ 3.4 M*	**€ 2.8 M**	**€ 11.9 M**	**€ 68.5 M**	**€ 84.4 M**	*-€ 7.8 M*	**€ 7.4 M**	*-€ 11.4 M*	*-€ 8.1 M*
1/4	20%	*-€ 27.1 M*	*-€ 1.4 M*	*-€ 6.8 M*	**€ 5.8 M**	**€ 24.4 M**	**€ 139.8 M**	**€ 168.9 M**	*-€ 15.6 M*	**€ 15.5 M**	*-€ 23.3 M*	*-€ 16.4 M*
1/4	30%	*-€ 40.7 M*	*-€ 2.0 M*	*-€ 10.2 M*	**€ 8.6 M**	**€ 36.6 M**	**€ 209.8 M**	**€ 253.4 M**	*-€ 23.5 M*	**€ 23.2 M**	*-€ 34.9 M*	*-€ 24.6 M*
1/4	40%	*-€ 138.8 M*	**€ 36.9 M**	*-€ 13.0 M*	**€ 24.1 M**	**€ 55.9 M**	**€ 317.8 M**	**€ 325.7 M**	*-€ 39.1 M*	**€ 43.1 M**	*-€ 71.0 M*	*-€ 53.0 M*
1/2	10%	*-€ 8.0 M*	*-€ 0.9 M*	*-€ 6.9 M*	**€ 2.8 M**	**€ 22.5 M**	**€ 128.9 M**	**€ 172.7 M**	*-€ 12.7 M*	**€ 12.4 M**	*-€ 11.4 M*	*-€ 8.1 M*
1/2	20%	*-€ 16.9 M*	*-€ 1.4 M*	*-€ 13.8 M*	**€ 5.8 M**	**€ 45.7 M**	**€ 260.6 M**	**€ 345.4 M**	*-€ 25.4 M*	**€ 25.4 M**	*-€ 23.3 M*	*-€ 16.4 M*
1/2	30%	*-€ 25.3 M*	*-€ 2.0 M*	*-€ 20.8 M*	**€ 8.6 M**	**€ 68.5 M**	**€ 391.0 M**	**€ 518.2 M**	*-€ 38.1 M*	**€ 38.1 M**	*-€ 34.9 M*	*-€ 24.6 M*
1/2	40%	*-€ 118.2 M*	**€ 36.9 M**	*-€ 27.1 M*	**€ 24.1 M**	**€ 98.5 M**	**€ 559.4 M**	**€ 678.8 M**	*-€ 58.6 M*	**€ 63.0 M**	*-€ 71.0 M*	*-€ 53.0 M*
3/4	10%	*-€ 2.8 M*	*-€ 0.9 M*	*-€ 10.5 M*	**€ 2.8 M**	**€ 33.2 M**	**€ 189.3 M**	**€ 260.9 M**	*-€ 17.6 M*	**€ 17.4 M**	*-€ 11.4 M*	*-€ 8.1 M*
3/4	20%	*-€ 6.6 M*	*-€ 1.4 M*	*-€ 20.9 M*	**€ 5.8 M**	**€ 67.0 M**	**€ 381.4 M**	**€ 522.0 M**	*-€ 35.2 M*	**€ 35.4 M**	*-€ 23.3 M*	*-€ 16.4 M*
3/4	30%	*-€ 9.9 M*	*-€ 2.0 M*	*-€ 31.3 M*	**€ 8.6 M**	**€ 100.4 M**	**€ 572.2 M**	**€ 783.0 M**	*-€ 52.8 M*	**€ 53.0 M**	*-€ 34.9 M*	*-€ 24.6 M*
3/4	40%	*-€ 97.7 M*	**€ 36.9 M**	*-€ 41.2 M*	**€ 24.1 M**	**€ 141.0 M**	**€ 801.0 M**	**€ 1,031.8 M**	*-€ 78.2 M*	**€ 82.9 M**	*-€ 71.0 M*	*-€ 53.0 M*
1	10%	**€ 2.3 M**	*-€ 0.9 M*	*-€ 14.0 M*	**€ 2.8 M**	**€ 43.8 M**	**€ 249.7 M**	**€ 349.2 M**	*-€ 22.5 M*	**€ 22.3 M**	*-€ 11.4 M*	*-€ 8.1 M*
1	20%	**€ 3.7 M**	*-€ 1.4 M*	*-€ 28.0 M*	**€ 5.8 M**	**€ 88.2 M**	**€ 502.2 M**	**€ 698.5 M**	*-€ 45.0 M*	**€ 45.3 M**	*-€ 23.3 M*	*-€ 16.4 M*
1	30%	**€ 5.5 M**	*-€ 2.0 M*	*-€ 41.9 M*	**€ 8.6 M**	**€ 132.4 M**	**€ 753.4 M**	**€ 1,047.8 M**	*-€ 67.5 M*	**€ 68.0 M**	*-€ 34.9 M*	*-€ 24.6 M*
1	40%	*-€ 77.2 M*	**€ 36.9 M**	*-€ 55.4 M*	**€ 24.1 M**	**€ 183.6 M**	**€ 1,042.6 M**	**€ 1,384.9 M**	*-€ 97.8 M*	**€ 102.8 M**	*-€ 71.0 M*	*-€ 53.0 M*

Figure 19-34: R.3 Monetised costs per vehicle area by

Appendix P Current anti-tampering legislation (Directive 97/24/EC), including analysis

	Original	**Notes**	**Example**
	CHAPTER 7		
	ANTI-TAMPERING MEASURES FOR TWO-WHEEL MOPEDS AND MOTORCYCLES	To prevent possible loopholes and confusion by mentioning specific names of vehicle, "L-Category" should be used, and if necessary its category or range of categories.	ANTI-TAMPERING MEASURES FOR L-CATEGORY VEHICLES
	ANNEX		
1	DEFINITIONS		
	or the purposes of this Chapter:		
1.1.	'Anti-tampering measures for two-wheel mopeds and motorcycles' means a series of technical requirements and specifications the aim of which is to prevent, as far as possible, unauthorized modifications which may prejudice safety, in particular by increasing vehicle performance, and damage the environment.		
1.2.	'Propulsion performance' means the propulsion power resulting in maximum vehicle speed and/or engine torque resulting in maximum acceleration rate.		
1.3.	'Vehicle categories' means vehicles subdivided into the following categories:	Replace with the L-category system and expand scope to any speed or power restricted l-category vehicle. Definitions which could be used are: speed limited, power limited and/or learner motorcycles. This could be split into Step 1 and 2 if restricted high performance vehicles are added (L3e-A2).	
1.3.1.	Category A vehicles — mopeds.		L1e, L2e, L6e
1.3.2.	Category B vehicles — motorcycles with a cylinder capacity not exceeding 125 cc and a power not exceeding 11 kW.		L3e-A1, L4e-A1, L7?e
1.3.3.	Category C vehicles — motorcycles with a power not exceeding 25 kW and a power/mass ratio not exceeding 0,16 kW/kg, mass in running order		L3e-A2, L4e-A2, L7?e

	as defined in section 2 of Note (d) in Annex II to Directive 92/61/EEC .		
1.3.4.	Category D vehicles — motorcycles other than those in categories B or C.		L3e-A3, L5e, L7?e
1.4.	‘Unauthorized modification’ means a modification which is not permitted by this Chapter.		
1.5.	‘Interchangeability of parts’ means the interchangeability of parts which are not identical.		
1.6.	‘Inlet conduit’ means the combination of the inlet passage and the intake pipe.		
1.7.	‘Inlet passage’ means the passage for the intake of air within the cylinder, cylinder-head or crankcase.		
1.8.	‘Intake pipe’ means a part connecting the carburettor or air-control system and the cylinder, cylinder-head or crankcase.		
1.9.	‘Intake system’: means the combination of the inlet conduit and the intake silencer.		
1.10.	‘Exhaust system’ means the assembly of the exhaust pipe, the expansion box, the exhaust silencer, catalytic converter(s) and the oxygen sensors (s) (if any).		
1.11.	‘Special tools’ means tools which are made available only to distributors authorized by the vehicle manufacturer and are not available to the general public.		
2	GENERAL PROVISIONS		
2.1.	Interchangeability of non-identical parts between component-type-approved vehicles:		
2.1.1.	For any vehicle in categories A or B, the interchangeability of the following components or of a set of the following components:	Technical advances mean that Fuel injector and Electronic Control Unit should be added to both engine types in this section. Additionally other propulsion types should be addressed.	For any L1e, L2e, L6e, L3e-A1 or L4e-A1 vehicle, the interchangeability of the following components or of a set of the following components, if present in the propulsive motor or engine:
	(a) for two-stroke vehicles: cylinder/piston		(a) for all vehicles: camshaft, cylinder/piston

	combination, carburettor, intake pipe, exhaust system,		combination, carburettor, fuel injector, intake pipe, exhaust system, (b) for four-stroke: cylinder head, (c) for CI: fuel pump, (d) for electric: ?,
	(b) for four-stroke vehicles: cylinder head, camshaft, cylinder/piston combination, carburettor, intake pipe, exhaust system,		
	between that vehicle and any other vehicle from the same manufacturer is not permitted if such interchangeability results in the vehicle's maximum design speed increasing by more than 5 km/h in the case of category A vehicles or the vehicle's power increasing by more than 10 % in the case of category B vehicles. In no case may the maximum design speed or the maximum net engine power of the relevant category be exceeded.		
	In particular, for the low-performance mopeds referred to in the Note in Annex I to Directive 92/61/EEC, the maximum design speed is 25 km/h.	Update reference	
2.1.1.1.	For any vehicle in Category B, of which variants exist pursuant to Article 2 of Directive 92/61/EEC which differ in respect of maximum speed or maximum net power as a result of additional restrictions imposed by Member States under Article 3 (5) of Council Directive 91/439/EEC of 29 July 1991 on driving licences (1), the requirements of 2.1.1(a) and (b) do not apply to the interchangeability of components unless this results in the vehicle's power exceeding 11 kW.		
2.1.2.	In cases involving the interchangeability of components, the manufacturer must ensure that the competent authorities are provided with the necessary information and, where appropriate, the necessary vehicles to enable them to verify that the requirements of this section have been met.		

2.2.	The manufacturer must declare that modifications of the following characteristics will not increase the maximum power of a category B motorcycle by more than 10 % or increase the maximum speed of a moped by more than 5 km/h and that in no case may the maximum design speed or the maximum net engine power for the category concerned be exceeded: ignition (advance, etc.), fuel feed system.	These allowed allowances are required, because changing any part is liable to effect the vehicle speed or power marginally, whether harmful or not.	... not increase the maximum power of a power restricted vehicle by more than 10 % and/or increase the maximum speed of a speed restricted vehicle by more than 5 km/h
2.3.	Category B motorcycles must comply with the requirements of either 2.3.1 or 2.3.2 or 2.3.3 and with 2.3.4 and 2.3.5.	Update category system, and expand so that these rules are implemented on all vehicles with an air restriction not just these where it is obligatory.	L3e-A1 vehicles must comply with the requirements of either 2.3.1 or 2.3.2 or 2.3.3 and with 2.3.4 and 2.3.5. Any other L-category vehicle with the exception of L3e-A3 and L4e-A3 covered by this legislation where the manufacturer chooses to restrict the airflow in a similar manner, shall apply these rules.
2.3.1.	An unremovable sleeve must be located in the inlet conduit. If such a sleeve is located in the intake pipe, the latter must be fixed to the engine block by means of shear-bolts or bolts removable only using special tools.	The second design option of "either the destruction of the sleeve and its support or complete and permanent malfunctioning of the engine" is impractical which may lead to the default use of the first option. The first design option is intended	

	The sleeve must have minimum hardness of 60 HRC. In the restricted section it must not exceed 4 mm in thickness. Any interference with the sleeve aimed at removing or modifying it must lead to either the destruction of the sleeve and its support or complete and permanent malfunctioning of the engine until it is restored to its approved condition. A marking with indication of the vehicle category or categories as defined in 1.3 must be legible on the surface of the sleeve or not far from it.	prevent users from reattaching the limiter just for inspection purposes, but does not limit the tampering. It has been shown from stakeholder information that this restriction method is well known to be easy to circumvent. For this reason either the first design option or the entire anti-tampering option in 2.3.1 may need to be removed from the legislation.	
2.3.2.	Each intake pipe must be fixed with shear-bolts or bolts removable only using special tools. A restricted section, indicated on the outside, must be located inside the pipes; at that point the wall must be less than 4 mm in thickness, or 5 mm if using a flexible material, such as rubber for example. Any interference with the pipes aimed at modifying the restricted section must lead to either the destruction of the pipes or complete and permanent malfunctioning of the engine until they are restored to their approved condition. A marking with indication of the vehicle category or categories as defined in 1.3 must be legible on the pipes.		
2.3.3.	The part of the inlet conduit located in the cylinder head must have a restricted section. In the whole inlet passage there must not be a more restricted section (except the valve-seat section). Any interference with the conduit aimed at modifying the restricted section must lead to either the destruction of the pipe or complete and permanent malfunctioning of the engine until it is restored to its approved condition. A marking with indication of the vehicle category as defined in 1.3 must		

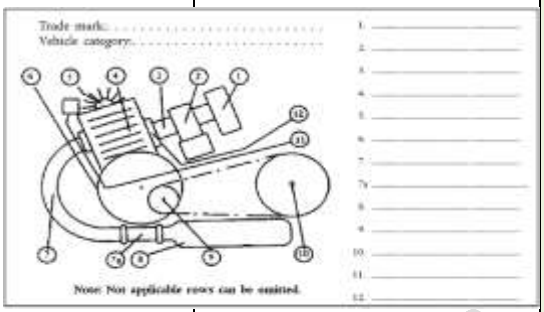
	be legible on the cylinder head.		
2.3.4.	The diameter of the restricted section referred to in sections 2.3.1, 2.3.2 and 2.3.3 varies according to the motorcycle concerned.		
2.3.5.	The manufacturer must supply the diameter of the restricted section and prove to the competent authorities that this restricted section is the most critical for the passage of gases, and that there is no other section which, if modified, could increase vehicle performance by more than 10 %.		
	Four years after this Directive is implemented, the maximum diameters of the restricted section for the various types of motorcycles must be determined numerically following the procedure set out in Article 6 on the basis of the diameters of the restricted sections supplied by the manufacturer.	Appropriate timings for the implementation of any changes will need to be decided. These should take due consideration with the implementation of design changes required by other areas of the new l-category type-approval legislation.	
2.4.	Removing the air filter must not have the effect of increasing a moped's maximum design speed by more than 10 %.	This compulsory requirement could be made for all restricted vehicles, it prevents the easily changed consumable from being a concern.	
3	SPECIFIC REQUIREMENTS FOR VEHICLES IN CATEGORIES A AND B	Replace with the L-category system and expand scope to any speed or power restricted l-category vehicle.	All L-vehicle categories except L3e-A3 and L4e-A3.
	The requirements in this section are not mandatory unless a single requirement or combination of requirements proves necessary to impede tampering resulting in the vehicle's maximum design speed increasing by more than 5 km/h in the case of category A vehicles or the vehicle's power increasing by more than 10 % in the case of category B vehicles. In no case may the maximum design speed or maximum net engine power of the relevant category be exceeded.		
3.1.	Cylinder-head gasket: after mounting, the maximum thickness of a cylinder-head gasket, if any, may not exceed — 1,3 mm for mopeds, and		

	— 1,6 mm for motorcycles.		
3.2.	Cylinder/crankcase gasket for two-stroke engines: the maximum thickness of any gasket between the base of the cylinder and the crankcase, if any, may not exceed 0,5 mm, after mounting.		
3.3.	Piston for two-stroke engines: the piston, when in position at top dead centre, must not cover the inlet port. This requirement does not apply to those parts of the transfer port which coincide with the inlet port in the case of vehicles the engine of which is equipped with an induction system incorporating reed valve(s).		
3.4.	For two-stroke engines, rotation of the piston through 180° must not increase engine performance.		
3.5.	Without prejudice to the provisions of 2.3, no artificial restriction is permitted in the exhaust system. The valve guides of a four-stroke engine are not considered to be artificial restrictions.		
3.6.	The part(s) of the exhaust system inside the silencer(s) which determine(s) the effective length of the exhaust pipe must be affixed to the silencer(s) or expansion box(es) in such a way that it (they) cannot be removed.	This part of the exhaust has been found from stakeholder information to be tampered while allowing the fact to remain hidden. This part is always liable to effect the effective length, but is required by silencers, therefore preventing its inclusion in a vehicle is not a viable option. To prevent this modification from being major concern, a limited criteria could be used which requires only that the limits are not exceeded, not amounts of change.	… If removed it should not increase the performance of the vehicle above the legislated performance limits for this vehicle.

3.7.	Any component (mechanical, electrical, structural, etc.) which limits full engine load (e.g. a throttle control stop or a twist-grip stop) is forbidden.	This article should be clarified. It can be read as forbidding such things as: transient response systems on carburettors or restricted fuel flow via the ECU at high engine speeds. Additionally, due to driveability issues there is stakeholder information to suggest banning twist grip stops outright, and due to the simplicity of deactivating the measure to ban throttle stops within the carburettor or mechanical links to an electronic control.	
3.8.	If a category A vehicle is equipped with electrical/electronic devices which limit its speed, the vehicle manufacturer must provide data and evidence to the test authorities to demonstrate that modification or disconnection of the device or its wiring system will not increase the moped's maximum speed by more than 10 %. Electrical/electronic devices which cut and/or inhibit spark ignition are forbidden if their operation results in an increase in fuel consumption or unburnt hydrocarbon emissions. Electrical/electronic devices which vary spark advance must be designed in such a way that the engine power, measured with the device functioning, does not differ by more than 10 % from the power measured with the device disconnected and with spark advance set for maximum road speed. The maximum road speed must be achieved with the spark advance set within ± 5 o of the value specified for the development of maximum power.		
3.9.	Should an engine be equipped with a reed valve, this must be fixed with shear-bolts which prevent re-use of its support or bolts removable only using special tools.		
3.10.	Requirements for the identification of a vehicle engine type	Separate into separate section on markings, reiterate which groups this section applies to.	

3.10.1.	Marking of original parts/components:
3.10.1.1.	The parts components listed below must be durably and indelibly marked with the code number(s) and symbols assigned for identification purposes either by the vehicle manufacturers of such parts or components. Such marking may take the form of a label provided that it remains legible in normal use and cannot be detached without being destroyed.
	In general, this marking must be visible without the necessity of dismantling the part in question or other parts of the vehicle. However, where the bodywork or other parts of the vehicle obscure a marking, the vehicle manufacturer must provide the competent authorities with indications for opening or dismantling the parts in question and the location of the markings.
3.10.1.2.	The letters, figures or symbols used must be at least 2,5 mm in height and be easily legible. However, for the marking of parts such as those specified in 3.10.1.3.7 and 3.10.1.3.8, the minimum height must be as specified in Chapter 9.
3.10.1.3.	The parts and components referred to in 3.10.1.1 are the following:
3.10.1.3.1.	intake silencer (air filter)
3.10.1.3.2.	carburettor or equivalent device
3.10.1.3.3.	inlet pipe (if cast separately from the carburettor or cylinder or crankcase)
3.10.1.3.4.	cylinder
3.10.1.3.5.	cylinder head
3.10.1.3.6.	crankcase
3.10.1.3.7.	exhaust pipe(s) (if separate from the silencer)
3.10.1.3.7a.	catalytic converter(s) (only if not integrated in the silencer)
3.10.1.3.8.	silencer(s)
3.10.1.3.9.	transmission driving part (front chain wheel (sprocket) or pulley)
3.10.1.3.10.	transmission driven part (rear chain wheel (sprocket) or pulley)
3.10.1.3.11.	any electrical/electronic devices for engine management (ignition, injection, etc.) and all the different electronic cards in the case of a device which is designed to be opened
3.10.1.3.12.	restricted section (sleeve or other).
3.10.2.	Anti-tampering control plate
3.10.2.1.	A plate of at least 60 mm × 40 mm must be fixed to each vehicle in a durable manner (it may be adhesive but not detachable without prejudice to its integrity) in an easily accessible place on the vehicle.
	On this plate the manufacturer must indicate:
3.10.2.1.1.	his name or trade mark;

3.10.2.1.2.	the letter representing the vehicle category;	Replace with L-category system.	Separated by a bar symbol; the vehicles category and sub-category, if applicable its additional national category, and the letter representing the vehicle category from Chapter 7 97/24/EC should also be shown for a period of ... years. E.g. "L1Be | ≤25 km/h | (A)"
3.10.2.1.3.	for the transmission driving and driven parts, the number of cogs (in the case of a sprocket), or the diameter (in mm) in the case of a pulley;		
3.10.2.1.4.	the code number(s) or symbol(s) identifying the parts or components marked in accordance with 3.10.1.		
3.10.2.2.	Letters, figures or symbols must be at least 2,5 mm in height and be easily legible. A simple drawing showing the correspondence between parts or components and their code numbers or symbols is given in Figure 1 (see INTERNAL LINK).		
3.10.3.	Marking of non-original parts/components		
3.10.3.1.	In the case of components type-approved for the vehicle in accordance with this Chapter which are alternatives to those listed in 3.10.1.3 and are sold by the vehicle manufacturer, the code number(s) or symbol(s) of such alternatives must be shown either on the control plate or on a sticker (which must remain legible in normal use and which cannot be detached without being destroyed), to be supplied with the component for attachment next to the	This article specifies that the parts must be supplied with a sticker or plate, what it must indicate how it must look, and how it must perform. It does not however enforce that the marking needs to be affixed.	

	control plate.		
3.10.3.2.	In the case of non-original replacement silencers, the code number (s) or symbol(s) of such separate technical units must be shown on a sticker (which must remain legible in normal use and which cannot be detached without being destroyed), to be supplied with the component for attachment next to the control plate.		
3.10.3.3.	When, pursuant to 3.10.3.1 and 3.10.3.2, non-original parts/components have to be marked, the markings must comply with the provisions of 3.10.1.1 to 3.10.2.2.		
	Image: 	It has been indicated through the stakeholder consultation that some of the information on this plate is not necessary, or at least not necessary for road-side inspection. Without further data on its use it could be seen that the images (which is standardised) could be removed and the space used for other purposes, without adding additional cost.	

Appendix Q UN Regulation on Noise

The following is an excerpt from the draft revision of UN Regulation Number 41.[43]

6.3.	Additional sound emission provisions
6.3.1.	The motor cycle manufacturer shall not intentionally alter, adjust, or introduce any device or procedure solely for the purpose of fulfilling the noise emission requirements of this Regulation, which will not be operational during typical on-road operation.
6.3.2.	The vehicle type to be approved shall meet the requirements of Annex 7 to this Regulation. If the motor cycle has user selectable software programs or modes which affect the sound emission of the vehicle, all these modes shall be in compliance with the requirements in Annex 7. Testing shall be based on the worst case scenario.
6.3.3.	In the application for type approval or for modification or extension of a type approval the manufacturer shall provide a statement in accordance with Annex 8 that the vehicle type to be approved complies with the requirements of paragraphs 6.3.1. and 6.3.2. of this Regulation.
6.3.4.	The competent authority may carry out any test prescribed in this Regulation.
6.4.	Additional specifications regarding exhaust or silencing systems filled with fibrous material
6.4.1.	If the exhaust or silencing system of the motor cycle contains fibrous materials the requirements of Annex 5 shall apply. If the intake of the engine is fitted with an air filter and/or an intake-noise absorber which is (are) necessary in order to ensure compliance with the permissible sound level, the filter and/or absorber shall be considered to be part of the silencing system, and the requirements of Annex 5 shall also apply to them.
6.5.	Additional prescriptions related to 'tamperability' and manually adjustable multimode exhaust or silencing systems
6.5.1.	All exhaust or silencing systems shall be constructed in a way that does not easily permit removal of baffles, exit-cones and other parts whose primary function is as part of the silencing/expansion chambers. Where incorporation of such a part is unavoidable, its method of attachment shall be such that removal is not facilitated easily (e.g. with conventional threaded fixings) and should also be attached such that removal causes permanent/ irrecoverable damage to the assembly.
6.5.2.	Exhaust or silencing systems with multiple, manually adjustable operating modes shall meet all requirements in all operating modes. The reported noise levels shall be those resulting from the mode with the highest noise levels.

Note: Annex 5 lays out how to test the durability of fibrous materials.

[43] http://www.unece.org/fileadmin/DAM/trans/doc/2010/wp29grb/06-R41WG-10e.pdf

Appendix R Vehicle design reference

R.1 Lambda (oxygen) sensor

The oxygen sensor is fitted within the flow of exhaust gas. It senses the oxygen concentration in the exhaust flow and compares this to the oxygen concentration of ambient air; its output signal is used as feedback signal to the engine control unit for closed loop fuel control, with the aim of toggling around stroichiometry.

There are two versions of this sensor; the Zirconica type provides a voltage depending on the Oxygen concentration and the Titania type changes in resistance. The Zirconica types have one end exposed to atmosphere to provide a gradient in oxygen levels, the flow difference in oxygen concentration between the two sides generates the signal. In the case of a conventional O2 sensor a high analogue voltage (+/- 900 mV) is generated in the case of low O2 concentration (rich mixture) in the exhaust flow and the sensor provides a low voltage (20 – 50 mV) in the case a high O2 concentration (lean mixture).

They require high temperatures to function, starting at approx. 300°C, running optimally in a range between approx. 600°C and 900°C and could become damaged if exposed to temperatures at or above 900°C-1,000°C for prolonged periods (Fred Schäfer, 1995). Most have a heating element built in to ensure they reach operating temperature quickly. The signal uses at least two wires (one signal and one ground) while the heating element requires two wires as the conventional types are operated with a pulse width modulated signal (PWM). The higher the duty cycle of the PWM, the greater the heating capacity.

The signal from this sensor might be ignored by the engine management system in some situations. For example, on engine start since both it and, if fitted, a catalytic converter, will not be at running temperature and so the sensor signal will be incorrect. The sensor signal might also be ignored when at full throttle for maximum propulsion performance, in cases of acceleration enrichment, in converter over-temperature, and in knock protection modes, as in all these cases a rich mixture might be required.

R.2 Powertrain Control Unit (PCU)/Engine Control Unit (ECU)

The ECU can be one or multiple control boxes, containing digital or analogue electronics. It takes various inputs from components and sensors around the vehicle to provide the appropriate output for the actuators. A PCU contains the functionality of an ECU but also receives additional input from sensors to actuate the gearbox, clutch and/or torque converter.

In order to change the behaviour of the vehicle, changes can be made to the signals output from this unit. This outcome can be brought about in a variety of ways: change the inputs, change the part receiving the signal, change the internal calculations performed by the ECU.

- Change the inputs: the input source can be changed to a one with different characteristics, the source can be adjusted to generate different signal, the source can be disconnected, or the signal can be modified at some point along the connecting cabling. This makes the PCU/ECU 'think' that the vehicle is in a different situation as it will have been designed to match specific signal to known situations.

- Change the destination: the output recipient can be changed, the recipient can be adjusted, the output can be disconnected, or the signal can be modified along the connecting cabling. This will make the vehicle react differently to how the PCU/ECU intended.
- Change the calculations performed by the PCU/ECU: the circuitry can be modified physically, it can be deactivated, it can be removed, the program can be changed, it can be replaced in its entirety or it could be added to a vehicle that previously did not have one. Replacing or reprogramming the PCU/ECU allow differing reactions (output signals) for differing situations, allowing a fuller control than simply modifying signals, it also allows the removal of limits directly rather than tricking anything.

The PCU/ECU can control many areas of the vehicle depending on its complexity, but it cannot change the actual capabilities of the vehicle's main parts. That said, the vehicles actual capabilities may be restricted, either for safety or emissions or to protect other parts of the vehicle. For instance rather than balancing all of the parts within the drivetrain the engine speed could be electronically limited to limits of the weakest part, this allows stock parts to be used without the need for customisation, saving on manufacture costs.

All of these changes can be used to provide the same effect, be it with differing levels of complexity, reliability, cost and consequences. Therefore this section of the vehicle it can be analysed in a modular way with the respective S, E, N, O, or D combined in the appropriate way.

Appendix S Markings

S.1 Controlled parts database

For the systems and components controlled by the anti-tampering legislation, the type approval authorities already have to examine their performance, characteristics, 'interchangeability' etc. quite closely. It may, therefore, be possible for those authorities to enter data into a computerised database to identify the parts that are considered permissible for each make, model and variant of vehicle. This would need to include serial numbers and other markings but could also include photographs of critical areas of the vehicle. If the resulting database was made readily accessible to in-service enforcement authorities, it would be expected to make the job of identifying any tampering substantially easier and more reliable, which would tend to reduce enforcement costs, while making the results more effective.

In theory, aftermarket manufacturers of modifying components could apply to have their products added to the permissible list for specific vehicle models. Additionally, custom made components could be given a special mark and added also, when they are taken through the single vehicle approval process, for instance.

However, depending on the level of equipment enforcement agencies already use, the ability to access the database from inspection sites may require enforcement authorities to purchase new equipment or to increase mobile data usage. This would tend to increase the costs of enforcement.

S.2 Form of marking

In the current regulation, it stipulates that if the marking takes the form of a label it cannot be detached without being destroyed. This is in order to prevent the label being transferred to a non-approved replacement part. It does not however restrict the ability to remove the marking, so for instance a part marked as approved for another category could have its label removed and a counterfeit one put in its place.

Stakeholder information followed by a quick internet search showed that counterfeit labels were easy to obtain. Therefore, a non-approved part could have an 'approved' label attached to it.

The following are some possible solutions to the problems stated above.

- One solution would be to remove the exception to allow labels, staying instead with direct markings. However, there could be significant cost implications with manufacturers changing their systems.
- The shape of the label, and therefore the fixing holes could be different and specified for each likely grouping.
- The fixings and hole size could be specified, used together with shearbolts it might be noticeable if they are replaced.
- Together with the label containing full details, a very simple but indelible mark could still be required to be made on the part itself.

S.3 RFID

The performance critical parts themselves are currently required to be marked "durably and indelibly", using "number(s) and symbols assigned for identification purposes", with the letters "at least 2.5 mm in height and easily legible". However, although it is specified that the marking must be visible without dismantling the part, this does not apply for the vehicle itself.

To allow full, easy and automatic access and analysis of the data an electronic means could be utilised. This would allow a scanner to interrogate the vehicle, obtain the various codes for the parts and match them against the records in a database, for either that model or specific vehicle.

RFID tags transmit their stored information via radio. The simplest versions of these transmit the information as soon as they have gained enough power to do so, which they receive via induction from the equipment used to read the data.

S.3.1 Interference

Multiple RFID chips may be present, either intentionally on multiple components, in other unrelated products in or around the vehicle (for instance in shopping or a wallet), or intentionally placed to block the signal. RFID systems that can cope with multiple signals are more complex and expensive, however these are becoming more common and so the cost is reducing. Libraries uses them in books to allow quick borrowing of piles of books, and they have replaced barcodes or the throw away labels attached to airline luggage.

Interference from the metal structure and electrical systems of the vehicle may cause problems when reading the tags. And so a stronger signal is need from the RFID tags and power source.

S.3.2 Powered/Unpowered

Powered RFID chips can be smarter and have a stronger signal strength, but will require either a battery or connected to the vehicle's power. These provide a route for debris and water to enter and a battery would require replacing.

Smarter chips could be beneficial as they could transmit encrypted data, transmit only on receiving a key code, or contain sensors for transmitting other parameters such as if and when a cover had been opened.

S.3.3 Temperature

Temperature is a problem. Standard RFID tags have the same temperature ranges as standard electronics (approximately -40°C to +80°C). The solder from the microchip to the aerial will crack at low temperatures and melt at high temperatures, and the chip itself will degrade if held for a sustained period at high temperatures even within its rated temperature range.

High temperature 'ruggedized' RFID tags have been developed for the oil and gas industry, these have been rated to survive temperatures of around 300°C. Ruggedized RFID tags have a lot of padding and are therefore; quite large (10-30mm per side), heavy, and very high cost relative to standard tags which are practically throw-away. Engine parts can exceed these temperatures and a fearing may be needed to distance

the tag from the hot areas; adding extra weight, complexity, and interfere when building and maintenance.

S.3.4 Bypass methods

As the RFID tag is intended to replace the need to physically 'see' the marking it opens a few routes to spoof the reader. For instance:

- A programmable RFID tag with the original one's signal could be kept within the vehicle.
- A fake chip could be kept within the vehicle.
- The original RFID tag could be removed from the original part and kept within the vehicle.

Encryption could be used within the chip to make it difficult to copy the data itself, however the entire chip could still be professionally copied without the need to crack the code. It is an expensive process but the technology is available and once done is then inexpensive to duplicate the data.

The RFID could be hidden or designed to brake if removed as is specified by the current labels, however as physically seeing the RFID tag isn't required the whole part or the area surrounding the chip could be cut of and kept with the vehicle. As the tag could be placed anywhere within the vehicle appearance would not matter.

In addition, interference could be used to scramble the signal, products are available to carry with you to prevent passers-by from reading your RFID data from credit cards and passport surreptitiously. The difficulty of picking up a signal could leave the enforcement authorities to simply ignore that step in the vehicle check.

S.3.5 Privacy

As RFID tags can be read wirelessly from a distance of several meters (whether the RFID tag was designed with that range or not). This raises the concern that data could be extracted from a vehicle on the road without the rider's knowledge. Because of this, careful thought should be put into what data the chip should contain. It should also be noted that any encryption system used will be cracked at some point.

S.4 Contact Smart-card

To avoid the interference problems, a connector could be used access the data from the device rather than the "contactless" RFID system. This will suffer from the same problems as visible marking the parts as the contacts will need to be found, cleaned, and accessed. And also the same problems as RFID chips do in regards to high temperatures.

All of the chips could feed their data, via cables, to one place or into one connector for ease of access. This will add complexity to the vehicles wiring and provide a place where the signals can be interfered with.

S.5 On Board Diagnostic (OBD) system

Rather than having an additional system, the data could be stored in the PCU/ECU and be read via the standardised OBD connector.

As part of the changes to the type approval legislation, the requirement of an OBD system likely to be included for at least the larger L-category vehicles. This will use the same interface and communication protocol as M category vehicles for compatibility.

The ECU could be connected to the components either; wirelessly via RFID, with wiring, or a mix of the two. The signals from the parts could then be queried by the ECU and read via the OBD system. The ECU would have to have an RFID reader built in if they are used.

Annex 1

Motive Power

Definitions of ‘motive power’ assessment

Power measurement for the purpose of type approval and enforcement authorities

1 Summary

The intention of this document is to specify and define measures to quantify the 'motive power' produced by all L-category vehicles, regardless of the nature of their propulsion system(s).

- The primary objective of this assessment is to develop techniques and measures that allow different propulsion systems to be compared with respect to their power output.
- The secondary purpose of this approach is to provide a relationship between the power that can be measured in a laboratory environment, for example by a type approval authority, and the power that can be measured by an enforcement agency, either at the road side, or at a testing station or workshop.

The first of these objectives is intended to provide a harmonized approach to the assessment of L-category vehicle power measurement, irrespective of whether the vehicle is propelled by a hybrid, all electric or internal combustion engine (or any other type).

The second objective is intended to aid enforcement agencies (or road side inspection and road worthiness testing organisations) by providing an objective measure of a vehicle's power to help them ascertain whether it is compliant with the power the manufacturer demonstrated and declared during type-approval. Four options are presented along with their associated advantages and disadvantages.

The study as a whole will feed into the EC's (European Commission) process of updating and clarifying the legislation on L-category vehicles for the future. With that in mind, the options put forward are intended to clarify and simplify the legislation wherever practicable and to remove any ambiguities.

2 Background

Each L-category vehicle can be classified in different ways according to propulsion characteristics. These definitions are used to ascertain the performance capabilities and sometimes as a proxy for vehicle size (Appendix E).

L-category vehicles have their propulsion power measured in one of two ways; Net power for internal combustion engines (ICE or IC engines) or Maximum Continuous Rated Power (MCRP) for electric motors.

These are measured using essentially the same test; measure the steady-state power during a certain timeframe, as far as practicable, directly from the output shaft of the propulsion. However, there is one distinct difference; the method used to determine whether the measured value has stabilised. This is determined by stabilised power, rotational engine speed and the temperatures of the lubricant and cooling fluids (if applicable) when measuring IC engines and stabilised temperature when measuring electric motors.

2.1 Current methodology limitations

On the whole these measures are based on sound engineering principals. However, the following should be pointed out:

- **Net Power** allows the measurement to be performed with the transmission fitted. The losses from the transmission are subsequently removed from the result. This is done mathematically using 'fixed factors' to represent each part (i.e. gear or belt). However this overlooks the true losses which may deviate from the fixed factors depending on the quality of the components.
- **MCRP** is the equivalent test of Net power used for electric motors. Electric motors have the property to either run at one speed/load constantly (defined in IEC[44] 60034-1 article 4.2.1 as "Continuous running duty"), or run at substantially higher power for short periods (article 4.2.2 "Short-time duty"). This is dependent on the waste heat generated and the ability of the motor to cool. Therefore, the maximum power provided by the engine may, in some driving conditions, be greater than the MCRP.
- **New motive power source**: There are no requirements that can be applied to a new motive power source requiring an alternative power measurement methodology and as such, a manufacturer wishing to use an alternative power source may find it more difficult to gain approval. This potential difficulty could be eased if the manufacturer were to be permitted to select one of the current methods (listed above) or, if this would not be feasible, to use another, provided it can be demonstrated to be equivalent.

Unless specified otherwise, for the remainder of the chapter all references to the measurements the power measured at the output shaft of the motive unit will be referred to as Net Power, irrespective of the specific methodology used.

[44] International Electrotechnical Commission, URL:<http://www.iec.ch>

2.2 Engine power

An engine usually follows a predictable power verses engine speed curve. For an ICE (see Figure 2-1) the power increases with speed until an optimum speed is reached and then the power would decrease slightly before the engine reached its maximum speed, where the torque reaches a peak towards the lower end of the engine's speed range. ICEs have a minimum speed below which they stall and a procedure under no load is required to restart them.

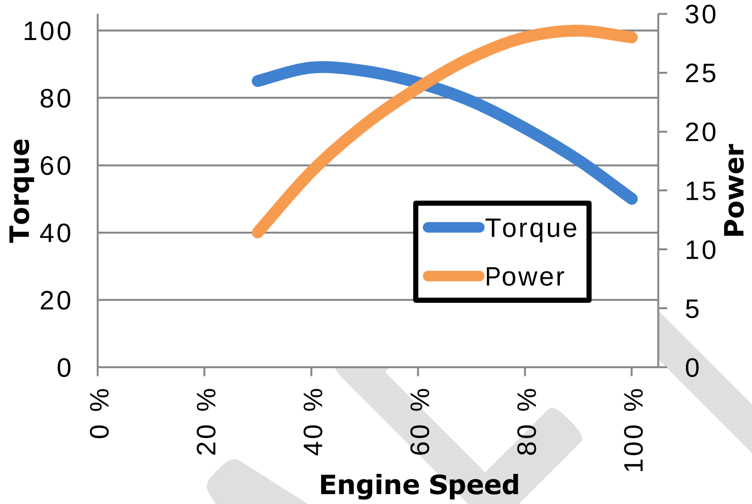


Figure 2-1: Torque and Power vs. Engine speed: Typical IC Engine

In traditional combustion engines, the maximum power can be found using a steady state test, as laid out in the relevant legislation or standard, running the engine at maximum load (full throttle) at a fixed speed and measuring the power. This is repeated at multiple engine speeds until the curve can be drawn and the maximum found.

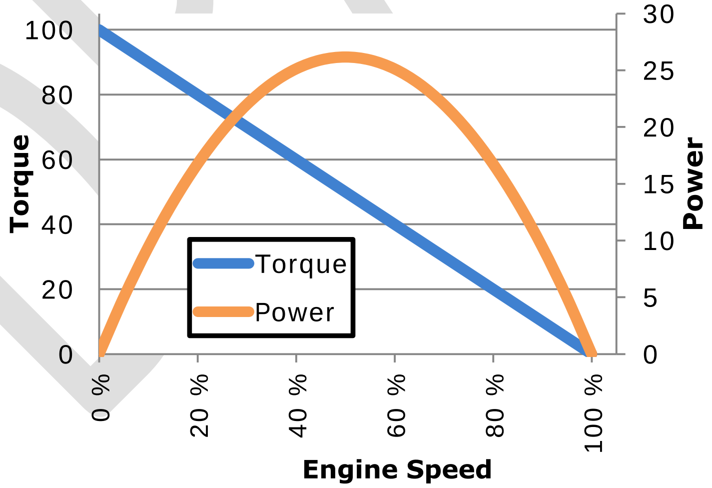


Figure 2-2: Torque and Power vs. Engine speed: Typical Electric Motor[45]

For some types of electric motor the highest torque is found at the lowest rotational speed (see Figure 2-2), decreasing with engine speed in a linear manner. They do not stall in the same manner as IC engines, simply stopping if the required torque is beyond its capabilities and starting again when this is reduced.

[45] http://www.ebikes.ca/simulator/

For electric motors the maximum power is not just a function of maximum torque and speed, but also of the amount of time that the power is required for. This is because the electrical components (the magnetic coils) are only able to tolerate a certain maximum temperature and this will build up over time when in use, this temperature can be below the speed where mechanical components (such as bearings) will experience problems, allowing a greater freedom in how the engine can be used. The IEC definition of MCRP (IEC 60034-1, 2004) is the maximum power with the motor in a state of thermal equilibrium. However, greater speeds, loads, and thus power can be achieved for short periods. The control systems of a vehicle can be designed to take this characteristic into account, with the greater short-term power likely to be utilised during acc.

A higher amount of power during acceleration is also of great use in hybrid vehicles, Figure 2-3 below shows how an electric engine (motor 2) could be used to supplement the vehicle's primary propulsion (motor 1) during acceleration in some configurations (see Appendix U.1).

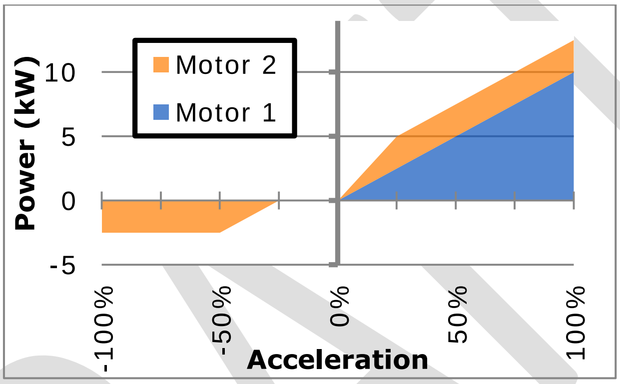


Figure 2-3: Utilisation of a characteristic of electric motors in acceleration

Figure 2-3 also shows how the electric motor can be used as generator during braking (see <0 power for motor 2, left in the picture). This generated power can be used to recharge the propulsion batteries when decelerating the vehicle.

2.3 Hybrid powertrain

The current legislation measures net power for combustion engines and MCRP for electric propulsion systems. Having multiple propulsion systems within a vehicle creates implications for the measurement of power. This is because the net power measurement is made for each propulsion system individually and thus does not account for the amount of power each is actually providing in different driving phases. Therefore, the net power is not necessarily representative of the maximum power that the combined propulsion systems are actually capable of delivering. In steady state conditions this could be considerably less than the sum of the component parts. The consequences of this are that:

- There is a potential risk that a hybrid vehicle could be classified in an inappropriately high power category at type approval if the motive sources are summed.
- Inversely there is a potential risk that a hybrid vehicle could be classified in an inappropriately low power category at type approval if the vehicle utilises short-time duty to boost power during acceleration.

- The current measurement of net power for hybrids is difficult to relate to the power delivered on the road, and makes comparison once in-use difficult.
- In addition, the ability of the propulsion system to provide increased power for limited periods of time is not accounted for.

This means that the measurement of net power could underestimate the level of power delivered in certain circumstances (for example in acceleration).

2.4 In-use testing of vehicles

Once a vehicle has entered use, it is no longer practical, and in some cases not possible, to measure the power of the motor separate from the drivetrain and chassis, as required by current type approval requirements. An alternative is to measure the power from the standard rotational power output of a vehicle, the wheel. The options for in-service testing are described in Table 2-1 below:

Table 2-1: In-use power measurement methods

Method	Advantages	Disadvantages
Net power measurement (current method)	Current measurement method Gives power per motive engine	Would require the vehicle to be dismantled. The engine(s), transmission, exhaust system and control electronics would need to be removed and placed in an engine dynamometer Not practical at roadside, a testing station or workshop and would have substantial cost and liability implications Does not provide a measurement of the combined power delivered on the road for a hybrid drivetrain
Modify vehicle to allow Net power to be measured with the engine(s) in situ (e.g. by providing access to a test shaft which can be accessed easily)	Could use a version based on the current measurement method Could give power per motive engine	Extra weight and mechanical complexity May not provide a measurement of the combined power delivered on the road for a hybrid drivetrain Design restrictions to ensure universal compatibility with dynamometer Would require the design

		and manufacture of specialised engine dynamometer
Require vehicle to be fitted with power measuring system	Could use a version based on the current measurement method Could give power per motive engine	Extra weight and mechanical/electronic complexity Extra cost to manufacture Significant development costs may be incurred to make to ensure such systems are sufficiently accurate and lightweight.
Measure power via wheel	Could use a version based on the current measurement method Could be used to measure mixed power in a hybrid drivetrain No modification to the vehicle design required No modification to the vehicle required Low cost to the manufacturer, user, and enforcement authorities	In order to obtain a result as found in the current measuring method, losses would need to be calculated/measured

2.4.1 The effect of vehicle configuration

Once the vehicle has entered use many variables can affect the measured power. These variables may not be harmful or intentional but their effect may be construed as the occurrence of intentional modifications. For instance, aftermarket tyres with a lower rolling resistance (then those originally sold with) would reduce power losses, whereas the extra mass of a rider or equipment such as panniers and luggage may increase the traction to the dynamometer.

Additional vehicle configurations could either be tested, estimated by calculation or be covered by best/worst case scenarios provided by the manufacturer when type approving a vehicle. Limits may need to be defined in order to decide if they are required.

3 Options

3.1 Net Power

Net power is a useful and appropriate measure for determining the power capabilities of individual propulsion sources, and can be used to allocate that vehicle to a particular size or class, which can be used to select its L-category vehicle category. If this measure were to be applied to hybrid vehicles, adding a requirement to measure the Net power of 'all' motive propulsion would offer benefits.

It can be foreseen that future alternative propulsive methods may not be compatible with the current testing methods. In this case, an alternative testing method equivalent or in addition to Net Power may be required.

3.2 Vehicle Power

A secondary measure would be required to determine the power capabilities of a whole vehicle to provide a measure of power which would be comparable to in-service tests of power. This measure would determine the real world capabilities (i.e. the power actually delivered in use), taking into account how the vehicle utilises power supplied by different propulsion systems and the effect of the drive train, mass and peripheral devices on power.

3.3 Power in Acceleration

The greater power produced in acceleration (as opposed to steady-state) is a valuable capability for some types of engine and hybridised drivetrains. If this capability is considered to have a significant impact on how the vehicle should be categorised, for example in relation to safety requirements, it would be important to measure this effect in both per engine and per vehicle configurations and have this reported during type-approval as "peak power".

Given these possibilities a number of options are proposed for the consideration of the Commission. These options detail distinct configurations of the choices available, partial adoptions of the options may be viable:

3.4 Option 1

- Retain current measurement methods for Net power
    - Make Net power tests compatible with hybrid and dual-fuel vehicles
    - Make Net power tests compatible with future alternative drives
- Do not add any other new tests

This could be achieved by measuring the net power delivered by each propulsion system according to the existing steady-state measurement of net power for spark and compression-ignition engines (Directive 95/1/EC) and electric engines (IEC 60034-1) independently.

A clause could be provided to permit an alternative propulsive method (not already included in a current testing method) to choose one of the current methods or, if this would not be feasible, use another method as long as it is deemed equivalent to Net Power by the testing authority.

Table 3-1: Advantages and Disadvantages of Option 1

Advantages	Disadvantages
It does not require any changes to the measurement of power and therefore may not increase test cost for manufacturers	The measurement of net power includes fixed factors of the power lost as a result of the transmission, which may mean that the estimate for the power delivered at the wheels could deviate from the calculated value depending on the actual efficiency of the transmission (see section 6.2)
	Will not provide a measurement of the combined power delivered on the road for a hybrid drivetrain
	The steady-state power will not be explicitly measured, making comparisons for the purpose of maintenance or in-use testing difficult
	The peak power will not be explicitly measured, making testing on a lower cost/porFigure dynamometer difficult
	There is a potential risk that a hybrid vehicle could be classified in an inappropriately high or low power category

3.5 Option 2

- Retain current measurement methods for Net power
  - Make Net power tests compatible with hybrid and dual-fuel vehicle
  - Make Net power tests compatible with future alternative drives
- Use a mathematical model to calculate the "Maximum Continuous Total Power" (MCTP) at the wheel, for steady-state behaviour
- Use a mathematical model to calculate the "Maximum Peak Total Power" (MPTP) at the wheel, for acceleration behaviour

The power delivered by each propulsion system could be measured according to the existing measurement of net power for spark and compression-ignition engines (Directive 95/1/EC) and electric engines (IEC 60034-1) independently, and using a steady-state measurement method.

A clause could be provided to permit an alternative propulsive method (not already included in a current testing method) to choose one of the current methods or, if this

would not be feasible, use another method as long as it is deemed equivalent to Net Power by the testing authority.

An estimate of the actual power delivered to the wheel of the "Maximum Continuous Total Power" (MCTP) and "Maximum Peak Total Power" (MPTP) could be calculated as the sum (in the proportions defined by the ECU and/or combination mechanisms, with due regard to power/torque/rpm limiters) of the measured values (found using the Net power, MCRP, and/or alternative test), minus all drivetrain losses (see Figure 3-1).

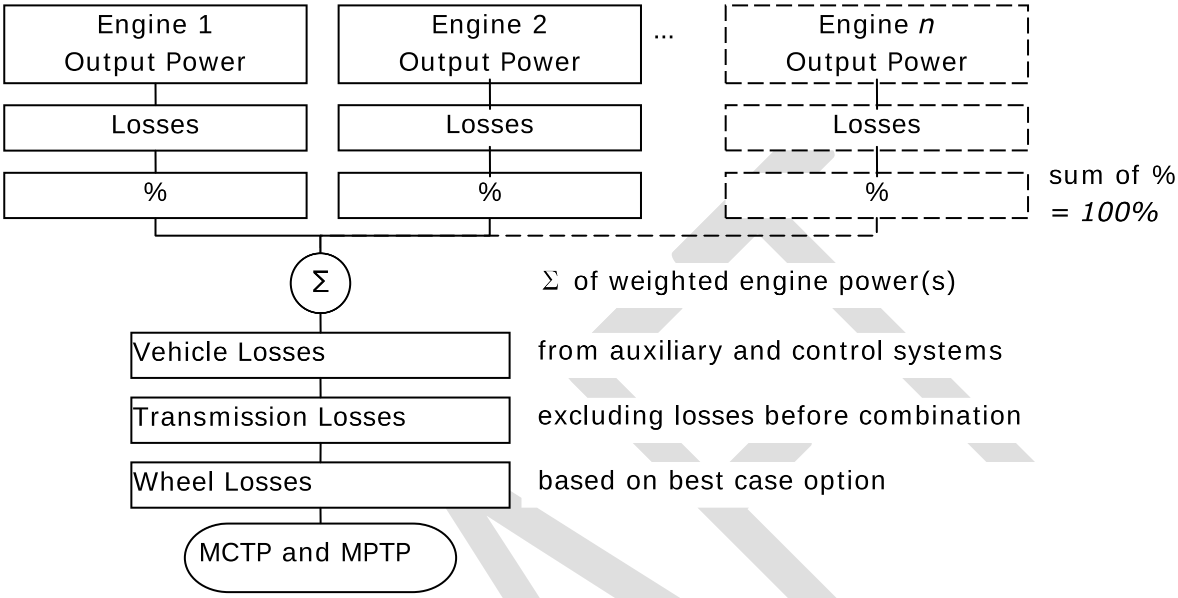


Figure 3-1: Flow diagram of MCTP and MPTP calculation

The calculation for MCTP should be performed multiple times, to generate values equivalent to Directive 95/1/EC such that the power curve for the vehicle is accurately characterised between 5-10 km/h and 130 km/h (or the vehicle's maximum speed, whichever is lower). This should be repeated for certain critical fuel or stored energy levels, appropriate gears, user selectable configuration and driving conditions which could generate different power levels.

For MPTP instead of using Net power and MCRP as the starting figures, values for a test of the propulsion sources accelerating should be used.

This new measure would be intended to estimate power at the wheel. It follows that in order to estimate this mathematically, all losses from the actual production vehicle must be taken into account, including auxiliary systems (such as lights, radio and heating if applicable, but these should be in a user selectable standby or off position) and control systems (such as alternator, generator or cooling system). It is proposed that values supplied by the manufacturer for the percentage of power lost could be used. In the case that the system utilises power from multiple engines in different driving phases, values supplied by the manufacturer for the percentage of power provided to the wheels at multiple charge states or fuel levels (see Table 4-1) could again be used.

Design of Experiments (DoE) or other intelligent selection methods could be utilised to limit the calculations needed to be performed and presented to the approval authority.

The losses for the wheel should be based on the rating from Regulation (EC) No 1222/2009, or, in the case of tyres not covered by this regulation, an equivalent

international standard. As mentioned in section 2.4.1, the lowest value should be used, i.e. the purchase option for the vehicle with the least rolling resistance.

Table 3-2: Advantages and Disadvantages of Option 2

Advantages	Disadvantages
It does not require any changes to the measurement of power and therefore may not increase test cost for manufacturers	The calculated measurement of MCTP will be an estimated, not a measured value; although if one configuration was verified, this would increase confidence in the estimates
It would provide an estimate for the power delivered at the wheels	The measurement of net power includes fixed factors of the power lost as a result of the transmission, which may mean that the estimate for the power delivered at the wheels could deviate from the calculated value depending on the actual efficiency of the transmission (see section 6.2)
It can be assumed that the majority of manufacturers will already perform similar calculations in the development of a vehicle	The calculations will need to be performed for every model and variant, rather than using a family approach of one test per engine as is done with the Net Power test (although intelligent experiment selection methods may limit this)
It would diminish the chance of hybrid vehicles from being classified in an inappropriately high or low power category at type approval	A new test of peak power will be required for IC engines, and electric motors will require the a short-time duty test to be performed (see section 6.1)

3.6 Option 3

- Retain current measurement methods for Net power
    - Make Net power tests compatible with hybrid and dual-fuel vehicle
    - Make Net power tests compatible with future alternative drives
- Measure MCTP at the wheel for steady-state behaviour
- Measure MPTP at the wheel for acceleration behaviour

The power delivered by each propulsion system could be measured according to the existing measurement of net power for spark and compression-ignition engines (Directive 95/1/EC) and electric engines (IEC 60034-1) independently, and using a steady-state measurement method.

Provide a clause for an alternative propulsive method, which is not already included in a current testing method, to choose one of the current methods or, if this would not be feasible, use another if it is deemed equivalent to Net Power by the testing authority.

The "Maximum Continuous Total Power" (MCTP) could be measured directly by placing the vehicle on a chassis dynamometer, and multiple iterations performed to generate

values equivalent to Directive 95/1/EC such that the power curve for the vehicle in a steady-state is accurately characterised between 5-10 km/h and 130 km/h (or the vehicle's maximum speed whichever is lower). This should be repeated for certain critical fuel or stored energy level, appropriate gears, user selectable configuration and driving conditions which could generate different power levels.

For "Maximum Peak Total Power" (MPTP) instead of using steady-state steps used in Directive 95/1/EC, critical acceleration rates with defined starting and ending speeds should be used, limited to the highest legal road speed in the EU (or advisory speed limit in the case of Germany). A testing programme is required to define these conditions, however accelerating from 0 km/h using WoT is likely to suffice for the majority of vehicle.

These tests would be carried out with all powered wheels providing drive, at multiple charge states or fuel levels (see Table 4-1) and including the losses from essential auxiliary systems, and including only those motors which provide drive to the wheels, i.e. excluding generators in series hybrids, starter motors, alternators, and pedals.

The tests could be performed by the manufacturer and the results declared to the approval authority. Design of Experiments (DoE) or other intelligent selection methods could be utilised to limit the physical tests needed to be performed. If the technical service was then required to choose one configuration at random to be independently verified it would give confidence in the results provided by the manufacturer broadly comparable to that achieved by independently testing all possible configurations.

Table 3-3: Advantages and Disadvantages of Option 3

Advantages	Disadvantages
The value for MCTP would be an objective and measured value which accurately reflects the power delivered to the wheels in use and includes actual power losses from the gearbox and other auxiliary systems	The tests will need to be performed for certain additional critical models and/or variants, rather than using a family approach as is done with the Net Power test (although intelligent experiment selection methods may limit this significantly)
The measurement is applicable to any propulsion system and therefore remains appropriate for the power measurement of hybrid drivetrains and future propulsion technologies	The MCTP measurement method requires a chassis dynamometer which can measure power in a steady-state engine operation condition. Some manufacturers (SMEs) may not already posses this, if they do not, and wish to perform the tests in-house, this could result in additional cost.
The power delivered at the wheels in a sweep test (MPTP) could, once in-use, be checked using an inexpensive and/or porFigure dynamometer	
It would prevent hybrid vehicles from being classified in an inappropriately high	

or low power category at type approval	
The MPTP measurement method can be performed on a simple chassis dynamometer which can measure power in a sweep or accelerating state, which most manufacturers are likely to already possess. If they do not, and wish to perform the tests in-house, this could result in additional cost.	

3.7 Option 4

- No longer measure Net power for individual motors
- Measure MCTP at the wheel for steady-state behaviour
- Measure MPTP at the wheel for acceleration behaviour

As Option 3, however the measurement of MCTP and MPTP fully replaces the existing measurement of Net power, thus minimising any additional cost burden.

Table 3-4: Advantages and Disadvantages of Option 4

Advantages	Disadvantages
The value for MTVP would be an objective and measured value which accurately reflects the power delivered to the wheels in use and includes actual power losses from the gearbox and other auxiliary systems	It involves a test additional to the established measurement method for power, which may require consequent amendments to the power limits for vehicle categorisation (COM 542 (2010), Annex 1) and potentially other legislative texts
The measurement is applicable to any propulsion system and therefore remains appropriate for the power measurement of hybrid drivetrains and future propulsion technologies	The tests will need to be performed for every model and variant, rather than using a family approach as is done with the Net Power test
The power delivered at the wheels in a sweep test (MPTP) could, once in-use, be checked using an inexpensive and/or porFigure dynamometer	The test would fully replace the established measurement method for power and this represents a significant methodological change.
Potentially a lower cost option than Option 3	Information for finding the root cause of power related engine problems would not be recorded
It would prevent hybrid vehicles from being classified in an inappropriate power category at type approval	The MCTP measurement method requires a chassis dynamometer which can measure power in a steady-state engine operation condition. Some manufacturers may not already

	posses this, if they do not, and wish to perform the tests in-house, this could result in additional cost.
The MPTP measurement method can be performed on a simple chassis dynamometer which can measure power in a sweep or accelerating state, which most manufacturers are likely to already possess. If they do not, and wish to perform the tests in-house, this could result in additional cost.	

The "Maximum Continuous Total Power" (MCTP) could be measured directly by placing the vehicle on a chassis dynamometer, and multiple iterations performed to generate values equivalent to Directive 95/1/EC such that the power curve for the vehicle in a steady-state is accurately characterised between idle (or the lowest possible rotational speed where motive power can be supplied, without causing the propulsion source to stall or stop) and maximum engine speed of all engines. This should be repeated for certain critical fuel or stored energy levels and user selectable configuration which could generate different power levels.

For "Maximum Peak Total Power" (MPTP) instead of using steady-state steps used in Directive 95/1/EC various acceleration rates with varying starting and ending speeds should be used, limited to the highest legal road speed in the EU (or advisory speed limit in the case of Germany).

This test would be carried out with all powered wheels providing drive, any identified critical charge state or fuel level (see Table 4-1) and including the losses from essential auxiliary systems, and including only those motive propulsion sources which provide drive to the wheels, i.e. excluding generators in series hybrids, starter motors, alternators, and pedals (see Appendix U.2).

The tests could be performed by the manufacturer and the results declared to the approval authority. Design of Experiments (DoE) or other intelligent selection methods could be utilised to limit the physical tests needed to be performed. If the technical service was then required to choose one configuration to be independently verified it would give confidence in the results provided by the manufacturer broadly comparable to that achieved by independently testing all possible configurations.

4 Definitions

This study has identified four possible options for changes to the legislated measures for vehicle power. Three of the options contain the "Maximum Continuous Total Power" (MCTP) and "Maximum Peak Total Power" (MPTP), to ascertain the maximum possible power which as vehicle can physically use for motive propulsion in the majority of situations.

4.1 Definition of Maximum Continuous Total Power

Maximum Continuous Total Power (MCTP) could be defined as "*the greatest motive power output which can be maintained over a time period*[46]*, with all energy storage systems and driver activated controls adjusted, such that the maximum power permitted by the propulsion system design will be achieved. The manufacturer shall measure and declare this to the type approval authority as the power limit of the vehicle's propulsion capability*".

Table 4-1: Explanation of text in definition of MCTP

Text	Explanation
the greatest motive power output…	The definition is intended to be used as a division for category classification and to be used to detect changes once in use
which can be maintained over a time period…	This refers to the "continuous" term in the title and relates to the methodology in Directive 95/1/EC Annex 2, Appendix 1, Section 3.3.4-3.3.7: 3.3.4. No measurement is taken until the torque, rate of rotation and temperatures have remained substantially constant for at least 30 seconds. 3.3.5. Once a rate of rotation has been selected to the measurements its value must not vary by more than ± 2 %. 3.3.6. The brake load and the temperature of the induction air must be recorded simultaneously and the value obtained must be the average of the two stabilized records taken in succession, which must not differ by more than 2 % as regards the brake load. 3.3.7. Where an automatically triggered device is used to measure rotational speed and consumption the measurement must last for at least 10 s and if the measuring device is manually controlled that period must be at least 20 s.

Hybrid vehicles are defined in the draft proposal; Com(2010) 542 final, Chapter 1, Article 3, Paragraph 24

with all energy storage systems and…	This relates to the fact that the amount of energy which can be delivered from some energy storage systems may differ depending on its level. Three levels of; minimum, mid, and maximum are suggested. This is because the maximum motive power may not necessarily be delivered when the storage systems are full, but could be dependent on; its temperature, the current demand, and with a hybrid drivetrain if one motive propulsion source's energy storage system is empty then another propulsion source may increase its power output.
driver activated controls adjusted, such that the maximum power permitted by the propulsion system design will be achieved…	This relates to two areas; Firstly, non-essential auxiliary devices should be places in an off or stand-by mode, to reduce their drain to the lowest amount. They should not be physically deactivated by removal or disconnection of fuses. These devices include but are not limited to; lights, radio, air conditioning, cigarette lighters, electric heaters and other peripherals using a 12V auxiliary power outlet. Secondly, all engine maps and traction control options which are selectable by the user should be included in the testing. This would include wording which specifically includes any hidden and test programs.
The manufacturer shall measure…	For option 3 and 4 this will be require the term "measure", for option 2 this will require the term "calculate"
and declare this to the type approval authority as the power limit of the vehicle's propulsion capability	This is standard text used in the current legislation

The definition requires only one value to be found, however in order to prove to the type approval authority that this value is the correct one, multiple tests or calculations may be required. Design of Experiments (DoE) or other intelligent selection methods could be utilised to limit the physical tests or calculations which need to be performed.

4.2 Definition of Maximum Peak Total Power

This definition of the "peak" power will be similar in every way except for the first removal of the words "maintained over a time period" to "repeatedly attained" and the following sentence "with the acceleration rate, initial and final speeds selected". Therefore:

Maximum Peak Vehicle Power (MPTP) could be defined as "*The greatest motive power output which can be repeatedly attained, with all energy storage systems and driver activated controls adjusted, and with the acceleration rate, initial and final speeds selected, such that the maximum power permitted by the propulsion system design will*

be achieved. The manufacturer shall measure and declare this to the type approval authority as the power limit of the vehicle's propulsion capability".

Table 4-2: Explanation of text in definition of MPTP

Text	Explanation
...which can be repeatedly attained...	This relates to the test to find the maximum speed during accelerations, not steady-state as in the "continuous" test. Repeated relates to the need to find design characteristics, such as; propulsion systems exceeding performing Short-time or Intermittent periodic duty modes (see IEC 60034-1 article 4.2.2 and 4.2.3), hybrid vehicles applying auxiliary engines, IC engines with turbo(s), compressor(s), or advanced ways to increase the charge air and fuel while under the thermal limit and not exceeding the knocking combustion limits. While preventing the inclusion of anomalies experienced during testing
...and with the acceleration rate, initial and final speeds selected...	Relates to the fact that the situations detailed above may be only evident under very specific situations

5 Conclusions: Maximum Continuous Total Power (MCTP)

The aim of these options are to provide a measure of vehicle power at type approval which can be applied to a range of propulsion systems (including hybrids) and which will represent the power delivered in use. This approach, as well as clarifying the categorisation of L-category vehicles according to their power in use, has potential advantages for enforcement and type-approval authorities.

Motive power could be applied and measured in a number of different ways.

- **Option 1 – Do not estimate or measure total motive power, expand net power measurements for alternative drivetrains**. Measure the net power delivered by each propulsion system according to the existing measurement of net power for spark and compression-ignition engines (Directive 95/1/EC), electric engines (IEC 60034-1) or another equivalent measure independently.
- **Option 2 – Estimate the power at the wheels using manufacturer data *in addition* to net power.** Retain measurement of net power delivered by each propulsion system according to the existing measurement of net power for spark and compression-ignition engines (Directive 95/1/EC), electric engines (IEC 60034-1) or another equivalent measure independently. In addition, use manufacturer information to estimate (using a mathematical model) the power provided to the wheels, in both peak and continuous states.
- **Option 3 – Measure power at the wheels *in addition* to net power**. Retain measurement of net power delivered by each propulsion system according to the existing measurement of net power for spark and compression-ignition engines (Directive 95/1/EC), electric engines (IEC 60034-1) or another equivalent measure independently. In addition, measure the power provided to the wheels on a chassis dynamometer such that the power curve is accurately characterised between idle and maximum engine speed.
- **Option 4 – Measure power at the wheels *instead* of the measurement of net power**

The Options get progressively more stringent from 1 to 3, but also progressively more costly. However, the progressive nature would allow them to be phased in over time, this could perhaps be done in line with the requirements to increase Euro emission levels. Option 4 reduces cost compared to option 3, but also means that information on individual power sources would no longer be collected. This option should only be considered if the availability of that data is considered less important than the total vehicle power and the test cost.

For each of the options, adding a measurement of power under acceleration might enable the vehicles to be better categorised according to risk and also to allow better identification of harmful tampering in-service. Furthermore, in each case, the conditions under which MCTP and MPTP ('continuous' steady-state and 'peak' under acceleration) was achieved, as well as the propulsion configuration, could be recorded and marked on the vehicle identification plate (along with fuel levels if applicable, user selectable engine map if applicable, wheel speed, and gear), or using another appropriate method. This information could then be used in roadside checks to provide an indication of the MPTP. If this measurement was outside acceptable tolerances (as yet undefined), then the

vehicle could be referred by the test authority for more accurate determination of the MPTP and/or the MCTP at a suitably equipped testing station.

6 Further work

6.1 Test methodologies

After reviewing UNECE, EC, and CEN regulations, directives, and standards an appropriate measure for MCRP could not be found. Nor is there one related to testing power at the wheel, or obtaining peak power from a sweep test.

Therefore, it would be appropriate to make amendments to Directive 95/1/EC or other appropriate European or international legislation, to:

- Transpose from IEC 60034-1 (2004), section 4.2.1, "Duty type S1 – Continuous running duty" to represent MCRP (for measuring a single electric motor)
  - *Required for option 1-3*
- Design and add a test for MCTP (Maximum continuous total power). This can be based on a combination of Directive 95/1/EC Annex 2 (for the measurement and testing strategy) and 97/24/EC Chapter 5 Annex 1, Sub-appendix 4 & Annex 2, Sub-appendix 4.
  - *Required for option 3-4*
- Design and add a test for MPTP (Maximum peak total power), this should have due regard to both chassis dynamometers allowable for the emission and MCTP tests, and also simple and low end dynamometers usable outside of laboratory conditions, and subsequently appropriate levels of allowable accuracy depending on the circumstances
  - *Required for option 3-4*
- Transpose from IEC 60034-1 (2004), section 4.2.2 or 4.2.3 "Duty type S2 – Short-time duty" or "Duty type S3 – Intermittent periodic duty", to be used when calculating peak power for a single electric motor.
  - *Required for option 2*

The testing methods designed or adapted must cover; two, three, and four wheeled vehicles, as well as one, two, and four wheel drive vehicles. Special considerations should be made for vehicles which include rider actuated pedals. To ensure test repeatability and reproducibility, an external motor could be used as a proxy for the power they provide.

6.2 Fixed factors

Due to the wide range of types and quality of components over the entire L-category, the fixed factors used to subtract the transmission in the Net power test may no longer be suiFigure. There has been anecdotal evidence from various stakeholders to suggest that fixed factors may not be suiFigure in the primary L3e category either.

For option 2 (see section 3.5) fixed factors may be required for the entire drivetrain which could exacerbate the problem, if such a problem does in fact exist.

Given current dynamometer technology, the fixed factors could, in some cases, be replaced with a roll down test.

6.3 Back pressure

When performing dynamometer testing during type-approval an environmentally controlled cell is used and the exhaust gasses are captured and extracted via a hose to be safely vented. In some cases, a special exhaust routing is required to fit the engine and exhaust in to the engine dynamometer, possibly changing the backpressure. This may impact on the naturally developed propulsion performance, power and emissions.

As the results of MCTP and/or MPTP are to be comparable with in-use testing, which may be performed outside and therefore not requiring extraction, these effects may need to be quantified.

6.4 Tyre efficiency

Values for efficiency, losses and/or rolling resistance of tyres are required when calculation MCTP and MPTP in option 2, and could also be used to adjust the results from option 3 and 4 once in-use if after market tyres are fitted. To do this the appropriate directives, regulations or standards need to be referenced, and if there is not an appropriate document available, the design of a new standard may be required.

The dynamometer's roller diameter and configuration may affect the rolling resistance, therefore this difference may need to be quantified for the various types of dynamometer used in both type-approval and in-use testing.

Appendix T Terminology and definitions

T.1 Current terminology and definitions

The terminology and names used to describe 'power' have distinct meanings behind them related to what they measure and the testing methods used.

- Engine capacity (for internal combustion engines only)
    - The total swept volume of all cylinders
    - No defined test, equal to area of engine bore x sweep x number of cylinders
    - Rotary engines are defined in the EC as having an equivalent capacity of double the swept volume
- Maximum net power (currently "other" internal combustion engines only)
    - Test methodology contained in Directive 95/1/EC
    - "Net" implies measuring directly at the output shaft;
    - Measuring a single engine;
    - The test is for the engine only and as such all losses, such as drain from an alternator or generator, are excluded unless they are required to keep the engine running, such as powering the spark coils, but not necessarily running the coolant pump
    - The test allows the exception of measuring the power with the transmission fitted, however the losses from this are removed mathematically using fixed factors
- Maximum continuous rated power (for electric motors only)
    - Test methodology contained in IEC 60034-1, section 4.2.1
    - This is measured at the output shaft as with "Net" power
    - Measuring a single engine
    - "Continuous" "Operation at a constant load maintained for sufficient time to allow the machine to reach thermal equilibrium" which can mean many minutes depending on the size of motor
    - "Rated" is showing that this measure is for the engine as a separate device not as configured for use in one situation

T.2 New terminology and definitions

In the draft proposal, the term Maximum Continuous Rated Power (MCRP) was initially used against the measures of engine power. However the term has been adapted to better represent power from all motive power sources, leaving the Net power and MCRP as their original meanings.

Table 6-1: Required feature of the power measurement test

Features required	Feature	Term
Level of power	The greatest level that can be generated in any situation	Maximum
Type of test to perform	Steady state test on a chassis dynamometer OR sweep test performed while accelerating	Continuous or Peak
Which engines are involved	All power sources	Total
Configuration of the engines	As fitted to the vehicle	Vehicle
Where the measurement should be taken from	As it would transfer this power into a motive force	Wheel
What is being measures	As defined by SI	Power

Combining these parameters in a single term gives the "Maximum Continuous/Peak Total Vehicle Power to the wheel(s)", and whether it is a steady-state test or under acceleration changing the term Continuous or Peak.

To make the term less unwieldy it could be shortened to "Maximum Continuous/Peak Total Power", "Maximum Continuous/Peak Total Power to the wheel(s)", or MCTP. The following are examples of possible terms:

- Maximum Continuous Total Power
- Maximum Continuous Total Power to the wheel(s)
- MCTP
- MCTP to the wheel(s)
- Maximum Peak Total Power
- Maximum Peak Total Power to the wheel(s)
- MPTP
- MPTP to the wheel(s)

Appendix U Vehicle configurations

U.1 Hybrid

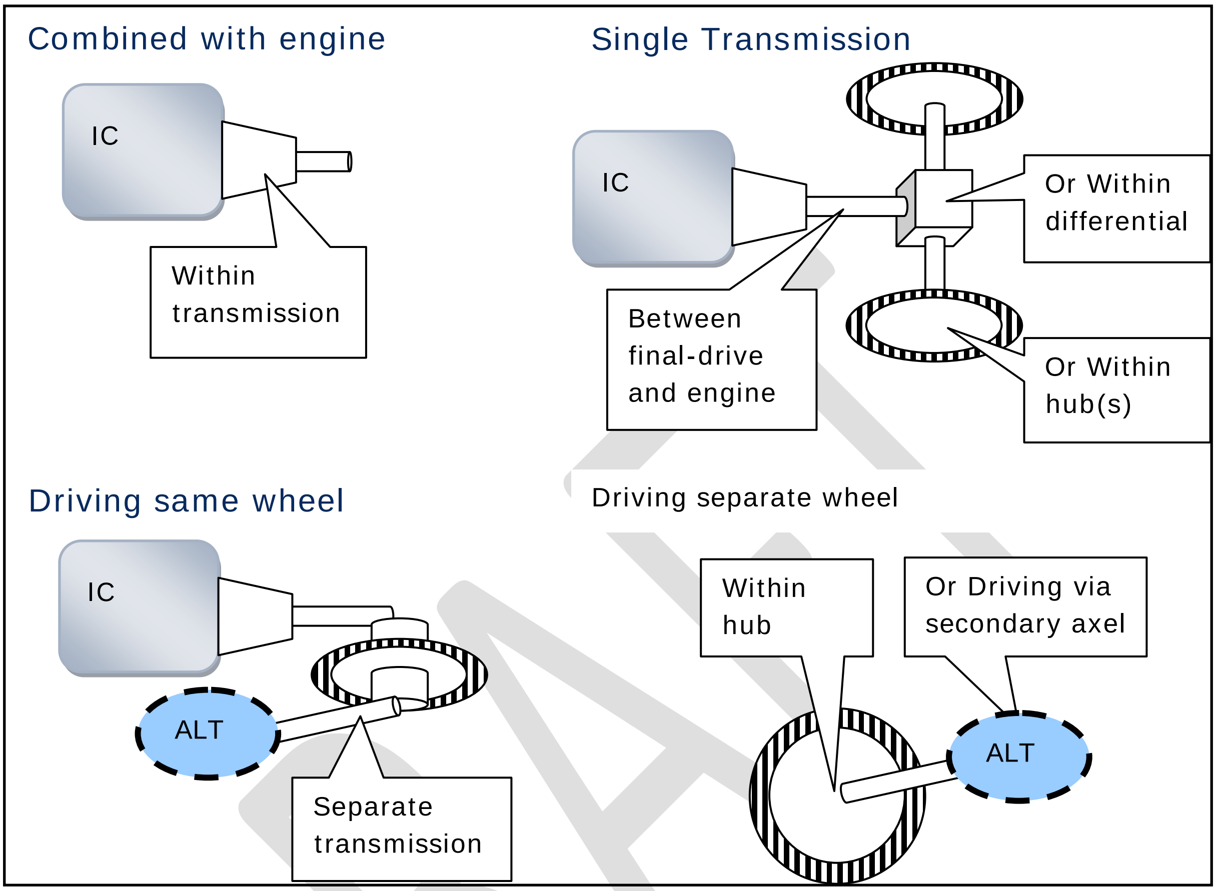


Figure 6-1: Some possible locations of auxiliary propulsion in a Hybrid vehicle

Types of The alternative motor could be electric, flywheel, compressed air could also work in these configurations.

It should be noted that only propulsion which provide motive power to the road are considered to be relevant to these measures. Therefore, generators used in serial hybrids, alternators and starter motors are not considered.

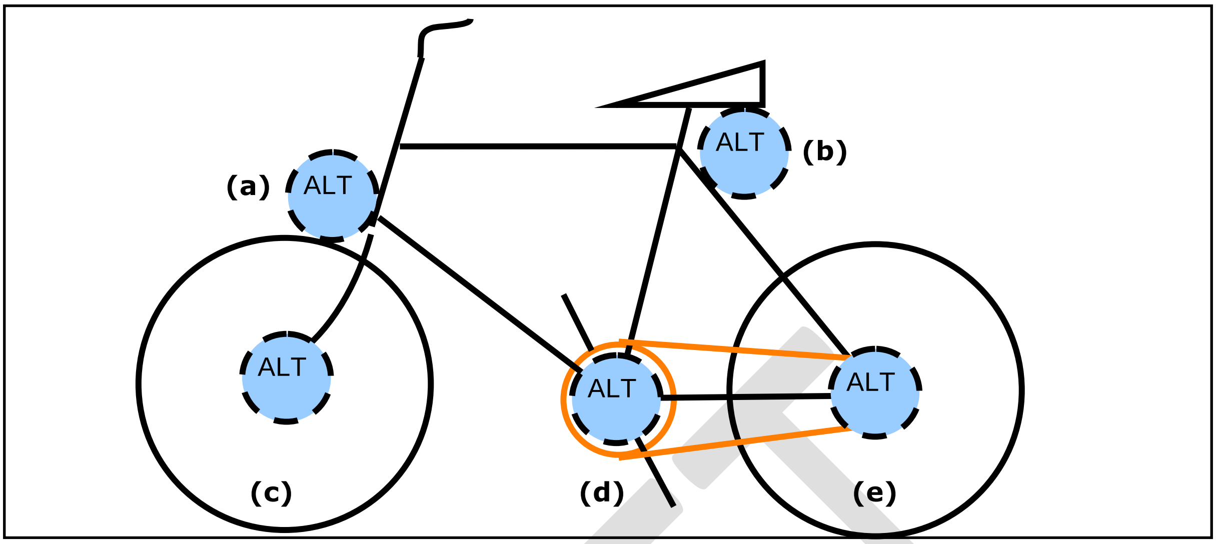
U.2 L1Ae - Bicycle with auxiliary propulsive source

When considering the power from all motive power sources, the L1Ae is a special case. These can have pedals coupled with an auxiliary motive power source. In this special case, the power from a rider pedalling must be excluded.

Also, under the definition for MCTP and MPTP, the entire drivetrain between the motive power source and the road surface (or dynamometer roller) is included in the losses. This will only include the transition used by the rider (chain, gears, and derailleur) if the motive power source utilises them as well. Figure 6-2 details some of the main locations for the auxiliary propulsion source in an L1Ae vehicle.

As an L1Ae vehicle will need pedals to be actuated in order to activate the motive power source, the power from this will need to be ascertained, in order to subtract it from the

total results. The losses from the drive train used by the rider should only be removed up to, and not including, the point where the power sources combine.



a) Above front wheel, using direct traction to front tyre (obsolete)

b) Above rear wheel, using direct traction or chain drive to rear wheel (obsolete)

c) Within front hub

d) Within or near the bottom bracket

e) Within rear hub

Figure 6-2: Locations for auxiliary propulsion in L1Ae vehicles

Annex 2

Electric Vehicles

Note: Additional testing on a range of electric vehicles, including power assisted bicycles, mopeds and motorcycles, was performed. This is presented in this supplementary annex to the main report.

Abstract

Evidence from previous research and limited testing on electric bicycles carried out in addition to the main test programme, suggests that tampering to de-restrict the motor should be covered by the same protection afforded to conventional engines by the anti-tampering legislation. An assessment using engineering expertise was performed; however without extensive test data, the effects could not be analysed and integrated into this report owing to timing and budget constraints and very few specific areas of the vehicle systems could be assessed. Nevertheless, manufacturers should take appropriate steps to prevent of the motor being derestricted and the anti-tampering legislation could be revised to include this aspect.

1 Introduction

Previous studies focussed on investigating tampering on L-category vehicles, for example Dittmar *et al.* (2003), Robinson *et al.* (2009), have highlighted that machines with an electric propulsion system may be susceptible to tampering in new ways compared to those vehicles with more traditional propulsion systems. Vehicles with electric propulsion are predicted to increase in popularity in the future. Therefore, it is considered appropriate that any options for the type approval requirements with respect to anti-tampering should also consider those vehicles with electric propulsion systems.

Although they are becoming most popular in the lower weight L1e category (power assisted bicycles and mopeds), there are electric and hybrid vehicles throughout the full L-category vehicle range. This includes high performance motorcycles and quadrimobiles (light and small car-like 4-wheel vehicles). That said, it is the smaller, performance-restricted types which will be concentrated on in this annex, because (as with ICE propulsion) vehicles of this type are the main focus of the anti-tampering legislation because these are the vehicles which are not designed for high speed use.

The main concern regarding tampered electric vehicles is that the maximum vehicle speed and/or power will be increased above the level that the safety critical parts are designed for, specifically the chassis, lights and brakes. In addition to this, by increasing the performance of the vehicle it may be classified in a different category, thereby becoming subject to different road legislation related to rider age limits and cycle path use.

1.1 Rider overall aims for modification

The reasons for modifying an electric vehicle are similar but not precisely the same as for conventional propulsion vehicles (see section 4.1.1). The following list shows possible vehicle performance and characteristic reasons for performing modifications:

1. Increase powertrain performance
    a. Increase maximum vehicle speed;
    b. Increase power as prerequisite to achieve greater vehicle speed;
    c. Increase maximum torque as prerequisite for faster acceleration;
    d. Mass reduction in order to benefit from effects of increased power/mass ratio;
2. Improve carrying ability and hill climb

Due to the characteristics of electric vehicles, an increase in noise is unlikely to be achievable. Similarly, electric vehicles do not have the same issue with tuning the air/fuel ratio, and without replacing the motor, tampering is unlikely to provide improved economy (reduced electricity use).

The final item is especially significant because a high proportion of the electric fleet are non L-category, power assisted bicycles, which are limited to 250 W. It is mentioned on internet forums that some of these vehicles do not perform well on inclines.

In addition to the cost savings of feigning a different category to avoid tax and insurance requirements, tampering with a bicycle could be done to allow continued use on cycle

paths, while effectively having a vehicle with the performance of a motorcycle, avoiding using a helmet, and bypassing the requirement to display a number plate.

1.2 Emissions and noise

One of the aims of this project as a whole was to add a greater emphasis on harmful emissions within the anti-tampering legislation, concerning both noise and gaseous emissions. For emission of pollutants, and although these vehicles output little or no emissions at the point of use, the effect that tampering had on energy efficiency proved difficult to measure and define and has therefore only been considered in a limited manner.

When considering noise, the majority of the responsibility has now been moved to the updated UN regulations, which in terms to tampering is primarily concerned with exhausts and engine noise. This is arguably not a concern even for large high powered electric vehicles (though it is still for hybrid vehicles). I.e. The increased noise solely from increased vehicle speed caused by tampering is unlikely exceed the limits set for conventional engine vehicles.

1.3 Overview of the market

TRL reviewed internet and other sources to determine the types of electric vehicle and tampering modes which might have harmful effects on safety or the environment. This highlighted that the main topic of information on the internet specifically related to l-category vehicles and their like concerned power-assisted bicycles (sometimes referred to as pedelecs) and so called "e-bikes". The former is where an electrical motor (with a maximum MCRP of 250 W) supplements pedalling by the rider up to 25 km/h and the latter are cycles equipped with a motor of greater power where the main propulsion is provided by the electric motor.

Power assisted bicycles are currently exempt from the type approval requirements of EU Directive 2002/24/EC and 97/24/EC and are instead covered by the Machineries Directive 2006/42/EC. The 250W limit is based on the approximate maximum power level that can be achieved by a typical rider through pedalling. Note: Although the L-category legislation is being updated (i.e. the codecision act that this research will feed into), at the time of writing, the 250 W and 25 km/h limit remained unchanged.

In addition to whole vehicle, there are also numerous examples of aftermarket kits that add an electric motor to the bicycle. Many of these kits result in high power being added to the cycle, reportedly enabling the rider to reach speeds in excess of 120km/h[47,48].Such kits are widely available on the internet and in some cases involve motors of up to 2kW[49,50]. The safety of the rider and other road users is undoubtedly affected by creating

[49]YouTube. CYCLONE Taiwan e-bike. Genuine Speed 120km/h (75 mile/h). Retrieved July 2012, from http://www.youtube.com/watch?v=Y6o-g7YeC4Q

[48]Cyclone e Bikes. Retrieved July 2012, from http://www.cyclone-tw.com/

[49]1000 W 48 V Electric Bicycle Bike Hub Conversion Kit. Retrieved July 2012, from http://www.ebay.co.uk/itm/1000-W-48-V-Electric-Bicycle-Bike-Hub-Conversion-Kit-/390312539360?pt=Cycling_Parts_Accessories&hash=item5ae070b4e0

a vehicle which can travel near-silently at high speeds which has totally inadequate braking, steering, markings and protection systems for this level of performance.

[50] Ebay search: electric bike conversion kit. Retrieved July 2012, from http://www.ebay.co.uk/sch/i.html?_nkw=electric+bike+conversion+kit&_frs=1&_trksid=p3286.c0.m359

2 Engineering theory

Electric vehicles are more suited to being analysed from an electrical engineering standpoint than the traditional mechanical-based skills of automotive engineering.

In an extremely simple configuration, the power to the motor could go directly via a potentiometer (like a dimmer switch); however, this simple method is bad practice since it is wasteful of energy and requires the main power to the motor to be fed around the vehicle. Instead, it is common practice to use a motor controller to better manage the flow of power from the battery to the motor, using signal from various sensors and controls to determine the correct amount.

From an electrical point of view, the main parts under consideration are the shown below and also as a schematic in Figure 2-1 indicating their likely configuration:

- Throttle, which could be:
    - Manual: Potentiometer or Optical
    - Automatic: Sensing pedal force or derived from the motor behaviour
- Speed sensor, which could be:
    - A separate device
    - Derived from the motor behaviour
- Battery
- Motor controller (in some ways comparable to an IC engine's ECU)
- Motor

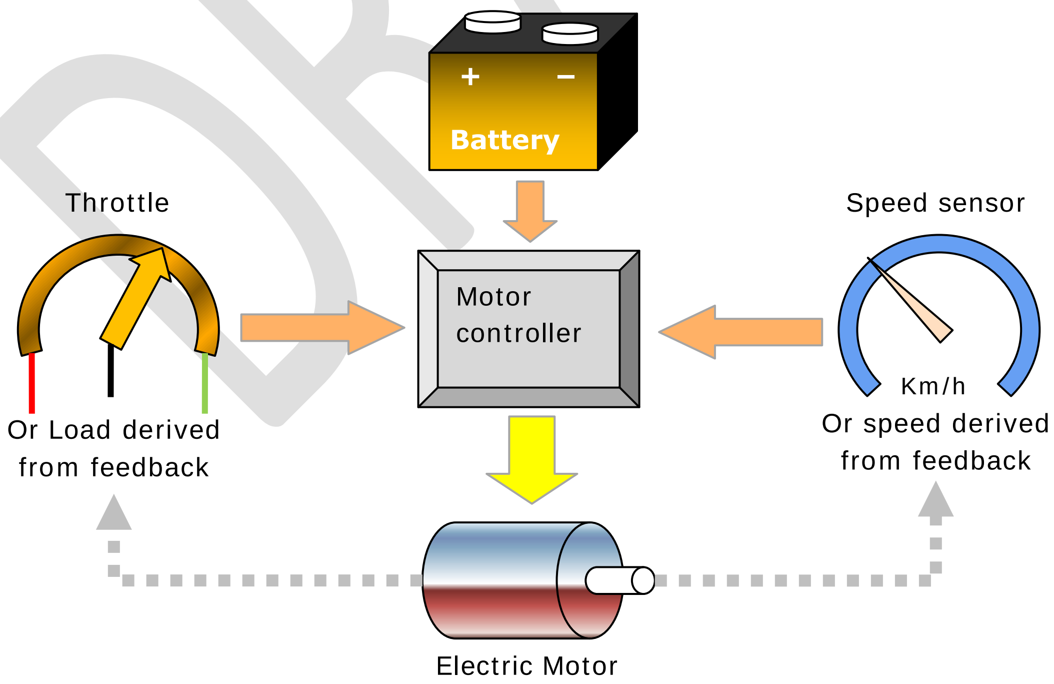


Figure 2-1: Simple schematic of electric vehicle

Vehicles may be power and speed restricted in one of two ways; through digital or analogue limits built into the motor controller, or through the physical performance characteristics of one or more of the components. As shown in the study on conventional vehicles, it is highly likely that the limit is created at least in part by the first method, which is simply due to the reduced manufacturing costs and complexity of using off the shelf parts. These parts may be above specification in one area in order to achieve other requirements. A good example of this is the motor itself: a high rated motor run below its maximum speed and load may allow better durability and heat management compared to one required to run at its limit.

2.1 Areas susceptible to tampering

Using the simple schematic (see Figure 2-1) the locations and methods of possible tampering can be identified.

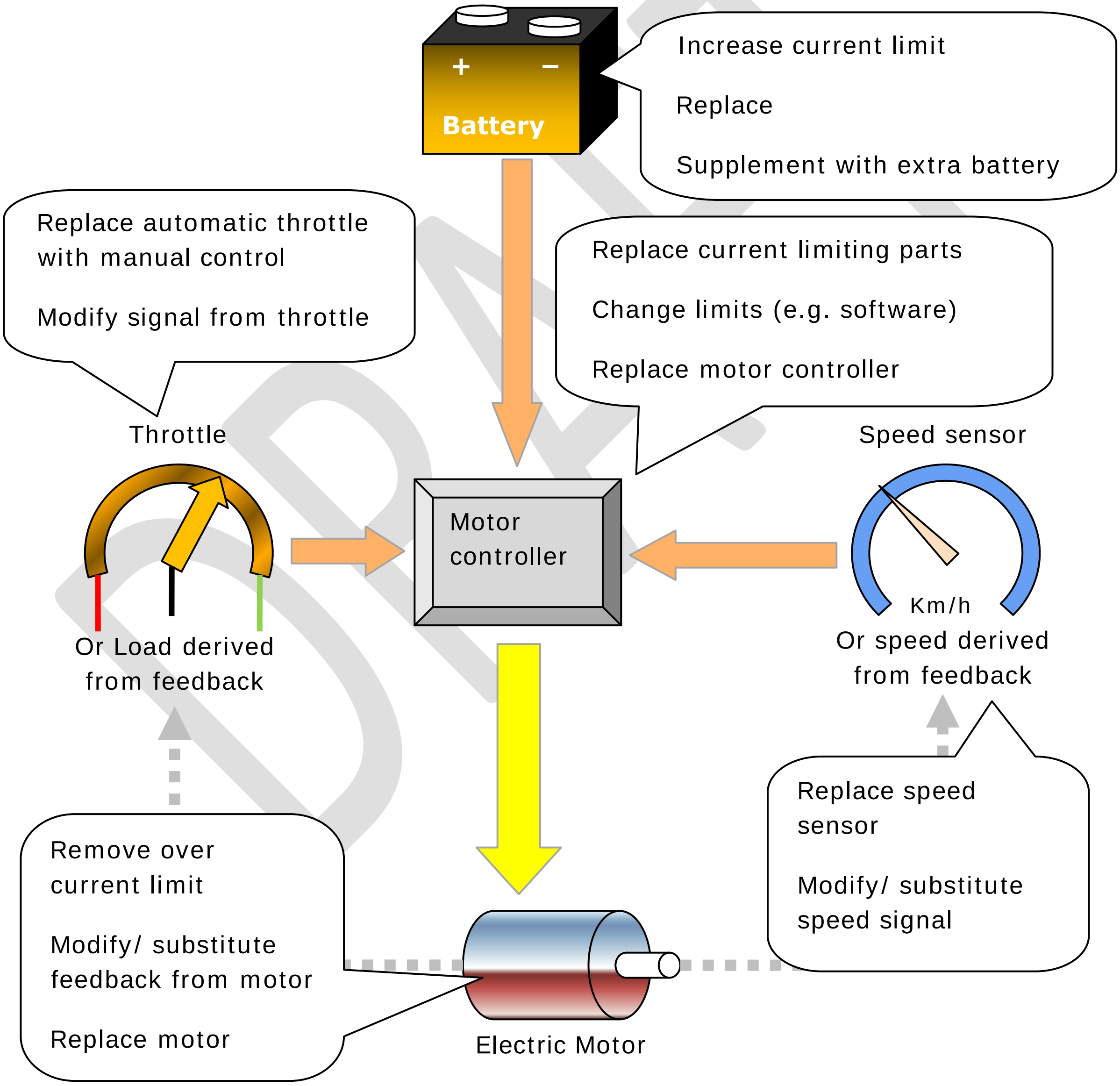


Figure 2-2: Possible routes of modification with the electronic systems

Of these possible routes for tampering, some may require much more complex modification to achieve and it is considered impossible to remove them all.

As with the anti-tampering articles for conventional vehicles, it is the intention to try to reduce, rather than prevent tampering, moving the practice from being straightforward to a complex process reserved for enthusiasts. It is therefore the intention to identify which of the possible tampering modes are easy and most significant with respect to safety of both the user and other road and cycle path users. By prioritising the tampering modes in this manner it will be possible to suggest which design routes should be avoided by manufacturers.

2.1.1 Throttle

The throttle in an electric vehicle is not necessarily a simply manual control, but could be an automatic system, assessing the required assistance and controlling the motor as appropriate. In automatic systems, a sensor can detect the rotation of the peddles and activate. Alternatively, the rotation of the wheels could be used, but this would make stopping difficult as it wouldn't cut off when attempting to stop. It may be possible to use the feedback from the motor or a sensor fitted within the motor.

For manual throttles, one method might be to use a potentiometer that changes a voltage sent to the motor controller. Another possibility is to detect the change in position of the throttle - perhaps optically - and send a digital signal to the motor controller. A manual throttle is likely to be designed to provide a signal in the range of zero to full throttle, and therefore tampering with this part is unlikely to increase the vehicle's maximum performance. It may be that a manufacturer is using a throttle stop, either in the control itself or at the interface with the motor controller. Under article 3.7. of Directive 97/24/EC, the use of throttle stops whether mechanical or electrical are forbidden. There is no reason to see why this should not also apply to electric vehicles.

Performance restricted power assisted bicycles are much more likely to use some form of automated throttle control. It is part of their category's criteria that the throttle (i.e. the level of assistance) is reduced and stopped above a specific speed (≥25 km/h). In these vehicles the automatic throttle is tampered for the following reasons:

- To activate the power assistance even when not peddling;
- To prevent deactivation of the assistance above 25 km/h;
- To increase the level of assistance while peddling.

In order to achieve this: the sensor can be tampered with to give a false signal, the signal to the motor controller could be modified, or an alternative manual control could be connected in its place. Another way in which this can be performed is to monitor the current that the motor is drawing, this combined with the speed can be used to ascertain the required throttle, although in this configuration a sensor to detect peddling would still be required.

2.1.1.1 Possible anti-tampering design

It has been see that in some vehicles, the pedal activated throttle sensor is integrated in such a way to the bottom bracket (where the peddles are fitted), that modifying it is highly complex. In others, the motor is integrated into the bottom bracket so that the sensor is practically part of the motor controller. These two designs allow very good protection from tampering and encouraging such designs would have the effect of making tampering of this type much more difficult.

The sensor signal is however open to tampering. If the system is digital, then modifying the signal with simple plug in modules or components to change the voltage becomes more difficult

2.1.2 Speed sensor

The speed sensor is a critical part for all speed-restricted electric vehicles. Some vehicles are designed to perform well at maximum speed and to do this they have higher performance parts that provide the required power/torque while carefully monitoring the vehicle speed so that a threshold value is not exceeded.

Tampering with the speed sensor so that the vehicle will falsely assume that this speed has not been exceeded in conjunction with a high throttle position, will cause the vehicle to continue supplying power up to its engine capacity.

Speed sensors detect the rotation of the motor or wheel, or determine the rate through feedback from the motor. Sometimes the sensor is intentionally placed on the unpowered wheel so that it is not misinformed due to wheel spin and to keep the parts and weight balanced throughout the vehicle.

A rotation sensor uses a disc or marking on a shaft, detecting the markings as they pass and transmitting this pulse to the motor controller (see Figure 2-3). The motor controller then takes this pulse and interprets the speed. The motor controller could therefore be tricked by changing the rate of pulses for a given rotation, either by adjusting the markings or by generating a simulated pulse creating a type of throttle.

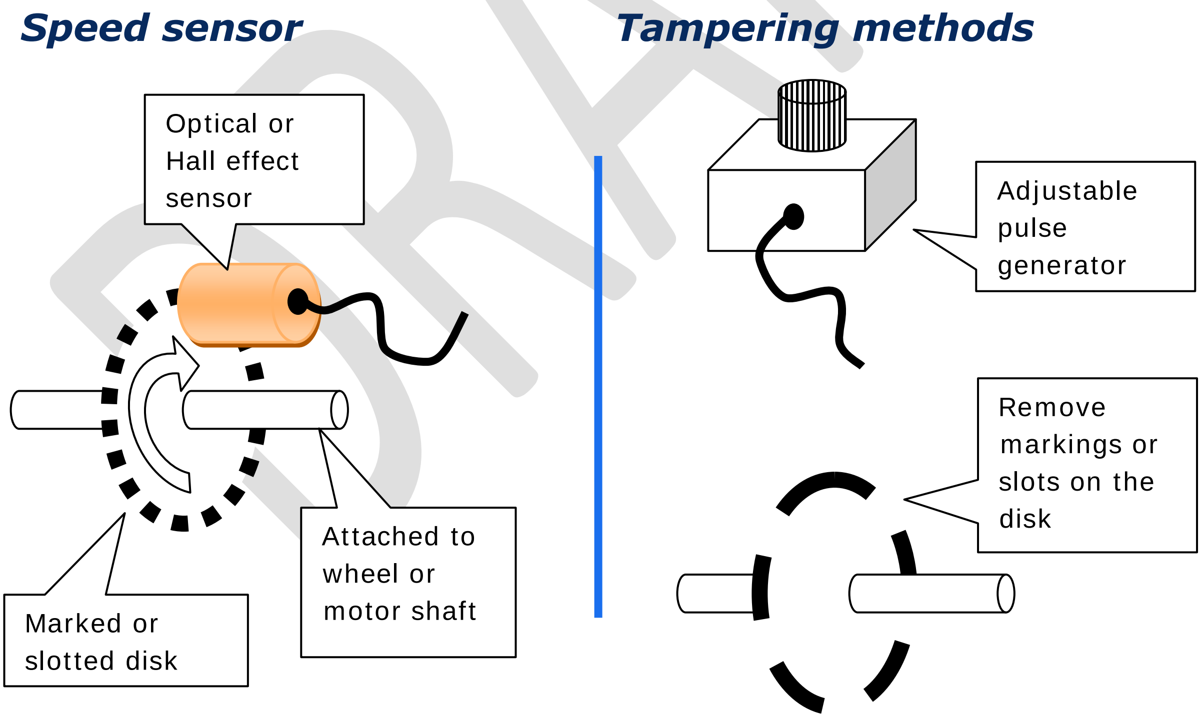


Figure 2-3: Speed sensor including tampering methods

In reality the sensor/markings system is quite delicate and trying to change the markings that it detects would require precision to achieve. Intercepting and replacing the signals on the other hand would be quite simple, the electronics needed to generate a pulse are easy to obtain and require very little electronics knowledge to make.

An alternative method to using additional sensors is to detect the feedback from the motor itself. This is only possible if the motor provides direct drive to a wheel, rather than through the user controllable transmission.

In simple terms every motor is also a generator, i.e. if power is added it rotates, if on the other hand the motor is rotated then power is generated. It is not possible to disable one use or the other, so all the time the motor is rotating there is feedback being forced back into the motor controller. The feedback is in the form of a pulse when one magnetic field passes another, and this pulse can be measured and used to detect the speed of rotation.

As this signal is obtained through the same wires that provide the power to the motor (from the motor controller) the signal cannot be intercepted and modified. The electronics required within the motor controller to detect this signal are more complex, but a separate speed sensor would not be required which could balance the manufacturing costs.

2.1.3 Battery

In a very simple configuration, changing the voltage of the battery will make a motor rotate faster for a given increment on a speed control. However, as mentioned above, it is highly unlikely that a vehicle will be designed in a way that makes simply increasing the voltage a possible way to increase the speed. Additionally, as batteries drain, their voltage drops. To prevent this causing the vehicle to slow, electronics are used to change the power from a battery irrespective of the voltage, into exactly what is required (this device is called a voltage regulator), although these electronics still have some variability which may allow a slight increase in power or vehicle speed.

A more expected limit of the battery is the current that it can supply i.e. the maximum drain or rate at which it can provide the power. Drawing the power at too high a current for a sustained period reduces efficiency, lowers capacity and overheats the battery, damaging it ultimately to the point of catastrophic failure (i.e. combustion). Therefore the motor controller must be designed to not exceed this rate.

Simply attaching a more capable higher drain battery, or attaching two connected in parallel (which will keep the same voltage but double the current), will not in themselves cause the vehicle to increase in speed or power. However, in conjunction with a modification to the motor controller and/or motor may result in increased maximum speed and power.

2.1.4 Motor controller

If the battery and motor are capable, the motor controller is the main part which limits vehicle performance. This limit can be established in two ways; a preset limit (e.g. a software or hardware defined maximum speed) or a design limit (e.g. its maximum current throughput).

2.1.4.1 Preset limit

If the vehicle is not L-category, then it may have a throttle stop which prevents the maximum signal of the throttle to be registered. This may be in the form of a filter capping the maximum voltage from the control, or in software taking the signal and

assigning a lower value for anything above a threshold value. To bypass this, either the limiting component could be removed or replaced, or the software modified.

Disregarding the fact that throttle stops are discouraged, the second of the two is the preferred design, as given appropriate security features, software should be harder to modify.

Another form of preset limit is by way of the speed limiter. To allow the vehicle to perform well precisely right up to the limit, irrespective of the weight of the rider or gradient of the road, a feedback control loop will be used. This takes the signal from the vehicle speed sensor and adjusts the power to the motor as appropriate. Adjusting the actual workings of the control loop, be it hardware of software, can be highly complex. However one route is to either to adjust the maximum speed to which it is limited or by changing the signal from the speed sensor.

2.1.4.2 Design limit

The design limit refers to the capabilities of the motor controller, as said before drawing too much current (or over-current) can cause the battery to be damaged, and the same can be said for the circuits of the motor controller.

The power for the motor passes from the battery, through some circuitry such as a filter and regulator, then it is set to the required amount before leaving via a socket (see Figure 2-4). The components which perform the processing of sensors and such are isolated from this, higher power, portion of the circuit to protect them.

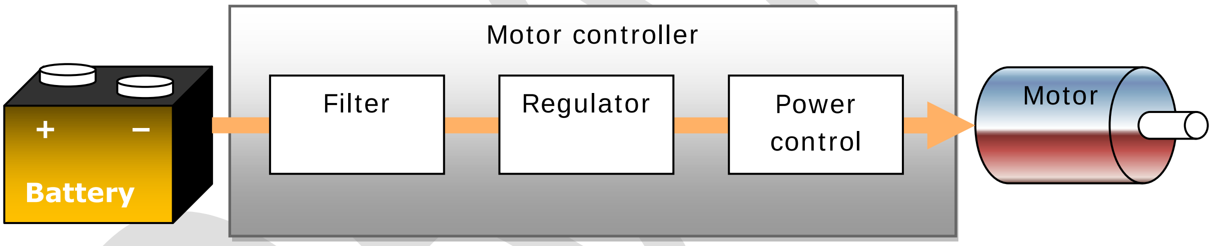


Figure 2-4: Example of components in path and susceptible to over-current

All of these must be capable of running at the required current of any modification. This might entail upgrading some components but could also require bypassing the traces on the circuit board itself (adding thicker wires), which may be too narrow to deal with a higher throughput.

2.1.5 Motor

There are three options in increasing the performance in relation to the motor:

- Do nothing, the motor may be capable of higher performance, but limited by the motor controller;
- Replace the motor, if requiring performance over and above a motors capabilities it is unlikely that it can be modified without having to fundamentally change it;
- Add an additional motor, depending on whether the current configuration powers the front or rear wheels, an additional hub motor could be fitted to the unpowered wheels.

It goes without saying for electric vehicles just as it does with conventional vehicles, over driving the motor/engine above its design capabilities risks permanent damage or at least a reduction to its expected life.

2.2 Hybrids

Depending on the type of hybrid tampering can take many forms. It may be that all the tampering modes that affect the conventional engine, plus all of the modes that affect an electric one are combined. However, due to the interdependencies of a hybrid some of these may be difficult to perform or unfeasible.

The main difficulty is with the ECU. In a hybrid this performs multiple tasks and intelligently maintains the correct balance of power. Amongst the software in this device there will be the standard engine and electric motor management, but as a single package it may take a long time for someone to decipher and redevelop modified software.

2.3 Motor Kits

Kits are widely available to adapt a bicycle into a power assisted one. These provide a large cost advantage over the complete vehicle option while providing better choice and configurability, although they do require a moderate level of skill to assemble.

Kits were able to become prevalent as: Bicycles are modular and highly configurable; users require a certain level of technical skill to keep them maintained. Motors, batteries and the relevant electronics have been developed for many applications for many years outside of motor vehicle use. Bicycle frames are lightweight and well suited to the low capacity of current battery technologies, especially compared to the power density of fuels such as petrol and diesel.

The issues that have arisen in relation to tampering is that they are sometimes capable of much higher speeds and powers than is allowed by legislation. Significantly, from the literature research, two pieces of anecdotal evidence emerged when it comes to vehicles which exceeded the performance limits:

- Users where frustrated with the lack of performance from complete (off the shelf) power assisted bicycles;
- Users displayed no knowledge of a power and/or speed restriction being in existence.

With respect to the first issue, the 250W limit is designed to mimic the abilities of an average rider, not provide any performance boost which is generally what people want from this type of technological advancement. If this value is exceeded, the vehicle by definition stops being a bicycle and starts being a low-powered moped.

For the second item, every part needed to make an electric power assisted bicycle is widely available and, even if obtaining the individual parts from non-vehicle specific suppliers, are easy to obtain and assemble. Custom made power assisted bicycles are put together outside of the type approval system, and on their own all of the parts could be approved for sale and use in the EU (e.g. CE marked). There is no obvious way that a user could become informed of the legislation stating when these parts cannot be used.

3 Limited testing programme on L-category vehicles with electric propulsion

As part of the main project a small selection of vehicles with electric motors were obtained and tested. This included two pedelecs, an e-bike (moped) and a hybrid tricycle. The following vehicles were obtained for the testing programme (see Table 3-1). As with the conventional vehicles, this selection was driven by market availability. It was recognised that due to the small and immature fleet this selection methodology may not fully expose the susceptible vehicles as it did for the vehicles obtained under the conventional L-category vehicle testing programme.

Table 3-1: Hybrid and electric vehicle modification

Vehicle	Category	Type	Modification
E1	L1Ae	Pedelec	Supplemented battery, Replaced high gear
E2	L1Ae	Pedelec	Supplemented battery, Replaced high gear
E3	L1Be	Moped, e-bike	n/a, used for range, power and torque tests
E4	L5Ae	Hybrid tricycle	Modify ECU via software and piggyback device

A literature study was performed concentrating on published modification instructions to the vehicles obtained. From this investigation the following tampering modes were found and attempted (see Table 3-2). Note that due to the very limited market this was primarily based on an internet survey.

Table 3-2: Tampering modes investigated for vehicles under test

Tampering modes	Performed
Attach shunt to increase current	
Modify torque or speed sensor	
Modify/replace ECU software	Yes
Piggyback ECU to adjust air/fuel ratio	Yes
Replace ECU/motor controller	
Replace gearing	Yes
Replace/supplement battery	Yes

3.1 Vehicle E1

The specification of vehicle E1 was:

- Battery: 36 V, 14 Ah
- Maximum range 40 km
- Motor: 250 W (brushes)
- Maximum speed: 25 km/h

The first tampering mode attempted on vehicles E1 and E2 was to alter the feedback signal to the control system of the electric motor. The aim of this was to simulate a lower input value to drive the power PID regulator in order to bypass the speed limitation and achieve greater maximum speed. It was found that this tampering type could not be implemented in practice because the electronic circuitry of the control system of these two cycles was fully integrated, preventing the necessary access.

In both cycles it was noted that an external resistor was used to calibrate the system response and changing the Ohm value of this resistor had some influence on the control behaviour. It was observed that a lower resistor value resulted in driving the system to assist pedal effort in a more aggressive manner; a higher value of the resistor introduced a smoother response and a more subtle intervention of the electric motor.

However, tampering with this single external resistor did not overcome the speed limitation integrated into the cycle. Once the maximum speed was reached, the electrical assistance ceased. It was concluded that in these examples the system cannot be easily tampered in this way by owners of such vehicles.

3.1.1 Supplemental battery

A second tampering mode was assessed by adding a 12V, 10Ah battery to the existing 36V 14 Ah battery on the vehicles. The effect on maximum speed is presented in the following graphs:

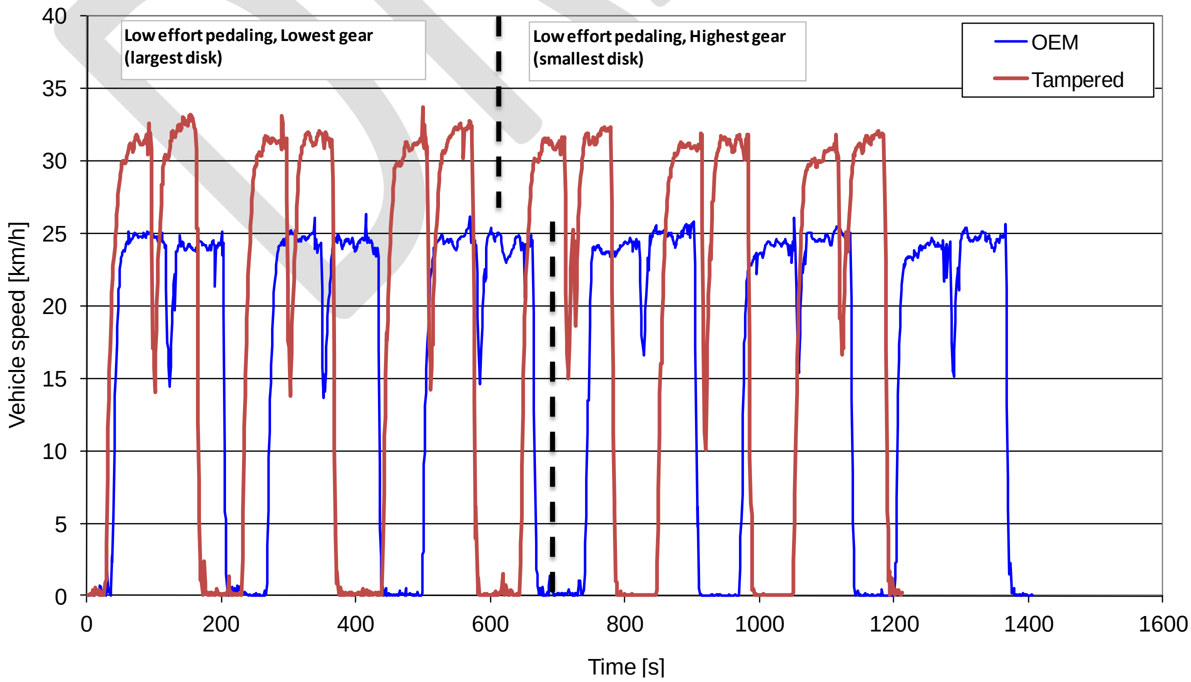


Figure 3-1: Vehicle E1: Supplement battery, Low effort pedalling

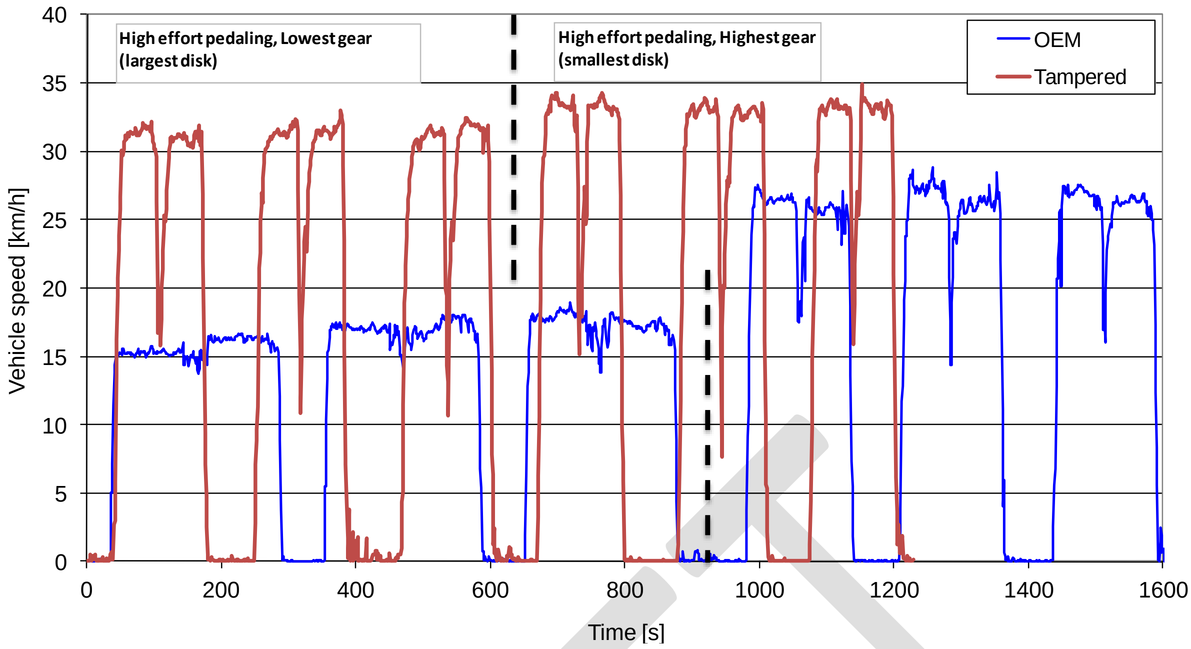


Figure 3-2: Vehicle E1: Supplement battery, High effort pedalling

This addition was simple to implement and had the effect of increasing maximum speed from 27.92 km/h to 33.86 km/h, an increase of over 21%. Unverified information on the internet suggests that greater effects on maximum speed may be possible.

3.1.2 Additional gear

The third tampering mode tried on this vehicle was to change the gearing between the motor and the final drive. As the controller also registers the vehicle speed via the wheel and gearing, this change in ratio should allow the vehicle to continue providing power above the speed that it should.

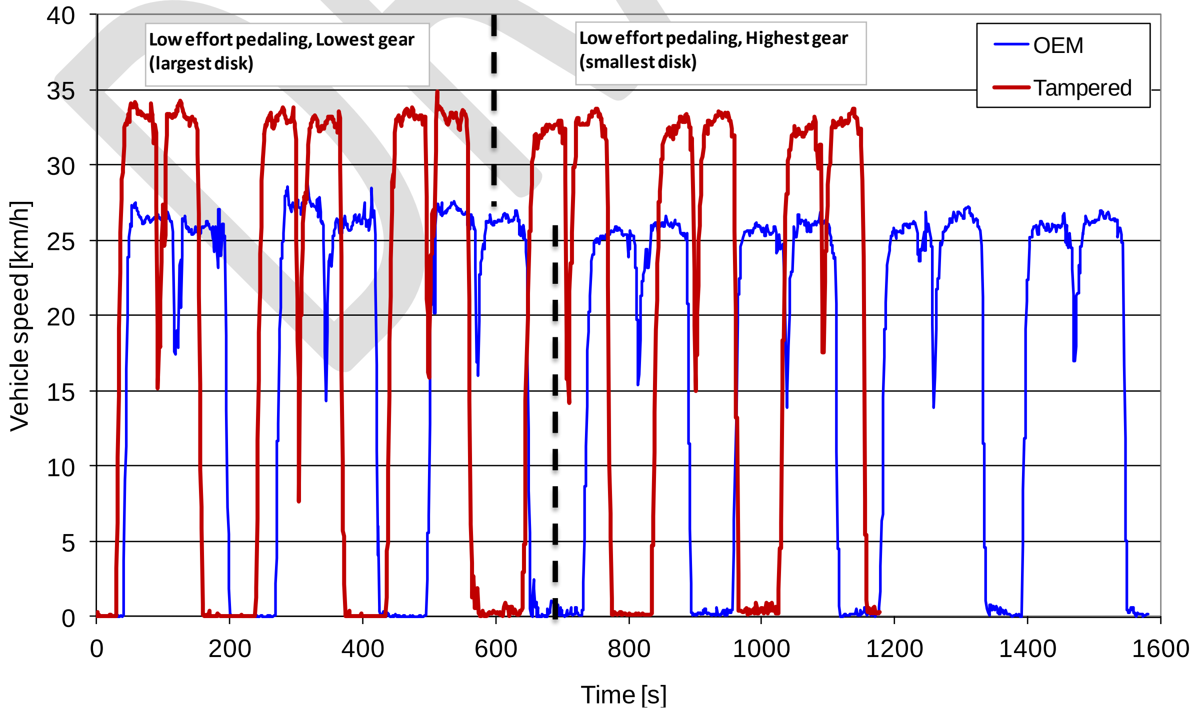


Figure 3-3: Vehicle E1: Additional gear, High effort pedalling

3.2 Vehicle E2

Vehicle E2 had the same tampering modes performed as vehicle E1. Again it was seen that a 250 W motor is capable of approximately 33 km/h on a chassis dynamometer with a rider who is approximately equivalent to a 50th percentile weight.

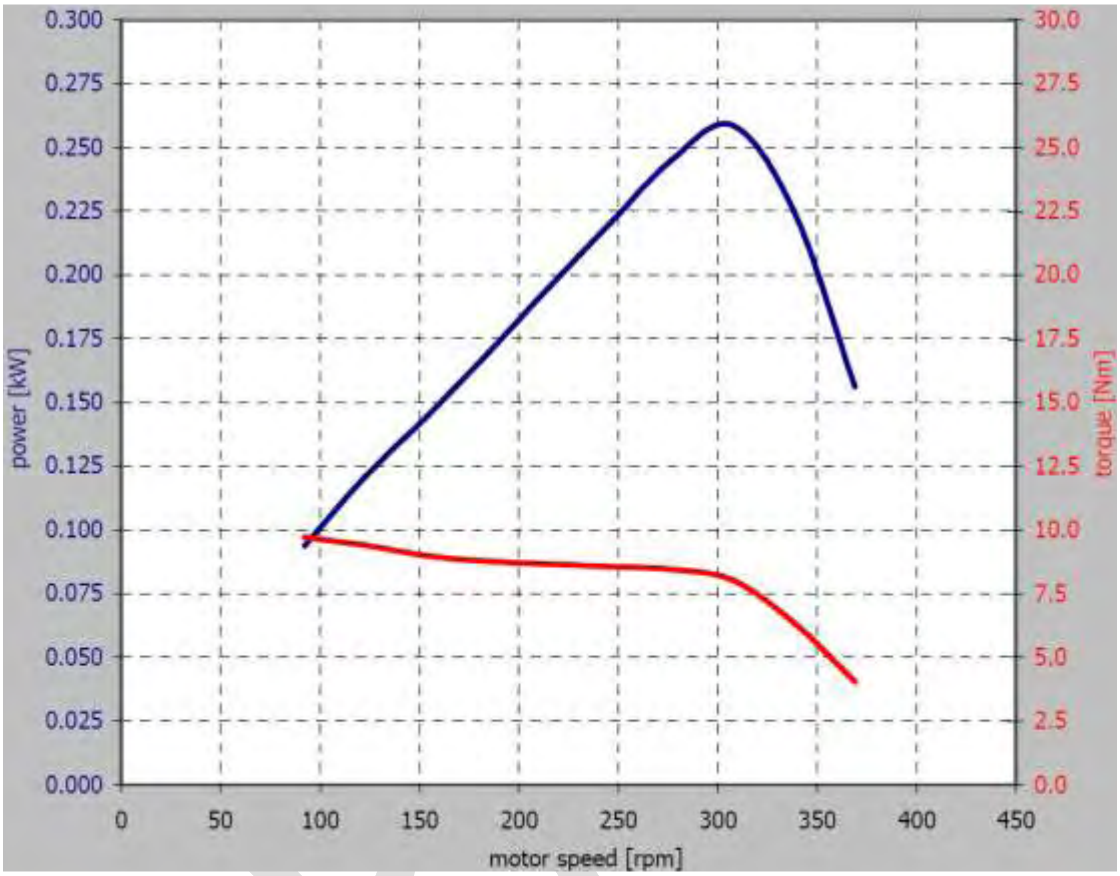


Figure 3-4: Vehicle E2: Power test, power [kW] and Torque [Nm] vs Engine speed [rpm], Untampered state

3.2.1 Additional gear

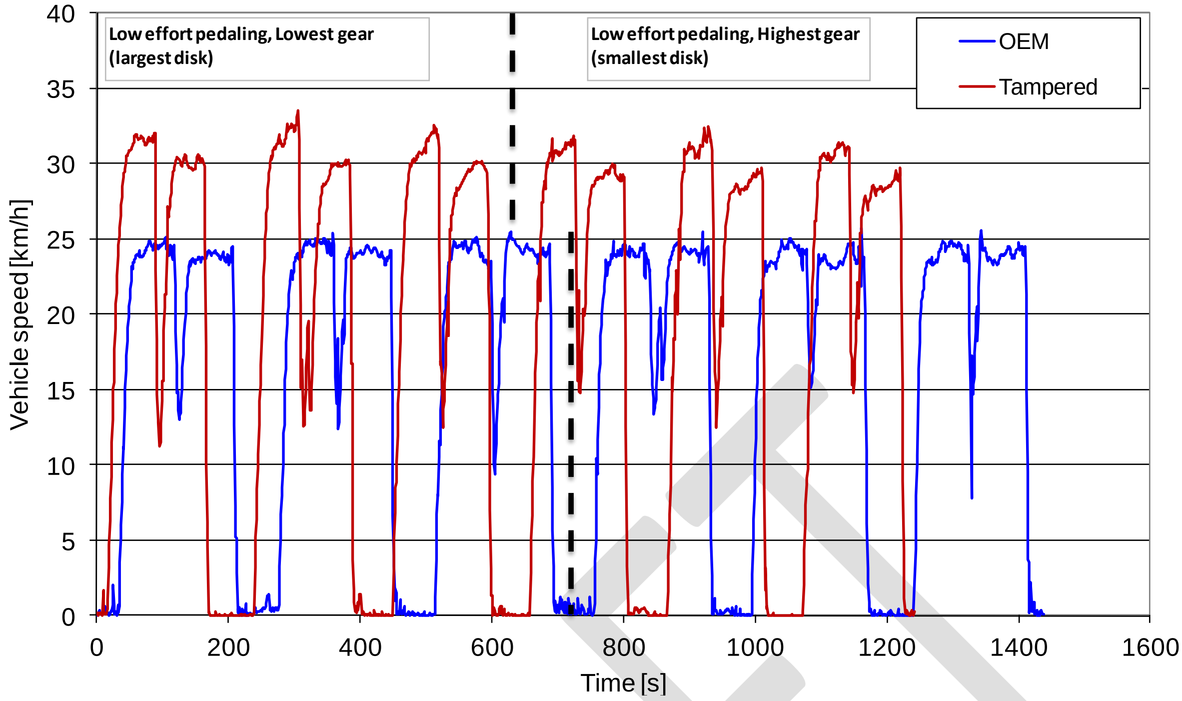


Figure 3-5: Vehicle E2: Additional gear, Low effort pedalling

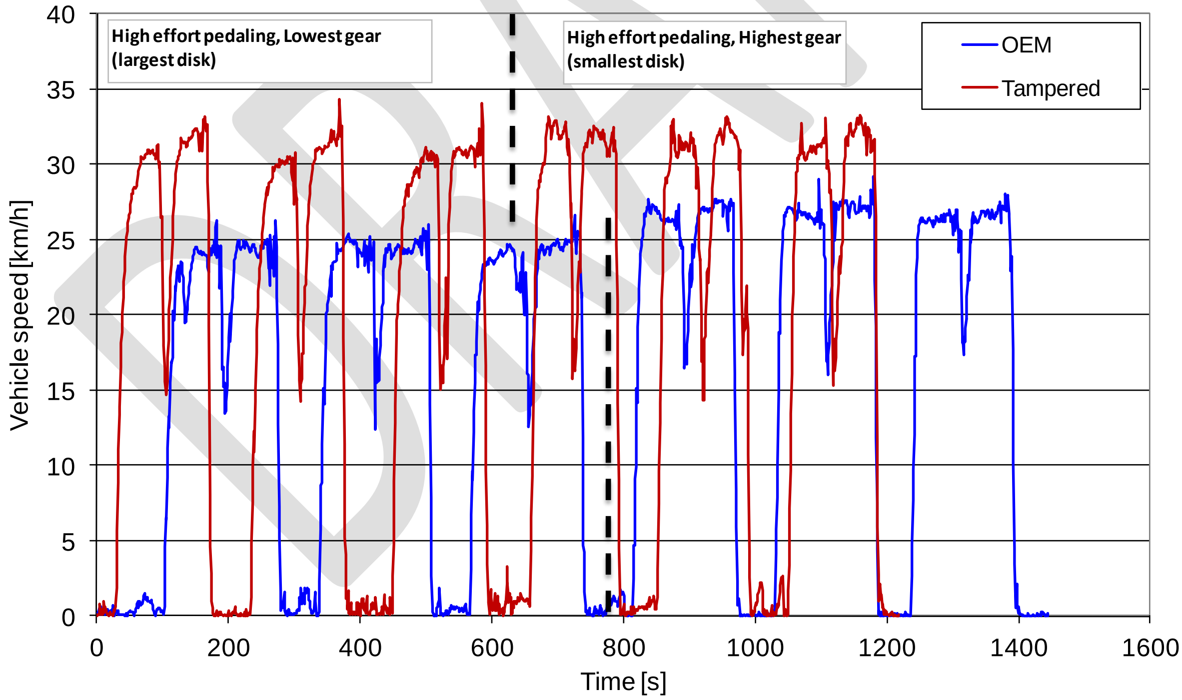


Figure 3-6: Vehicle E2: Additional gear, High effort pedalling

3.3 Vehicle E3

This vehicle is an L1Be (a moped). Tampering was not performed on this vehicle, but a maximum power and torque test was, as well as a range test over both the revised WMTC cycle and UN Regulation 47 cycle. This vehicle has an electric motor with the

following specifications: DC 60V brushless, rated at 2,500 W. Note that the battery was fully charged before each test.

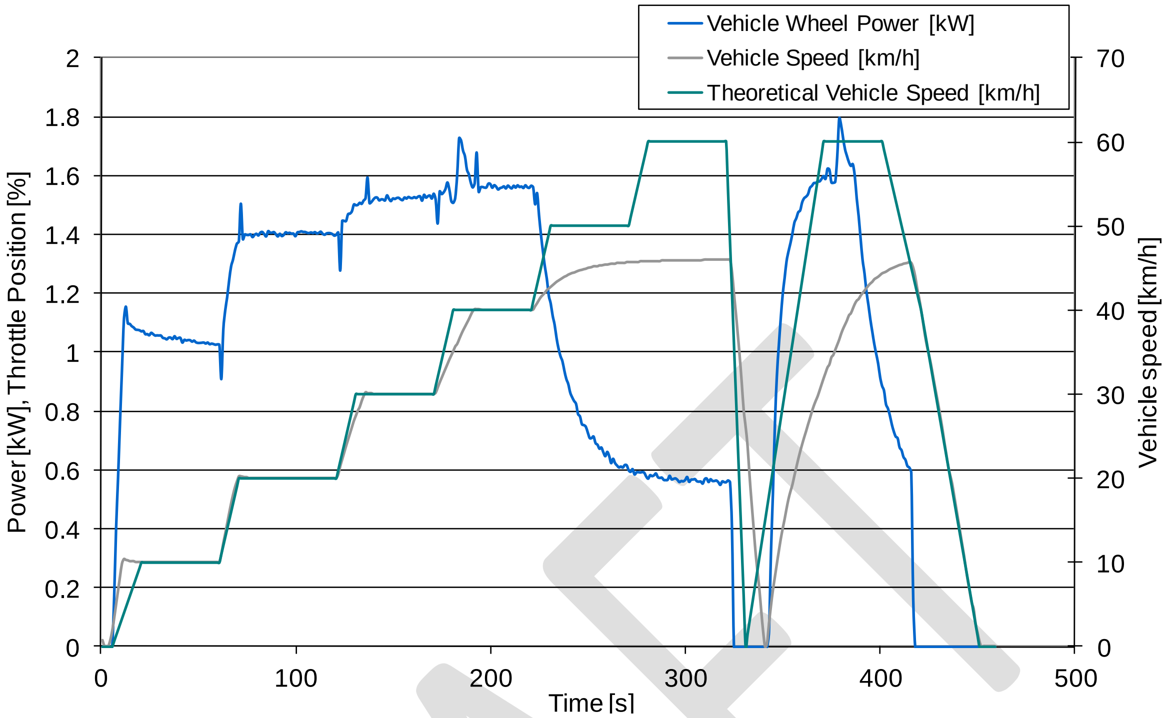


Figure 3-7: Vehicle E3: Power test, power [kW] against Vehicle speed [km/h]

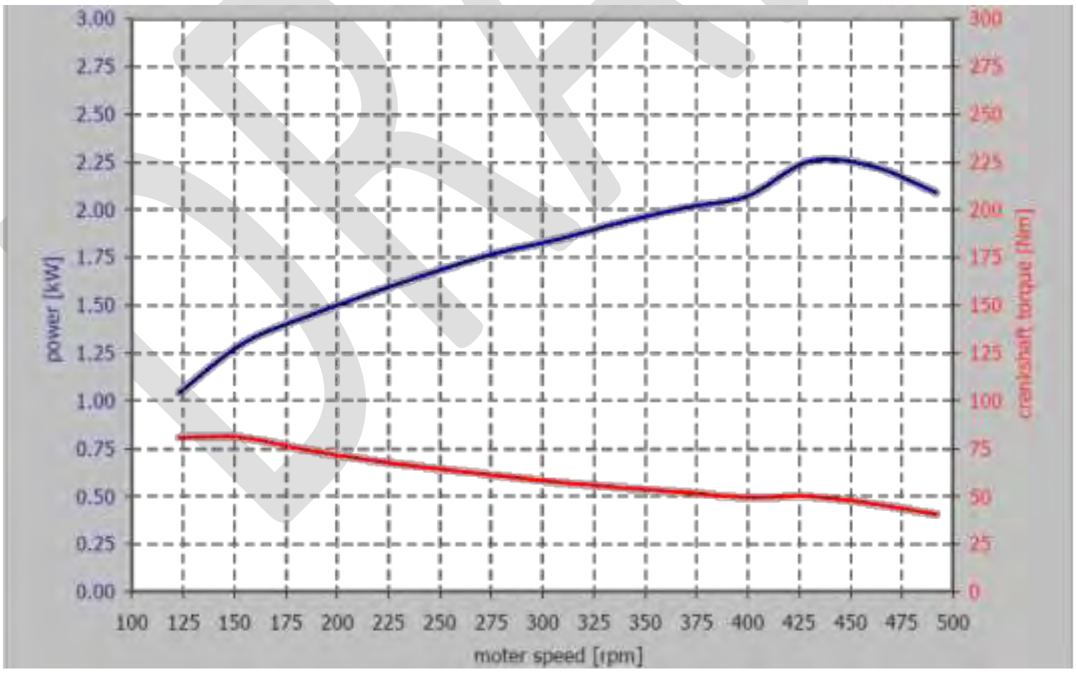


Figure 3-8: Vehicle E3: Power test, power [kW] and Torque [Nm] vs Engine speed [rpm]

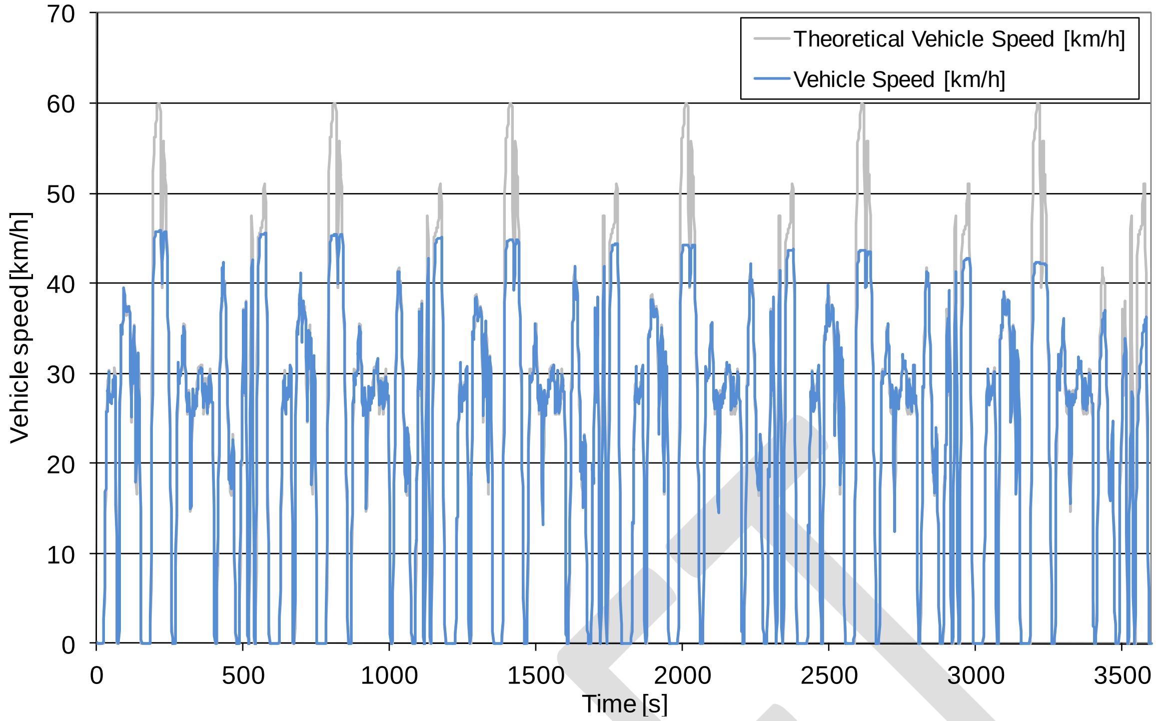


Figure 3-9: Vehicle E3: Range, Revised WMTC, part 1/2

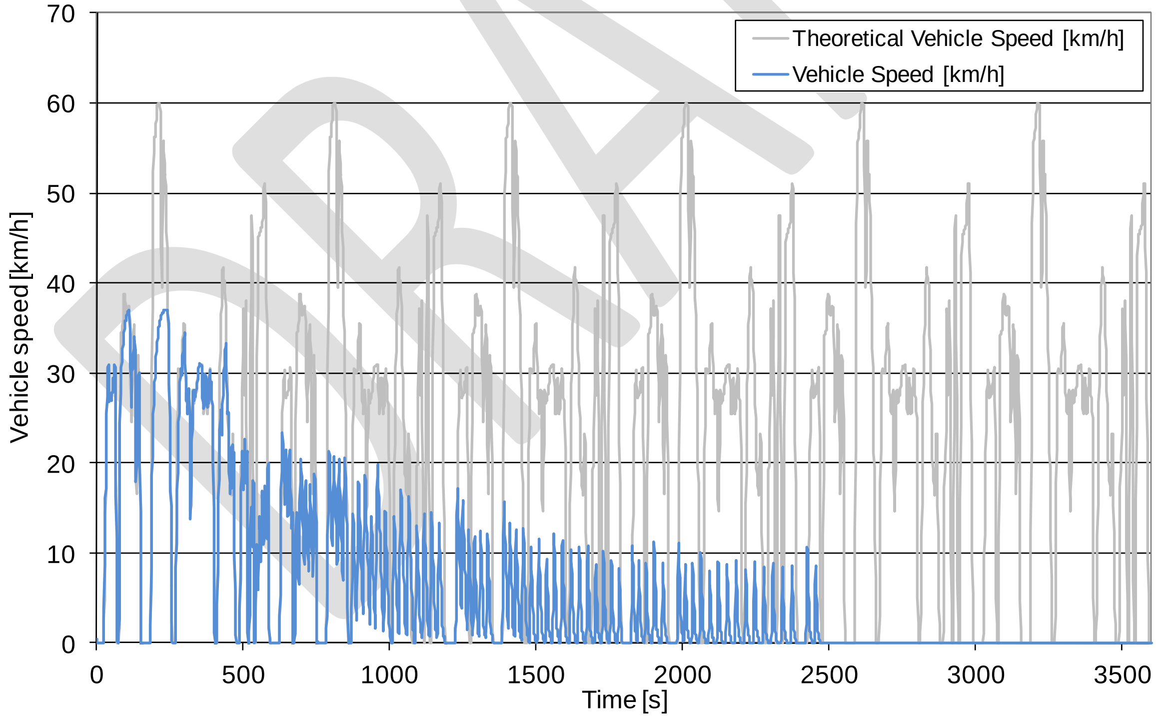


Figure 3-10: Vehicle E3: Range, Revised WMTC, part 2/2

Totals WMTC: Distance 28.8 km, Time 1.68 hours, Average speed 17.1 km/h

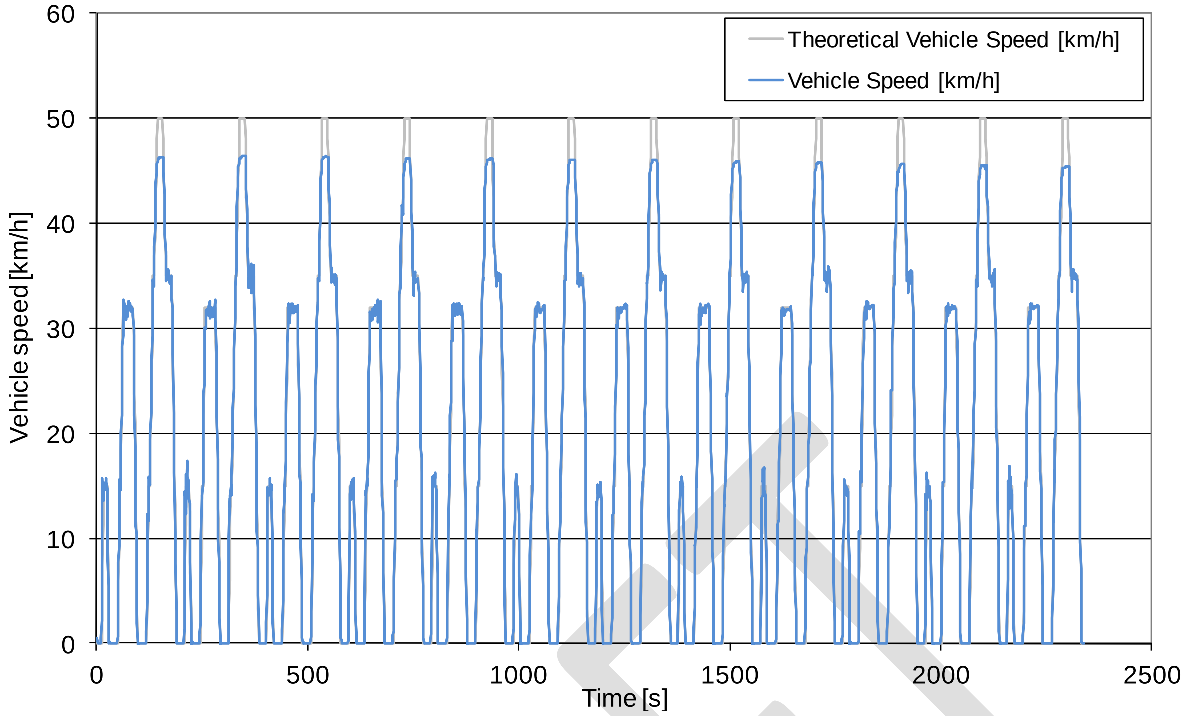


Figure 3-11: Vehicle E3: Range, UN R40, part 1/3

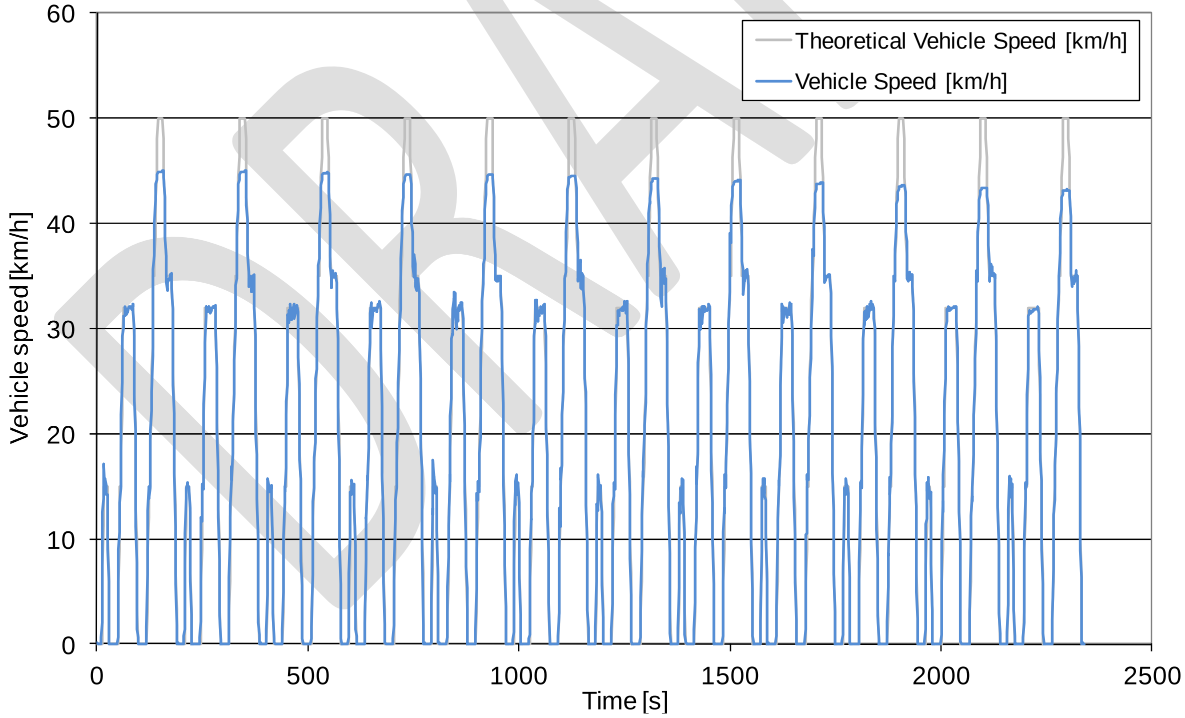


Figure 3-12: Range, UN R40, part 2/3

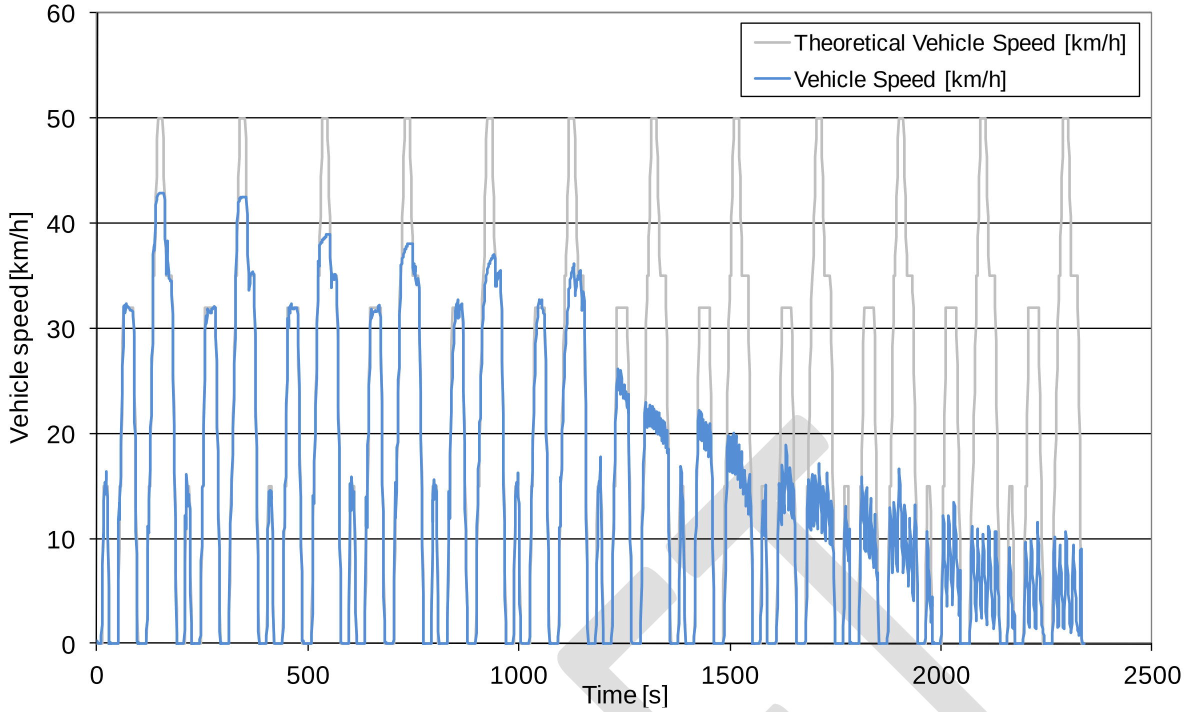


Figure 3-13: Range, UN R40, part 3/3

Totals UN R47: Distance 32.1 km, Time 7.94 hours, Average speed 16.4 km/h

3.4 Vehicle E4

This vehicle was a hybrid three wheeled L5e. Attempts were made to modify the ECU software in an attempt to cause the motor to provide a continuous boost, which would have provided power above the limit of the L5e category. This proved impossible with generic ECU engine map modifying tools. A second unsuccessful attempt was made to simply change the combustion engine's fuel injection and air/fuel ratio.

In both cases the tampering caused the vehicle to enter a reduced performance 'limp-home' mode. This shows that the ECU protection mechanisms the manufacturer has in place are effective at preventing these types of tampering and could be used by the manufacturer in their other vehicles.

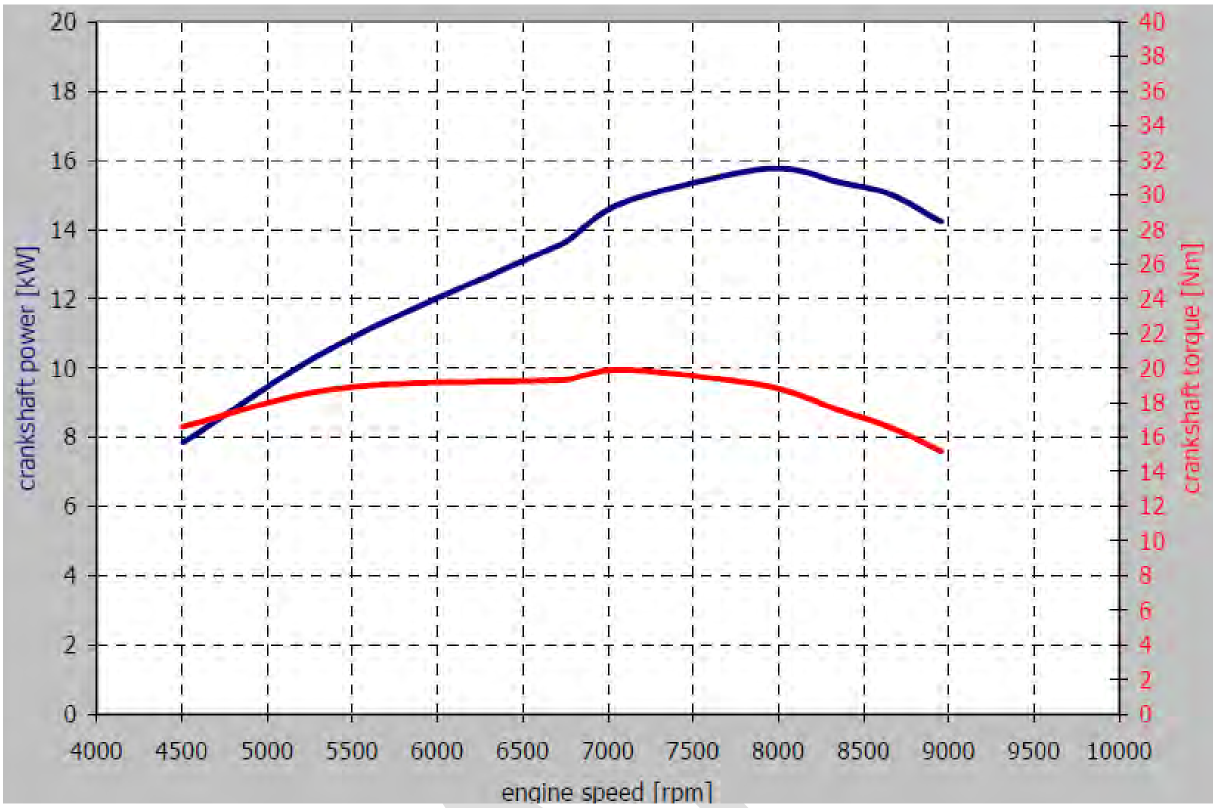


Figure 3-14: Vehicle E4: Power test, power [kW] and Torque [Nm] vs Engine speed [rpm]

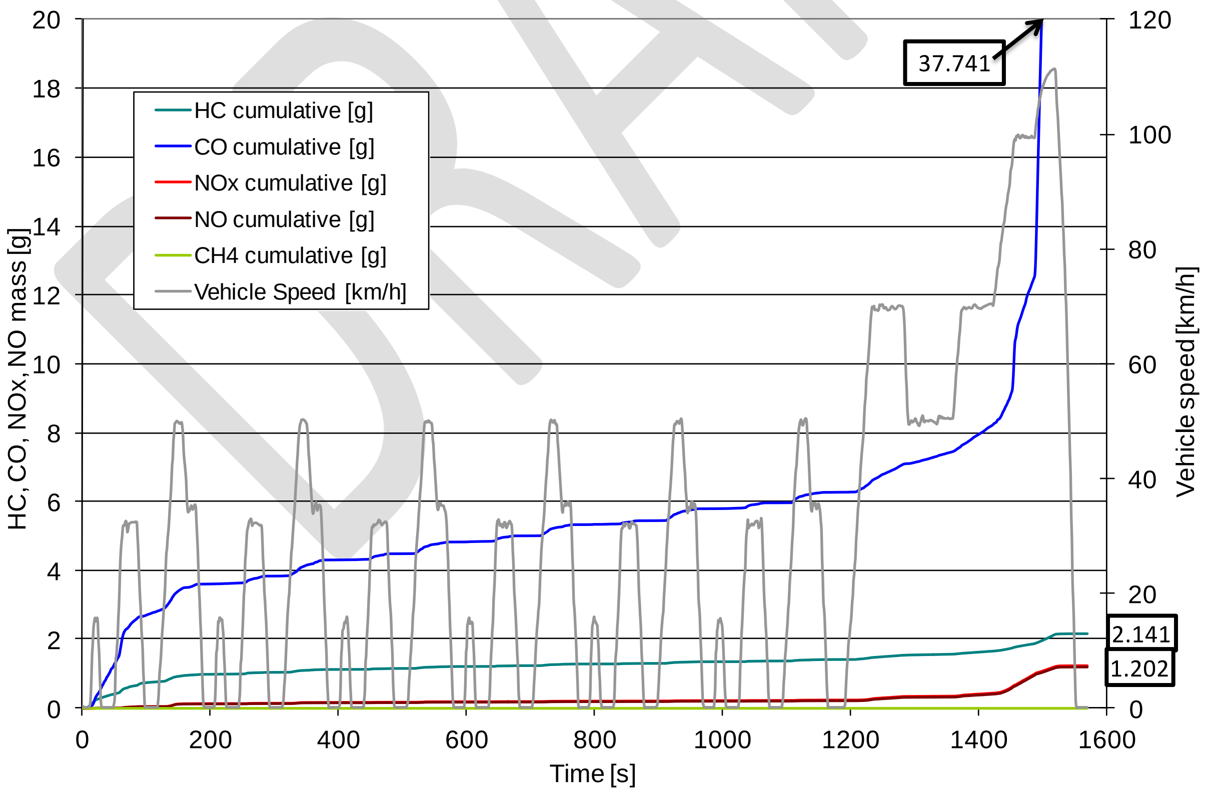


Figure 3-15: Vehicle E4, cumulative emissions, UN R40 cycle, battery 100% at start

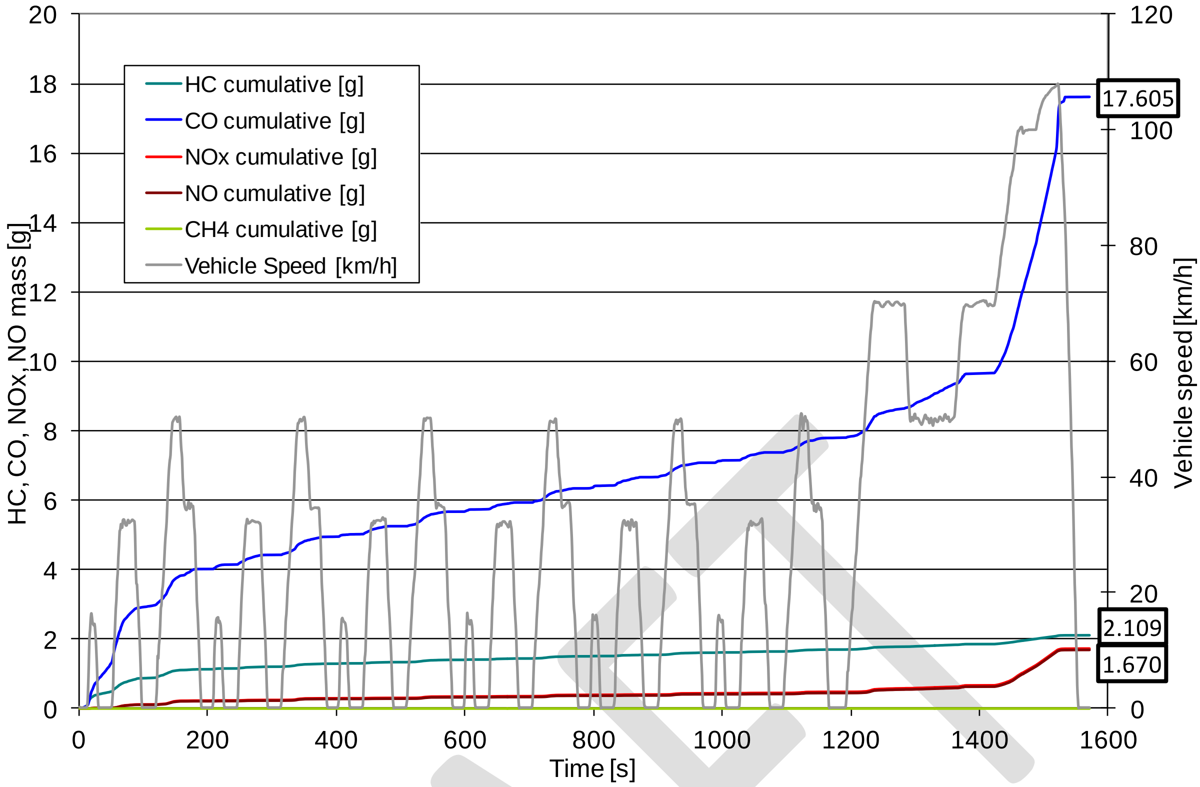


Figure 3-16: Vehicle E4, cumulative emissions, UN R40 cycle, battery 25% at start

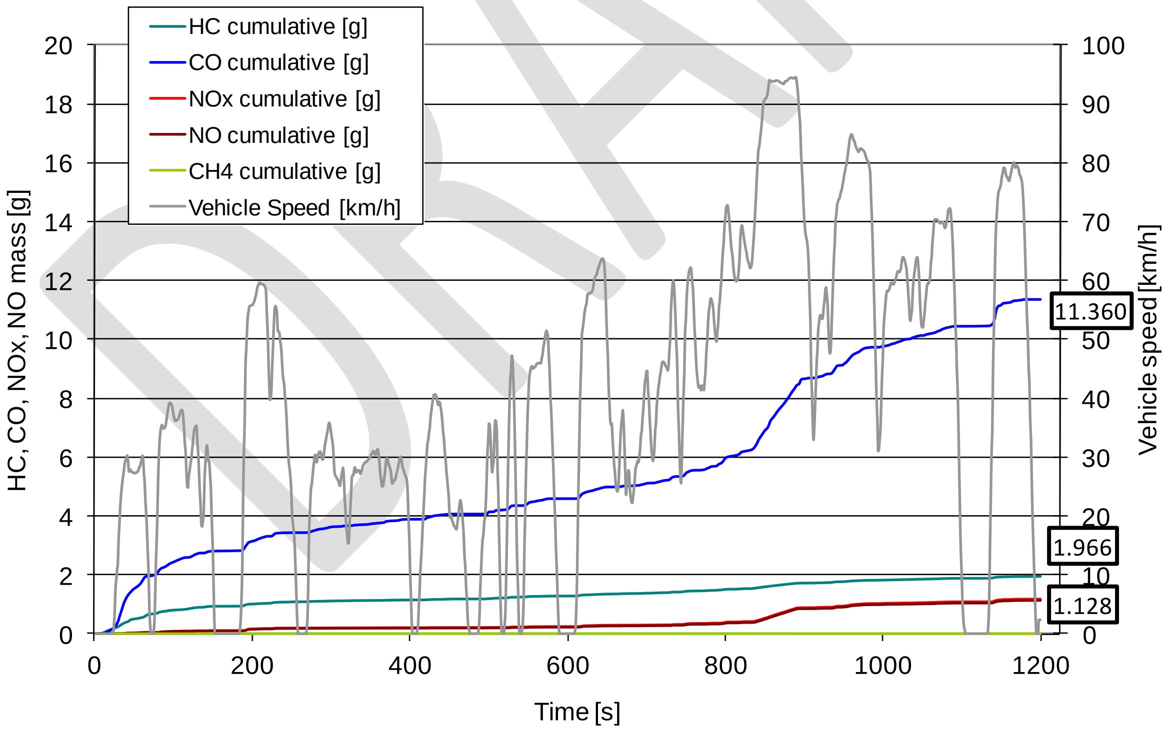


Figure 3-17: Vehicle E4, cumulative emissions, WMTC stage 2, Battery 100% at start

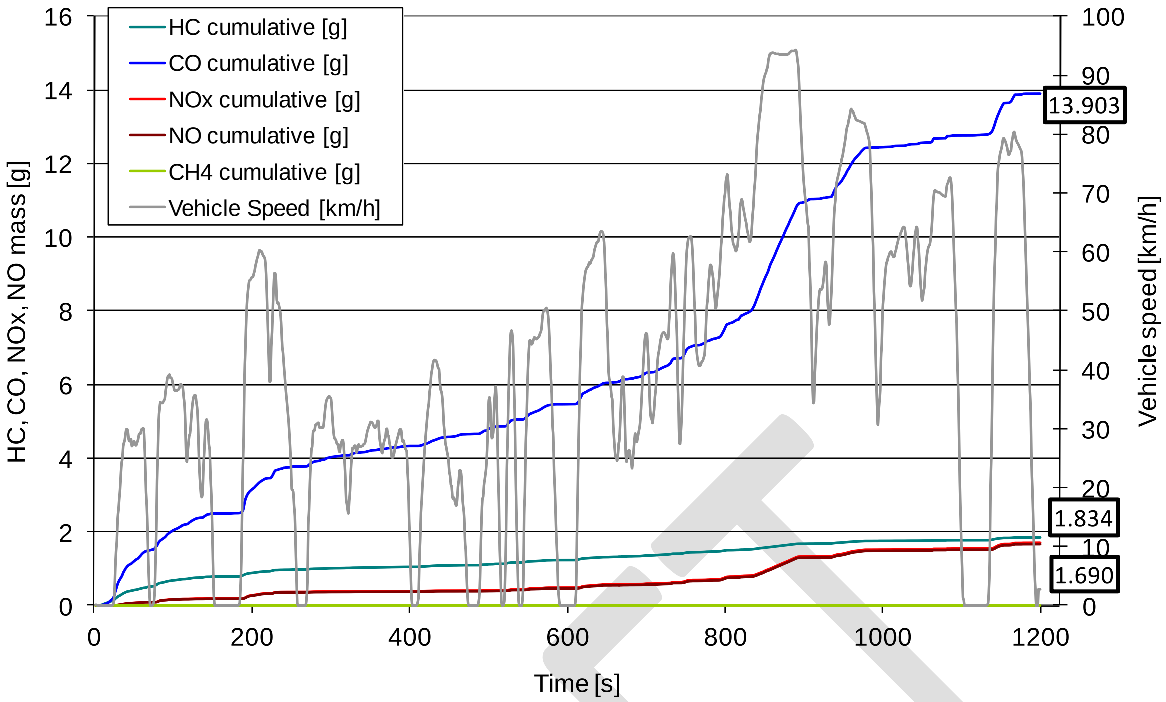


Figure 3-18: Vehicle E4, cumulative emissions, WMTC stage 2, Battery 25% at start

4 Analysis of results

In this limited study of the literature, engineering principles, and testing, the following pieces of information arose:

- The market for model-specific plug-in tampering modules is not yet mature
- The community discussing DIY modifications is established
- Non-vehicle specific parts are widely available and not regulated for this use
- There are multiple places within the electrical system where tampering could be performed
- Depending on specific vehicle design (both in the drivetrain and motor controller/ECU) not all tampering methods are possible
- A well designed ECU can thwart some forms of tampering
- A 250 W motor is capable of speeds of approximately 20-40% or 5-10 km/h in excess of the legislated limit, when the motor is used with low or high effort pedalling respectively.

Additionally, it was seen that the assumption that the structure of a bicycle is unsuiFigure for higher speeds may not always be accurate. Given that many now have disc brakes, it seems not unfeasible that one could be enhanced to qualify as an L1. The literature study has shown that registering a high powered pedelec as a moped is not only possible but sometimes done through the single vehicle approval scheme. When it comes to upgrading a bicycle to the performance of a motorcycle it begins to seem increasingly unlikely, however this should not be discounted until they can be tested.

4.1 Options for type approval

As with the possible options for conventional vehicles, these do not always fall within the scope of the type-approval, anti-tampering legislation. For electric vehicles this is even more so because a significant proportion are not categorised as L-category vehicles unless tampered to exceed the limits, or in the case of kits, not even a vehicle when passing through any approval process.

4.1.1 Anti-tampering measures

4.1.1.1 Battery

It may be difficult to prevent additional batteries being added since even if the integration of the battery into the design makes adding a battery difficult, additional wiring could still be added to another battery mounting location on the vehicle. Access to the battery is important for servicing: further investigation is required on the types and feasibility of measures to prevent additional batteries being added to achieve greater maximum speed and power than intended.

Alternatively, the motor controller could use current and voltage limiting regulation so that any increase in battery capability is translated into increased range and performance beyond the legislated limits.

4.1.1.2 Motor

In order to reduce the risk associated with speed-limited vehicles that are equipped with larger power motors, one option is to add an additional power limitation requirement to the L1Ae category. This would be in addition to the maximum MCRP criterion and would have the effect of reducing the potential speed increase that might be realised if the speed-limitation was bypassed by the user.

For instance the legislation for sub L-category power assisted vehicles is 250 W. The motor may be limited to this propulsive power output by electronics, and could have a MCRP of 1 kW or more. Therefore, on top of the regulated power limit of 250 W there could be an additional power limit of 300-500 W to prevent excess power being utilised if tampered with. The design and manufacturing requirements of manufacturers should be assessed before a specific value is set.

This practice is not limited to electric vehicles and it should be placed in context of common manufacturer practice used at reducing production costs. For instance, the same engine block in a moped ICE engine limited to 4 kW can output over 4.5 kW when configured differently for use in go-karts or agricultural machinery. Using the same parts not only reduces production costs but also increases the longevity of the parts.

It should be noted that these values are the propulsive output of the engine/motor not the energy use, which will be higher due to losses.

4.1.1.3 Motor controller

Although tampering with or replacing the motor controller is always an option, a possible anti-tampering method could be the requirement for limiting the current and voltage both at the input from the battery and the output to the motor.

In some motor controllers investigated they are limited in their capabilities by the current limitations of their components. However replacing these and bypassing narrow traces (the copper surface on the circuit board between components) allow this to be circumvented without too much difficulty or technical knowledge.

Therefore rather than relying on a components limits, the circuitry could be designed so that it is actively monitoring and limiting the throughput. Adapting this circuitry would be much more complex to achieve.

4.1.1.4 Throttle stop

As stipulated in the current L-category anti-tampering legislation, throttle stops should be forbidden. This should be implemented with the added clarity that this stop is forbidden when implemented electronically also.

4.1.2 Other options for changes to legislation

4.1.2.1 Changes to the categories

One of the main questions is whether power assisted bicycles should be transferred to the L-category. By looking just at the anti-tampering legislation it does seem that this would be a logical step. However, after a review of the machineries directive it can be seen that the complexity and burden on manufacturers is at least in some areas equal, and could provide equal protection. Therefore it seems that if an anti-tampering measure

is deemed necessary, then it could just as easily be placed in the machineries directive. As greater attention is being paid to non road engine emission (such as from lawn mowers and track vehicles), the opportunity is visible.

Arguably, a more significant issue with changing the category is the effect to general users. Effecting European and national legislation, the rights and responsibilities of users, as well as design requirement for manufacturers in the following areas:

- Tax
- Insurance
- Path use
- Helmet use and design
- Passenger transport
- Viability: Lights, brakes, indicators, reflectors
- Registration
- Number plates
- Maintenance and road worthiness
- Toll payments
- Age limits

The changes that would be caused are therefore significant and far-reaching, and before any change is made these should be fully considered (see section 4.3.2).

4.1.2.2 Kits

Due to the popularity of kits for the conversion of unpowered bicycles, it seems necessary that they should be considered in any updates to legislation. Using a kit can provide the user with a cost effective solution, and just as some are available of significantly higher power and speeds others are available which do not exceed these limits. Some stakeholders have suggested that they could be prohibited due to the safety concerns, however due to the prevalence of parts, made not just for use in vehicles, any attempt is unlikely to be workable.

However, there are limited options that can be implemented at type approval to prevent the safety risks associated with the fitment of these kits; other mechanisms are more appropriate to tackle this issue. Such as making the legislation on kits, complete power assisted bicycles, and light L-category vehicles comparable for their given characteristics.

4.1.2.3 Markings

The issue of differentiating the category of one vehicle from another plays a significant role in how other road and cycle path users and enforcement authorities perceive these vehicles.

Enforcement would be made more efficient if power assisted bicycles exempt from L-category type-approval requirements could be easily distinguished in use, from e-bikes with power limits in excess of 250 kW and those cycles equipped with electric propulsion kits.

The inclusion of high visibility markings on these vehicles could assist the enforcement authorities in distinguishing vehicles.

In the Netherlands, to assist with their national regulations on cycle path use, have a colour coded number plate system which differentiates between ≤ 25 km/h mopeds, ≤ 45 km/h mopeds and > 45 km/h motorcycles. Although extending the number plating system to bicycles may be unviable, a fourth coloured marking plate could be attached to a non L-category power assisted bicycle depending on its capabilities.

Alternatively, it has been proposed at a MCWG meeting that speed restricted vehicles have a plate or sticker indicating its limits in a similar way as is currently used on HGVs. This making could be made a requirement for power assisted bicycles as well, and would not add a significant burden to a user to affix such a marking.

4.1.2.4 Limited motor

Another take on the marking system could be to use an externally visible module, which guarantees that an electric motor has certain power limits.

The module, which would contain a combination of a fuse and zener diode, would be sealed in a colour-coded box and attached between the motor and its supply. This module will be fitted to an externally visible spot on the vehicle.

Vehicles which are supplied complete, with the motor and motor controller integrated into the bottom bracket the manufacturer to prove that a certain level of protection is already used (as indicated in previous sections), and as such would be except, but instead have a marking plate attached to indicate as much.

The key requirement of this protection is that it is visible and changing it will be detectable; any modification to attempt to increase the voltage or current before the module would cause the fuse to blow.

Each manufacturer's motor may have different current and voltage requirements to provide the MCRP limit that it is intended for. Losses and acceptable tolerances should be taken into account.

4.1.2.5 Testing

A roadside maximum speed test could be used to check that the speed limitation of the vehicle was retained.

As with some types, some in the L1Ae category may have a "boost" function; the MCRP level and maximum speed used for categorisation should be that achieved with controls adjusted in such a way that the maximum power and speed possible is delivered.

4.1.2.6 Nomenclature

A small but useful addition could be the a categorisation system for non L-category light vehicles. This could be useful for use in documentation for enforcement authorities and legislation. The following is a possible suggestion:

Table 4-1: Pedal cycle categorisation

	Unassisted	ICE propulsion	Electric propulsion	Alternative propulsion
2 wheeler (bicycle)	P1Ae	P1Be	P1Ce	P1De
3 wheeler (tricycle)	P2Ae	P2Be	P2Ce	P2De
4 wheeler (quadricycle)	P3Ae	P3Be	P3Ce	P3De

4.2 Conclusion

This short study has shown that for some vehicles even simple tampering was possible and gave a relatively significant speed increase. It also showed that the correct design of both the vehicle and the ECU can be used to prevent some forms of tampering. Any legislative protection to limit tampering for electric vehicles will likely be complex and may require support from enforcement authorities.

On the power assisted bicycles tested, of the two methods tried, simple changes to the vehicle were able to increase both the speed and change the behaviour to give them the characteristic of mopeds. It was also seen from the literature study that other tampering methods could give similar results although these were not tested.

Of the vehicles tested, vehicle E4 showed some of the most important results for both the electric and conventional vehicles in that it was not possible to tamper with the vehicle. Any attempt at a change to the characteristics of either the conventional engine or electric motor resulted in the activation of 'limp home' mode, limiting torque and speed. The ECU was designed with a level of protection that would afford a good level of both emissions and safety protection if implemented by the whole fleet. However, this may be not be the case for all electric vehicles, especially those equipped with a large motor limited in output. If the limitation is removed, the full performance would be available and it would be possible to realise much higher maximum vehicle speeds and acceleration rates than demanded at type-approval.

Although a change of legislative scope and reclassification of vehicles may not be require, at least without a proper study of the consequences, consistency between the legislation could be valuable. A reduced set of clauses from the L-category anti-tampering legislation could be mirrored in the machineries directive, specifically those which afford protection to protection of the environment and requirements in the electronic controls such as throttle stops.

The final point is of education of users and the markings for enforcement authorities. To be able to recognise a vehicle's category and therefore it's permitted use and required paperwork, effective markings would not only assist in catching abuses, but also educate and discourage users from tampering with their vehicles.

4.3 Future work

From this limited study two areas of further work came to light, the need for a dedicated study and a reassessment of the groupings and uses of light vehicles:

4.3.1 Dedicated testing programme

As mentioned earlier, this study was limited to look for the existence of the issues, but was unable to find all of the areas which are susceptible to tampering.

Therefore a study aimed specifically at analysing this new type of vehicle could be performed. It could be split into four parts (see Table 4-2), looking at whole vehicles and kits for both sub-L-category vehicle and performance restricted EVs. It would be beneficial for it to be performed by experienced electrical and software engineers as well as experts in bicycles.

Table 4-2: Proposed testing programme matrix

	Whole vehicle	Kit
Sub L-category	X	X
Speed restricted	X	X

It should not be assumed that if something is complex to discover or develop that it will not be possible to be widely used. Once a method has been found, simple instructions, kits, and implementation services could be made available for others to follow.

4.3.2 Societal issues

A large proportion of the stakeholders concerns revolved around the redefinition of a vehicle's category and the impact this would have to their community and industry. This project was performed from the view point of L-category legislation and therefore for an improvement to be applied in the short term, changing this definition seemed a simple step. However to full societal impact of such a change was not initially considered with this preliminary suggestion.

With the technological advances, changes to vehicle use and concerns for climate change perhaps an in-depth study into these lighter vehicles is required. Looking at many areas that separate the different types and their consequences:

- Tax
- Insurance
- Path use
- Helmet
- Passenger transport
- Viability: Lights, brakes, indicators, reflectors
- Registration
- Number plates
- Maintenance and roadworthiness

- Toll payments
- Age limits
- Safety
- Lane sharing
- Environment
- Speeds

This should not be constrained to one category or group, but all light forms of transport: bicycles (adult, child, and commuter), power assisted, rickshaws, mopeds, tricycles, and quadricycles.

Appendix V Testing report on vehicle E1 and E2

Provided by JRC-ISPRA:

"TECHNICAL REPORT: TAMPERING OF ELECTRIC BIKES PERFORMANCE LIMITATION

European Union directive 2002/24/EC exempts vehicles with the following definition from

type approval: "Cycles with pedal assistance which are equipped with an auxiliary electric motor having a maximum continuous rated power of 0.25 kW, of which the output is progressively reduced and finally cut off as the vehicle reaches a speed of 25 km/h or if the cyclist stops pedalling."

This is the de facto definition of an electrically-assisted pedal cycle in the EU. As with all EU directives, individual member countries of the EU are left to implement the requirements in national legislation.

As part of the program "Performance and driveability testing of scooters, motorcycles, tricycles and quadricycles" ETA engineTechnology has investigated the possibility to tamper the control system of two electric cycles with the following performances:

- *Vehicle number E1, L1Ae: 0.259 kW @25km/h*
- *Vehicle number E2, L1Ae: 0.283 kW @26km/h*

The tampering has been tried altering the feed-back signal to the control system of the electric motor: the simulation of an input of lower value is actually supposed to drive the power PID regulator to stabilize the vehicle over an higher speed.

This concept is theoretically correct but not easy to implement in practice, at least for an averagely skilled operator: the electronic circuitry of the control system of these two cycles is fully integrated – to keep production costs as low as possible – and is not possible to modify it.

In both cases anyway an external resistor is used to calibrate the system response and changing the Ohm value of this resistor has some influence in the control behaviour.

It has been observed that a lower resistor value is driving the system to "assist" the human effort on the pedals in a more effective and sharp way; an higher value of the resistor introduces a smoother response and softer intervention of the electric motor.

Both cycles and their electronics control system are of far-eastern manufacture and is quite possible that the strategy of control is very similar in the two cases.

On the other hand, this observed different behaviour of the electrical assistance doesn't have any influence on the maximum speed of the cycles: as soon as the maximum speed is reached the assistance is released and the speed is not exceeded also with this altered control.

We believe that the external resistor value has some actual influence on the quality of intervention of the electrical assistance but that the effective feed-back signal of the vehicle speed is not easily accessible in the integrated electronics and therefore not easily 'tamperable' for the average owner of this kind of vehicles."