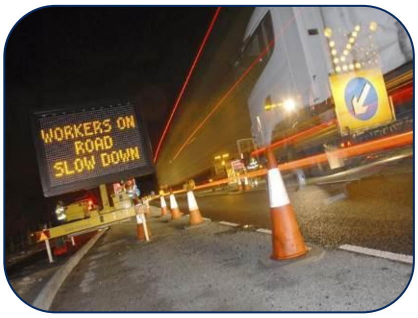
Transport Research Laboratory
Creating the future of transport



PUBLISHED PROJECT REPORT PPR627

Durability of pollution control measures for L-category vehicles

R Cuerden, A Nathanson, O Goodacre, M McCarthy, I Knight, M Muirhead and T Barlow

---

Prepared for: EC, DG ENTR / D5

Project Ref: ENTR/09/030, SI2.583952

Quality approved:

J Nelson
(Project Manager)

JNelson

I Knight
(Technical Referee)

I.Knight

M McCarthy
(Technical Referee)

© Transport Research Laboratory 2012

Disclaimer

This report has been produced by the Transport Research Laboratory under a contract with the European Commission (EC). Any views expressed in this report are not necessarily those of the EC.

The information contained herein is the property of TRL Limited and does not necessarily reflect the views or policies of the customer for whom this report was prepared. Whilst every effort has been made to ensure that the matter presented in this report is relevant, accurate and up-to-date, TRL Limited cannot accept any liability for any error or omission, or reliance on part or all of the content in another context.

When purchased in hard copy, this publication is printed on paper that is FSC (Forest Stewardship Council) and TCF (Totally Chlorine Free) registered.

Contents amendment record

This report has been amended and issued as follows:

Version	Date	Description	Editor	Technical Referee
1	November 2012	Final (excluding legislative text)	Richard Cuerden, Andrew Nathanson	Iain Knight, Mike McCarthy, Matthias Seidl

Executive summary

Vehicle emissions confer significant negative environmental and public health impacts. A series of increasingly stringent emission requirements (known as 'Euro stages') have been instrumental in reducing 'regulated emissions', including Carbon Monoxide (CO), Oxides of Nitrogen (NO_x), Hydrocarbons (HC) and Particulate Matter (PM). However, as well as the emissions measured when the vehicle is new, the overall effectiveness of emission control measures are dependent on preventing significant degradation of emissions throughout the lifetime of the vehicle.

In Europe, L-category vehicles are currently the only type approved road vehicle not subject to any requirements for the durability of pollution control systems and components at type approval. Other countries, including China, India, Japan, Singapore, Taiwan, Thailand and the USA all prescribe such durability requirements for L-category vehicles. In response to this, the European Commission adopted a proposal for a Regulation of the European Council and Parliament on approval and market surveillance of two- or three-wheel vehicles and quadric-cycles (COM(2010) 542 final) that included proposals for the introduction of minimum durability requirements for L-category vehicles.

The aim of this project was to define a mileage accumulation methodology that would appropriately test the durability of emissions relevant components and systems and to propose associated regulatory text, capable of ensuring that the tailpipe emissions of regulated pollutants are below the required Euro stage limits during and at the end of the L-category vehicle's typical life. Furthermore, the objectives were that the mileage accumulation methodology defined should result in an emissions durability test that is:

- Challenging, aimed at controlling lifetime emissions from L-category vehicles, i.e. 'work' all the emission critical components in current vehicles
- Practical, relatively easy to undertake and repeatable
- Representative of real-world usage
- Efficient and not over-burdensome on manufacturers, especially with respect to SMEs

An in-depth review of available international durability mileage accumulation cycles found that none were ideal for L-category vehicles in Europe. As a consequence, a new durability cycle, the SRC-LeCV, was developed by this project which was designed to balance the aforementioned criteria.

To address the first objective, from a literature study and stakeholder consultation key degradation mechanisms were identified as: thermal ageing of the pollution control devices (such as the catalytic converter and lambda sensor), poisoning of the pollution control devices, carbon deposits and mechanical wear, shocks and vibrations. Of these, thermal ageing of the pollution control devices was deemed important, with the temperature of those pollution control devices fitted in the exhaust being most closely related to engine load and thermal cycling, and to a lesser extent to engine or vehicle speed. Frequency of thermal cycling is linked to the pattern of the cycle and how representative this is of real-world use. It was found that carbon deposits are predominately created at low engine loads and are no longer a major issue for current engines and fuels, however still played an important role in durability both with older designs and newer fuelling techniques.

TRL compared existing US durability cycles for motorcycles (US EPA AMA) and those for cars and light goods vehicles (US EPA, EU and UN: SRC) and the world harmonised emissions laboratory test cycle for motorcycles (WMTC) in terms of the proportions of time (and distance) of the cycle spent at engine loads likely to lead to degradation of the emission critical parts. The WMTC was specifically developed to represent real-world use around the globe and therefore was used as a benchmark for both the analysis of current cycles and design of the proposed durability cycle(s). This comparison found that the SRC shared a greater similarity with the varied real-world use represented in the WMTC emission cycle than the AMA, meaning that the SRC was a better basis for the design of a cycle compatible with L-category vehicle use.

Testing carried out by the Commissions Joint Research Centre (JRC) according to the WMTC, EDC / UN Regulation 47 and EDC / UN Regulation 40 emission test cycles showed that in these tests exhaust temperatures adjacent to the catalytic converter did not exceed 850°C. Previous studies have shown that modern catalysts remain durable after prolonged and realistic exposure to temperatures around 950°C and that current engine management systems are capable of protecting the catalyst and other exhaust components if the exhaust temperature rises above the design limit.

Using the key degradation mechanisms identified as important for the entire L-category fleet, a range of four cycles was developed. These "phase 1" cycles were reassessed against the initial objectives. This found that the burden to manufacturers was still significant and therefore was given greater priority over the inclusion of low engine load section used for carbon deposit creation. A "phase 2" cycle was then developed which removed two slower speed sections from the test, changing them from 7 lap to 5 lap cycles which could be completed in a shorter period of time. A comparison of estimated test cost between the SRC-LeCV (5 and 7 lap) and US AMA test cycle found that the SRC-LeCV was more cost-effective (5 lap) or generally equivalent (7 lap).

These "phase 2" cycles, including a categorisation system to match vehicles against the appropriate cycles, were published. Stakeholders were then able to provide feedback and this process raised a range of issue with the new cycles; the categorisation system was not able to appropriately class the vehicles and some special fuelling regimes were not sufficiently addressed (such as mixture enrichment to protect the catalyst and DFCO).

A validation of the proposed cycles was carried out to ensure that vehicles across the L-category range could follow the relevant cycle and to check that the cycle invoked the intended ageing mechanisms. The result of this validation was that cycles 1 and 2 required further adjustment, the categorisation system was replaced with one aligned with that of the UN GTR No. 2 (WMTC) and changes were made to the instructions to both simplify the execution of the test and better ensure that the intentions of the test were carried out fully. These changes are presented as "phase 3" and were revalidated to demonstrate their feasibility.

The main conclusions of the study can be summarised as follows:

- The US EPA AMA motorcycle durability cycle developed in the 1970s does not reflect the current ageing mechanisms of the emissions system as well as the SRC durability cycle dedicated for cars.
- The SRC durability cycle for cars does not fully cater for the characteristics and performance of the entire L-category fleet. Therefore, a modified version of the

SRC for passenger cars has been developed for L-category vehicles, the SRC-LeCV.

- The SRC-LeCV contains relevant degradation mechanisms for both modern pollution control devices fitted on L-category vehicles and less complex systems still in use, including: thermal ageing (highest priority), poisoning, mechanical wear of the engine (assumed worse at higher engine speed and load), carbon deposits (from bad combustion at low load engine operation etc.) and thermal shock from deceleration fuel cut-off (DFCO).
- The SRC-LeCV follows a journey which represents an averaged representation of real-world use, so that the proportions of degradation mechanisms are not accelerated but balanced.
- The SRC-LeCV durability cycle has been demonstrated to be more cost-effective than the US durability standards for cars and motorcycles, and has been validated with respect to real-world applicability by correlation with the WMTC emission data.
- A balance was drawn between the various objectives of the programme, with special emphasis placed on a test cycle which induces relevant and realistic ageing and which can be carried out most efficiently.
- Options for the application of the durability cycle comprise comparison of emissions with limit values specified by COM 542(2010):
    - a) Direct measurement of emissions after the appropriate full durability distance specified by COM 542(2010)
    - b) Extrapolation of emission measurements taken after 50% of appropriate durability distance specified by COM 542(2010)
    - c) Initial emission measurements (Type I test) multiplied by fixed DFs specified by COM 542(2010).
- Four SRC-LeCV durability cycles were developed to cover all of the varying capabilities and designs of L-category vehicles. The final SRC-LeCV cycles are presented in Appendix Q.
- A supplementary test programme was carried out in which the SRC-LeCV was applied to a wide range of L-category vehicles as a validation exercise, investigating technical feasibility and providing confirmation of the theoretical analysis and conclusions contained within this report.
- The result of this validation was that while cycles 3 and 4 were shown to be technically feasible and appropriate for use, cycles 1 and 2 required further adjustment and the categorisation system needed further adjustment. The required changes were made and reported. Final revisions of these cycles and categorisation system were revalidated to demonstrate their feasibility.
- The results of this revalidation of changes made to cycles 1 and 2 have shown that they are now technically feasible and appropriate for use.
- Estimates for the time duration required to run the full durability distances were made. These show that the speed capabilities of the vehicle and average total vehicle milage set in EC, 2010 are the primary factors in the time taken to complete the final cycles.

Table of Contents

1 Introduction

1.1 L-category vehicles

On 4th October 2010, the European Commission adopted a proposal for a Regulation of the European Council and Parliament on approval and market surveillance of two- or three-wheel vehicles and quadric-cycles (COM(2010) 542 final[1]). These vehicles are grouped under the family name "L-category vehicles", where the "L" stands for "Light". A wide range of different vehicle types are within the scope of this regulation, among others: powered cycles, two- and three-wheel mopeds, two- and three-wheeled motorcycles, motorcycles with side cars, commercial tricycles, and also four-wheel quadricycles and 'car-like' four-wheeled vehicles, referred to hereafter as 'quadri-mobiles'. The L-category vehicles are further divided into 7 sub-categories (L1e to L7e, where: L = light, # = sub-category, e = Europe).

Appendix A provides a detailed classification of L-category vehicle characteristics.

1.2 Vehicle emissions durability requirements

Emissions, both from the exhaust system and evaporative emissions from the fuel system, are known to have negative environmental and public health impacts. A series of increasingly stringent tailpipe emission requirements have been instrumental in reducing regulated emissions, including carbon monoxide (CO), nitrogen oxides (NO_x), hydrocarbons (HCs) and particulate matter (PM). If the intentions of overall emission control are to be met, the emissions are important not only when the vehicle is new, but also as the distance the vehicle travels increases, where significant degradation should be prevented.

For this reason, emissions control can be divided into different areas:

- The emissions performance of a new vehicle measured at type approval. The test types are shown in the glossary.
- The designed degradation of the emissions performance of the vehicle, measured at type approval by testing the change in emissions performance before, after and at intermediate stages of a durability test designed to quickly accumulate distance travelled and age systems and components in a manner that remains representative of normal service and use. Ageing means mechanical, chemical and thermal wear of the emissions critical components such as the catalyst material within catalytic converters, lambda sensors and parts that make up the engine's combustion chamber.
- The in-service emissions performance, measured during routine maintenance, roadside enforcement and, in a few member states, during roadworthiness testing.

In Europe, L-category vehicles are currently the only type approved road vehicle not subject to any requirements for the durability of pollution control systems and

---

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

components at type approval. Other countries, including the USA, India, China, Thailand, Taiwan and Singapore, prescribe such durability requirements for L-category vehicles.

Favre C (2009) conducted a durability test on a 500 cm^3 one cylinder scooter and found that after only 2,000 km the CO emissions exceeded the Euro 3 limit and NO_x type approval limits began to be exceeded after 5,000 km. Durability was stopped after 20,000 km as NO_x emissions had reached twice the Euro 3 limit. Although this is only one example, it demonstrates that in practice it is possible that at least some older vehicles in use may emit more than twice the limits after 20,000 km.

Ideally, the vehicles components and systems would be designed in such a way that the emissions performance would remain constant as new over the whole vehicle life. While this is not likely to be possible with current technologies, this research programme aimed to identify a cost effective solution for demonstrating certain minimum standards of durability of the emission controls.

Vehicle emission deterioration will be influenced by the quality and functionality of exhaust after-treatment components and systems such as catalytic converters and lambda sensors. In addition, as engines wear, this can increase the raw emissions from the engine even if the exhaust after-treatment systems do not significantly deteriorate. Raw emissions are those pollutants that are contained in the exhaust gas passing through the exhaust valves but not yet entering into the exhaust after-treatment system. Raw emissions tend to increase over vehicle life due to mechanical wear of engine components. Therefore, owing to catalyst efficiency reduction and at the same time increased raw emissions over vehicle life future durability requirements should not just apply to exhaust after-treatment systems, but to the whole vehicle.

The premise of this programme is that, as vehicles age, it is preferable that their emissions should only deteriorate according to pre-engineered efficiency losses of emission relevant systems and components. The relative importance of the different degradation mechanisms, which contribute to the emissions performance over the whole vehicle life, including the necessity to replicate thermal ageing is discussed further in Section 2.1. A key part of the durability requirement is, as far as practicable, to replicate relevant real-world driving conditions, which should encompass the higher range of operating temperatures and the associated cycling of temperatures and the thermal shock that vehicles experience during day to day operation. Although vehicle speed correlates well with engine speed, it does not correlate well with thermal exposure. Therefore, the importance of the relationship between engine load (the pressure on the piston(s) owing to combustion) and catalyst temperature is emphasised within this programme.

However, measures to demonstrate that L-category vehicles meet a minimum emission durability requirement at type approval, should be implemented in a way that balances this preference with the need not to excessively burden the manufacturer. This is because durability testing is, by its nature, time consuming and can often only be undertaken towards the end of the design and development process, thus having the potential to significantly affect the time and cost required to bring new models to market. The precise terms of reference for this research programme are guided by the COM (2010) 542 final proposal.

1.3 Aims and objectives

The aim of this study was to define a mileage accumulation methodology that would appropriately test the durability of emissions relevant components and systems and to propose associated regulatory text, capable of ensuring that the tailpipe emissions of regulated pollutants are below the required limits (Euro 3, 4 or 5, see Appendix E) at the end of the L-category vehicle's typical life.

The objectives were, that the mileage accumulation methodology defined should result in an emissions durability test that is:

- Challenging – measure aimed to control the life time emissions from L-category vehicles
    - 'work' all the emission critical components in current vehicles.
- Practical – relatively easy to undertake and repeatable
    - e.g. can't be too complicated, but must be flexible, so different types of test procedures can be employed to accumulate the durability distance whilst following the cycle (e.g. on dynamometer, test track or public road).
- Representative of real-world usage
    - e.g. trip based journey data; referenced to relevant parts of WMTC emission cycle which was created to represent real-world driving characteristics (see Section 1.4.3).
- Efficient and not over-burdensome on manufacturers, especially SMEs
    - Durability testing may require the use of expensive facilities, may take considerable precious development time and typically has a direct effect on the time taken to bring new vehicle models to market. Minimising the time it takes to accumulate the distance therefore has a direct effect on costs and development time for new models.

1.4 Background

The durability of L-category vehicles has been defined as:

Durability means the ability of components and systems to last so that the environmental performance as laid down in Article 21 and Annex V can still be met after a mileage as defined in Annex VII [reproduced in Table 1-1] *and so that vehicle functional safety is ensured if the vehicle is used under normal or intended circumstances and serviced according to the manufacturer's recommendations.* EC, 2010

1.4.1 COM(2010) 542 durability requirements (Article 21)

The principal terms of reference for this project are detailed in Article 21, paragraph 3. This has been reproduced below for completeness:

Manufacturers shall ensure that type-approval requirements for verifying durability requirements are met. At the choice of the manufacturer one of the following durability test procedures shall be used to provide evidence to the type-approval authority that the environmental performance of a type-approved vehicle is durable:

(a) Actual durability testing with full mileage accumulation:

> *The test vehicles shall physically accumulate the full distance set out in part A of Annex VII and shall be tested in accordance with the procedure laid down in test type V as set out in the delegated act referred to in paragraph 12. The emission test results up to and including the full distance set out in part A of Annex VII shall be lower than the environmental limits set out in part A of Annex VI.*

(b) Actual durability testing with partial mileage accumulation:

> *The test vehicles shall physically accumulate a minimum of 50% of the full distance set out in part A of Annex VII and shall be tested in accordance with the procedure laid down in test type V as set out in the delegated act referred to in paragraph 12. As specified in that act, the test results shall be extrapolated up to the full distance set out in part A of Annex VII. Both the test results and the extrapolated results shall be lower than the environmental limits set out in part A of Annex VI.*

(c) Mathematical durability procedure:

> *For each emission constituent, the product of the multiplication of the deterioration factor set out in part B of Annex VII and the environmental test result of a vehicle which has accumulated more than 100 km after it was first started at the end of the production line shall be lower than the environmental limit set out in part A of Annex VI.*

In summary, COM (2010) 542 final proposes that manufacturers shall ensure that the type approval requirements for verifying durability requirements are met. The proposal allows the manufacturer to choose one of three options for verifying durability performance. These are:

- Actual full distance durability mileage accumulation (a);
- Part mileage accumulation using the durability cycle defined in (a) to demonstrate the validity of the ageing process; or
- Multiplying assigned deterioration factors (DFs) with de-greened emission results.

The proposed durability mileages for the L-category vehicle categories and sub-categories (set out in part A of Annex VII of COM(2010) 542 final) are shown in Table 1-1, and were fixed with respect to the scope of this study.

Note: in further development of the new legislation there have been changes to the durability distances, deterioration factors and emission limits.

Table 1-1: Proposed durability mileages for L-category vehicles

Vehicle category	**Vehicle category name**	**Euro 3 durability mileage (km)**	**Euro 4 durability mileage (km)**	**Euro 5 durability mileage (km)**
L1Ae	- Powered cycle	5,000	5,500	6,000
L1Be L2e L6Ae	- Two-wheel moped - Three-wheel moped - Light on-road quad	10,000	11,000	12,000
L3e L4e L5e L6Be L7Be	- Two-wheel motorcycle, with and without sidecar (v_{max}<130 km/h) - Tricycle - Light quadri-mobile - Heavy quadri-mobile	18,000	20,000	30,000
L3e L4e L7Ae	- Two-wheel motorcycle, with and without sidecar (v_{max}>130 km/h) - Heavy on-road quad	30,000	35,000	50,000

Further, the deterioration factors set out in part B of Annex VII of COM(2010) 542 final are also treated as fixed with respect to the scope of this evaluation of suitable durability emission tests. The values are reproduced in Table 1-2 and Table 1-3.

Table 1-2: Proposed deterioration factors (DFs) for L-category vehicles Euro 3 and 4 steps (Euro 4 and 5 steps for motorcycles L3e)

Vehicle category	**Vehicle category**	**Euro 3 DF(-)**				**Euro 4 DF (-)**			
		CO	**HC**	**NO_x**	**PM**	**CO**	**HC**	**NO_x**	**PM**
L1e-L7e	All	1.3	1.2	1.2	1.0	1.3	1.2	1.2	1.1

Table 1-3: Proposed deterioration factors (DFs) for L-category vehicles Euro 5 step (Euro 6 step for motorcycles L3e)

Vehicle category	**Vehicle category**	**Euro 5 DF(-)**							
		CO	**THC**		**NMHC**		**NO_x**		**PM**
			PI	CI	PI	CI	PI	CI	CI
L1e-L7e	All	1.5	1.3	1.1	1.3	1.1	1.3	1.1	1.0

1.4.2 L-category fleet stock

The composition of the L-category vehicle fleet in Europe is diverse, ranging from electrically powered cycles, more conventional petroleum powered mopeds and motorcycles (Powered Two Wheelers, PTWs), tricycles, off-road quads (also called All-Terrain Vehicles, ATVs) and quadri-mobiles (mini-cars). The largest segment of the L-category vehicle stock in Europe is comprised of the PTWs, or essentially L1Be mopeds and L3e motorcycles. A large share of the L3e motorcycle fleet is composed of low and medium performance variants. There are some differences in how vehicles are defined between countries, but Table 1-4 provides a high level summary of the 'motorcycle' stock across Europe and compares this with Japan and the USA.

There are limitations associated with the available data, but in 2008, there were approximately 34 million registered or licensed motorcycles in the European Union, and the trend has been for the vehicle stock to have generally increased in the respective countries over the last 10 years.

1.4.3 Real-world characteristics of the use of L-category vehicles

A key consideration when developing a durability emission test cycle is that it reflects, as far as practicable, the real-world driving experience of the individual vehicles. Indeed, a principal objective of this work programme is that it should be representative of real-world usage. Therefore, the project references the world harmonised motorcycle test cycle (WMTC), because this emission laboratory test cycle was created to represent the best source of data to describe real-world driving characteristics.

1.4.3.1 *World harmonised motorcycle test cycle (WMTC)*

The WMTC was designed by taking the driving patterns of users from across the world and combining them into a way which can be used to represent the real-world use of L3e vehicles. However, as an emissions driving cycle (a Type I test), it has to be both repeatable and reproducible, so has tight tolerances of ±1 km/h and ±1 second. To achieve this requirement; gear changing, acceleration rates, deceleration rates and maximum speeds were adjusted to be slightly less demanding then was shown from the real-world driving used in its development.

Three versions of the cycle were assessed; stage 1 (the currently applied stage for type approval in the EU), stage 2 and the revised cycle (stage 3). The changes that have occurred have been with the gear changing regime, easing the acceleration rates on the reduced speed versions for smaller vehicles and an amendment to the vehicle classes.

Within the WMTC shown in Figure 1-1 there are 3 parts, relating to slow, medium and fast vehicle speeds, plus a reduced speed version of each of the three, this give a total of six individual parts which can be selected from to build a test cycle. The UNECE Global Technical Regulation (GTR) No 2, which encompasses the WMTC driving cycle plus the testing procedures in a legislative framework, defines three classes of vehicle, with five sub classes to determine which parts to perform; these are summarised in Appendix D.2.

Table 1-4: Vehicle licensing Statistics: motorcycle stock[2,3] by country[4]

Country	**1998 (1,000s)**	**2008 (1,000s)**	**Stock per 1,000 population (2008)**
Austria	601	691	82.7
Belgium	241	388	36.1
Bulgaria	516	107	14.1
Cyprus	44	43	54.2
Czech Republic	..	893	85.3
Denmark	112	205	37.2
Estonia	6	18	0.4
Finland	173	422	79.1
France	2,321	2,704	43.3
Germany	4,909	5,852	71.4
Greece	..	1,389	123.3
Hungary	..	142	14.1
Irish Republic	24	39	8.9
Italy	6,823	9,189	153.0
Latvia	19	51	22.7
Lithuania	19	46	13.6
Luxembourg	31	40	81.6
Malta	15	14	34.8
Norway	184	296	61.8
Netherlands	451	1,480	89.7
Poland	820	1,607	42.1
Portugal	301	550	51.8
Romania	246	72	3.3
Slovak Republic	101	70	13.0
Slovenia	..	82	40.4
Spain	1,361	4,912	107.2
Sweden	286	554	59.8
Switzerland	435	637	82.6
United Kingdom	828	1,322	21.5
Japan	..	3,502	27.4
USA	3,879	7,753	25.5

---

[2] *There are differences in definition between countries which limit comparisons*

[3] *Includes mopeds and three-wheeled vehicles but excludes pedal cycles*

[4] *Source: EU Energy and Transport Figures (EUROSTAT); Ministry of Land, Infrastructure and Transport, Japan; Highway Statistics, USA.*

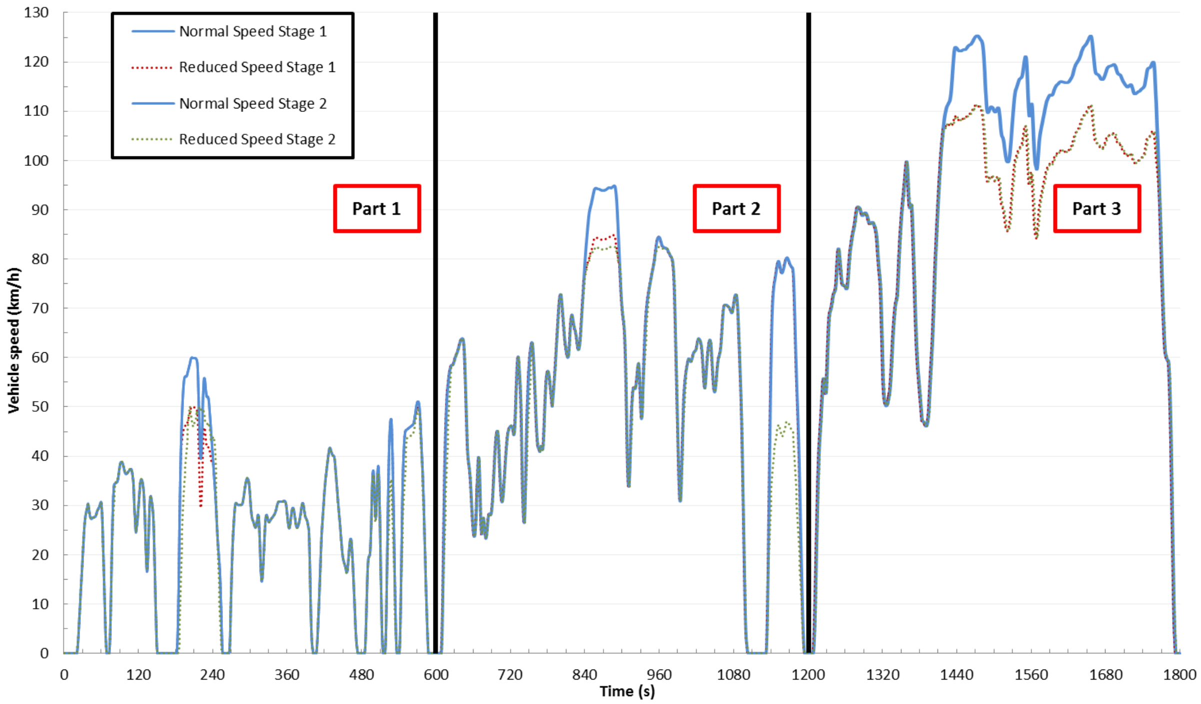


Figure 1-1: WMTC Emission Cycle (stage 1 and 2), normal and reduced vehicle speed[5]

1.5 Overview of study methodology and report structure

The study has brought together evidence from pertinent stakeholders, emission test results, theoretical assessments and a literature review, and used these findings to develop a durability test cycle (SRC-LeCV).

The report is structured to reflect the tasks which led to the development of the cycle. This includes a full description of the cycle and a comparison of the duration and costs of the SRC-LeCV with the US EPA AMA durability test, for the different sub-categories of L-category vehicles. To aid the reader to navigate through the report, the remaining chapters are summarised below:

- **Chapter 2: Identification of important durability cycle actions**
    - A theoretical assessment of degradation mechanisms and their relative importance and a review of emission cycle test data.
- **Chapter 3: Existing durability cycles**
    - A presentation of the existing durability cycles and a comparison of their advantages and disadvantages.
- **Chapter 4: Development of the SRC-LeCV ("phases 1 and 2")**
    - The proposed cycle was developed by analysing the two main durability (test Type V) driving cycles and emissions driving cycles (test Type I), with respect to how the vehicle may be used in the real-world over its life. Special attention was paid towards the consequences of repeatable

---

[5] http://www.unece.org/trans/main/wp29/wp29wgs/wp29gen/wp29glob_registry.html

    - actions with respect to their probable effect on emission critical components.
    - This chapter highlights the development of "phases 1 and 2" of the SRC-LeCV cycle.
- **Chapter 5: Application of durability emission requirements**
    - This chapter provides an overview of how the SRC-LeCV mileage accumulation cycle, developed in Chapter 4, should be used in practical terms and thus form an integral element of the durability of pollution control devices Type V test procedures (EC 692/08).
- **Chapter 6: Duration and costs for US EPA and SRC-LeCV**
    - An independent analysis of the costs of undertaking durability testing was undertaken. The aim was to quantify the likely costs and time periods required and to assess whether the SRC-LeCV is a cost effective durability test method compared with the US EPA AMA cycle.
    - This analysis is intended to be indicative rather than a comprehensive estimate of the average cost to industry or specific sectors of it, for example, it does not include the value of the vehicle. Though this type of omission will affect the absolute accuracy of the test costs, it should not affect the relative comparison of the cost of one type of test, or one changed variable within those tests, to another.
- **Chapter 7: Validation and derivation of SRC-LeCV ("phase 3")**
    - After the completion and publication of the phase 2 cycles, stakeholders highlighted the requirement of a validation programme before the implementation of these cycles to commercially produced vehicles.
    - Therefore, the EC commissioned a validation programme. The scope of the study included an experimental programme in which the feasibility of the designed Test Type V durability test cycles for L-category vehicles (SRC-LeCV "phase 2") was assessed.
    - The results from the validation exercise led to a re-design of the SRC-LeCV and the methodology behind this and "phase 3" of the Type V durability test cycles are presented.
- **Chapter 8: Durability of pollution control devices requirements**
    - This section provides a summary of the draft text for the Test Type V requirements (durability of pollution control devices); it is included to help the reader understand further how the SRC-LeCV cycles will be incorporated into the wider requirements.
    - In principle, the specific implementation of requirements should be in line with existing durability procedures wherever possible. The chapter presents a number of important considerations with respect to the implementation of the durability procedure

- **Chapter 9: Conclusions and recommendations**
    - A balance was drawn between the various objectives of the programme, with special emphasis placed on:
        - **Representative of real-world usage**
        - **Relevant ageing mechanisms**
        - **Efficient and not over-burdensome on manufacturers, especially SMEs**
    - The final four durability cycles which are collectively known as the SRC-LeCV are designed to be as cost effective as practicable.
- **Chapter 10: Further work**
    - At the time of writing, revalidation work of the SRC-LeCV “phase 3” is being undertaken.
    - The chapter suggests continual improvement and gives some examples of areas where this may be appropriate to consider.

2 Identification of important durability cycle actions

The objectives of the study require a future European durability cycle to be challenging with respect to actively exercising all the emissions critical components in current vehicles, but also to be practical to undertake and representative of real-world driving conditions. This chapter examines the driving actions which are important and can lead to degradation from a theoretical standpoint and from an examination of data following an emission cycle experimental programme.

2.1 Theoretical assessment

The durability cycles are intended to cause wear on the vehicle representative of the usual wear and tear incurred over a typical whole life driving distance. This is to demonstrate that the vehicle can continue to stay below the emission limits for their entire useful life.

Many areas of the vehicle, and especially the engine and exhaust components, wear and they are each affected in varying amounts by differing driving styles. In general however, the higher the engine speed and engine load, the higher the mechanical wear. Therefore the entire durability driving cycle is made up of many parts, each of which is designed to represent those styles and task vehicle and power-train in that area. The wide range of vehicles within the L-category means that the way in which these vehicle speeds and acceleration and deceleration rates translate to wear on the vehicle's components depends on the configuration of the vehicle and the maximum engine speed and load it is designed to achieve.

By raising the priority of some driving styles found within real-world driving it may be possible to accelerate certain types of wear and consequently reduce the overall driving time and/or distance. This reduction in test length could be used to reduce the cost implications of the test and the time required to bring a new vehicle type to market. This is because the durability test is on the critical path of development so reduced test time directly affects time to market.

L-category vehicle engines typically produce their maximum power by high engine speed and their maximum torque at medium to higher engine speeds, whereas passenger car engines generally only reach half the revolutions, or less, than the maximum engine speed of motorcycles. The combustion temperature and exhaust temperature are more or less proportional with torque and it is widely reported (Twigg M., 2002) that high exhaust temperatures lead to fast thermal ageing of emission relevant components.

2.1.1 Degradation mechanisms

A theoretical assessment of which degradation mechanisms of pollution control devices should be assessed as part of a vehicle durability test was undertaken and the main findings are summarised below.

2.1.1.1 *Thermal ageing*

Thermal exposure is reported Twigg M., 2002 to be the most important degradation factor to emission relevant components. This includes heat from exhaust gasses, the additional heat coming from the exothermic reaction in the catalyst, but also temperature cycling causing thermal shock, for example, from a ambient temperature start, perhaps 20°C, the catalyst can heat up to 800–900°C within one minute. In addition coast-through decelerations leading to fuel cut-off can also result in thermal shock because cold intake air comes into contact with the hot catalyst, causing the temperature to fall rapidly from operating temperature (850 – 950°C) to significantly lower levels.

With respect to catalyst temperature there is a good correlation with engine load, but a weaker one with engine speed and vehicle speed. This can be explained with the following example; if we consider a vehicle driving at a constant 100 km/h uphill, when at a given point the slope increases moderately, then in order for the vehicle speed (and engine speed) not to decrease, the rider must further open the throttle. Consequently more air flows in to the engine, which needs more fuel, leading to higher pressure on the pistons, whilst the engine speed remains unchanged, but consequently leads to higher combustion temperatures. The higher combustion temperatures cause more heat to be evacuated via the engine cooling system and also result in higher exhaust temperatures leaving the engine into the exhaust system. The higher exhaust temperatures lead to higher lambda sensor and catalyst temperatures, which leads to greater thermal exposure of pollution control devices. If operating temperatures are at a higher level, then the magnitude of the temperature drop during deceleration with fuel cut-off will be greater, leading to a higher impact of thermal shock and temperature cycling.

With respect to thermal ageing, it is important to take into account engine load. High engine loads can be achieved from a variety of conditions, including:

- during low average vehicle speeds experienced in stop and go traffic conditions, where acceleration rates are relatively high; and
- when applying fuel efficient driving styles, such as early shifting to high gears.

High engine loads cannot be achieved during low vehicle speed steady state operation like that simulated in the AMA EPA cycle (see Section 3.2). Therefore, in order to simulate higher, but not excessive loads for each category (for instance, full throttle in a higher performance vehicle may be an infrequent occurrence, but for a lower performance vehicle such as a moped, full throttle would not be excessive or infrequent), higher average vehicle speeds than in traffic are needed or longer timeframes while accelerating, to compensate for the frequency of stop and go in modern traffic.

2.1.1.2 *Poisoning*

Poisoning can be caused by combustion of lubrication oil, or by certain fuel additives or by other typically used substances. For example, lambda sensor poisoning can be caused by the use of silicon based repair kits on intake manifolds or by "wrong" intake system specifications by replacement component manufacturers etc. The impact of poisoning may partly recover during high engine load operation (heat exposure), however the more fuel that is flushed through the system during high load operations, the more emission relevant components are exposed to the adverse effects of poisoning.

2.1.1.3 *Carbon deposits*

Carbon deposits can be produced due to poor engine design, poor fuel quality, and owing to low combustion temperatures, typically at low engine load operation. Carbon build-up inside the combustion chamber of the engine is typically formed at low engine load (low combustion temperature) and is generally caused by old fashioned combustion chamber design and poor fuel quality. Carbon deposits were often reported on valves, spark plugs and piston rings and this is not a significant concern anymore owing to improved engine design and fuel quality over the last 2 decades.

2.1.1.4 *Mechanical wear, shocks and vibrations*

Mechanical wear of engine components can lead to higher raw emissions. Mechanical shocks and vibrations even under normal use conditions and with the vehicle maintained according to the manufacturer's instructions, can cause damage to emission critical components, hence increasing raw emissions from the vehicles.

2.2 Information from emission cycle testing

2.2.1 Testing overview

Testing was performed by JRC on a range of 12 L-category vehicles to typical emission cycles including UN Regulation No 40, UN Regulation No 47 and WMTC. The tests that were performed with each vehicle are shown in Table 2-1.

The parameters recorded during the testing included (where available):

- Roller vehicle speed
- Engine vehicle speed
- Exhaust flow rate
- Vehicle wheel power
- Oil temperature
- Temperature pre- and post- catalyst
- Lambda
- HC, CO, CO_2, O_2, NO_x, NO, CH_4, PM emissions
- Fuel consumption
- Fuel flow rate
- Intake air flow rate or throttle position

Table 2-1: Tests undertaken by JRC

Vehicle	Category	Category name	Test Cycle 1	Test Cycle 2
1	L1Ae	Powered cycle	R47	Revised WMTC Part 1 x 2
2	L1Be	Two-wheel mopeds	R47	Revised WMTC Part 1 x 2
3			R47	Revised WMTC Part 1 x 2
4			R47	Revised WMTC Part 1 x 2
5	L3e – A1	Low performance motorcycle	WMTC Stage 1 Part 1 and 2	WMTC Stage 2 Part 1 and 2
6	L3e – A3	High performance motorcycle	WMTC Stage 1 Part 1, 2 and 3	WMTC Stage 2 Part 1, 2 and 3
7	L5Ae	Tricycle	R40	WMTC Stage 2 Part 1 and 2
8	L5Be	Commercial tricycle	R40 without EUDC	Revised WMTC Part 1 x 2
9	L6Ae	Light on-road quad	R47	Revised WMTC Part 1 x 2
10	L7Ae	Heavy on road quad	R40 without EUDC	WMTC Stage 2 Part 1 and 2
11	L7Be	Heavy mini-car[6]	R40 without EUDC	WMTC Stage 2 Part 1 and 2
12			R40 without EUDC	WMTC Stage 2 Part 1 and 2

2.2.1.1 *Results*

Figure 2-1 to Figure 2-6 show that as the vehicle speed increases, the temperature pre and post cat increases (increased engine speed and load).

The position where the temperature was recorded relative to the catalytic converter could vary per vehicle, but nonetheless the trend data is important, as well as the absolute values recorded.

Further testing data and information is provided in Appendix G.

---

[6] The terminology for "mini-cars" has since been changed to "quadri-mobile"

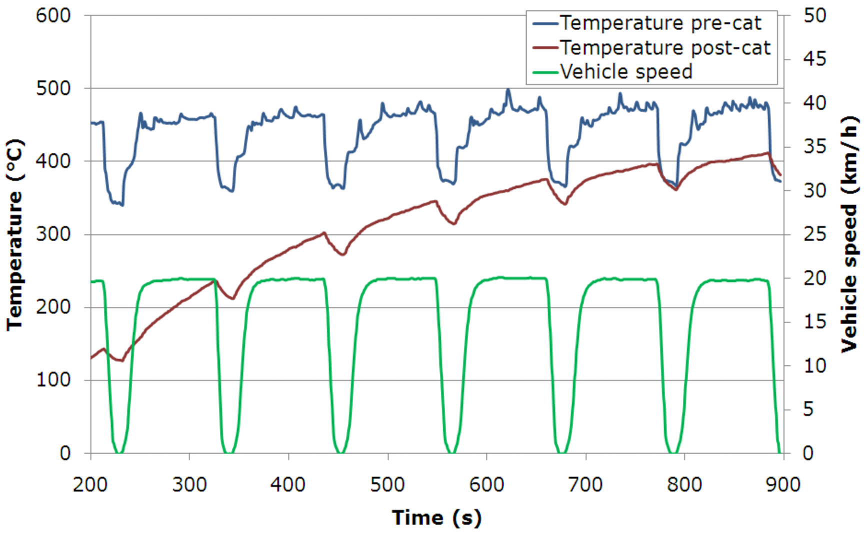


Figure 2-1: Vehicle 1: temperature and vehicle speed for L1Ae for R47 cycle

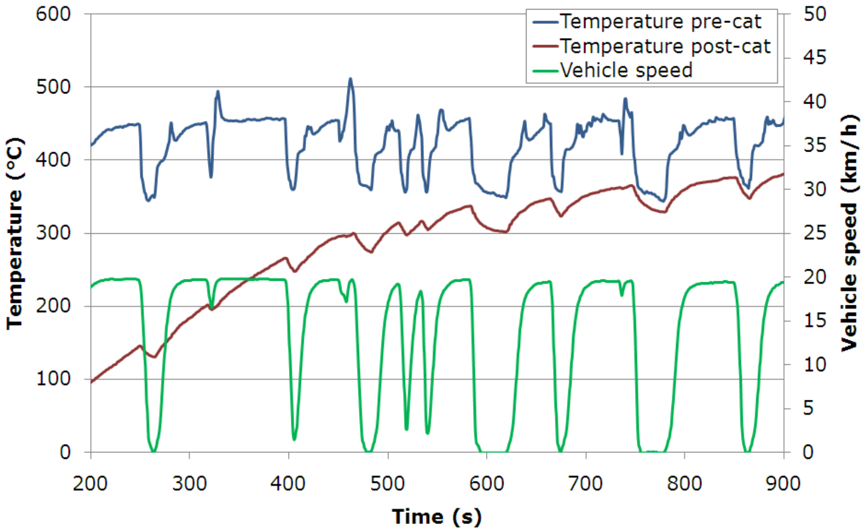


Figure 2-2: Vehicle 1: temperature and vehicle speed for L1Ae for revised WMTC cycle

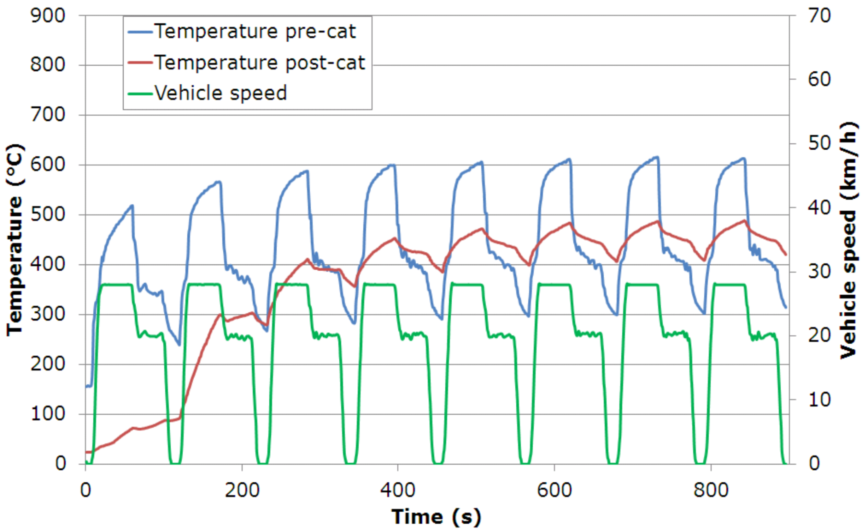


Figure 2-3: Vehicle 2: temperature and vehicle speed for L1Be for R47 cycle

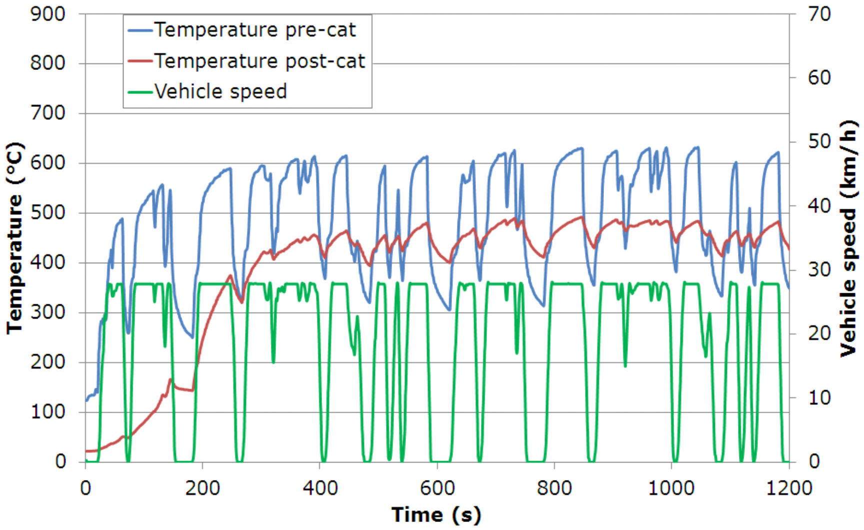


Figure 2-4: Vehicle 2: temperature and vehicle speed for L1Be for revised WMTC cycle

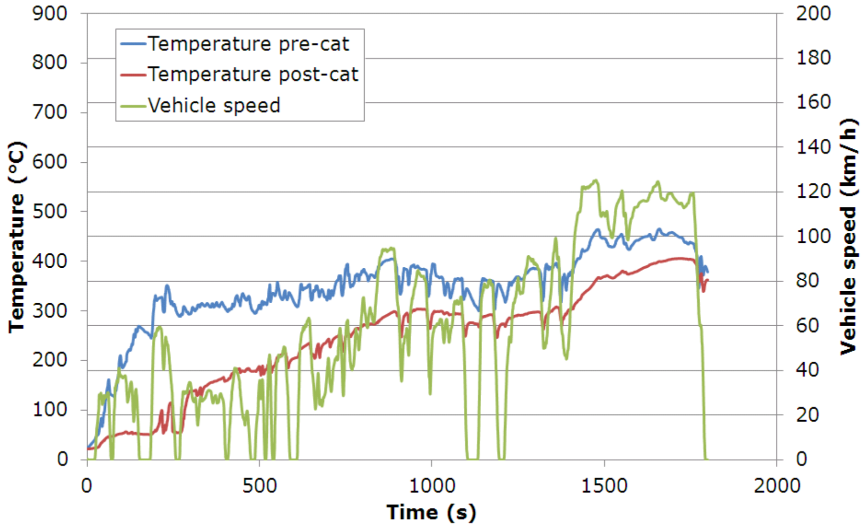


Figure 2-5: Vehicle 6: temperature and vehicle speed for L7Ae for WMTC stage 2 cycle

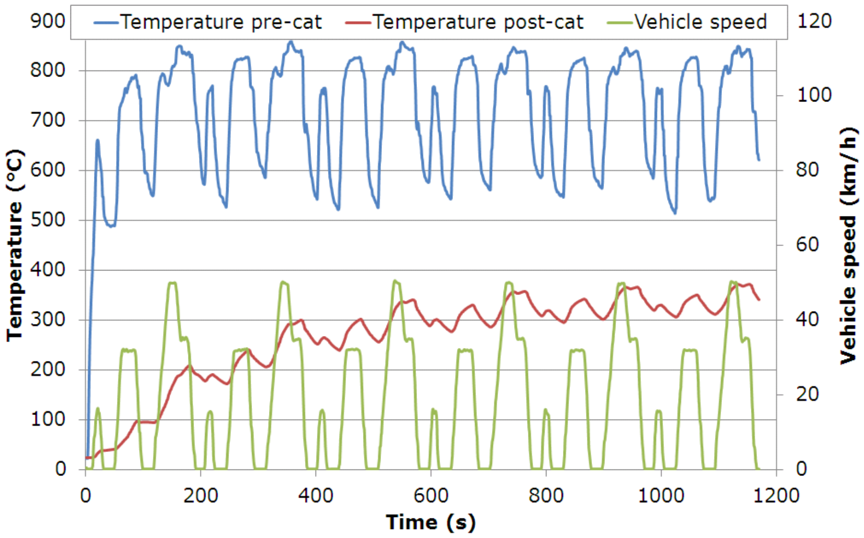


Figure 2-6: Vehicle 6: temperature and vehicle speed for L7Ae for R40 cycle

The majority of the temperatures pre and post catalyst were below 650°C, with the exception of the L7Ae, where the pre catalyst temperatures were over 800°C.

Figure 2-7 to Figure 2-12 show that the HC output level (un-burnt fuel etc.) is highest when the vehicle is decelerating. These spikes are likely to be due to continued fuel delivery at closed throttle. The high HC level is more notable in the larger vehicles than the smaller vehicles, but this is not a problem as the exhaust flow is very low, therefore not giving a high contribution to the overall results. The same is true for idle. Even if the spikes are enormous in idle, the overall effect is likely to be negligible on the total test results in comparison to high spikes during accelerations and steady states, owing to low exhaust flow under idle and deceleration.

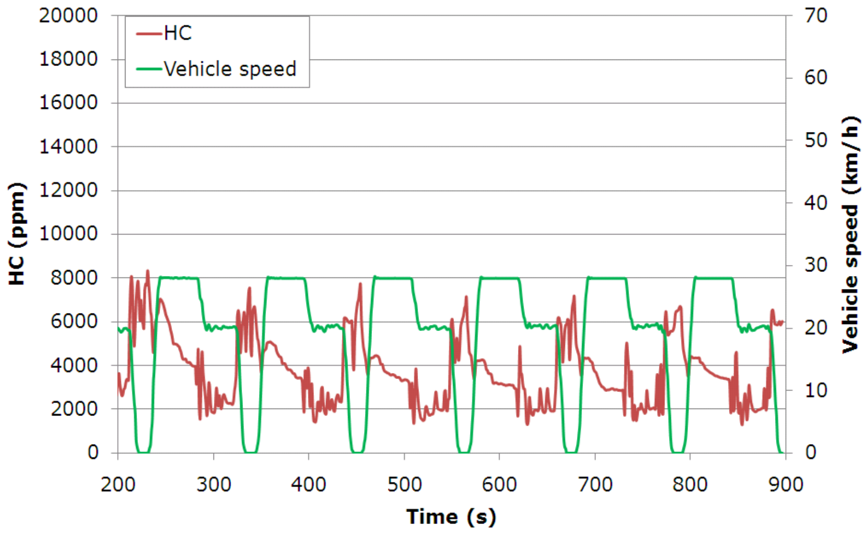


Figure 2-7: Vehicle 4: HC output for L1Be for R47 cycle, time based trace

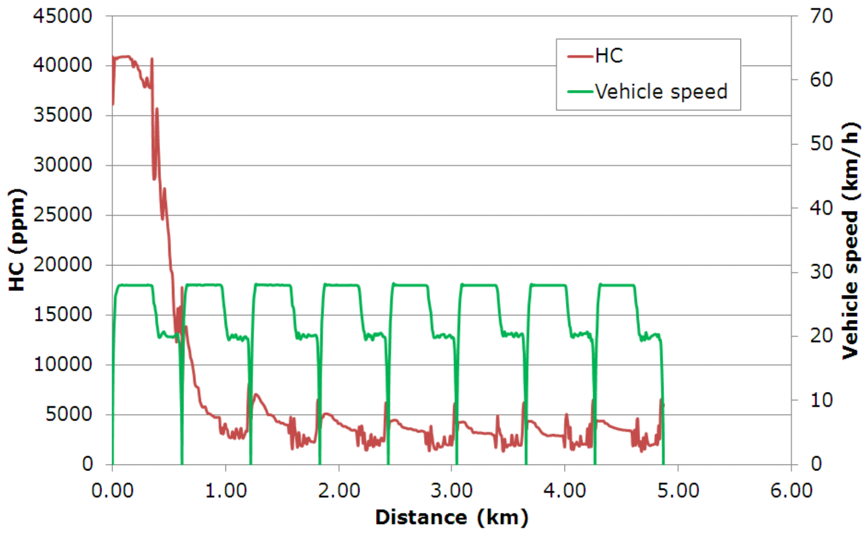


Figure 2-8: Vehicle 4: HC output for L1Be for R47 cycle, distance based trace

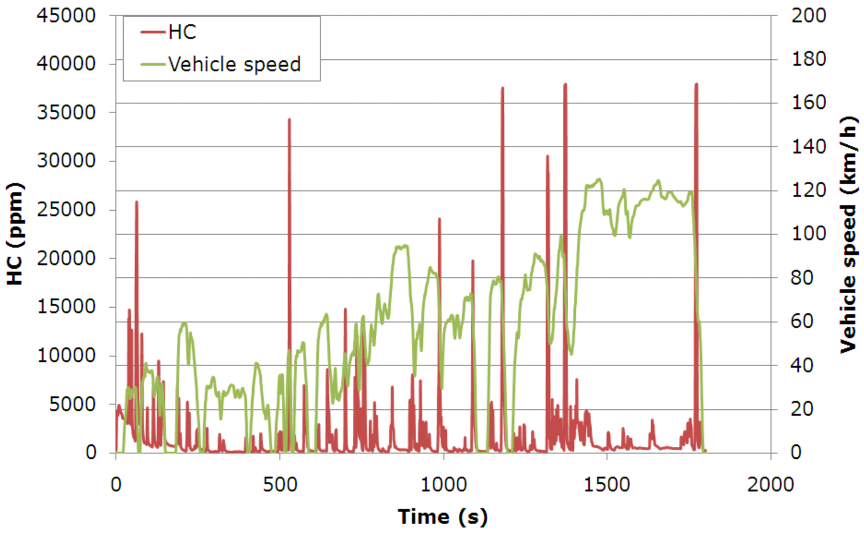


Figure 2-9: Vehicle 6: HC output for L3e-A3 for WMTC cycle, time based trace

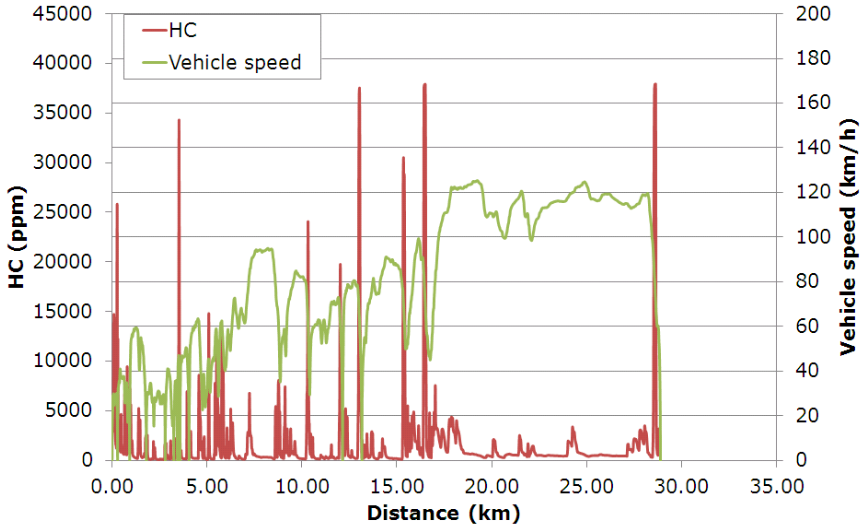


Figure 2-10: Vehicle 6: HC output for L3e - A3 for WMTC Stage 2 cycle, distance based trace

Note: In the main body of the study the large 'spikes' in HC emissions were originally deduced to be caused by deceleration mixture enrichment or carburettor mis-fuelling. This is discussed further in Section 7.6.1.3.

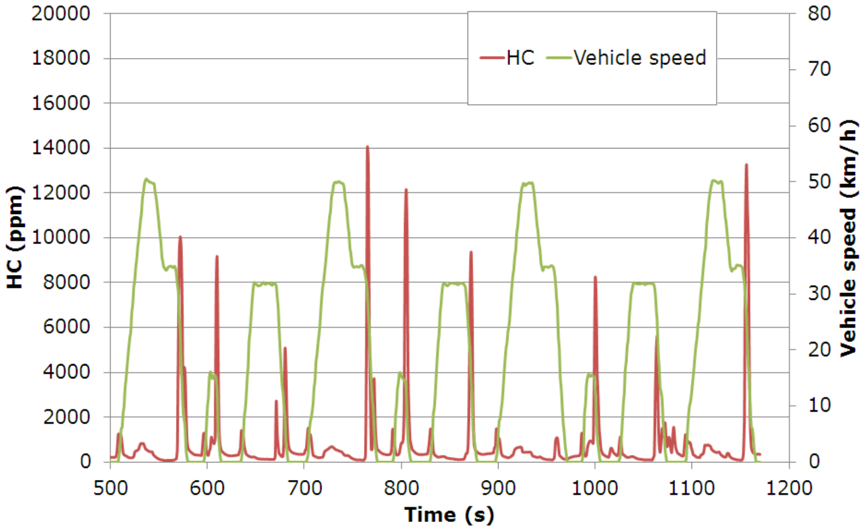


Figure 2-11 Vehicle 10: HC output for L7Ae for R40 cycle, time based trace

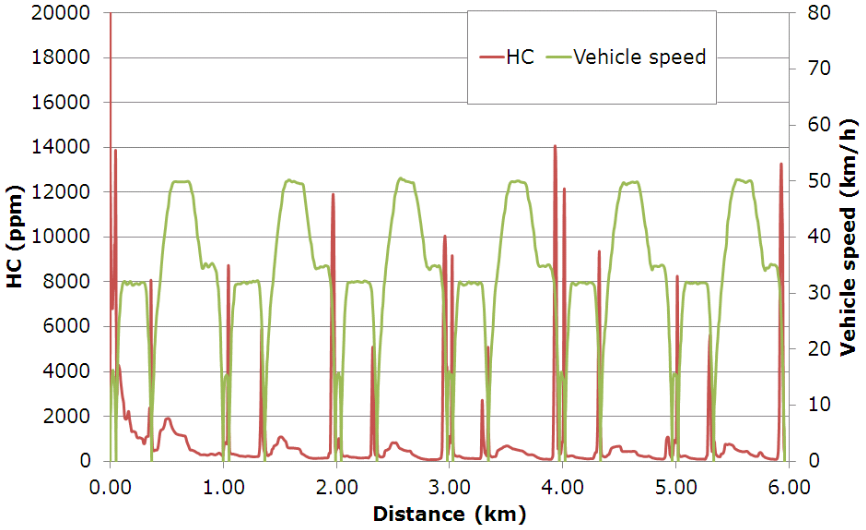


Figure 2-12: Vehicle 10: HC output for L7Ae for R40 cycle, distance based trace

2.2.1.2 *Discussion*

The testing results show that, in general, the higher the engine speed and load of the vehicle, the higher the temperature of the catalytic converter. This is likely to age the pollution control devices during the durability process. High vehicle speeds may be necessary in a durability drive cycle to simulate higher engine loads that typically occur during accelerations in stop and go traffic, or during extended accelerations following moderate vehicle speed cruises in high gear.

The testing results also show that sharp decelerations from medium or high vehicle speeds to low vehicle speeds (i.e. completely lifting off the throttle) induce higher levels of HC emissions. A possible explanation could be that the engine management system does not cut off fuel for the sake of a smooth deceleration feel (for improved driveability) when transitioning from open to closed throttle operation.

The temperatures seen in the tests may not correspond to the actual temperatures in the catalyst. This is due to the location of the thermocouples that had to be fitted up- and downstream of the catalyst rather than on the hottest spot in the catalyst.

2.2.1.3 *Summary of test results*

- The test results show that in general, the higher the engine speed and load, partly represented by a higher vehicle speed, the higher the temperature of the catalytic converter.
- The testing results also show that sharp decelerations from medium or high vehicle speeds to low vehicle speeds (i.e. completely lifting off the throttle) induce higher levels of HC emissions.
- The temperatures seen in the tests may not correspond to the actual temperatures in the catalyst. This is due to the location of the thermocouples.
- A priority is to include actions which replicate thermal ageing.

2.2.2 ***Typical speed characteristics of L-category vehicles***

2.2.2.1 *Defining 'high' and 'low' vehicle speed*

Difficulties in measuring engine load directly lead to the use of vehicle speeds at which maximum torque and power occur to evaluate how hard a durability or emission cycle is working a vehicle. Quantifying vehicle speed with respect to its engine speed and load is a complex correlation. However, a relatively simple method was applied to define the vehicle speed at which the maximum 'power' occurs for each vehicle type. Note that maximum torque was not measured and could not be calculated mathematically with the information recorded in the tests which measured power at the wheel and engine speed without information on gear selection (due to the infinitely variable characteristic of the CVT used on a large proportion of vehicles under test). Therefore, the best available measure of engine load was provided by maximum power.

Figure 2-13 is an example of a plot of vehicle power and vehicle speed against time. Further information is provided in Appendix H.

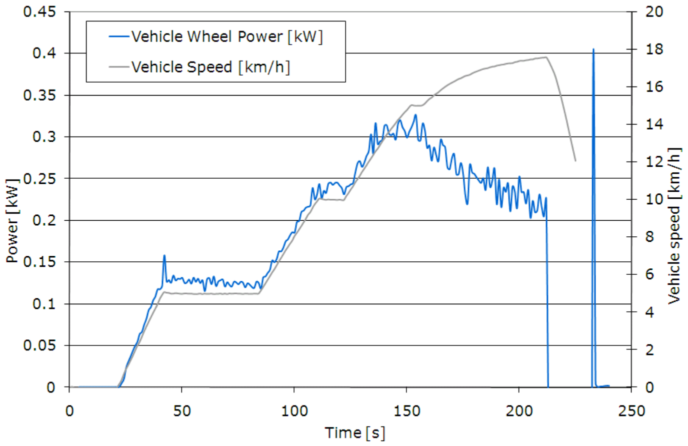


Figure 2-13: Vehicle 1: power and vehicle speed against time for L1Ae

Table 2-2 provides an overview of the approximate vehicle speeds of the vehicles in the cycle at which the maximum power occurs.

Table 2-2: Vehicle speed at which maximum power occurs (all vehicle power and speed plots are shown in Appendix H)

Vehicle	Vehicle category	Approximate maximum vehicle speed	Vehicle speed at which maximum power occurs
1	L1Ae	18 km/h	15 km/h
2	L1Be	45 km/h	20 – 30 km/h
3	L1Be	46 km/h	20 – 40 km/h
4	L1Be	28 km/h	20 km/h
5	L3e – A1	100 km/h	60 – 80 km/h
6	L3e – A3	? km/h	120 km/h[7]
7	L5Ae	120 km/h	60 – 100 km/h
8	L5Ae	65 km/h	50 km/h
9	L6Ae	62 km/h	10 – 20 km/h
10	L7Ae	85 km/h	60 – 70 km/h
11	L7Ae	60 km/h	10 km/h
12	L7Be	70 km/h	20 – 30 km/h

---

[7] The vehicle’s theoretical maximum speed is far in excess of the chassis dynamometer’s capabilities. The peak was taken from the highest point in the data (see Figure 16-70).

2.2.2.2 *Defining acceleration rates*

The values for acceleration and deceleration used in the existing EPA durability cycles (AMA and SRC, see Section 3.2 and Section 3.3) are defined as "typical acceleration rate(s)" based on the average of the entire step. Actual acceleration with a steady throttle position over a flat even surface generates an acceleration curve where the acceleration rate reduces as vehicle speed increases. A light acceleration over a smaller speed change and/or starting from a lower initial speed may have a higher average acceleration rate than a hard acceleration over a longer period and/or to a higher vehicle speed (see Figure 2-14).

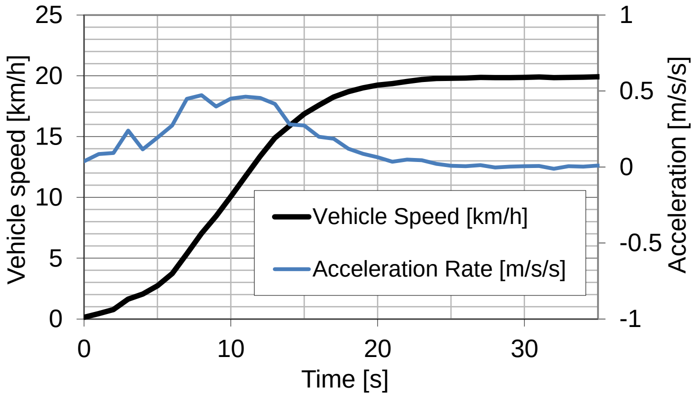


Figure 2-14: Example of an L1Ae accelerating to maximum vehicle speed

Therefore, rather than specifying the actual acceleration rates, they need to be ascertained for each vehicle based on its mass, power and torque to match them to the required consequences. Table 2-3 details the intended situation that the vehicle should be in for four states of acceleration and deceleration. The manufacturer should ascertain the correct configuration required to achieve these actions and sub-actions for each of the steps in the cycle, and demonstrate that they are suitable to the type approval authority. This task can be performed at the same time as the gear change regime is planned.

Table 2-3. Acceleration and deceleration sub-action definitions

Action	Sub-action	Definition
Acceleration	Moderate Hard	- Normal part-load acceleration (half throttle) - High part-load up to full throttle acceleration
Deceleration	Moderate Coast-down	- Normal let-off of the throttle from part-load, brakes allowed as required - Full let-off of the throttle, clutch engaged, no brakes

3 Existing durability cycles

At present durability testing is performed on light-duty and heavy-duty vehicles around the world,and on motorcycles, mopeds etc. in the US and some other regions. For light-duty vehicles in the US the original cycle was referred to as the EPA (Environmental Protection Agency) Durability Driving Schedule, or the Approved Mileage Accumulation (AMA) test cycle. For passenger cars at least, this has since then been largely superseded by the Standard Road Cycle (SRC) in the US and UNECE Regulation 83 and SRC in Europe (for all light-duty vehicles).

For motorcycles and mopeds (no other vehicles in the L-category) in the US, the AMA test cycle is used, with the top vehicle speeds of various parts of the cycle defined in relation to categories of vehicle engine capacity.

3.1 Overview of European endurance test for verifying the durability of pollution control devices for passenger cars (EC 692/08)

For light-duty vehicles (cars and vans), the latest Euro 5/6 European emission regulations follow a split level approach:

- Co-decision Regulation EC 715/2007, 20 June 2007
- Comitology Regulation EC 692/2008, 18 July 2008

The second regulation prescribes the technical details necessary to implement the first regulation.

The durability requirements (Type V test) are specified in Regulation EC 692/2008, Annex VII. The manufacturer may choose between three options:

- Perform a whole vehicle durability test representing an ageing test of 160,000 kilometres driven on a test track, on the road, or on a chassis dynamometer; or
- Use a bench ageing durability test; or
- Apply the assigned deterioration factors from Table 3-1 to the emission test results (Type I test results).

Table 3-1: Assigned (fixed) deterioration factors (DFs) for Euro 5 light-duty vehicles in Europe

	Assigned deterioration factors						
Engine Category	**CO**	**THC**	**NMHC**	**NO_x**	**HC + NO_x**	**PM**	**PN**
Positive-ignition	1.5	1.3	1.3	1.6	-	1.0	1.0
Compression-ignition (Euro 5)	1.5	-	-	1.1	1.1	1.0	1.0

For type approval in Europe, manufacturers may process and apply the assigned DFs to the Type I emission test result with no requirement to accumulate any durability distances. There is no requirement for the manufacturer to prove that these assigned DFs are appropriate for use.

Either the SRC or the accumulation cycle specified by UN Regulation 83 can be used, though the distance for Euro 5/6 is 160,000 km for EC type approval, as opposed to

80,000 km in UN Regulation 83 (for UN ECE type approval). Annex VII of EC 692/08 states that:

- The technical requirements and specifications shall be those set out in Section 2 to 6 of Annex 9 to UNECE Regulation No 83, with the exceptions set out in subsections 2.1.1 to 2.1.4. These exceptions are that:
  As an alternative to the operating cycle described in paragraph 6.1. of Annex 9 of UNECE Regulation No 83 for the whole vehicle durability test, the vehicle manufacturer may use Standard Road Cycle (SRC) described in Appendix 3 of this Annex. This test cycle shall be conducted until the vehicle has covered a minimum of 160,000 km.
- In paragraph 5.3 and paragraph 6 of Annex 9 of UNECE Regulation No 83, the reference to 80,000 km shall be understood as reference to 160,000 km.

Passenger cars sold in Europe are required to meet the 'Type V Test' as described in Annex VII of EC 692/08. This annex describes the test for verifying the durability of anti-pollution devices equipped vehicles with positive-ignition or compression-ignition engines during an ageing test of 160,000 km. It states that the test vehicle:

'The vehicle shall be in good mechanical order; the engine and the anti-pollution devices shall be new. The vehicle may be the same as that presented for the Type I test; this Type I test has to be done after the vehicle has run at least 3,000 km of the ageing cycle.'

During operation on track, road or on roller test bench, the distance shall be covered according to the driving schedule shown in Figure 3-1, where the durability test schedule is composed of 11 cycles covering 6 kilometres each. During the first nine cycles, the vehicle is stopped four times in the middle of each cycle, with the engine idling each time for 15 seconds, normal acceleration and deceleration. There are five decelerations in the middle of each cycle, dropping from cycle vehicle speed to 32 km/h, and the vehicle is gradually accelerated again until the cycle speed is attained.

The 10th cycle is carried out at a steady vehicle speed of 89 km/h. The 11th cycle begins with maximum acceleration from stop point up to 113 km/h. At half-way, braking is employed normally until the vehicle comes to a stop. This is followed by an idle period of 15 seconds and a second maximum acceleration. The schedule is then restarted from the beginning. The maximum vehicle speed of each cycle is given in Table 3-2. Annex 9 states that:

'*At the request of the manufacturer, an alternative road test schedule may be used. Such alternative test schedules shall be approved by the technical service in advance of the test and shall have substantially the same average speed, distribution of speeds, number of stops per kilometres and number of accelerations per kilometres as the driving schedule used on track or roller test bench, as detailed..*'.

Therefore, there is some flexibility with regards to how the vehicle is aged and mileage accumulated.

If the test is undertaken using a chassis dynamometer, Section 5.4.1 of Annex 9 (Regulation 83) outlines the overall criteria required.

Table 3-2. UNECE Reg. 83 durability schedule maximum lap (cycle) vehicle speeds (km/h)

Cycle	Cycle vehicle speed in km/h
1	64
2	48
3	64
4	64
5	56
6	48
7	56
8	72
9	56
10	89
11	113

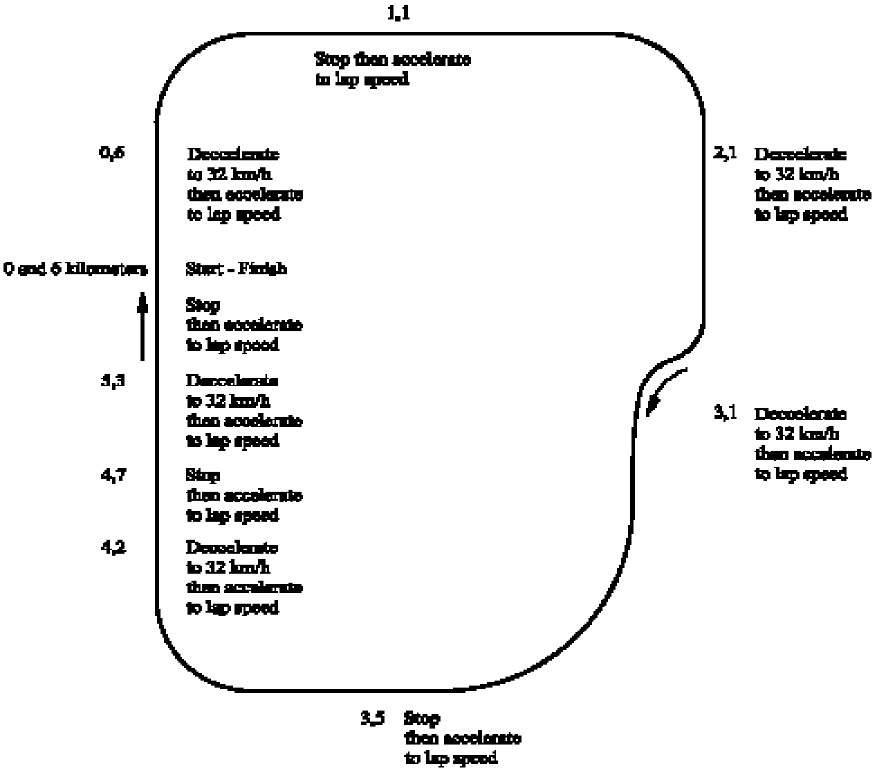


Figure 3-1: UNECE Reg. 83 driving schedule

3.2 Overview of EPA AMA durability driving schedule for motorcycles

Since the 1970s there has been a durability driving schedule for motorcycles in the US, as detailed in the Federal Register Environmental Protection Agency (EPA) part 86. This standard consists of 11 laps of a 6 km (3.7 mile) course, as shown in Figure 3-2.

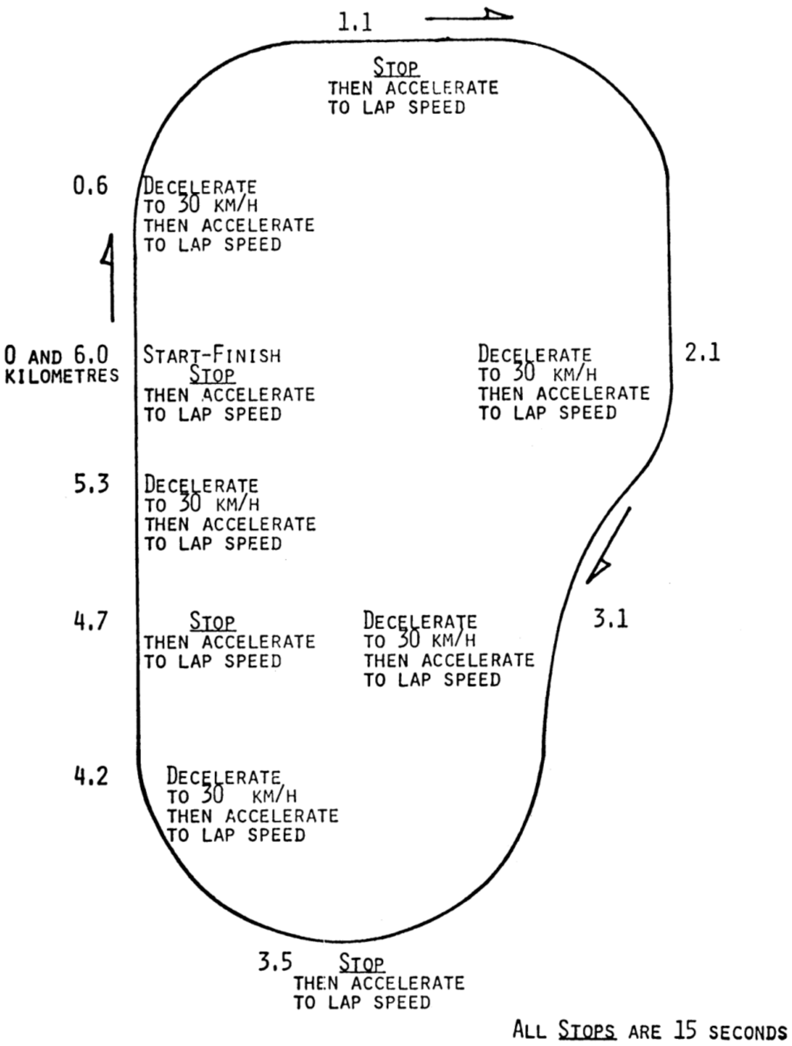


Figure 3-2: EPA mileage accumulation schedule for motorcycles

Motorcycles are classified based on their engine displacement (Table 3-3) and a relationship is established between this and the maximum vehicle speed they should attain whilst following the mileage accumulation schedule. Estimates of their useful life are used to define the amount of mileage accumulation that is necessary to demonstrate emission durability performance. There is some flexibility in how the durability schedule may be followed, for example it may be modified with the advance approval of the administrator (EPA) if it results in unsafe operation of the vehicle.

The schedule consists of 11 laps of the 6 km course (Figure 3-2), which is either:

- Repeated until the appropriate full accumulation distance is covered and the vehicle is demonstrated to be compliant with the relevant emission standards; or
- A percentage (at least half) of the full distance is reached and predictions are made based on iterative measurements that demonstrate that if the vehicle was to run the full distance it would be compliant with the relevant emission standards.

The durability test is designed to age the whole vehicle and can be conducted on a test track, on the road or on a chassis dynamometer.

Table 3-3: Classification of motorcycles for US EPA durability testing[8]

Class	Displacement	Useful life
Class I-A	< 50 cm^3	5 years/ 6,000 km
Class I-B	50-169 cm^3	5 years/ 12,000 km
Class II	170-279 cm^3	5 years/ 18,000 km
Class III	> 279 cm^3	5 years/ 30,000 km

The maximum vehicle speed for each lap is listed in Table 3-4. Where the vehicle is unable to meet this maximum speed, the maximum speed of the vehicle should be reached. During each of the first nine laps there are 4 stops with 15 second idle. Normal accelerations and decelerations are used. In addition, there are 5 light decelerations each lap from the base speed to 30 km/h followed by light accelerations to the base speed. The tenth lap is run at a constant speed. The eleventh lap is begun using a 'wide open throttle' acceleration from stop. A normal deceleration to idle followed by a second wide open throttle acceleration occurs at the midpoint of the lap. Procedures and conditions for acceleration and deceleration are specified in US EPA CFR Title 40 part 86.

Table 3-4: EPA durability schedule maximum lap vehicle speeds (km/h)

Lap	Class I	Class II	Class III
1	65	65	65
2	45	45	65
3	65	65	55
4	65	65	45
5	55	55	55
6	45	45	55
7	55	55	70
8	70	70	55
9	55	55	46
10	70	90	90
11	70	90	110

---

[8] http://www.epa.gov/otaq/regs/roadbike/1-hmc-regs-pres.pdf

3.3 Overview of EPA Standard Road Cycle (SRC) for passenger cars

The Federal Register Environmental Protection Agency (EPA) part 86 describes a Standard Road Cycle (SRC) which is a mileage accumulation cycle that may be used for vehicles meeting the provisions of § 86.1801 (passenger cars and trucks). The vehicle may be run on a track or on a mileage accumulation dynamometer.

The cycle consists of 7 laps of a 6 km course, although the length of the lap may be changed to accommodate the length of the service-accumulation track. The track requirements are identical to the EPA AMA durability driving schedule for motorcycles (see Figure 3-2)

3.4 EPA evolution from Approved Mileage Accumulation (AMA) test cycle to Standard Road Cycle (SRC)

In the US, before a manufacturer may introduce a new vehicle into the fleet, they must obtain an EPA certificate of conformity indicating compliance with all applicable emission standards over the vehicle's useful life period. The useful life for cars and light trucks is currently defined as 100,000 miles or 10 years, whichever occurs first. For heavy trucks, light trucks, medium-duty passenger vehicles (MDPV) and complete heavy-duty vehicles the useful life period is defined as 120,000 miles or 11 years, whichever occurs first.

EPA's regulations have been in place for decades and describe the process motor vehicle manufacturers must follow to obtain EPA emissions certification. However, in 2000, EPA issued a comprehensive update to the certification regulations for light-duty vehicles and light-duty trucks, called the Compliance Assurance Program (CAP) 2000. This includes detailed procedures on the selection of vehicles for testing and testing protocols, specifications on the information that must be submitted to EPA, and other requirements pertaining to reporting and testing. This section briefly reviews the original EPA emission durability programme and highlights the reasons behind why this was updated, ultimately, with the agency instituting a comprehensive revision to the durability process as part of the CAP 2000 rulemaking.

3.4.1 History of emission durability demonstration in the US

Prior to the introduction of the CAP 2000, to simulate the real-world ageing of the vehicle's emissions control systems over the vehicle's useful life, the EPA required manufacturers to accumulate mileage on a pre-production car, called a Durability Data Vehicle (DDV), by driving it over the prescribed AMA driving cycle for the full useful life mileage.

The DDV was tested in a laboratory for emissions at periodic intervals during mileage accumulation in the AMA test cycle, and a linear regression of the pollutant emission test data was performed to calculate a multiplicative deterioration factor (DF) for each exhaust constituent. Then, low mileage vehicles more representative of those intended to go into production (referred to as 'Emission Data Vehicles' or EDVs) were emission-tested. The emission results from these tests were multiplied by the DFs to predict the emissions levels at full useful life (referred to as the 'certification levels'). The certification levels had to be at or below the applicable emission standards in order to obtain a certificate of conformity.

Before the introduction of the CAP 2000, a whole vehicle mileage accumulation cycle was specified (40 CFR Part 86) to demonstrate a vehicle's emission durability, commonly referred to as the Approved Mileage Accumulation (AMA) test cycle. This method consisted of 11 laps of the 6 km (3.7 mile) cycle shown in Figure 3-2, the maximum lap speeds are shown in Table 3-5.

Table 3-5: Approved Mileage Accumulation (AMA) test cycle

Lap	Base Vehicle speed	
	mile/h	km/h
1	40	64
2	30	48
3	40	64
4	40	64
5	35	56
6	30	48
7	35	56
8	45	72
9	35	56
10	55	89
11	70	113

During each of the first nine laps of the AMA test cycle there are 4 stops with 15 seconds idle time. The EPA describes the accelerations and decelerations as ‘normal’. In addition, there are five ‘light’ decelerations each lap from the specified lap speed (also referred to as base speed, see Table 3-5) to 32 km/h (20 mile/h) followed by ‘light’ accelerations to the base lap speed. The tenth lap is run at a constant speed of 89 km/h (55 mile/h). The eleventh lap begins with a ‘wide open’ throttle acceleration from stop to 113 km/h (70 mile/h), followed by a normal deceleration to idle at the midpoint of the lap and then another wide open throttle acceleration from stop to 70 mile/h, followed by a normal deceleration to idle at the end of the lap. Specific guidance is provided regarding the acceleration and deceleration actions.

The AMA test cycle procedures are still followed for motorcycles as described in Section 3.2, but the base vehicle speeds are modified for each class of vehicle, with the larger engine capacity motorcycles (Class III) matching the speeds used for passenger cars and light trucks shown in Table 3-5, and the smaller capacity vehicles (Class I and II) having a lower base speed profile distribution (Table 3-4).

3.4.2 Reasons behind the evolution from AMA test cycle to SRC

In the mid-1990s there were a number of concerns about the measures in place at this time to ensure durable vehicle emission control as vehicles aged, these were summarised in the (40 CFR Part 86) report as:

- Can any single fixed cycle, including the AMA test cycle, produce emission durability data that accurately predicts in-use deterioration for all vehicles?

- Was the AMA test cycle representative of current driving patterns and did it appropriately age current design vehicles?
- Manufacturers had identified that the durability process based on mileage accumulation using the AMA test cycle was very costly and required extensive lead time for completion.

Given these concerns, the EPA came to believe that the AMA test cycle had become outdated. The AMA test cycle contains a substantial portion of low vehicle speed driving, designed to identify the effects of any carbon deposits in the engine, possibly caused by poor combustion (typically at low combustion temperatures) and poor fuel quality. The EPA stated

'*that while engine deposits were a major source of emissions deterioration in pre-catalyst vehicles, the advent of catalytic converters, better fuel control, and the use of unleaded fuel shifted the causes of deterioration from low vehicle speed driving to driving modes which include higher vehicle speed/load regimes that cause elevated catalyst temperatures.*' (EPA, 2006)

The EPA therefore concluded that the AMA driving cycle did not adequately focus on the higher catalyst temperature driving modes experienced by cars and light goods vehicles on the road at the time of the review. They also argued that the AMA test cycle contains numerous driving modes which do not significantly contribute to deterioration; which makes the process longer, but adds little benefit in predicting emission deterioration.

In response to these concerns, in the mid to late 1990s the EPA worked with industry and relevant stakeholders to develop procedures to evaluate durability and deterioration subject to prior agency approval. Ultimately, the agency instituted a comprehensive revision to the durability process as part of the CAP 2000 rulemaking and the SRC was fully integrated as an option into the regulatory framework. Three types of emission durability programmes are approved under these procedures: whole vehicle, full mileage, whole vehicle, accelerated mileage; and bench ageing procedures which involved thermal ageing of the catalyst-plus-oxygen-sensor system.

3.5 Overview of advantages and disadvantages of other durability cycles

3.5.1 UNECE Regulation 83, SRC

Advantages:

- De facto international standard (UNECE R83) for passenger cars.
- Used for passenger cars globally for contracting parties to the UNECE 1958 Agreement when acceded to UNECE R83.
- Uses the same infrastructure as the AMA test cycle.
- Higher average vehicle speed than in the AMA test cycle simulating higher engine load as obtained during higher engine load accelerations at low average vehicle speeds in stop and go traffic.
- Defined accelerations and prolonged decelerations, if a vehicle uses DFCO decelerations could lead to an oxygen shower on the catalytic material, as the engine pumps relatively cold air onto a hot catalyst causing thermal shock, if it

uses catalytic converter protecting fuel enrichment it could lead to catalyst poisoning. Prolonged decelerations could be as common as accelerations in modern stop and go traffic.

- Higher average vehicle speed for the same overall test distance leading to faster completion of Type V testing, saving cost of Type V test and allowing manufacturer to bring new vehicle type faster on the market (competitive advantage).
- Owing to higher representative engine loads a higher fuel flow occurs leading to a higher exhaust flow, possibly exposing the pollution control devices to pollutant components and leading to a representative, real-world level of poisoning by fuel additives and combusted blow-by gasses.
- Higher average engine and vehicle speeds are more likely to induce mechanical wear.

Disadvantages:

- Suitability for L-category vehicles has not been proven. While it can be hypothesised that L-category vehicles move through modern stop and go traffic at similar speeds, or even higher, to larger passenger cars, the overall suitability cannot be quantified with the available data.
- May not best represent real-world driving conditions as like in the case of every fixed drive cycle an average driving style is assumed for an average vehicle not capable of covering the whole distribution of all different driving styles, ambient conditions and other related parameters. However, this is a general concern for all types of predefined driving cycles.

3.5.2 US EPA/AMA test cycle for motorcycles

Advantages:

- De facto standard in the USA for motorcycles.
- Some L-category manufacturers in Europe already develop motorcycles to this standard when exporting them to the USA.
- Some stakeholders believe that it is a more stringent test than real-world driving conditions.
- Infrastructure (e.g. tracks) can support this test cycle as well as any other test cycle.
- Pollution control devices may hardly recuperate from low level of poisoning owing to lack of high engine load, the fuel and oil deposits may not oxidize and collect as carbon depots on the catalytic converter surface, which may also be a real-world degradation mechanism for some vehicles of the fleet.

Disadvantages:

- Was devised to induce carbon build up inside the combustion chamber of the engine. Such build up was typically formed at low engine load (low combustion temperature) and caused by old fashioned combustion chamber design and poor fuel quality. Carbon deposits were often reported on valves, spark plugs and piston rings. This is not a reported durability concern anymore owing to improved engine design and fuel quality over the last 2 decades.

- Lower average vehicle speeds and low engine load for larger vehicles, may not induce moderate to high catalyst temperatures and only produces low fuel and exhaust flows not leading to any significant ageing of the exhaust components.
- May not best represent real-world driving conditions owing to average, low engine loads.
- No defined acceleration or deceleration rates so potentially low engine loads in the test compared with potentially very quick acceleration of L-category vehicles in real traffic. This means that the pollution control devices are less likely to be challenged on thermal load than they might be in real service.
- Possibly outdated as has been largely replaced for light-duty vehicles in US and Europe, same conclusions from EPA may be applicable on L-category vehicles running at higher engine speeds and loads than light duty vehicles (cars).
- Does not contain many full prolonged let-offs from high vehicle speeds (70-100% throttle to 0% inducing DFCO) at hot engine and catalyst and with gear engaged.

3.5.3 Summary

The US EPA AMA cycle is focussed on the US market vehicles in the 1970s and contains numerous driving modes which no longer contribute significantly to deterioration; which makes the process longer and adds little benefit in predicting emission deterioration especially for use in the European fleet.

4 Development of the SRC-LeCV

The cycle put forward was developed by analysing the two main durability (test Type V) driving cycles and emissions driving cycles (test Type I), with respect to how the vehicle may be used in the real-world over its life. Special attention was paid towards the consequences of repeatable actions with respect to their probable effect on emission critical components.

The analysis of each cycle was based on identifying consequences, in regards to wear, that a specific driving style may tend to bring about. A worst case scenario was always used when matching an action to a consequence, as the durability test is intended to highlight bad design not to be harsh to durable vehicles. This analysis is based on experimental data, literature review, and engineering knowledge.

The AMA durability test cycle, SRC durability cycle, and WMTC emission laboratory test cycle, contain 3, 4, and 3 parts respectively. Each of these parts is distinct as the various cruising vehicle speeds are comparable to certain driving condition. These driving conditions have in turn differing effects on: thermal exposure, poisoning, mechanical wear and carbon deposits of the vehicle's combustion engine and its pollution control devices, and also the time and/or distance taken to perform the test.

For both the AMA test cycle and SRC each lap is a fixed length of 5.9 km (3.7 miles), but with 11 or 7 laps respectively giving a full cycle distance of 65.5 km for the AMA test cycle and 41.7 km for the SRC. The time taken for the cycle varies depending on the class and capabilities of the vehicle under test. However for the WMTC emission cycle both the time and distance are fixed, to make this possible the cycle is adapted to match the capabilities of the vehicle by selecting the appropriate parts. This gives six possible configurations for the stage 1 version and five for stages 2 and 3, with total distances between 7.866 km and 46.155 km and a time of 1,200 s (20 minutes) or 1,800 s (30 minutes).

With both of the EPA durability driving cycles (AMA and SRC), the acceleration and deceleration rates are left imprecise; this helps to keep the cycles compatible with a wide range of vehicles without undue complications. However, this also makes it difficult to predict accurately the exact time required to run the cycle, and may create the possibility of avoiding testing the main deterioration mechanism (thermal shock and ageing).

4.1 Review of AMA durability test cycle characteristics

- The AMA test cycle mostly involves low engine speeds and loads.
- The EPA document on its design reveals that it was only designed to test low load/high soot creation
- It was designed to solve one of the main problems of the 1970’s, which was soot build up, to motivate vehicle manufacturers to improve engine design to better cope with this and for the oil industry to develop higher quality fuels.
  Old fashioned combustion chamber design and poor fuel quality caused soot build-up around certain engine parts and locations which remain cooler like piston rings which in turn caused increased blow-by, carbon deposits in the combustion chamber which may lead to knocking combustion as well as deposits on the intake and exhaust valves allowing the un-burnt or burning high temperature

gases to escape the combustion chamber leading in the worst case to engine damage.

- As it is designed to test one problem and is not intended to be representative of real-world use it is therefore an accelerated cycle.

The cycle adapts to the vehicle based on two vehicle speeds, the lap vehicle speed (the top vehicle speed for each lap) and the base vehicle speed (a fixed vehicle speed to accelerate/decelerate to/from). The acceleration rates to use are either: normal, light or wide-open-throttle (WoT); these are not stated as precise rates. Deceleration rates are defined as normal or light, again no specific values are given.

As shown in Figure 4-1, the cycle has 9 repeats of the Normal Lap (AMA test cycle part 1, laps 1 to 9), 1 constant vehicle speed lap (AMA test cycle part 2, lap 10) and 1 wide open throttle lap (AMA test cycle part 3, lap 11). Apart from the final lap, normal accelerations are used between lap and idle and light accelerations and decelerations between lap vehicle speed and base vehicle speed.

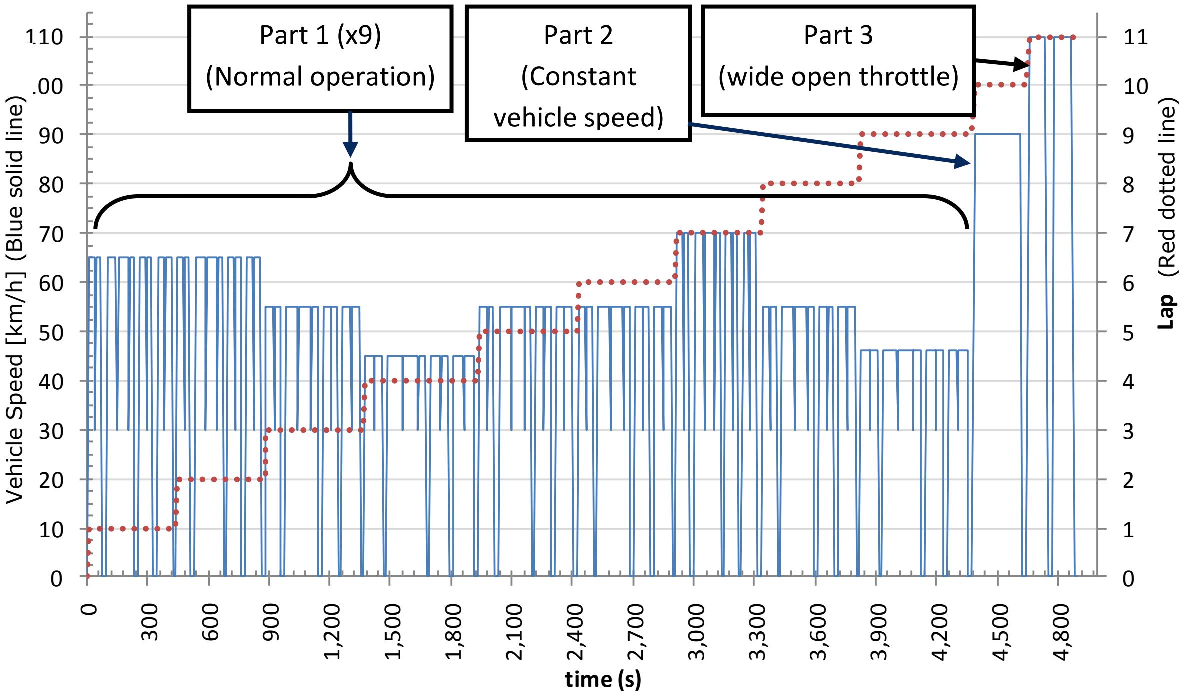


Figure 4-1: AMA durability test cycle, all parts (US EPA Class III lap vehicle speeds vs test time)

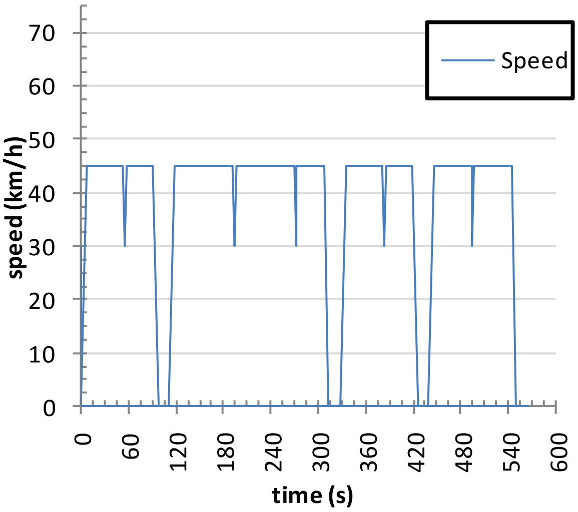


Figure 4-2: AMA test cycle, part 1 at lowest vehicle speed

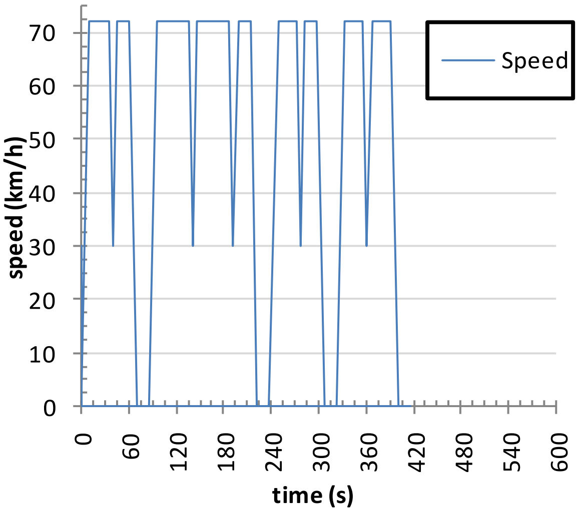


Figure 4-3: AMA test cycle, part 1 at highest vehicle speed

Part 1, shown in Figure 4-2 and Figure 4-3, consists of multiple stops and low vehicle speed areas with periods of acceleration, deceleration, and cruising connecting them.

This part is intended to represent driving a short distance with traffic and stopping at junctions using urban low or medium vehicle speed roads. For a category L3e-A3 this may be significantly lower than its maximum design vehicle speed. For an L1Be this is completely normal driving which the vehicle will have been designed for. For an L1Ae both the base and lap vehicle speeds may be beyond its capabilities, and therefore in such a case these vehicles would simply travel at their maximum vehicle speed. Travelling at maximum design speed may be representative of real-world conditions where low powered vehicles have to travel at maximum design vehicle speed just to keep up with normal traffic whereas keeping up with traffic would represent a very light duty for larger machines. The light acceleration and decelerations to and from the base vehicle speed will not cause over-heating above what could already be generated by the low vehicle speeds, however the slow accelerations will not burn away any soot build-up.

The following table details possible consequences and damage that may be caused by particular features of the stated part of the cycle.

Table 4-1: Type of wear intended: AMA test cycle, part 1

Feature	Consequence	Damage
Lower vehicle speeds for vehicle with a higher design vehicle speed	Soot build-up in and around the cylinder	Valves may not close correctly, and un-burnt hydrocarbons and soot may escape via the exhaust and air inlet
		The cylinder capacity may reduce, deteriorating gas exchange and increasing the pressure in the combustion chamber. Consequently premature ignition could occur, leading to material damage and, in the worst case, to the breaking of piston rings or carbon deposits burning a hole in the piston.
		Friction between the cylinder walls and pistons may increase and efficiency may drop
		Blow by may increase, burnt or un-burnt gases may escape into the crankcase
		Combustion may deteriorate. A combustion chamber is designed to support swirl and tumble of the entering and ignited fuel-air mixture. In the case that carbon deposits block the gas flow entering the chamber or leading to it, the ignited gas flow within the chamber follows a different path than designed and the flame front will propagate in an entirely different way leading to incomplete combustion and therefore to higher exhaust emissions.
	Soot and particulates might be generated and clog the catalytic converter	The catalytic material within the catalytic converter may become covered with soot, preventing it from functioning, therefore higher tailpipe emission may be generated
		The airflow through the catalyst may be reduced owing to a back pressure increase in the exhaust, deteriorating volumetric efficiency in the combustion chamber reducing torque
		If a high amount of soot builds up followed by a high acceleration the catalytic converter could be physically damaged owing to the extreme high temperature that occurs when carbon deposits are oxidised.

Feature	Consequence	Damage
Normal acceleration and deceleration	General wear and tear	Wear to all moving parts, tyres, and engine and transmission lubrication oil
Deceleration to idle and stop	Quickly releasing the throttle may cause a rich mixture This might be because of mis-fuelling, which means an incorrect fuel and air mixture for the given high engine speed/ low engine load conditions that typically occur during deceleration. In idle bad fuel-air mixture distribution leading to inherently unstable combustion.	"Cold" combustion leading to thermal shock in case of prolonged coast-through decelerations. In idle the concern is inherently unstable combustion possibly leading to carbon deposits.
Light to moderate acceleration	Not opening up the throttle will not cause excessive wear or heat, however it will also not burn away any soot built up on the slower cruises	Damage from soot will continue as above

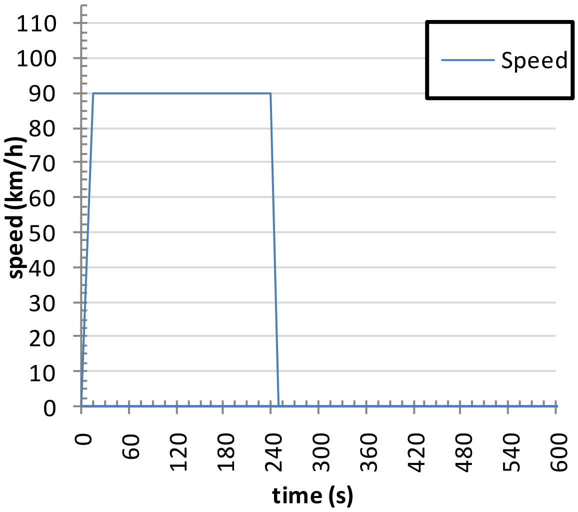


Figure 4-4: AMA test cycle, part 2

Part 2, shown in Figure 4-4, consists of a relatively high constant vehicle speed for the entire 6 km lap. This represents travelling on a clear US highway at higher vehicle speed (see Appendix B) or on a major road in Europe.

For the majority of L-category vehicles (by fleet size), this should be the optimum vehicle speed for both energy efficiency, power/torque at lowest toxic emissions. It would not be expected to present any specific hazards to the components of the vehicle except for general wear and tear.

However, for some vehicles with a lower maximum speed and speed restricted vehicles it causes the vehicle to travel at the vehicle's maximum design speed for a sustained period.

The following table details possible consequences and damage that may be caused by particular features of the stated part of the cycle.

Table 4-2: Type of wear intended: AMA test cycle, part 2

Feature	Consequence	Damage
Travelling at design vehicle speed, medium load for a sustained period	General wear and tear	Wear to all moving parts, tyres, and engine oil
Travelling at very high load or vehicle speed for a sustained period (i.e. above the red line)	The engine and/or exhaust system may become hot	The exhaust gases will be hotter, and depending on calibration may result in high NO_x or high HC/CO emissions
		The excess heat may cause knocking combustion
		In extreme cases the engine may seize
		The catalytic converter may overheat
Normal acceleration and deceleration	General wear and tear	Wear to all moving parts, tyres, and engine and transmission lubrication oil
Deceleration to idle and stop	Quickly releasing the throttle may cause a rich mixture In carburetted vehicles this is because of mis-fuelling, for the given high engine speed/low engine load conditions	In theory HC may be emitted and in extreme conditions could possibly coat the catalyst[9]
		"Cold" combustion leading to thermal shock in case of prolonged coast-through decelerations. In idle the concern is inherently unstable combustion possibly leading to carbon deposits.

---

[9] HC coating the catalyst is not likely to occur during ordinary driving situations, but may be associated with low loads or misfire situations and is included here for consideration.

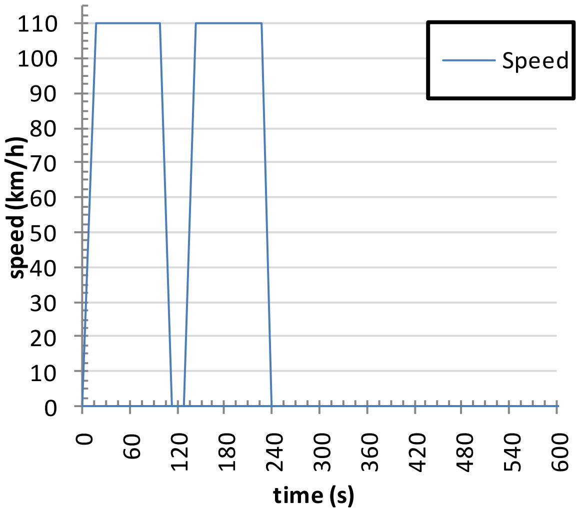


Figure 4-5: AMA test cycle, part 3

Part 3, shown in Figure 4-5, consists of two high speed cruises with an idling period between. The vehicle must reach the cruising lap speed with a wide-open-throttle (WoT). This represents travelling on a US freeway or expressway at a higher vehicle speed or on a motorway in Europe (see Appendix B), including the initial high acceleration needed to match the traffic already travelling on the road.

For a significant amount of low to medium performance L-category vehicles (by fleet size), this should be the maximum design vehicle speed, which would be expected to be higher than the optimum vehicle speed for energy efficiency and peak torque/power. It causes the vehicle to perform at high vehicle speed and high load with long periods of high acceleration and short periods of low vehicle speed.

The following table details possible consequences and damage that may be caused by particular features of the stated part of the cycle.

Table 4-3: Type of wear intended: AMA test cycle, part 3

Feature	Consequence	Damage
WoT (Wide open throttle, i.e. full throttle and high engine load)	Enrichment of fuel-air mixture to: 1) ensure that there is more than sufficient fuel to deliver maximum engine performance 2) Rich fuelling lowers combustion temperature considerably, consequently pollution control devices are less exposed to excessive heat and remain within maximum temperature operation specification.	This will increase the HC and CO emitted to the atmosphere (increasing fuel consumption above what is required for propulsion)
		The temperature of the exhaust and exhaust system will be reduced because of mixture enrichment, therefore less effect in terms of thermal ageing
		The catalyst may become coated with soot if the mixture is excessively rich, therefore increased chance on poisoning of catalyst and lambda sensor(s).
		Higher level of vibrations possibly leading to mechanical damage of catalyst and O2 sensor(s).
Travelling at very high load or vehicle speed for a sustained period (i.e. above the red line)	The engine and/or exhaust system may become hot	The exhaust gases will be hotter, and depending on calibration may result in high NO_x or high HC/CO emissions
		The excess heat may cause knocking combustion
		In extreme cases the engine may seize
		The catalytic converter may overheat if not sufficiently protected
Normal acceleration and deceleration	General wear and tear	Wear to all moving parts, tyres, and engine and transmission lubrication oil
Deceleration to idle and stop	Quickly releasing the throttle may cause a rich mixture This might be because of mis-fuelling, for the given high engine speed/low engine load conditions	In theory HC may be emitted and in extreme conditions could possibly coat the catalyst[10]
		"Cold" combustion leading to thermal shock in case of prolonged coast-through decelerations. In idle the concern is inherently unstable combustion possibly leading to carbon deposits.

---

[10] HC coating the catalyst is not likely to occur during ordinary driving situations, but may be associated with low loads or misfire situations and is included here for consideration.

4.2 Review of Standard Road Cycle (SRC) characteristics

The SRC was also developed by the US EPA and is used to test the durability of pollution control devices for cars in both the US and for contracting parties to the UNECE 1958 Agreement that have acceded to Regulation No 83.

The cycle is designed primarily for standard modern cars and as such does not inherently contain the capability to be adapted for a variety of vehicle capabilities. The lap and base vehicle speeds are different and stated for each lap, the base speed ranges from 16 to 40 km/h below the lap speed, the lap speeds start at 48 km/h and increase up to a maximum of 120 km/h, there are also two WoT accelerations followed by a coast-down to lap speed, the fastest of which reaches 128 km/h.

The 7 lap cycle can be divided into four distinct phases (or parts) which show similar characteristics, as shown in Figure 4-6. Part 1 is lap 1 and 2, part 2 is lap 3 and 7, part 3 is lap 4 and 6, and part 4 is lap 5.

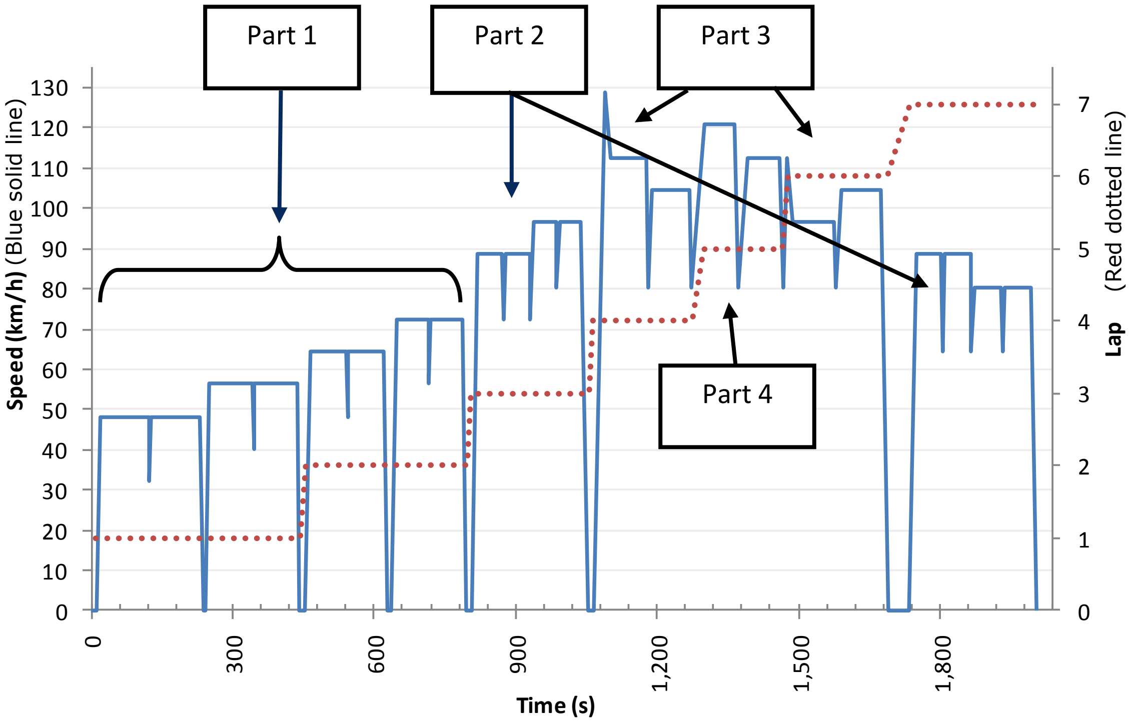


Figure 4-6: SRC Durability Cycle, all parts (US Car vehicle speeds vs test time)

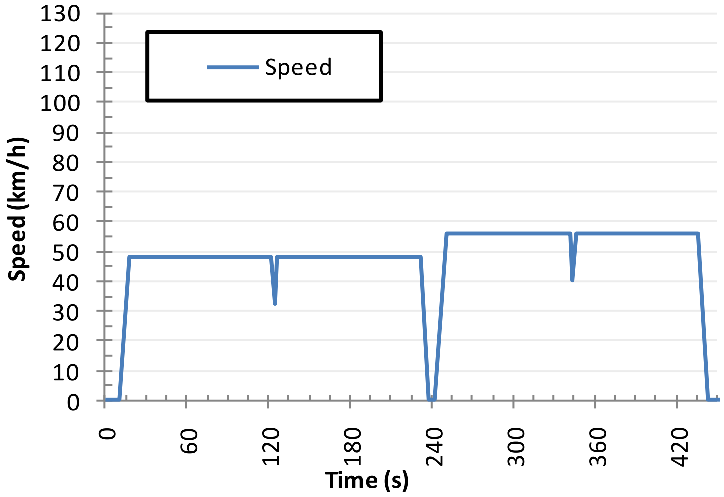


Figure 4-7: SRC test cycle, Part 1

Part 1, shown in Figure 4-7, consist of two low speed cruise sections, with reduced vehicle speed points dropping 16 km/h from the cruise speed, and idle periods between the cruising sections. All the acceleration and decelerations are classed as moderate.

Taking the two laps together, the cruising vehicle speed gets progressively faster in four 8 km/h steps. These laps could be representative of travelling in a medium vehicle speed urban area and moving onto progressively faster traffic. For some vehicles this could result in soot build-up.

For L-category vehicles with a restricted maximum vehicle speed (L1e, L2e and L6e) all of these lap speeds exceed their maximum achievable vehicle speed. However, unlike the AMA durability driving cycle, the base vehicle speed is defined relative to the lap vehicle speed rather than as a fixed absolute vehicle speed. Thus, the base vehicle speed will be changed to match the lap vehicle speed that can actually be achieved (base speed of vehicle = lap vehicle speed minus 16 km/h). Despite this flexibility, vehicles with a low maximum design vehicle speed will still be travelling at that maximum vehicle speed for most of the cruise time, which may be representative for real-world operation.

The following table details possible consequences and damage that may be caused by particular features of the stated part of the cycle.

Table 4-4: Type of wear intended: SRC test cycle, Part 1

Feature	Consequence	Damage
Lower vehicle speeds for vehicle with a higher design vehicle speed	Soot build-up in and around the cylinder	Valves may not close correctly, and un-burnt hydrocarbons may escape via the exhaust and air inlet
		The cylinder capacity may reduce, deteriorating gas exchange and increasing the pressure in the combustion chamber. Consequently premature ignition could occur, leading to material damage and worst case to breaking of piston rings or carbon deposits burning a hole in the piston
		Friction between the cylinder walls and pistons may increase and efficiency may drop
		Blow-by may increase, burnt or un-burnt gases may escape into the crankcase
		Combustion may deteriorate A combustion chamber is designed to support swirl and tumble of the entering and ignited fuel-air mixture. In the case that carbon deposits block the gas flow entering the chamber, the ignited gas flow within the chamber will be on another path than designed, and the flame front will propagate in an entirely different way leading to incomplete combustion and therefore to higher exhaust emissions
	Soot and particulates might be generated and clog the catalytic converter	The catalytic material within the catalytic converter may become covered with soot, preventing it from functioning, therefore higher tailpipe emission may be generated
		The airflow through the catalyst may be reduced because of increased back pressure increase in the exhaust, deteriorating volumetric efficiency in the combustion chamber, reducing torque
		If a high amount of soot builds up followed by a high acceleration the catalytic converter could be physically damaged because of the high temperature that occurs when carbon deposits are oxidised

Feature	**Consequence**	**Damage**
Normal acceleration and deceleration	General wear and tear	Wear to all moving parts, tyres, engine and transmission lubrication oil
Deceleration to idle and stop	Quickly releasing the throttle may cause a rich mixture In carburetted vehicles this is because of mis-fuelling, for the given high engine speed/low engine load conditions	In theory HC may be emitted and in extreme conditions could possibly coat the catalyst[11]
		"Cold" combustion leading to thermal shock in case of prolonged coast-through decelerations. In idle the concern is inherently unstable combustion possibly leading to carbon deposits

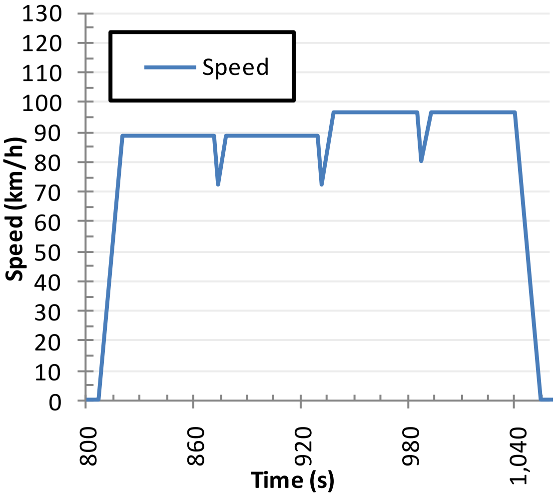


Figure 4-8: SRC test cycle, part 2

Part 2 used in laps 3 and 7 (see Figure 4-8), is similar in some ways to Part 1. However, it has a higher lap vehicle speed, which continues the steps to and from motorway vehicle speeds. There is no mid-lap idle period, and the initial acceleration is classed as "hard".

This hard acceleration is stated to be an average of 1.79 ms^{-2} (4 mile/h per second), over the initial acceleration to 88 km/h. This is equivalent to the Wide-open-Throttle acceleration in part 2 of the AMA durability driving cycle. In some ways it will have effects such as generating higher heat, and may also have the effect of burning away the soot built-up from the slower laps in part 1.

The vehicle speed of this lap seems high in comparison to part 1, however it can be shown that it represents just the low to medium vehicle speed and low load characteristics for a medium or high performance L3-A3 category vehicle with a high maximum design speed. For the medium performance vehicles this part can be shown as

---

[11] HC coating the catalyst is not likely to occur during ordinary driving situations, but may be associated with low loads or misfire situations and is included here for consideration.

causing a high part-load condition and for vehicle speed/power restricted vehicles the cruising vehicle speed will in effect be the same as the part 1 laps.

The following table details possible consequences and damage that may be caused by particular features of the stated part of the cycle.

Table 4-5: Type of wear intended: SRC test cycle, Part 2

Feature	Consequence	Damage
High load acceleration (but not at full throttle)	Higher heat exposure of pollution control devices and engine	Higher level of deterioration of catalytic capability owing to thermal exposure of catalyst and lambda sensor(s) to heat from exhaust Conversely the heat may burn away soot and/or poisons, increasing exhaust flow and regenerating the catalyst
	High exhaust flow to a possibly partially clogged or soot coated catalyst	The deposits could be oxidised actually ageing the catalytic converter and lambda sensor(s)
		The airflow through a partially clogged catalyst may be reduced owing to a back pressure increase in the exhaust, deteriorating volumetric efficiency in the combustion chamber, reducing torque
Travelling at design vehicle speed, medium load for a sustained period	General wear and tear	Wear to all moving parts, tyres, engine and transmission lubrication oil
WoT (Wide open throttle, i.e. full throttle and high engine load)	Enrichment of fuel-air mixture to: 1) ensure that there is more than sufficient fuel to deliver maximum engine performance 2) Rich fuelling lowers combustion temperature considerably, consequently pollution control devices are less exposed to excessive heat and remain within maximum temperature operation specification.	This will increase the HC and CO emitted to the atmosphere (increasing fuel consumption above what is required for propulsion)
		The temperature of the exhaust and exhaust system will be reduced owing to enrichment, therefore less effect in terms of thermal ageing
		The catalyst will become coated with soot if the mixture is too rich, therefore increased chance on poisoning of catalyst and lambda sensor(s)
		Higher level of vibrations possibly leading to mechanical damage of catalyst and lambda sensor(s)

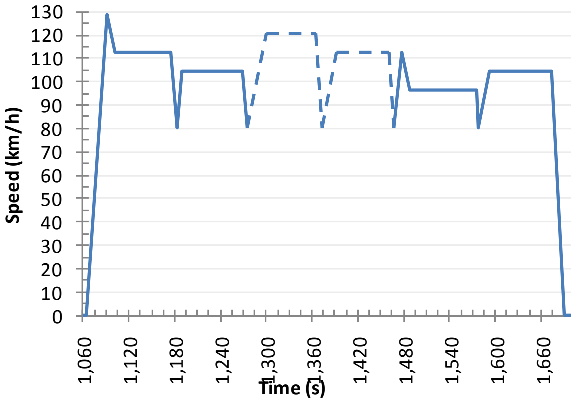


Figure 4-9: SRC test cycle, part 3 (2 laps)

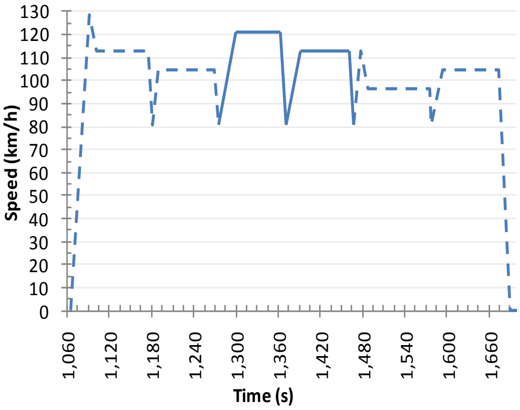


Figure 4-10: test SRC cycle, part 4

Part 3 and 4 form one block of three laps (see Figure 4-9 and Figure 4-10), where the vehicle travels at more than 80 km/h without stopping. Part 3 contains a hard acceleration at the start followed by a coast-down deceleration to the main lap vehicle speed, first from 128 km/h to 112 km/h and then from 112 km/h to 96 km/h. Part 4 and the actions following the peaks in part 3 contain two varying speed cruises, divided at their mid-point with a light deceleration to a base vehicle speed of 80 km/h.

These actions represent travelling on a motorway, with an initial acceleration to meet the traffic speed, then again to overtake another vehicle, with slow points representing interactions with other slower traffic.

The following table details possible consequences and damage that may be caused by particular features of the stated part of the cycle.

Table 4-6: Type of wear intended: SRC cycle, Part 3 and 4

Feature	Consequence	Damage
High load acceleration (but not at full throttle)	Higher heat exposure of pollution control devices and engine	Deterioration of catalytic capability owing to thermal ageing Conversely the heat may burn away soot and/or poisons, increasing exhaust flow and regenerating the catalyst
	High exhaust flow to a possibly partially clogged or soot coated catalyst	The deposits could oxidise actually ageing the catalytic converter and lambda sensor(s)
		The reduced airflow through the catalyst may be caused owing to a back pressure increase in the exhaust reducing volumetric efficiency of the combustion chamber, reducing torque

Feature	**Consequence**	**Damage**
Travelling at very high load or vehicle speed for a sustained period (i.e. above the red line)	The engine and/or exhaust system may become hot	The exhaust gases will be hotter, and depending on calibration may result in high NO_x or high HC/CO emissions
		The excess heat may cause knocking combustion
		In extreme cases the engine may seize
		The catalytic converter may overheat if not sufficiently protected
Travelling at design vehicle speed, medium load for a sustained period	General wear and tear	Wear to all moving parts, tyres, engine and transmission lubrication oil
WoT (Wide open throttle, i.e. full throttle and high engine load)	Enrichment of fuel-air mixture to: 1) ensure that there is more than sufficient fuel to deliver maximum engine performance 2) Rich fuelling lowers combustion temperature considerably, consequently pollution control devices are less exposed to excessive heat and remain within maximum temperature operation specification	This will increase the HC and CO emitted to the atmosphere (increasing fuel consumption above what is required for propulsion)
		The temperature of the exhaust and exhaust system will be reduced because of mixture enrichment, therefore less effect in terms of thermal ageing
		The catalyst may become coated with soot if the mixture is too rich, therefore increased chance on poisoning of catalyst and lambda sensor(s)
		Higher level of vibrations possibly leading to mechanical damage of catalyst and lambda sensor(s)

4.3 Review of WMTC emission laboratory test cycle characteristics

Within the WMTC emissions driving cycle shown in Figure 4-11 there are 3 parts, relating to slow, medium and fast vehicle speeds. The UNECE Global Technical Regulation (GTR) No 2 defines three classes of vehicles, with five sub classes to determine which parts to perform. Vehicles capable of travelling at less than 130 km/h perform normal or reduced speed parts 1 and 2 in various configurations, and vehicles capable of 130 km/h or more perform parts 1, 2 and 3 consecutively. The two vehicle speed profiles for each of the parts (normal and reduced vehicle speed) allow the cycle to be used by all vehicles to represent the same actions; the only exceptions currently are L-category vehicles with a maximum design vehicle speed < 50 km/h. This means that the current UNECE GTR No. 2 containing the WMTC stage 2 excludes L1e, L2e and L6e vehicles from its scope. COM (542) proposes to test these vehicle categories in the future with a revised WMTC that allows low performance vehicles also to be emission tested according to this test procedure.

The test is designed so that any one of the cycles could be the only one used, so all of the cycles contain most of the features which are spread out in the durability driving cycles but to differing degrees.

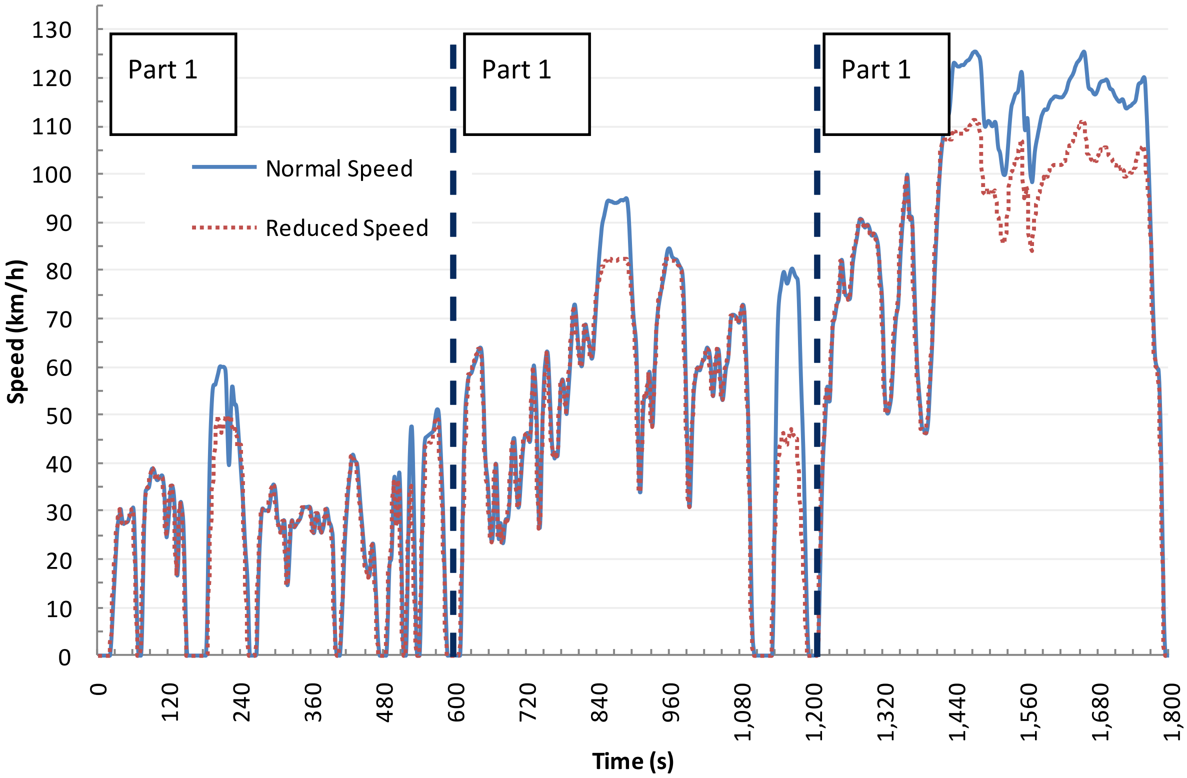


Figure 4-11: Full Revised WMTC Emission Cycle, normal and reduced vehicle speed vs test time

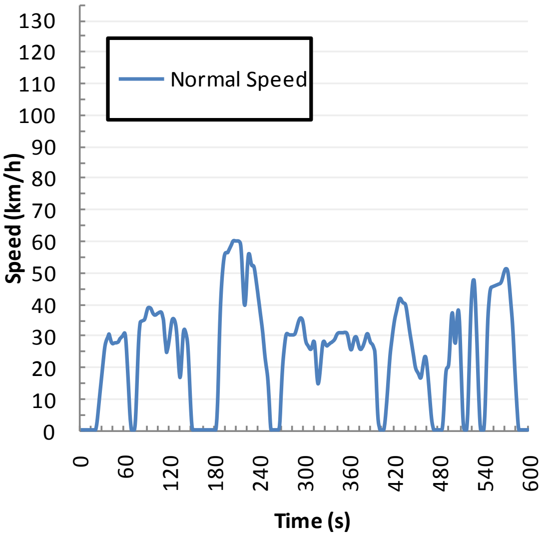


Figure 4-12: Revised WMTC, normal vehicle speed, part 1

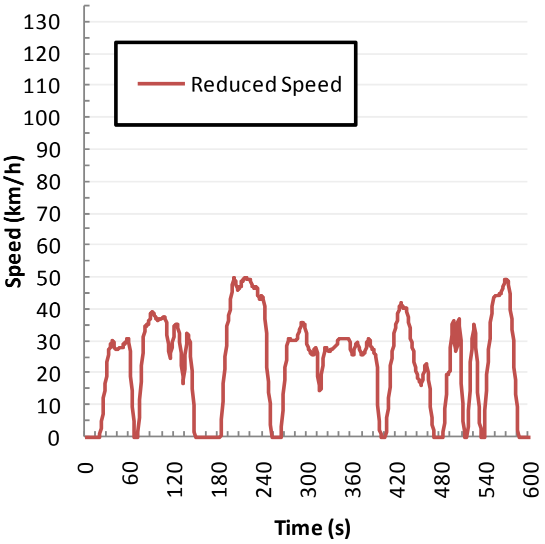


Figure 4-13: Revised WMTC, reduced vehicle speed, part 1

Part 1 is made up of a slow vehicle speed urban driving cycle (see Figure 4-12 and Figure 4-13), comprising of a complex range of phases including eight stops, representative of driving around a congested city. There are slow, fast and WoT accelerations, and slow and fast decelerations.

For low speed vehicles, this will represent normal driving, but even for these vehicles the vehicle speeds are sometimes very low. For medium and high speed vehicles these are very low speeds. However all L-category vehicles must adapt their vehicle speeds to normal traffic speeds and the engine must operate under all possible engine speed and load conditions and therefore is potentially a good feature to include in a cycle.

The following table details possible consequences and damage that may be caused by particular features of the stated part of the cycle.

Table 4-7: Type of wear intended revised WMTC, part 1

Feature	Consequence	Damage
Lower vehicle speeds for vehicle with a higher design vehicle speed	Soot build-up in and around the cylinder	Valves may not close correctly, and un-burnt hydrocarbons may escape via the exhaust and air inlet
		The cylinder capacity may reduce, deteriorating gas exchange and increasing the pressure in the combustion chamber. Consequently premature ignition could occur, leading to material damage and worst case to breaking of piston rings or carbon deposits burning a hole in the piston
		Friction between the cylinder walls and pistons may increase and efficiency may drop

Feature	Consequence	Damage
		Blow-by may increase, burnt or un-burnt gases may escape into the crankcase
		Combustion may deteriorate A combustion chamber is designed to support swirl and tumble of the entering and ignited fuel-air mixture. In the case that carbon deposits block the gas flow entering the chamber, the ignited gas flow within the chamber will be on another path than designed, and the flame front will propagate in an entirely different way leading to incomplete combustion and therefore to higher exhaust emissions
	Soot and particulates might be generated and clog the catalytic converter	The catalytic material within the catalytic converter may become covered with soot, preventing it from functioning, therefore higher tailpipe emission may be generated
		The airflow through the catalyst may be reduced because of increased back pressure increase in the exhaust, deteriorating volumetric efficiency in the combustion chamber, reducing torque
		If a high amount of soot builds up followed by a high acceleration the catalytic converter could be physically damaged because of the high temperature that occurs when carbon deposits are oxidised.
Normal acceleration and deceleration	General wear and tear	Wear to all moving parts, tyres, and engine oil
Deceleration to idle and stop	Quickly releasing the throttle may cause a rich mixture In carburetted vehicles this is because of mis-fuelling, for the given high engine speed/low engine load conditions	In theory HC may be emitted and in extreme conditions could possibly coat the catalyst[12]
		"Cold" combustion leading to thermal shock in case of prolonged coast-through decelerations. In idle the concern is inherently unstable combustion possibly leading to carbon deposits

---

[12] HC coating the catalyst is not likely to occur during ordinary driving situations, but may be associated with low loads or misfire situations and is included here for consideration

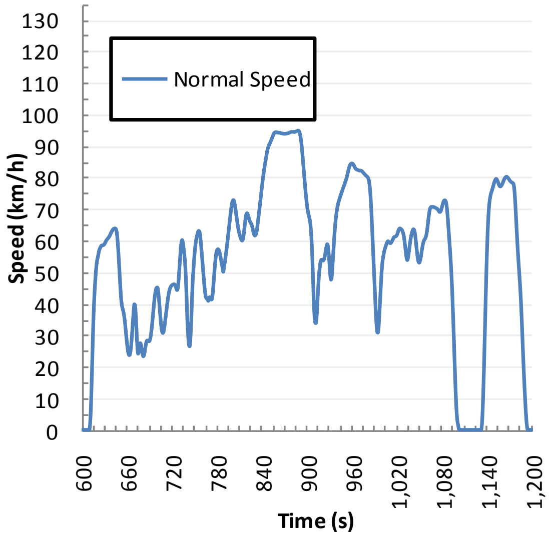


Figure 4-14: Revised WMTC, normal vehicle speed, part 2

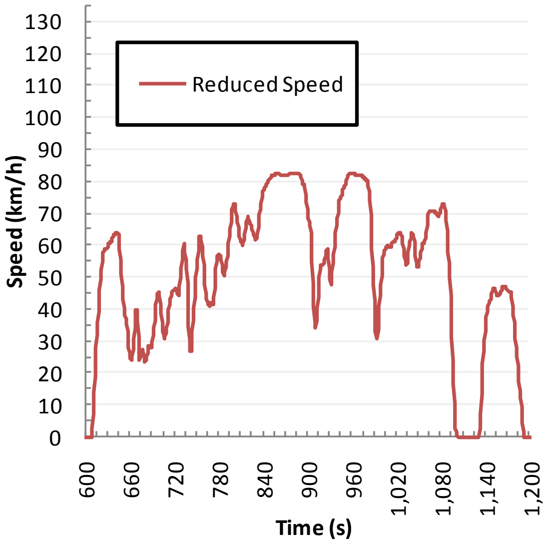


Figure 4-15: Revised WMTC, reduced vehicle speed, part 2

Part 2 is made up of a medium vehicle speed urban driving cycle (see Figure 4-14 and Figure 4-15), including only one complete stop but also a sequence of accelerations and decelerations, representative of driving around a non-congested city consisting of higher vehicle speed roads. The majority of the part is spent varying vehicle speed between 25 km/h and 70 km/h with an average vehicle speed of 54.8 km/h.

The following table details possible consequences and damage that may be caused by particular features of the stated part of the cycle.

Table 4-8: Type of wear intended: revised WMTC, part 2

Feature	Consequence	Damage
Travelling at design vehicle speed, medium load for a sustained period	General wear and tear	Wear to all moving parts, tyres, and engine oil
Normal acceleration and deceleration	General wear and tear	Wear to all moving parts, tires, and engine oil
Deceleration to idle and stop	Quickly releasing the throttle may cause a rich mixture In carburetted vehicles this is because of mis-fuelling, for the given high engine speed/low engine load conditions	In theory HC may be emitted and in extreme conditions could possibly coat the catalyst[13] "Cold" combustion leading to thermal shock in case of prolonged coast-through decelerations. In idle the concern is inherently unstable combustion possibly leading to carbon deposits.

---

[13] HC coating the catalyst is not likely to occur during ordinary driving situations, but may be associated with low loads or misfire situations and is included here for consideration

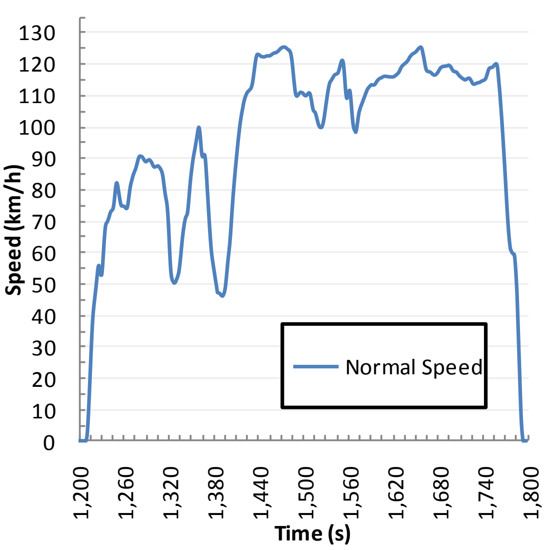


Figure 4-16: Revised WMTC, normal speed, part 3

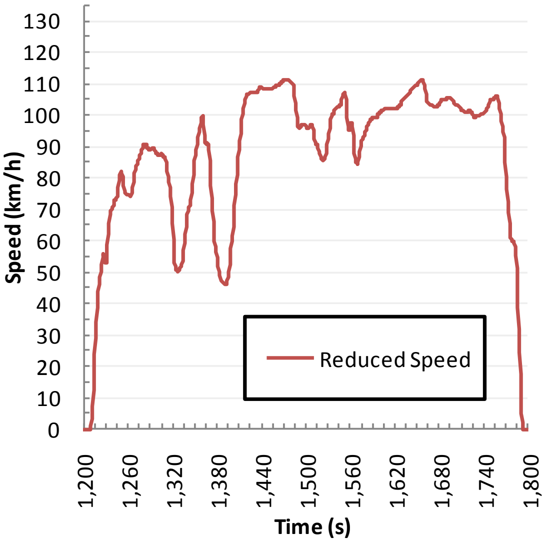


Figure 4-17: Revised WMTC, reduced speed, part 3

Part 3 is a high vehicle speed extra-urban driving cycle (see Figure 4-16 and Figure 4-17), comprising of smaller vehicle speed changes, representative of driving on a motorway.

The following table details possible consequences and damage that may be caused by particular features of the stated part of the cycle.

Table 4-9: Type of wear intended: revised WMTC, part 3

Feature	Consequence	Damage
Travelling at design vehicle speed, medium load for a sustained period	General wear and tear	Wear to all moving parts, tires, and engine oil
Travelling at very high load or vehicle speed for a sustained period (i.e. above the red line)	The engine and/or exhaust system may become hot	The exhaust gases will be hotter, and depending on calibration may result in high NO_x or high HC/CO emissions
		The excess heat may cause knocking combustion
		In extreme cases the engine may seize
		The catalytic converter may overheat if not sufficiently protected
Normal acceleration and deceleration	General wear and tear	Wear to all moving parts, tires, and engine oil

Feature	**Consequence**	**Damage**
Deceleration to idle and stop	Quickly releasing the throttle may cause a rich mixture In carburetted vehicles this is because of mis-fuelling, for the given high engine speed/low engine load conditions	In theory HC may be emitted and in extreme conditions could possibly coat the catalyst[14]
		"Cold" combustion leading to thermal shock in case of prolonged coast-through decelerations. In idle the concern is inherently unstable combustion possibly leading to carbon deposits

4.4 New SRC-LeCV durability cycle elements

By taking all of the data from the analysis, together with an analysis of the testing programme and the finding of the EPA in developing the AMA test cycle and SRC, Table 4-10 was compiled. This lists the causes and possible consequences of those actions. By combining the types of consequences which are linked,

Table 4-11 has been compiled. This shows the parts of the cycle which produce these consequences.

Table 4-12 shows the vehicle speeds that are required to obtain these consequences.

Table 4-10: Summary of actions and consequences

Action	Consequences	High heat			Increased emissions			Ageing			Benefit
		Engine	Exhaust	Exhaust gas temp.	CO & HC	NO_x	PM / Soot	Pollution control devices temporarily	Pollution control devices permanently	Engine	Burn soot
Idling (stop)	When cold				X		X	X			
	When hot	X			X		X	X			
Accelerating	Low load				X		X				
	high load	X	X	X	X	X		X	X	X	X

---

[14] HC coating the catalyst is not likely to occur during ordinary driving situations, but may be associated with low loads or misfire situations and is included here for consideration

Action	Consequences	High heat			Increased emissions			Ageing			Benefit
		Engine	Exhaust	Exhaust gas temp.	CO & HC	NO_x	PM / Soot	Pollution control devices temporarily	Pollution control devices permanently	Engine	Burn soot
	Full load (WoT)	X	X	X	-/X[15]	X/-[15]	X	X	X/-[15]	X	X/-[15]
Cruising	Low load				X		X				
	Medium load									X	
	Full load (WoT)	X	X	X	X	X	X	X	X	X	X
Decelerating	Low throttle w/o DFCO		?[16]		X		X	X[16]	X[16]		
	Cut throttle (coast) with DFCO		?[16]					X[16]	X[16]		

Where: X = applicable consequence of action

Following from the cycle analysis, vehicle speeds, acceleration and deceleration rates were chosen (using data from the vehicles used in the testing programme) which are likely to generate the required consequences for the four groups of L-category vehicles (shown in Annex VII of the draft proposal COM(2010) 542 final). The vehicle speeds and rates have then been used to simulate the engine speed and load and to adapt the chosen parts and generate modified cycle parts. The four cycles are based on the maximum speed of the L-category vehicle, namely:

---

[15] Some vehicles use a fuelling regime which reduces the temperature and protect the catalytic converter at high throttle/load by enriching the mixture. This reduces NO_x but increases HC and CO emissions.

[16] A range of conflicting information was obtained from experts and stakeholders regarding a high temperature peak when decelerating from an initial high load. Unconfirmed information suggests that as the load is reduced the temperature should reduce, but some fuelling regimes could increase the temperature in this case. This could be caused by mis-fueling or air/fuel ratio enrichment leading to unburned HCs oxidising in the hot catalyst.

- Cycle 1: ≤25 km/h
- Cycle 2: ≤45 km/h
- Cycle 3: ≈100 km/h
- Cycle 4: >130 km/h

Table 4-11: Consequences to cycle best match

Consequence	Action	Cycle Parts
Soot creation	Idle and low engine load, simulated by low vehicle speed Overly rich mixture during WoT acceleration and/or WoT cruise	AMA test cycle Part 1 vehicle speed and SRC Part 1 at low load areas
High exhaust temperatures	High engine load during higher vehicle speeds and loads (Unconfirmed information suggests that reduced load directly following a high load may in some vehicles cause high temperatures in catalytic converters)	AMA test cycle Part 3, AMA test cycle Part 2, SRC Part 4 and SRC Part 5
HC release (rich mixture)	Significant: During mixture enrichment (i.e. cold start, power/acceleration and catalyst over temperature protection)	AMA test cycle Part 1, SRC two coast-downs and SRC fourteen moderate decelerations
	Less significant: Bad fuelling at deceleration	AMA test cycle Part 3, AMA test cycle Part 2, SRC Part 4 and SRC Part 5
Rich mixture (only some vehicles)	The cause of some of the issues noted above; but specifically when done purposefully for catalyst over temperature protection enrichment during high load accelerations using WoT	AMA test cycle Part 3, AMA test cycle Part 2, SRC Part 4 and SRC Part 5

The points at which these consequences occur for a given vehicle differ. The typical location for each of the four groups of L-category vehicles (shown in Annex VII of the draft proposal COM(2010) 542 final) has been used.

Table 4-12: Vehicle speeds required to obtain required consequence

Consequence	Group	Cycle 1 ≤25 km/h	Cycle 2 ≤45 km/h	Cycle 3 ≤100 km/h	Cycle 4 >130 km/h
Low engine load simulated by idle and low vehicle speed (soot creation)	Lap:	≤ 15	≤ 17.5	≤ 40	≤ 90
	Accel' Rate:	Slow increments			
	Decel' Rate:	Never fully off the throttle			
High engine load, higher vehicle speed (higher exhaust gas temperatures)	Lap:	≥ 15	≥ 27.5	≥ 54	≥ 132
Decelerating sharp throttle release (cooling regime may be initiated, high HC)	From:	15	min 20	min 20	min 30
	To:	10 less	10 less	15 less	15 less
	Rate:	Throttle Off (≤-1.5 ms^{-2})			
Accelerating hard/WoT (rich air/fuel ratio possible for some vehicles)	To:	15	30	75	90
	From:	0	0	0	0
	Rate:	Hard or Wide Open Throttle (WoT) (≥1.5 ms^{-2})			

With the actions likely to cause the key consequences defined for the vehicles under test, the data could be used to first asses the current cycles and, if found necessary, design a new cycle by ascertaining how much of the time and distance the vehicle was performing these actions. To do this for all vehicle types, some modification of the cycles was necessary.

The AMA test cycle has the three classes which could account for all but the ≤25 km/h L1Ae category, so for this one group the Class I profile was scaled down to match. The SRC test cycle for cars has only a single cycle designed for medium to high performance vehicles, the majority of M- and N-category fleet are capable of maintaining this profile. Consequently, the profile has to be scaled appropriately for each of the L-category groupings. It should be noted that although there is a version of the SRC cycle in both a UN regulation and an EU directive, the original US EPA version was used. This was to prevent compound errors with the conversion to from mile/h to km/h.

The WMTC emission driving cycle is designed to be adapted for a range of L-category vehicle capabilities; therefore, a different cycle was used in the analysis for each of the groups. However, it should be noted that the WMTC cycle was designed using, and for, powered-two-wheelers with an engine capacity ≤50 cm^3 and a maximum speed >50 km/h i.e. category L3e motorcycles. Also the WMTC did not have a configuration option for ≤25 km/h L1Ae category vehicles as with the AMA test cycle, or for the ≤45 km/h L1Be category. However, as stated in COM(2010) 542 final, the Revised WMTC (stage 3) may be applied to the entire L-category fleet in the EU in the future. The only group of vehicles which substantially falls outside of the cycle's requirements are ≤25 km/h capable L1Ae sub-category (i.e. power assisted bicycles) and low speed mopeds L1Be (≤25 km/h), therefore, as per the regulations in UN GTR No. 2, the cycle was capped at 25 km/h before the analysis.

To perform the comparison and analysis, a tool was made to generate and display the cycles, as well as analyse and compare the proportions of key areas of interest and to allow modification of the new cycles under development giving instant feedback and comparison.

The WMTC cycle was designed to be representative of real-world L-category vehicle driving not only for Europe but world-wide as it is being used to replace the current UN Regulation 40 test for motorcycles, and proposed by the EC to replace the UN Regulation 47 test for mopeds. As such, it was decided to use this as a benchmark to compare the other cycles against. This benchmarking would be performed for each of the vehicle groups defined above.

The traces and instructions for the three parts of the WMTC cycle were transferred into tables, the stage 2 version was used for the analysis being the latest published version and the version to be used in the most advanced step (revised WMTC or WMTC stage 3 which is stage 2 including low performance vehicles such as mopeds and opening the scope to other vehicle categories than only L3e motorcycles) of the EU L-category legislation as it stood at the time of the analysis. The WMTC cycle is described using the instantaneous speeds at one second intervals, with data points for each of the three normal and three reduced speeds parts, this is combined with information on the action(s) to be performed during that moment: stopped, accelerating, cruising, decelerating, gear shifting permitted, and if the 1st gear is required.

With the information converted to an appropriate format, these parts were used to build the four configurations required to match the groups of categories as set out in part A of Annex VII of ‘COM(2010) 542 final’ (see Table 1-1 as is defined by the criteria in UN GTR No. 2, see Appendix D.2).

As some vehicles performing these cycles have speed restrictions, a cap was required to modify the cycle's speed trace down to the speed the vehicle would actually be able to perform. In UN GTR No. 2, deviating from the designated speed because of a limitation of the vehicle is permitted. Figure 4-18 shows the speed trace generated using subclass 1-1 for a vehicle with engine capacity ≤50 cm^3 and 50 km/h<v_{max}≤60 km/h, this is the lowest performance category in the WMTC, this was then capped to 25 km/h for L1Ae and ≤25 km/h L1Be mopeds.

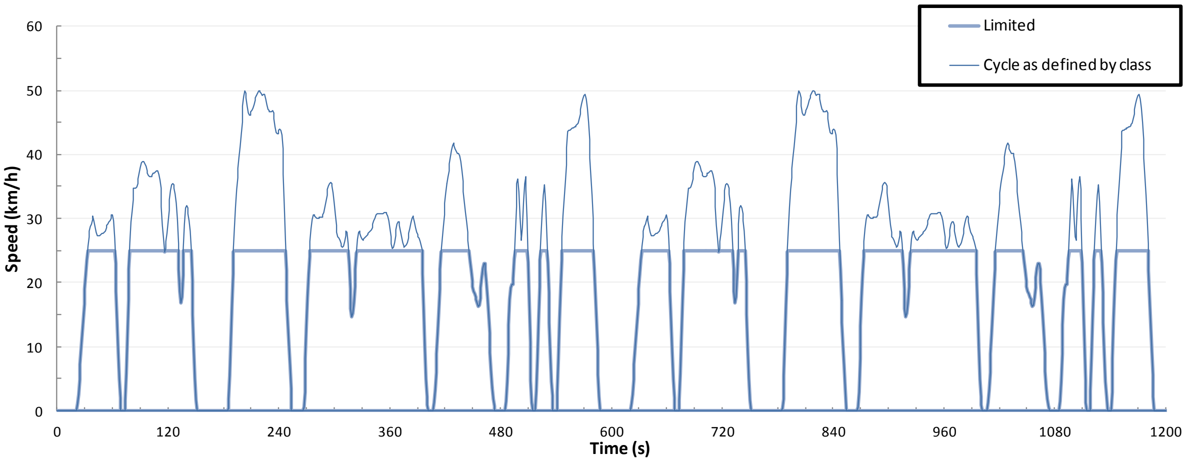


Figure 4-18: Trace of WMTC revised (stage 3) cycle for class 1, limited to 25 km/h

With the cycles generated, various values were calculated using the equations of motion to obtain: distance travelled, acceleration and declaration rate, and from these: the duration and distance travelled while performing a given action and finally the duration and distance travelled while performing the four key actions identified in the previous section. These times and distances were then converted into percentages of the whole cycle and tabulated (see Table 4-13 below).

Table 4-13: Proportion of key actions for WMTC revised (stage 3) cycle for class 1, limited to 25 km/h

	Time					Distance				
	Speed			Change		Speed			Change	
	Slow vehicle speed	**Peak torque**	**High vehicle speed**	**Decelerating**	**Accelerating**	**Slow vehicle speed**	**Peak torque**	**High vehicle speed**	**Decelerating**	**Accelerating**
Group 1	6.4 %	3.9 %	89.7 %	6.1 %	3.9 %	1.2 %	1.0 %	97.8 %	3.6 %	2.8 %
Group 2	8.4 %	27.7 %	64.0 %	8.1 %	5.4 %	2.0 %	20.1 %	77.9 %	4.5 %	4.1 %
Group 3	38.9 %	20.3 %	40.8 %	9.1 %	6.9 %	22.3 %	16.8 %	60.9 %	5.6 %	4.5 %
Group 4	62.7 %	37.3 %	0.0 %	6.3 %	6.0 %	46.0 %	54.0 %	0.0 %	2.7 %	3.0 %

Where:

Group	Parts used	Speed cap
1	reduced speed part 1 twice	25 km/h
2	reduced speed part 1 twice	45 km/h
3	normal speed part 1 and 2	unlimited
4	normal speed part 1, 2 and 3	unlimited

Rather than looking at a percentage of the whole cycle, the values show the proportion the consequence was calculated to occur within the total of the appropriate action; e.g. out of the total time that the vehicle is accelerating, what proportion was theoretically above the vehicles peak torque?:

- Periods at specific speeds is the whole cycle excluding deceleration and idle, acceleration is not excluded as in this situation the engine is also under load;

- Periods looking at acceleration rates exclude the idle, cruise and decelerating;
- Periods looking at deceleration rates exclude the idle, cruise and accelerating.

Following the analysis of the WMTC emissions cycle, a similar process was performed on the EPA AMA and EPA SRC durability cycles. As the instructions for these cycles are designed primarily to be simple to implement on a test track not for transfer to software used in dynamometer testing, they contained mixed instruction types depending on what would be clearest for a rider such as: vehicle speed, test time or portion of a lap (see Appendix D.2). Therefore, the instructions had to be used to calculate all of the metrics used to evaluate the WMTC.

The equations of motion were used first to calculate the times and distances for the changes in speed, these distances were then taken from the total lap length to obtain the remainder used for the cruise sections which are defined as divisions of the lap length.

As the durability cycles may need to be used in the creation of a new one, rather than integrating the speed points into the table, the speed points, acceleration and deceleration rates were kept in a separate table with links to the correct places in the cycles.

With the cycles tabulated, the analysis to find the proportions of key actions was calculated in the same way as was performed on the WMTC cycle, these are presented below in Table 4-14 and Table 4-15:

Table 4-14: Proportion of key actions for EPA AMA

	Time					Distance				
	Speed			Change		Speed			Change	
	Slow vehicle speed	Peak torque	High vehicle speed	Decelerating	Accelerating	Slow vehicle speed	Peak torque	High vehicle speed	Decelerating	Accelerating
Group 1	54.7 %	45.3 %	0.0 %	60.4 %	0.1 %	54.5 %	45.3 %	0.2 %	54.8 %	11.3 %
Group 2	0.2 %	99.7 %	0.0 %	62.2 %	0.2 %	1.1 %	98.2 %	0.7 %	55.9 %	11.7 %
Group 3	0.5 %	99.4 %	0.1 %	69.4 %	0.9 %	4.6 %	90.0 %	5.3 %	61.1 %	13.1 %
Group 4	80.3 %	19.7 %	0.0 %	63.2 %	1.5 %	80.4 %	19.6 %	0.0 %	56.6 %	12.1 %

Table 4-15: Proportion of key actions for EPA SRC

	Time					Distance				
	Speed			Change		Speed			Change	
	Slow vehicle speed	Peak torque	High vehicle speed	Decelerating	Accelerating	Slow vehicle speed	Peak torque	High vehicle speed	Decelerating	Accelerating
Group 1	40.9 %	0.0 %	59.1 %	0.3 %	0.2 %	28.5 %	0.1 %	71.3 %	0.2 %	0.1 %
Group 2	13.9 %	27.4 %	58.8 %	0.7 %	0.6 %	7.1 %	22.1 %	70.8 %	0.4 %	0.4 %
Group 3	15.8 %	19.2 %	65.0 %	3.6 %	3.2 %	7.0 %	17.8 %	75.2 %	2.0 %	1.9 %
Group 4	64.3 %	35.7 %	0.0 %	6.0 %	5.5 %	48.0 %	52.0 %	0.0 %	3.4 %	3.2 %

All of these values are shown in the two charts below (see Figure 4-19 and Figure 4-20 for time and distance proportions respectively) to allow comparison of the proportion of each action between cycles and vehicle groups.

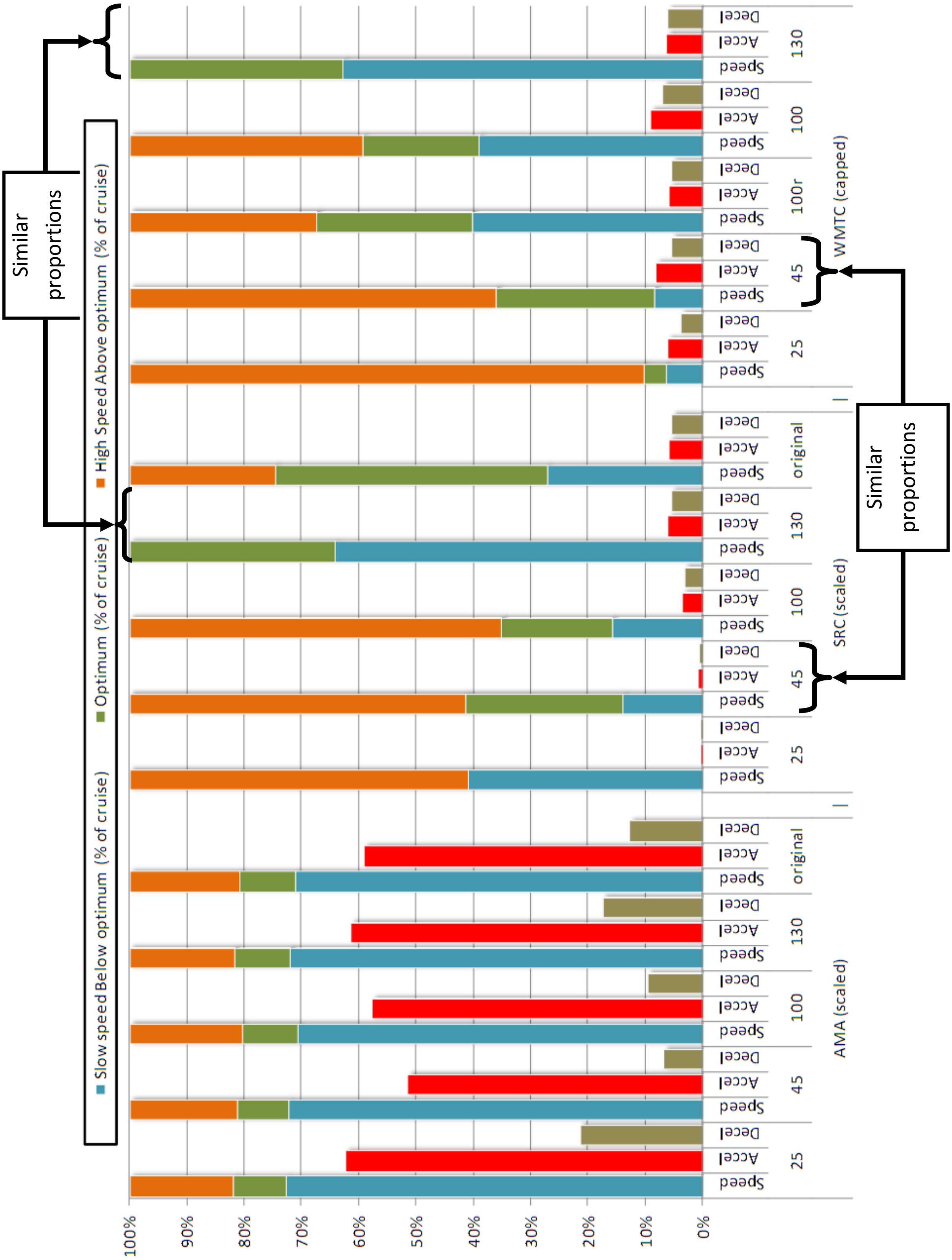


Figure 4-19: Percentage of time performing actions (optimum being the vehicle speed at which the vehicle is producing peak torque, travelling on a simulated level surface in the appropriate gear)

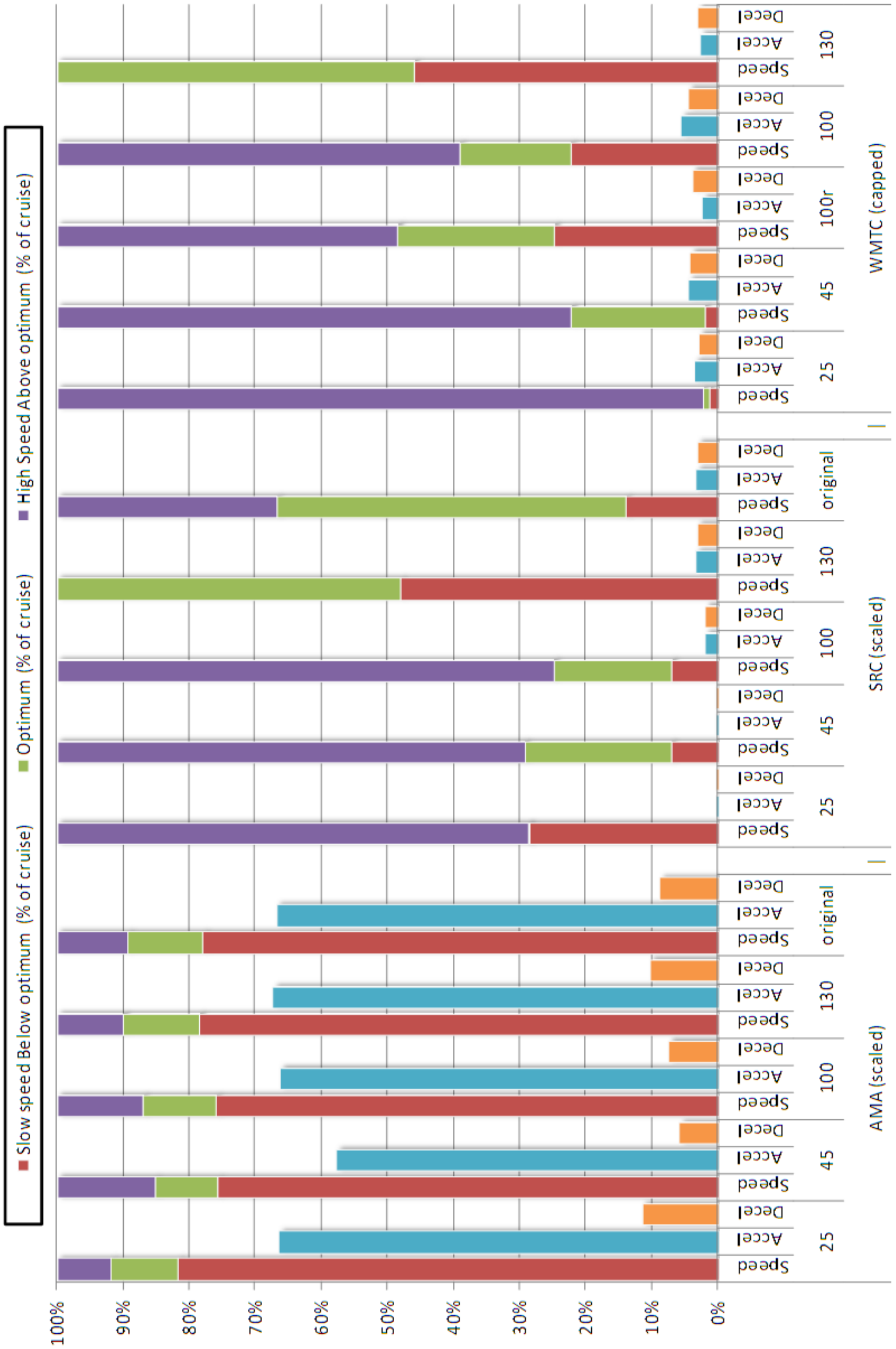


Figure 4-20: Percentage of distance performing actions (optimum being the vehicle speed at which the vehicle is producing peak torque, travelling on a simulated level surface in the appropriate gear)

From this data, as well as the analysis above, the intentions of the EPA when designing the two driveability cycles can be surmised. For the AMA test cycle, between 75% and 82% of the cycle is spent at low engine load, simulated by moderate to low vehicle speeds. Taking the plot shown in Figure 4-1 it can be seen that this low vehicle speed period is intended to cover the majority of the cycle (9 of the 11 laps), causing the build-up of soot, HC and carbon deposits in the susceptible parts. Following this there is a moderately high speed lap, presumably designed to partially clear the soot before a final two stage high vehicle speed and high load WoT acceleration lap to moderate or high vehicle speeds. This design basis, to cause a single problem for a sustained period while not performing real-world actions, means that the EPA AMA durability diving cycle can be defined as an accelerated cycle to simulate the deposition of carbon in the combustion chamber, valves and piston rings.

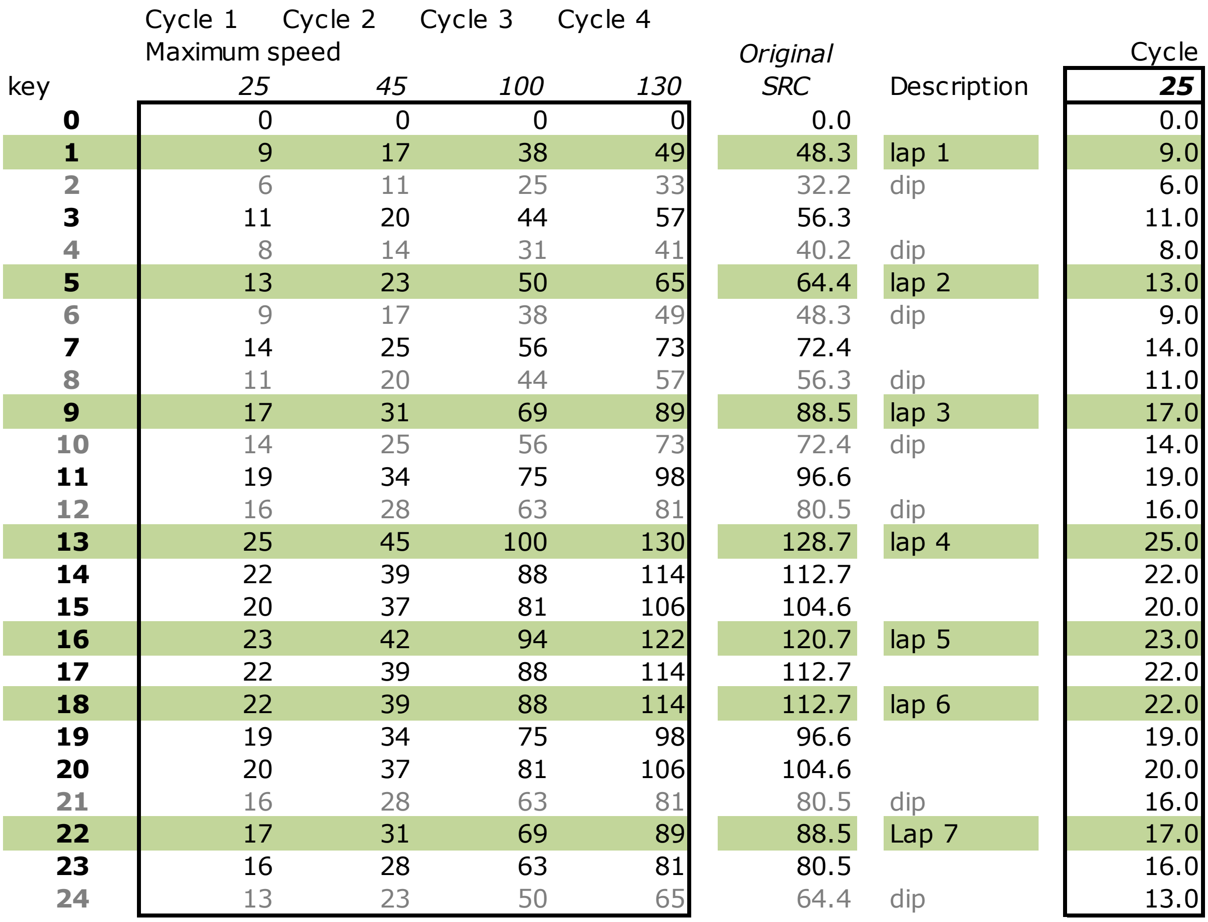
The SRC shares many of the characteristics of the WMTC emission laboratory test cycle, both in its appearance and consequences to the vehicle and emission abatement parts. In both cycles the actions are spread out over a simplified course intended to mimic an average journey. Therefore, the EPA SRC can be defined as a real-world cycle and, when compared with the EPA AMA, would be expected to produce increased thermal ageing, a higher level of poisoning and mechanical wear at higher engine loads and a lesser extent of carbon deposits at lower engine loads in line with experiences in the current fleet.

The analysis of the proportion of actions shows that the EPA SRC durability driving cycle is more representative of motorcycle riding and more likely to impose demands on the vehicle relevant to the ageing of modern pollution control systems. Two of the groups (with scaled speeds) had a distribution of actions which were very close to the appropriate WMTC analysis (Group 2; 45 km/h v_{max} and Group 4; 130 km/h v_{max}). For these reasons, the TRL proposal for a new durability cycle for L-category vehicles has been based on an adaptation of the SRC distance accumulation cycle. However, although it is a better starting point it cannot be used in its current form. It should also be understood that, matching precisely the percentages of actions between the new cycle and the WMTC cannot and does not need to be achieved due to the fundamental differences with the cycles' intentions and feasibility with regards to repeatability. An emissions cycle has tight tolerances to give repeatability and reproducibility in a period of just 30 minutes, while a durability cycle only has to show this in the results over many days, if not weeks, of testing. In addition, for practical reasons it would not be feasible to have tight tolerances due to changing conditions on a track or road, where an emission test is performed in a lab under well-defined and stable environmental conditions.

4.5 Development of Standard Road Cycle for L-Category Vehicles (SRC-LeCV)

Figure 4-19 and Figure 4-20 in the preceding section showed that the proportions of the key actions in the real-world WMTC emissions driving cycle were closer matched by the SRC cycle than the AMA. However, although they are closer, they did not match exactly.

As mentioned above, the tool created to analyse the cycles was also designed in such as to be used in the development of a new cycle. Certain features used in the two durability cycles analysed were cited by stakeholders as being essential in regards to practicality to perform the cycle and preventing any costs in regards to infrastructure, namely using the same length of track and using the same points around the track as markers for actions. Therefore, the points and distances used in the original EPA SRC were kept fixed, but the main vehicle speeds, acceleration and deceleration points were able to be adjusted separately. The acceleration and deceleration rates used were based on the EPA SRC typical acceleration rates.



	Cycle 1	Cycle 2	Cycle 3	Cycle 4			
	Maximum speed				*Original*		Cycle
key	*25*	*45*	*100*	*130*	*SRC*	Description	***25***
0	0	0	0	0	0.0		0.0
1	9	17	38	49	48.3	lap 1	9.0
2	6	11	25	33	32.2	dip	6.0
3	11	20	44	57	56.3		11.0
4	8	14	31	41	40.2	dip	8.0
5	13	23	50	65	64.4	lap 2	13.0
6	9	17	38	49	48.3	dip	9.0
7	14	25	56	73	72.4		14.0
8	11	20	44	57	56.3	dip	11.0
9	17	31	69	89	88.5	lap 3	17.0
10	14	25	56	73	72.4	dip	14.0
11	19	34	75	98	96.6		19.0
12	16	28	63	81	80.5	dip	16.0
13	25	45	100	130	128.7	lap 4	25.0
14	22	39	88	114	112.7		22.0
15	20	37	81	106	104.6		20.0
16	23	42	94	122	120.7	lap 5	23.0
17	22	39	88	114	112.7		22.0
18	22	39	88	114	112.7	lap 6	22.0
19	19	34	75	98	96.6		19.0
20	20	37	81	106	104.6		20.0
21	16	28	63	81	80.5	dip	16.0
22	17	31	69	89	88.5	Lap 7	17.0
23	16	28	63	81	80.5		16.0
24	13	23	50	65	64.4	dip	13.0

Figure 4-21: Cycle speed point selection used in the cycle development tool

Figure 4-21 above shows how the key values for the SRC cycles were separated in the main table with coloured bands showing the start of a lap and if the point refers to a cruise or up/down dip in the lap. The cycle under development could be selected from a menu (currently "25" under "cycle" in the top right corner) to allow the analysis of the proportion of actions (see Figure 4-22) and display a dynamically generated trace (see Figure 4-23).

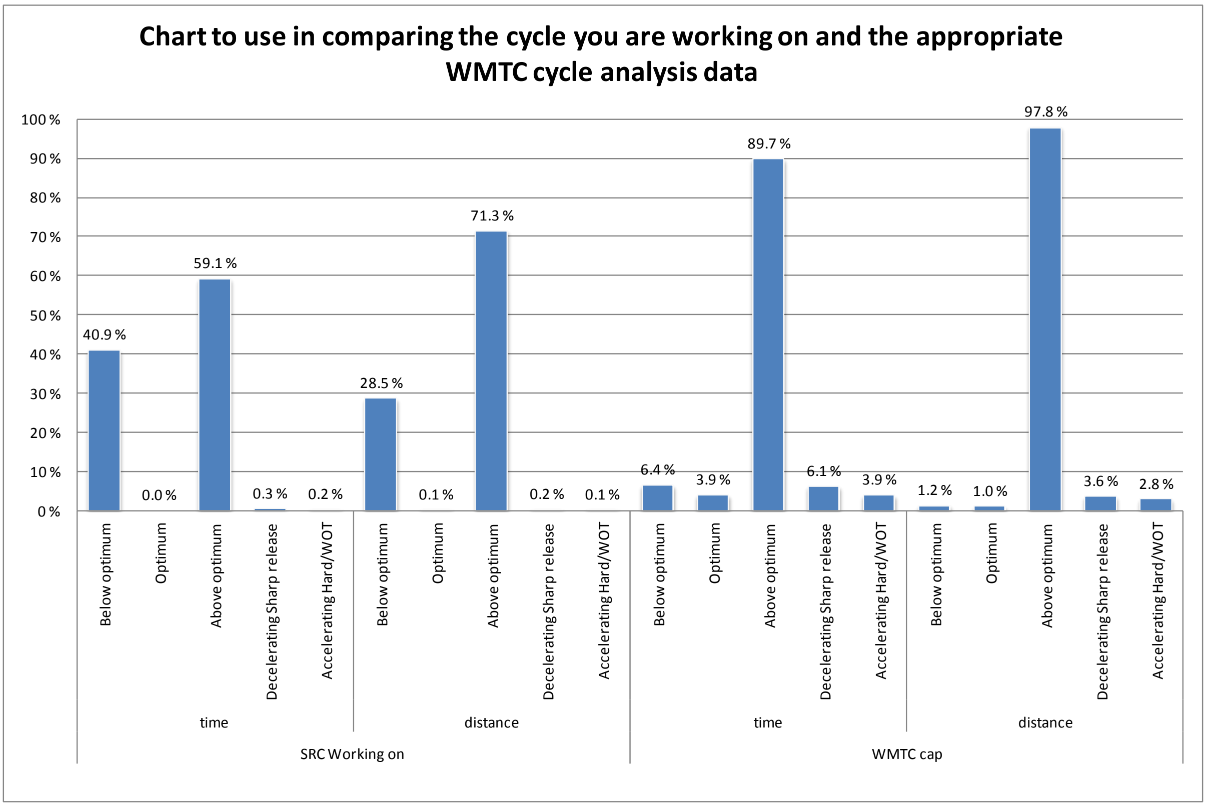


Figure 4-22: Example of proportion of actions of new cycle under development

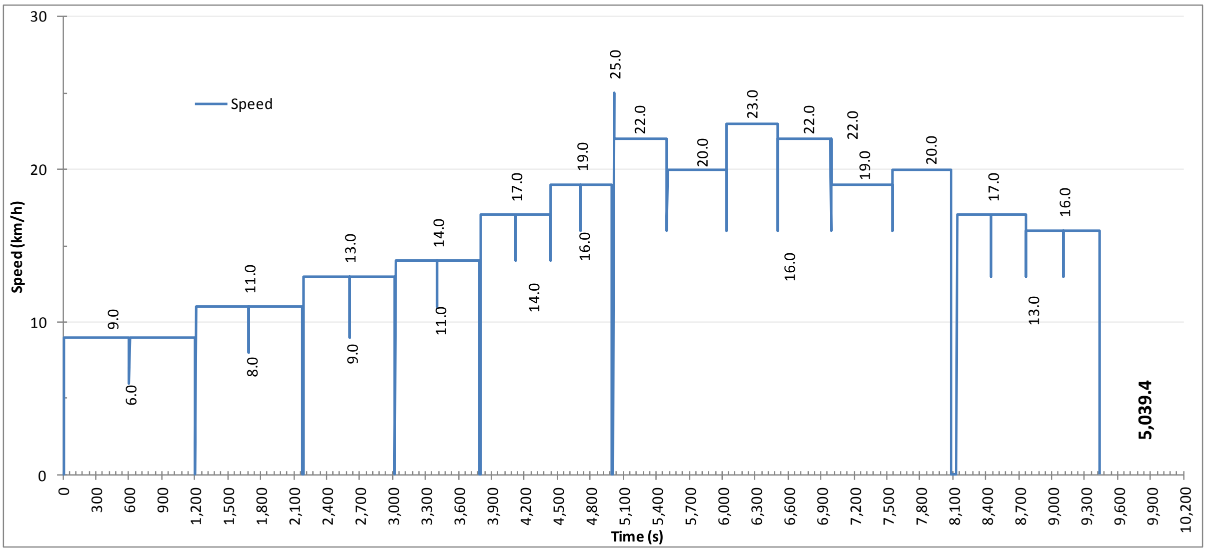


Figure 4-23: Example of dynamically generated speed trace of new cycle under development

Due to the complexity of the cycles and number of variables, it was not possible to automate the cycle generation. Using the graph of proportions and speed trace the speeds were manually changed until the distributions were as close as practicable between the new cycle and the equivalent WMTC cycle.

During the design phase an effort was made to not change the intention of each lap and to keep the journey "story" played out by the cycle the same, i.e. travelling at a slow but realistic vehicle speed for a small road, overtaking other traffic or travelling on a highway.

Consideration also had to be made to the usability of the cycle at the expense of exactly matching the distribution of actions. The vehicle speed changes were kept to whole numbers and speed changes to at least 3 km/h.

Using this methodology phase 1 of the four cycles were created, with the actions, sub-actions and key distances shown in Table 4-16 for the complete kilometre accumulation laps for the four cycles.

Table 4-16: Revised Standard Road Cycle (SRC-LeCV phase 1) (development cycle)

Lap	**Action**	**Sub-action**	**Distance [Share of 1 lap of test circuit]**	**Time (s)**	**To final vehicle speed (km/h)**			
					Cycle 1 ≤ 25 km/h	**Cycle 2 ≤ 45 km/h**	**Cycle 3 ≤ 100 km/h**	**Cycle 4 > 130 km/h**
0	*If not running start engine (if applicable)*				*0*	*0*	*0*	*0*
1	Idle			10	0	0	0	0
1	Accelerate	Moderate			14	17	30	49
1	Cruise		1/4 lap		14	17	30	49
1	Decelerate	Moderate			6	11	15	33
1	Accelerate	Moderate			14	17	30	49
1	Cruise		1/4 lap		14	17	30	49
1	Decelerate	Moderate			0	0	0	0
1	Idle			5	0	0	0	0
1	Accelerate	Moderate			15	20	30	57
1	Cruise		1/4 lap		15	20	30	57
1	Decelerate	Moderate			5	14	15	41
1	Accelerate	Moderate			15	20	30	57
1	Cruise		1/4 lap		15	20	30	57
1	Decelerate	Moderate			0	0	0	0
2	Idle			10	0	0	0	0
2	Accelerate	Moderate			17	23	41	65
2	Cruise		1/4 lap		17	23	41	65
2	Decelerate	Moderate			6	17	30	49

Lap	Action	Sub-action	Distance [Share of 1 lap of test circuit]	Time (s)	To final vehicle speed (km/h)			
					Cycle 1 ≤ 25 km/h	Cycle 2 ≤ 45 km/h	Cycle 3 ≤ 100 km/h	Cycle 4 > 130 km/h
2	Accelerate	Moderate			17	23	41	65
2	Cruise		1/4 lap		17	23	41	65
2	Decelerate	Moderate			0	0	0	0
2	Idle			5	0	0	0	0
2	Accelerate	Moderate			18	25	41	73
2	Cruise		1/4 lap		18	25	41	73
2	Decelerate	Moderate			10	20	30	57
2	Accelerate	Moderate			18	25	41	73
2	Cruise		1/4 lap		18	25	41	73
2	Decelerate	Moderate			0	0	0	0
3	Idle			10	0	0	0	0
3	Accelerate	Hard			20	31	55	89
3	Cruise		1/4 lap		20	31	55	89
3	Decelerate	Moderate			15	25	40	73
3	Accelerate	Moderate			20	31	55	89
3	Cruise		1/4 lap		20	31	55	89
3	Decelerate	Moderate			15	25	40	73
3	Accelerate	Moderate			24	34	75	98
3	Cruise		1/4 lap		24	34	75	98
3	Decelerate	Moderate			16	28	60	81
3	Accelerate	Moderate			24	34	75	98
3	Cruise		1/4 lap		24	34	75	98
3	Decelerate	Moderate			0	0	0	0
4	Idle			10	0	0	0	0
4	Accelerate	Hard			25	45	100	130
4	Decelerate	Coast-down			20	39	88	114
4	Cruise		1/2 lap		20	39	88	114
4	Decelerate	Moderate			10	28	63	81

Lap	Action	Sub-action	Distance [Share of 1 lap of test circuit]	Time (s)	To final vehicle speed (km/h)			
					Cycle 1 ≤ 25 km/h	Cycle 2 ≤ 45 km/h	Cycle 3 ≤ 100 km/h	Cycle 4 > 130 km/h
4	Accelerate	Moderate			25	37	81	106
4	Cruise		1/2 lap		25	37	81	106
4	Decelerate	Moderate			10	28	63	81
5	Accelerate	Moderate			25	42	94	122
5	Cruise		1/2 lap		25	42	94	122
5	Decelerate	Moderate			10	28	63	81
5	Accelerate	Light			25	39	88	114
5	Cruise		1/2 lap		25	39	88	114
5	Decelerate	Moderate			10	28	63	81
6	Accelerate	Moderate			25	39	88	114
6	Decelerate	Coast-down			20	34	75	98
6	Cruise		1/2 lap		20	34	75	98
6	Decelerate	Moderate			10	28	63	81
6	Accelerate	Moderate			20	37	81	106
6	Cruise		1/2 lap		20	37	81	106
6	Decelerate	Moderate			0	0	0	0
7	Idle			45	0	0	0	0
7	Accelerate	Hard			17	31	69	89
7	Cruise		1/4 lap		17	31	69	89
7	Decelerate	Moderate			12	23	50	65
7	Accelerate	Moderate			17	31	69	89
7	Cruise		1/4 lap		17	31	69	89
7	Decelerate	Moderate			12	23	50	65
7	Accelerate	Moderate			16	28	63	81
7	Cruise		1/4 lap		16	28	63	81
7	Decelerate	Moderate			12	23	50	65
7	Accelerate	Moderate			16	28	63	81
7	Cruise		1/4 lap		16	28	63	81

Lap	Action	Sub-action	Distance [Share of 1 lap of test circuit]	Time (s)	To final vehicle speed (km/h)			
					Cycle 1 ≤ 25 km/h	Cycle 2 ≤ 45 km/h	Cycle 3 ≤ 100 km/h	Cycle 4 > 130 km/h
7	Decelerate	Moderate			0	0	0	0
n	Repeat from lap 1 to end of lap 7 until necessary				#	#	#	#

As mentioned previously, the vehicle speeds of Groups 2 and 4 required very little modification beyond scaling of the groups maximum design vehicle speed to that of the group and conversion to metric. Group 1 required changes to 18 of the 25 cruises (72%), increasing the vehicle speed by 20% on average. Group 3 required a 27% reduction to 11 of the 25 vehicle speed points to make it match the WMTC percentages.

4.5.1 Efficiency of cycle (reduction in number of laps)

At this point in the process the new cycle was still tentative. The first step in scrutinising phase 1 of the cycle was seeing if it achieved all of the aims of the original criteria.

- Challenging – measure aimed to control the life time emissions from L-category vehicles
    - 'work' all the emission critical components in current vehicles.
- Practical – relatively easy to undertake, and repeatable
    - e.g. can't be too complicated but must be flexible, so different types of test procedures can be employed to accumulate the durability distance whilst following the cycle (e.g. on dynamometer, test track or public road).
- Representative of real-world usage
    - e.g. trip based journey data; reference to relevant parts of WMTC emission cycle.
- Efficient and not over-burdensome on manufacturers, especially SMEs
    - Durability testing may require the use of expensive facilities, may take considerable precious development time and typically has a direct effect on the time taken to bring new vehicle models to market. Minimising the time it takes to accumulate the distance therefore has a direct effect on costs and development time for new models.

The cycles were designed using a method which intended to ensure that the vehicles, and their emission critical components, were challenged in as close a manner as the real-world WMTC test did; therefore this objective was achieved.

The cycles were based on a proven cycle, with simple instructions and long periods between actions (there are less actions than in both the WMTC and EPA AMA cycles). On the other hand, additional instructions were devised for the four types of acceleration and declaration rates rather than the previous list of typical acceleration rates, it was felt that these additional instructions would provide clarity rather than complexity and that this was only a small change, therefore this criteria is also achieved.

A second issue in regards to practicality was the use of final speeds with an accuracy of 1 km/h and speed changes of 3 km/h were considered much to small changes, the cycle would have to be performed on a track by a rider with little or no additional telemetry besides what is fitted to the vehicle, therefore to align with the capabilities of the majority of speedometers a minimum vehicle speed step and change of 5 km/h was set. Also for the two higher performance groups minimum steps of 10 km/h were sometimes used.

As mentioned earlier, the use of the WMTC cycle as a basic of the analysis and design ensured that the test was representative of real-world use.

Finally, the burden to the manufactures was assessed. This burden is considered to be: the cost of equipment, test track or chassis dynamometer availability and configuration and the time to complete the durability test. The equipment requirements are no more or less burdensome than either the SRC or AMA durability test currently used for their respective vehicles in Europe and abroad, similarly no evidence was found requiring a change to the requirements of the track and careful attention was paid to keeping the cycle compatible with current tracks. One part however, and arguably the largest issue, is the time to complete the cycle itself. For some vehicles, the overall estimate of the time and costs were not significantly lower than the US EPA AMA cycle but for the majority of the categories there is a significant saving. If however they are looked at by fleet size and specifically the types of vehicles produced by SMEs it was felt that this advantage was not always as pronounced or there at all. Therefore, it was decided to look at the costs further and the cycle itself to see if they could be reduced without harming the scientific integrity of the test.

Given that the processes, preparation and equipment costs are fixed, only shortening the test time would reduce the costs. This can be done in two ways; by shortening the distance covered or increasing the average speed. The distances for the tests are based on fleet averages, and as one of the key criteria was to be real-world and it cannot be defined as an accelerated cycle, these distances cannot be reduced unless actual vehicle use in Europe changes. The total durability test distances for the various (sub-) categories of L-category vehicles are set-out by the Council and European Parliament in the co-decision act. Given the current trend in vehicle use this is more likely to increase than reduce.

Each of the seven laps has specific characteristics that can be correlated with different degradation mechanisms. The first two laps of the seven lap SRC-LeCV were designed to generate ‘soot’ and carbon deposits on key components, which is a degradation mechanism linked to lower quality fuel, older powertrain technologies, fuel delivery systems and combustion chamber design as was found in the 1970’s. This is one of the reasons that the older US EPA AMA test cycle was designed to look at just this issue, and as a result vehicles and fuel has improved to the point that this is no longer a key issue. These first two laps are also the slowest and considering the lower significance to degradation in modern vehicles, it was proposed to remove these laps to increase the average vehicle speed of the whole cycle.

However, this is not the whole picture, as although modern vehicles and fuels are said to negate the original major issues of soot creation and carbon build-up, they do not do so fully and it cannot be supposed that all vehicles in the L-category fleet have improved their combustion chamber designs. Consequently the, be it small proportions of, soot being generated by today’s vehicles are likely to greatly effect two technologies designed to reduce the emission of toxic substances: Firstly, with the requirements of stricter limits on gaseous emissions there is a trend for more vehicles in the L-category fleet to use pollution control devices. And secondly, with the concerns of many groups regarding particulates and their effect on breathing difficulties and cancers, including research from the WHO, in the future vehicles might need particulate filters if the problem cannot be resolved by changes to fuel or improvement of combustion. Both of these devices can become clogged by soot and carbon build-up both reducing their effectiveness and the performance of the vehicle.

Given the reason above, rather than removing the soot creation proportions from the test, they could instead be reduced and/or replaced with a separate test. Research was performed to find other mechanisms that would have the same effect, this showed that soot was created at both very high loads and engine speeds in addition to excessively low vehicle speeds and load, but only low loads caused carbon build-up and to replace the degradation mechanism of low vehicle speeds one clear method was presented: idling. This research provided the following options:

- Option 1: Unchanged, keep first two laps
- Option 2: Reduce instances of first two laps
- Option 3: Run the vehicle at idle, remove low load sections an actions

It has already been given that option 1 is the least preferred option and it was considered that partially adjusting the cycle itself, i.e. intermittently running the first two laps or not depending on a given criteria, would add additional complexity and leave the implementation of the test open to error.

Therefore, the decision was taken to use option 3: add an ‘idling’ section into the test protocol, remove the first two laps (changing it from a 7 lap to a 5 lap cycle) and remove the single ‘light acceleration’ point from lap 5 (or lap 3 in the shortened version). Excluding the pre-test laboratory tests, which are actually performed as part of the Type I emissions test, there are a minimum of four points where the cycle must be stopped for such things as emission testing, soak periods, refuelling and maintenance. Rather than adding the requirement of additional stops, the idling periods were added to these obligatory stops.

To allow the additional procedure to add to carbon build-up, without directly affecting the emissions testing, the idling period was placed after these tests. Similarly, to prevent the soak period from being circumvented, the idle period was placed before that step.

The idle period itself was designed to not be overly excessive, i.e. a length of time that was not unheard of occurring in the real-world, but long enough that if the vehicle is susceptible to carbon deposits that they will be able to build-up. Therefore, a period of 1 hour was chosen.

Two key points must be made on the running of this idling period. As low engine load is required, low-idle is used not high-idle, i.e. apart from starting the vehicle, no other input is given and the throttle is not applied. Secondly, if the vehicle has any special settings and capabilities such as shutting off the engine when idling at a standstill (0 km/h) for long periods to save fuel (i.e. a start-stop system) then this should be deactivated or inhibited. It can be seen that the start-stop feature could be designed in a way that prevented it from being easily disabled by users. However, situations such as during maintenance could require it to be disabled. Therefore, the vehicle should be designed so that the start-stop function can be disabled.

Table 4-17 provides an overview of the different durability cycles (existing and proposed) and compares how well they match the main degradation mechanisms and their real-world consequences based on a comparison with WMTC.

Table 4-17: Comparison of L-category durability test cycles

	Soot creation and carbon deposits (low combustion temperature)	**High exhaust temp**	**High HC**	**Rich air/fuel ratio**	**Represents real-world riding**
US EPA AMA test cycle	✓				
US EPA SRC test cycle	✓	✓	✓	✓	
SRC-LeCV (phase 1, 7 lap)	✓	✓	✓	✓	✓
SRC-LeCV (modified phase 1, 5 lap)		✓	✓	✓	**Partial**
SRC-LeCV and Idle period (phase 2, 5 lap)	✓	✓	✓	✓	✓ **- simulated section**

Therefore, balancing the programme's objectives the 5 lap SRC-LeCV durability cycle phase 2 was proposed. See Table 4-18 and Figure 4-24 for the speed points and plots for each of the four cycles.

Table 4-18: Revised Standard Road Cycle (SRC-LeCV phase 2)(development cycle)

Lap	Action	Sub-action	Distance [share of 1 lap of test circuit]	Time (s)	To final vehicle speed (km/h)			
					Cycle 1 ≤ 25 km/h	Cycle 2 ≤ 45 km/h	Cycle 3 ≤ 100 km/h	Cycle 4 > 130 km/h
0	*If not running start engine (if applicable)*				0	0	0	0
1	Idle			10	0	0	0	0
1	Accelerate	Hard			20	30	55	90
1	Cruise		1/4 lap		20	30	55	90
1	Decelerate	Moderate			15	25	40	75
1	Accelerate	Moderate			20	30	55	90
1	Cruise		1/4 lap		20	30	55	90
1	Decelerate	Moderate			15	25	40	75
1	Accelerate	Moderate			25	35	75	100
1	Cruise		1/4 lap		25	35	75	100
1	Decelerate	Moderate			15	30	60	80
1	Accelerate	Moderate			25	35	75	100
1	Cruise		1/4 lap		25	35	75	100
1	Decelerate	Moderate			0	0	0	0
2	Idle			10	0	0	0	0
2	Accelerate	Hard			25	45	100	130
2	Decelerate	Coast-down			20	40	90	115
2	Cruise		1/2 lap		20	40	90	115
2	Decelerate	Moderate			10	30	65	80
2	Accelerate	Moderate			25	35	80	105
2	Cruise		1/2 lap		25	35	80	105
2	Decelerate	Moderate			10	30	65	80
3	Accelerate	Moderate			25	40	95	120
3	Cruise		1/2 lap		25	40	95	120

Lap	Action	Sub-action	Distance [share of 1 lap of test circuit]	Time (s)	To final vehicle speed (km/h)			
					Cycle 1 ≤ 25 km/h	Cycle 2 ≤ 45 km/h	Cycle 3 ≤ 100 km/h	Cycle 4 > 130 km/h
3	Decelerate	Moderate			10	30	65	80
3	Accelerate	Moderate			25	40	90	115
3	Cruise		1/2 lap		25	40	90	115
3	Decelerate	Moderate			10	30	65	80
4	Accelerate	Moderate			25	40	90	115
4	Decelerate	Coast-down			20	35	75	100
4	Cruise		1/2 lap		20	35	75	100
4	Decelerate	Moderate			10	30	65	80
4	Accelerate	Moderate			20	35	80	105
4	Cruise		1/2 lap		20	35	80	105
4	Decelerate	Moderate			0	0	0	0
5	Idle			45	0	0	0	0
5	Accelerate	Hard			15	30	70	90
5	Cruise		1/4 lap		15	30	70	90
5	Decelerate	Moderate			10	25	50	65
5	Accelerate	Moderate			15	30	70	90
5	Cruise		1/4 lap		15	30	70	90
5	Decelerate	Moderate			10	25	50	65
5	Accelerate	Moderate			15	30	65	80
5	Cruise		1/4 lap		15	30	65	80
5	Decelerate	Moderate			10	25	50	65
5	Accelerate	Moderate			15	30	65	80
5	Cruise		1/4 lap		15	30	65	80
5	Decelerate	Moderate			0	0	0	0
n	Repeat from lap 1 to end of lap 5 until necessary				#	#	#	#

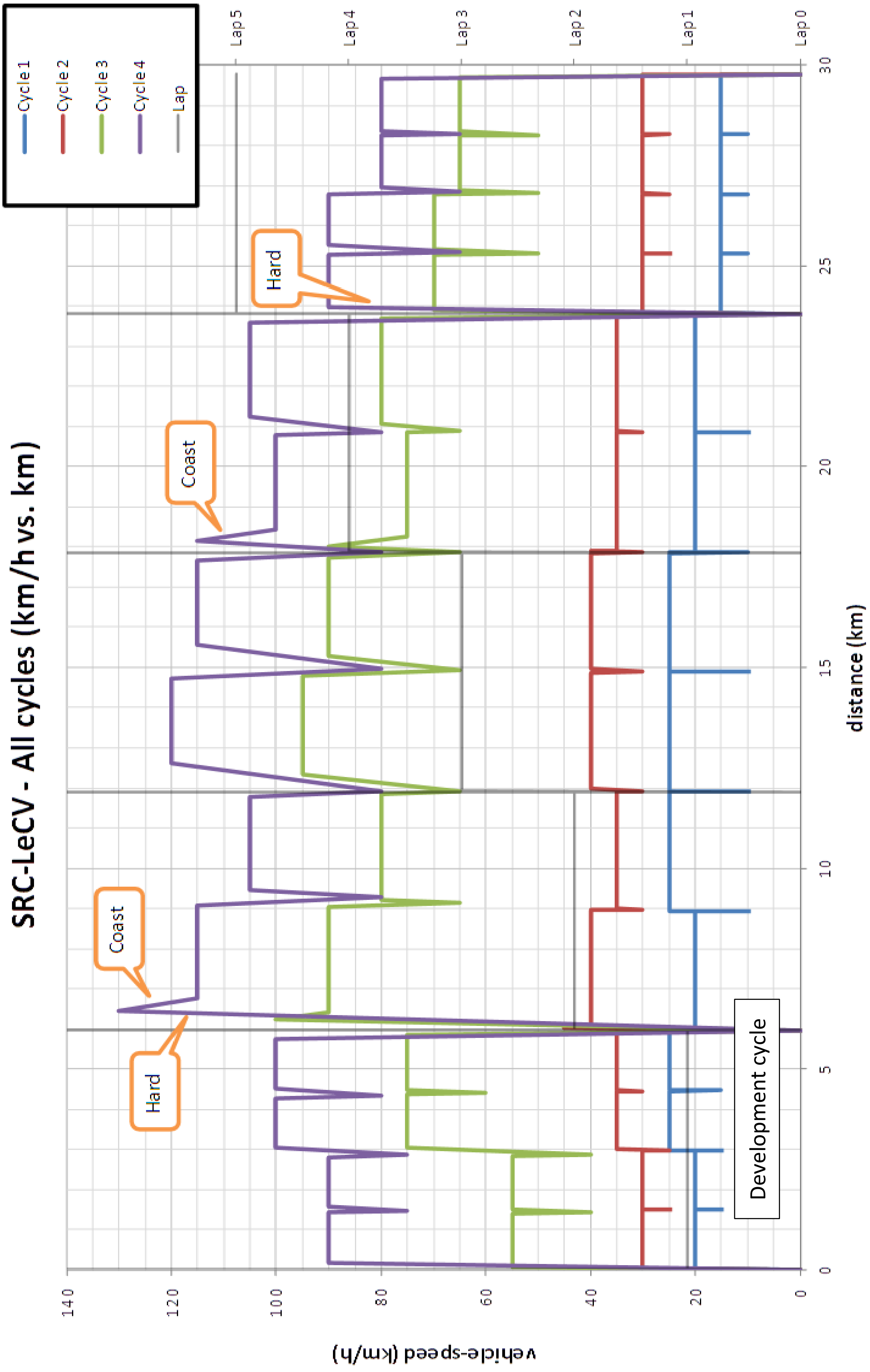


Figure 4-24 Plot of all SRC-LeCV cycles (phase 2) (development cycle)

5 Application of durability emission requirements

This chapter provides an overview of how the SRC-LeCV mileage accumulation cycle, developed in Chapter 4, could be used in practical terms and thus form an integral element of the durability of pollution control devices Type V test procedures (EC 692/08).

The SRC-LeCV cycle is the principal ingredient of potential durability emission requirements, but it has to be framed within the wider proposed regulatory context and the associated set of rules and guidelines. This Chapter sets out how the SRC-LeCV could be used.

Taking the original draft concept in the COM(2010) 542 final document as a starting point, these procedures have been developed over the course of the project using current M, N and L-category legislation in combination with analysis of information provided through stakeholder consultations, both directly and via the EC's MCWG meetings. In addition, vehicle testing at the premises of JRC in Ispra (Italy) was used to collect data used to verify the theoretical analysis.

5.1 Testing options

Within the Type V test procedures there are three options for manufacturers to follow in order to certify the lifetime durability of a vehicle's emission as outlined in Chapter 3 (Section 3.1), namely:

(a) Actual durability testing with full mileage accumulation;

(b) Actual durability testing with partial mileage accumulation and extrapolation of the trend line to full mileage accumulation; or

(c) Mathematical durability procedure.

Options (a) and (b) require the vehicle to accumulate mileage in a repeatable manner following a prescribed cycle, where option (c) allows for a mathematical proof based on the application of weightings (fixed deterioration factors) to the results of an emission test. The SRC-LeCV durability cycle has been designed to balance the objectives of this research programme, set out in Section 1.3, and it is therefore proposed that this cycle will be used in the Type V test requirements for L-category vehicles.

For all three options there are requirements that apply to the vehicle and the measured emissions; and for options (a) and (b) there are requirements that apply to the means of mileage accumulation.

A key to realizing the importance of the entire durability test procedure is to place the options in the context of a vehicle design process. On their own it may seem that having three options is superfluous as it is likely that the least demanding, or lowest cost option will always be selected. However, if they are used in a logical manner, the three options become, not only a test to pass, but a useful set of steps in assessing a prototype, and ways of certifying vehicle durability to as high a degree as necessary.

5.1.1 Use of the testing option

The following flow diagram (see Figure 5-1 below) shows how the results of one test can be used to obtain certification of the durability of a vehicle's emission critical components. The three parts are used in reverse order; if passed the vehicle is considered to have fulfilled its requirements. However, if it fails the vehicle can perform the next step which illustrates the vehicle's capabilities is a more stringent manner. At any step along the way, the vehicle could be retired from the testing to improve its design.

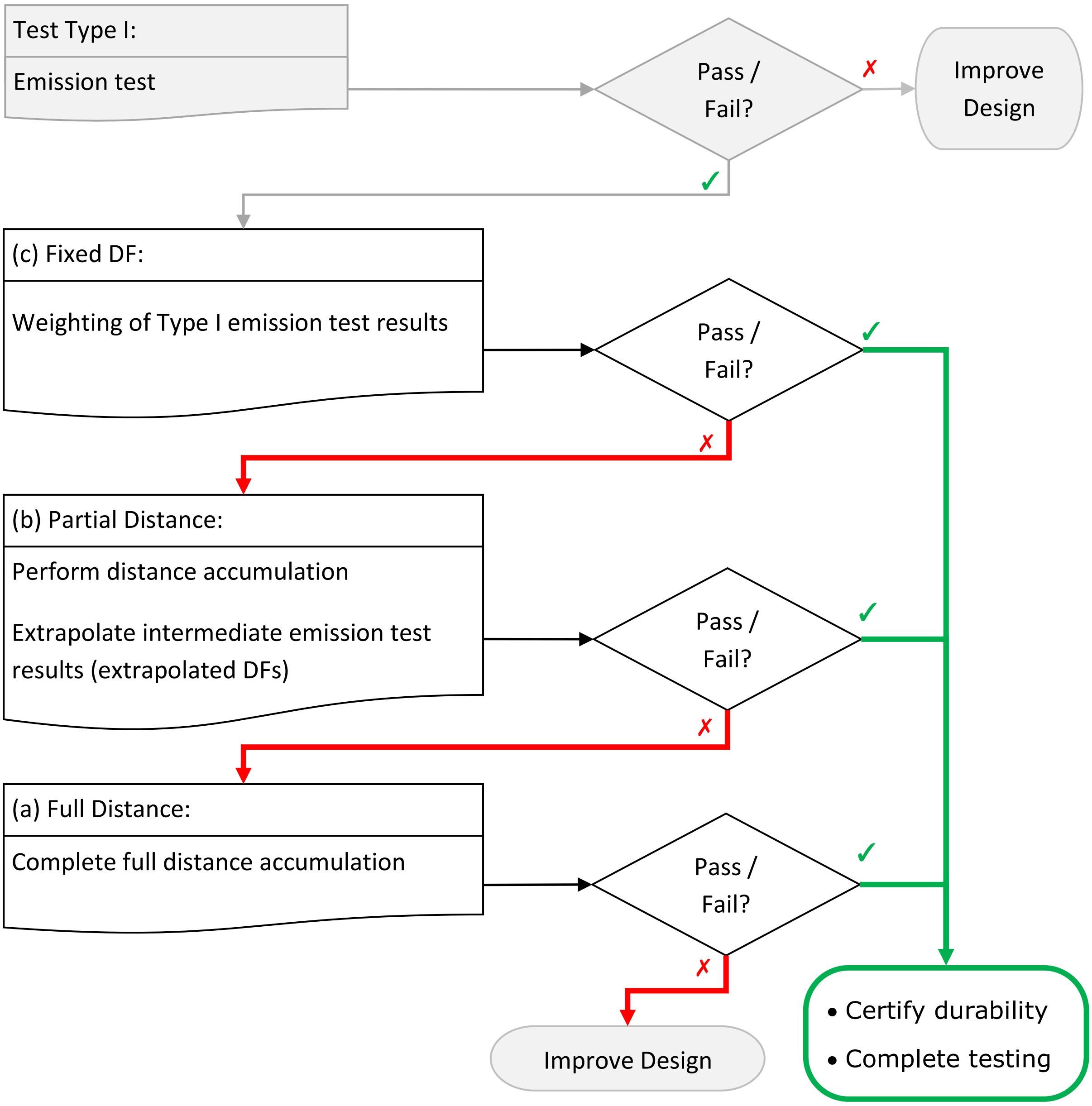


Figure 5-1: Possible (non-obligatory) use of the three testing options

Initially, a large proportion of the L-category vehicles in the type approval process will pass at option (c). Here, each of the regulated emissions measured in the Type I test will be weighted by fixed DFs and the results must still be below the limits given for the emission of tailpipe gasses. Even when passing the test it is no guarantee that the emission performance of the approved vehicle is maintained when accumulating mileage, but the design builds in a safety factor to anticipate worsening catalyst efficiency over vehicle life.

A manufacturer can balance the added cost of fitting a more advanced or higher capacity catalytic converter against the cost and time of performing the durability test’s mileage accumulation stage. And so some vehicle will not pass at this stage.

If the weighted emission results exceed the tailpipe emission limits the manufacturer could then decide to progress to option (b), durability testing with partial mileage accumulation. The vehicle performs the SRC-LeCV mileage accumulation cycle, and at certain steps during this process a test Type I is performed to assess the aged vehicles emissions. Given that a minimum amount of stops for emission tests are performed and distance accumulated, the emission values are extrapolated to the full distance. If the values do not exceed the tailpipe emission limits the vehicle has passed the Type V test.

If however, the extrapolated values exceed the tailpipe limits, the accumulation of distance can continue, stopping at relevant points to perform additional Type I emissions tests to add to the extrapolation data until one of two events happen: the extrapolated values drop below the tailpipe emission limits, or the full distance has been accumulated.

Once the full distance is reached no extrapolation is required. The results of a final emissions test (Type I) is then compared directly to the tailpipe emission results.

5.1.2 Aged parts

In some cases the likely time required to perform the durability procedure does not fit well with the time-lines and design process that a manufacturer has decided for a new vehicle.

In this case the manufacturer can, while the rest of the vehicle is on the drawing board, design the emission critical parts and start the distance accumulation process using a surrogate chassis.

The appropriately aged parts (which can be referred to as golden parts) can then be stored for when the final complete vehicle or advanced prototype is ready. These golden parts are then transferred and a test Type I performed. If a partial distance is used the extrapolation is taken from emissions tests on a vehicle with the same design but un-aged parts, to the results of this merged vehicle. If full distance has been performed just the comparison with the tailpipe emission limits are required.

Once the advanced prototype is ready, the manufacturer is still able to perform option (c) and pass, however if it fails at this step it can in effect jump to the final stages of option (b), and continue the process to option (a) if required.

6 Duration and costs for US EPA AMA and SRC-LeCV

6.1 Calculation method

Certain industry stakeholders consulted during this study had suggested that the costs of undertaking durability testing could potentially be very high. This would be a potential barrier to the objectives of the study, to develop a cost effective durability test method. An independent analysis was, therefore, undertaken with the aim firstly of verifying the stakeholder input and secondly to identify which aspects of the test requirements were responsible for adding substantially to the time or cost. This analysis was, therefore, intended to be indicative rather than a comprehensive estimate of the average cost to industry or specific sectors of it, for example, it does not include the value of the vehicle. Though this type of omission will affect the absolute accuracy of the test costs, it should not affect the relative comparison of the cost of one type of test, or one changed variable within those tests, to another.

The first step in the analysis was to estimate duration and cost of the US EPA AMA, with some assumed adaptations to enable a better fit with EU vehicle categories and the durability distances proposed by the EC. It also considered a wide range of options for the allowance of partial distances and for different test approaches (e.g. track, dynamometer, human or robot rider, single shift, double shift etc.).

The total durability distances assumed were those proposed by the European Commission, as presented in Table 6-1, below.

Table 6-1: Category L durability distances originally proposed by the European Commission

Vehicle Category	Category name	Durability distances (km)		
		Euro 3	Euro 4	Euro 5
L1Ae	Powered cycle	5,000	5,500	6,000
L1Be	Two wheel moped	10,000	11,000	12,000
L2e	Three wheel moped			
L6Ae	Light on-road quad			
L3e	Two wheel motorcycle with/without side-car (v_{max}<130km/h)	18,000	20,000	30,000
L4e				
L5e	Tricycle			
L6Be	Light quadrimobile			
L7Be	Heavy quadrimobile			
L3e	Two wheel motorcycle with/without side-car (v_{max}>=130km/h)	30,000	35,000	50,000
L4e				
L7Ae	Heavy on-road quad			

Subsequently, the analysis was expanded to consider different variants of the SRC-LeCV test developed as part of the project, but still including all possible options for test methods and partial distance accumulation. The Council and the European Commission Parliament during the co-decision process also decided to make some amendments to the vehicle categories and the allocation of certain sub-categories to durability distances. Also, it was identified that the proposed durability distances did not always correlate closely with the maximum design vehicle speed capabilities of the vehicles and thus it was necessary to consider the option of subjecting the vehicle to different durability cycles that were appropriate for a vehicle’s speed capability. These factors were taken into account in the final comparison of different methods but were not applied retrospectively to the individual analyses already completed.

Once the analysis was complete and a refined proposal for durability was presented, a new comparative analysis was undertaken based on the much more limited range of defined variables, to assess the relative cost and time implications of the final options considered.

The results from this staged analysis are presented in separate subsections below.

6.2 US EPA AMA

6.2.1 Matching and adapting the test cycle to different sub-categories

The US EPA AMA test cycle varies according to the class of motorcycle tested. The classes are defined as follows:

- Class I – engine capacity <170 cm^3
- Class II – engine capacity from 170 cm^3 to 279 cm^3
- Class III – engine capacity of 280 cm^3 and above

The base speeds and upper speeds for each lap of the cycle are shown in Table 6-2, below.

Table 6-2: Vehicle speeds by lap for different classes of motorcycle in the US EPA test [km/h]

cycle	Lap	Class I	Class II	Class III
Base speed		*30*	*30*	*30*
normal	1	65	65	65
normal	2	45	45	65
normal	3	65	65	55
normal	4	65	65	45
normal	5	55	55	55
normal	6	45	45	55
normal	7	55	55	70
normal	8	70	70	55
normal	9	55	55	46
const	10	70	90	90
wot*2	11	70	90	110

Where: wot*2 = a wide open throttle acceleration is performed twice during this lap

Some of the classes considered in the proposed EU type approval regulation for L-category vehicles are, by definition, not capable of achieving the maximum speeds quoted in the table above. The restrictions are either to a maximum of 25 km/h (e.g. L1Ae, L2e, L6e) or 45 km/h (L1Be). The EPA AMA cycle states that where the desired test vehicle speed defined exceeds the maximum vehicle speed then the speed on that lap should just be the maximum attainable. This produces the following cycles for vehicles limited by category definition to lower speeds than required by the US EPA (see Table 6-3).

Table 6-3: Modified speed cycles for European low vehicle speed categories [km/h]

course	Lap	Max speed 25 km/h	Max speed 45 km/h
Base speed	*km/h*	*25*	*30*
normal	1	*25*	*45*
normal	2	*25*	*45*
normal	3	*25*	*45*
normal	4	*25*	*45*
normal	5	*25*	*45*
normal	6	*25*	*45*
normal	7	*25*	*45*
normal	8	*25*	*45*
normal	9	*25*	*45*
const	10	*25*	*45*
wot*2	11	*25*	*45*

Where: wot*2 = a wide open throttle acceleration is performed twice during this lap

Thus the categories were assigned test cycles as follows:

- L1Ae, L1Be modified class I for <25 km/h
- L1Be, L2e, L6Ae, L6Be - modified class I for <45 km/h
- L3e-A1, L4e-A1, L5e (<170 cm^3) – class I
- L3e-A2/3 (<130 km/h), L4e-A2/3 (<130 km/h), L5e (>169 cm^3 <130 km/h) – class II
- L3e-A2/3 (>130 km/h), L4e-A2/3 (>130 km/h), L7Ae, L7Be – class III

6.2.2 Estimating the time required to complete each distance accumulation cycle

This was undertaken by applying certain assumed levels of acceleration and deceleration to the transitions between the vehicle speeds defined by the EPA AMA cycle and using Newton's equations of motion to calculate the time taken to complete each lap. The results are summarised in Table 6-4.

Table 6-4: US EPA 11 lap test cycle time and distance by vehicle class

	Class I	Class I <25 km/h	Class I <45 km/h	Class II	Class II
Distance for 11 lap cycle (km)	65.5	65.5	65.5	65.5	65.5
Time taken for 11 lap cycle (hours)	1.39	2.82	1.69	1.36	1.36

It can be seen that the difference in average vehicle speed between the different US cycles is relatively small, resulting in only small differences in the time taken for 65.5 km. However, where vehicle speeds are substantially reduced for the low vehicle speed EU categories, it can be seen that this has a substantial effect on the time taken for each 65.5 km cycle. By extension, a substantial increase in the vehicle speeds would be expected to substantially reduce the time taken, thus reducing the costs and saving development time, allowing a new vehicle to be introduced to the market more quickly.

6.2.3 *The scope for completing partial distances*

The US EPA allows tests to be run using a partial mileage accumulation distance, provided that:

- At least four emission test result data points are available from the partial mileage accumulation phase on which to base the correlation used to extrapolate the result to full distance; and
- The minimum distance for the first test during mileage accumulation is 2,500 km for class I and II vehicles and 3,500 km for class III vehicles.

On this basis it was assumed that for each test modelled there would be a total of four soak tests, four engine emission tests, and four evaporative emissions tests.

Note: The requirement for evaporative testing is not within the scope of this project and therefore was not assessed fully at this point. With further discussion with other stakeholders it has been shown that only a single test on a vehicle is required to assess its evaporative performance. This will be discussed further in Section 7.8.

6.2.4 *Test shift patterns*

The costs were calculated using four possible scenarios. These were selected to not be comprehensive, but to cover a wide range of configurations.

- Track
  - 8 hours per day, 5 days per week (40 hour/week)
    A normal "single shift" 40 hour per week pattern
  - 16 hours per day, 7 days per week (112 hours/week)
    Two shifts per working day with 7 days in a workweek

- Dynamometer
    - Robot rider, 16 hours per day 7 days per week (112 hours/week)
      As above but with the different costs of using a robot rider
    - Robot rider, 24 hours per day, 7 days per week (168 hours/week)
      A 24/7 treble shift approach (note that this still does not mean continuous running because of the need for soak tests, refuelling, servicing etc.)

6.2.5 Estimating the total test duration

For each modelled configuration the total duration of the test was calculated by calculating how many 11 lap cycles would be required to complete the total required distance accumulation, calculating how many 11 lap cycles could be completed in a single 8 hour shift and thus how many 8 hour shifts were required. In addition to this it was assumed that soak tests could be completed overnight, unless 24 hour running was being used, in which case an additional 8 hour shift was allowed. Each emissions test was assumed to take 1 shift, each evaporative test between 1 and 3 shifts and each service 1 shift. Service intervals were assumed to be between 10,000 km and 20,000 km and the appropriate number of services was calculated based on the total distance divided by the interval.

6.2.6 Estimating the total test cost

A single figure was used to represent the fuel used by the test vehicle and no account was taken of any depreciation cost of the vehicle itself. Track tests and dynamometer tests (with and without robot rider) were considered. It was assumed that the distance accumulation tests, if undertaken on a test track, would be undertaken at a commercial proving ground and thus a simple rate was used for track and rider hire of €1,000 per 8 hour shift. However, it was considered quite likely that manufacturers would undertake chassis dynamometer tests on in-house facilities. It was thus assumed that a dynamometer was purchased for €0.75m, had a useful life of 5 years, a zero residual value, and was used for 75% of the possible working time available. Thus an hourly cost was derived to cover the facility cost in the 5 year period. For tests involving a human rider an additional cost of €300/shift was applied. For test involving a robot rider, the same approach was used to derive an hourly cost for the facility assuming the initial cost of a robot rider was €250,000.

Note: The capital costs of test equipment have been applied as a utilisation cost and therefore can be considered comparable with the costs of rental or subcontracting.

6.2.7 Results

Note for the following tables:

- Minimum time and cost is calculated with the Euro 3 distances
- Maximum time and cost is calculated with the Euro 5 distances
- Mean time and cost is the mean cost from all of the calculations performed. This is not necessarily based on the Euro 4 values as it could be influenced by the differing testing shift patterns assessed.

The overall range of results is shown in Table 6-5.

Table 6-5: Summary of full range of results (US EPA AMA)

Vehicle Category	Category name	Calendar time required for test			Estimated cost of test (€)		
		Min	Max	Mean	Min	Max	Mean
L1Ae	Powered cycle	1.2	12.8	4.5	€ 6,414	€ 54,758	€ 27,098
L1Be	Two wheel moped	1.3	24.0	7.0	€ 7,304	€ 101,599	€ 42,568
L2e	Three wheel moped	1.3	24.0	7.0	€ 7,304	€ 101,599	€ 42,568
L6Ae	Light on-road quad	1.3	24.0	7.0	€ 7,304	€ 101,599	€ 42,568
L3e	Two wheel motorcycle with/without side-car (Vmax<130km/h)	1.7	24.4	7.5	€ 9,465	€ 104,219	€ 46,456
L4e		1.7	24.4	7.5	€ 9,465	€ 104,219	€ 46,456
L5e	Tricycle	1.7	24.4	7.5	€ 9,465	€ 104,219	€ 46,456
L6Be	Light quadrimobile	2.0	29.8	9.0	€ 10,876	€ 127,120	€ 55,391
L7Be	Heavy quadrimobile	1.7	24.4	7.4	€ 9,465	€ 104,219	€ 45,951
L3e	Two wheel motorcycle with/without side-car (Vmax>=130km/h)	2.4	39.4	11.8	€ 13,882	€ 168,088	€ 73,951
L4e		2.4	39.4	11.8	€ 13,882	€ 168,088	€ 73,951
L7Ae	Heavy on-road quad	2.4	39.4	11.8	€ 13,882	€ 168,088	€ 73,951

Where the actual time and cost lies within the wide ranges identified above will depend very strongly on variables contained within these results such as how the tests are undertaken regarding the shift pattern.

In general, the shortest durations and lowest costs are generated based on tests being run 24 hours a day, 7 days per week, on a chassis dynamometer with a robot rider, allowing them to run highly efficiently with minimal human input and supervision. Small manufacturers may not have the initial capital investment, or have the quantity of testing, required to support such an approach. However, the relative costs are such that it is likely that outsourcing to a test house that could run this sort of efficient operation would still provide a better solution than track testing or using an in-house dynamometer with low utilisation and a human operative. As such, it is relatively unlikely that the actual costs will approach the maxima identified above.

One interesting result is that the minimum duration of the short distance categories such as L1Ae is not much less than that of high distance categories such as L3e>130 km/h. This is because of the greater vehicle speed despite the greater (partial) durability distance.

6.3 SRC-LeCV results

The same analysis was repeated for a first definition of the new SRC-LeCV test cycle, based on a 7 lap cycle. Adopting the same approach for calculating test times produced the following estimates.

Table 6-6: Initial estimates of cycle time and distance for SRC-LeCV 7 lap test

Group	Durability distance (km)			Minimum distance (km)	Cycle distance (km)	Cycle time (h)	Average speed (km/h)
	Euro 3	Euro 4	Euro 5				
1	5,000	5,500	6,000	1,000	41.682	2.22	18.7
2	10,000	11,000	12,000	1,000	41.682	1.47	28.4
3	18,000	20,000	30,000	2,500	41.682	0.79	53.0
4	30,000	35,000	50,000	3,500	41.682	0.55	75.5

The overall range of results is shown in Table 6-7. Note that this includes all the different modes of operation (track, dynamometer etc.) as well as full and partial distances.

Table 6-7: Summary of full range of results (Initial SRC-LeCV 7 lap)

Vehicle Category	Category name	Calendar time required for test (weeks)			Estimated cost of test (€)		
		Min	Max	Mean	Min	Max	Mean
L1Ae	Powered cycle	1.4	13.2	5.5	€ 7,220	€ 60,980	€ 31,310
L1Be	Two wheel moped (<25 km/h)	2.2	25.0	9.4	€ 11,590	€ 114,050	€ 57,640
	Two wheel moped (<45 km/h)	1.6	15.8	6.2	€ 8,770	€ 72,430	€ 37,890
L2e	Three wheel moped	1.6	15.8	6.2	€ 8,770	€ 72,430	€ 37,890
L6Ae	Light on-road quad	1.6	15.8	6.2	€ 8,770	€ 72,430	€ 37,890
L3e	Two wheel motorcycle with/without side-car (Vmax<130km/h)	1.6	19.6	6.3	€ 8,770	€ 84,590	€ 38,270
L4e		1.6	19.6	6.6	€ 8,940	€ 90,660	€ 40,510
L5e	Tricycle	1.6	19.6	6.6	€ 8,940	€ 90,660	€ 40,510
L6Be	Light quadrimobile	1.6	36.8	8.2	€ 8,940	€ 156,560	€ 47,300
L7Be	Heavy quadrimobile	2.5	31.0	10.1	€ 13,510	€ 168,700	€ 65,460
L3e	Two wheel motorcycle with/without side-car (Vmax>=130km/h)	1.6	23.2	6.9	€ 8,940	€ 101,100	€ 42,170
L4e		1.8	23.2	7.7	€ 10,370	€ 108,320	€ 48,640
L7Ae	Heavy on-road quad	1.8	23.2	7.7	€ 10,370	€ 108,320	€ 48,640

A revised version of the SRC-LeCV was developed in order to assess the scope for further reductions in the cost and duration of the durability testing, so that the burden of proving compliance could be minimised for the manufacturer. As described earlier this involved removing two of the slower speed laps from the cycle to produce a 5 lap version. This resulted in the following estimates of cycle distance, time and average speed.

Table 6-8: Initial estimates of cycle time and distance for SRC-LeCV 5 lap test

Group	Durability distance (km)			Minimum distance (km)	Cycle distance (km)	Cycle time (h)	Average speed (km/h)
	Euro 3	Euro 4	Euro 5				
1	5,000	5,500	6,000	1,000	29.773	1.49	20.0
2	10,000	11,000	12,000	1,000	29.773	0.88	33.7
3	18,000	20,000	30,000	2,500	29.773	0.42	70.1
4	30,000	35,000	50,000	3,500	29.773	0.33	89.7

The overall range of results is shown in Table 6-9. Note that this includes all the different modes of operation (track, dynamometer etc.) as well as full and partial distances.

Table 6-9: Summary of full range of results (Initial SRC-LeCV 5 lap)

Vehicle Categor	Category name	Calendar time required for test (weeks)			Estimated cost of test (€)		
		Min	Max	Mean	Min	Max	Mean
L1Ae	Powered cycle	1.3	11.4	4.7	€ 6,961	€ 52,659	€ 27,837
L1Be	Two wheel moped (<25 km/h)	2.1	21.2	8.3	€ 11,083	€ 97,403	€ 50,624
	Two wheel moped (<45 km/h)	1.5	12.6	5.2	€ 7,913	€ 58,555	€ 31,432
L3e-A**x**T	Two-wheel Trial motorcycle	2.1	21.2	8.3	€ 11,083	€ 97,403	€ 50,624
L2e	Three wheel moped	1.5	12.6	5.2	€ 7,913	€ 58,555	€ 31,432
L6Ae	Light on-road quad	1.5	12.6	5.2	€ 7,913	€ 58,555	€ 31,432
L3e	Two wheel motorcycle with/without side-car (Vmax<130km/h)	1.3	15.8	5.4	€ 7,645	€ 73,315	€ 32,996
L4e		1.3	15.8	5.4	€ 7,645	€ 73,315	€ 32,996
L5e	Tricycle	1.3	15.8	5.4	€ 7,645	€ 73,315	€ 32,996
L3e-A**x**E	Two-wheel Enduro motorcycle	2.2	29.2	9.6	€ 11,973	€ 134,014	€ 58,960
L6Be	Light quadrimobile	2.2	29.2	9.6	€ 11,973	€ 134,014	€ 58,960
L7Be	Heavy quadrimobile	2.2	29.2	9.6	€ 11,973	€ 134,014	€ 58,960
L7Ce	Heavy quadri-mobile	2.2	29.2	9.6	€ 11,973	€ 134,014	€ 58,960
L3e	Two wheel motorcycle with/without side-car	1.6	19.4	6.6	€ 9,394	€ 91,290	€ 41,641
L4e		1.8	25.2	8.6	€ 10,849	€ 116,581	€ 56,734
L7Ae	Heavy on-road quad	1.8	25.2	8.6	€ 10,849	€ 116,581	€ 56,734

Where the actual time and cost lies within the wide ranges identified above will depend very strongly on variables detailed in Section 6.2.7.

6.4 Comparative analysis of final options

A final analysis of duration and cost was undertaken at the end of the study. At this time, a number of small changes had been made in light of parallel developments in the regulatory process and in light of the findings of other parts of the studies. The main changes were as follows:

- It was considered unrealistic to assume that vehicles with a relatively low maximum speed would be required to travel at maximum speed if subjected to the US EPA AMA durability test. A revised profile was developed based on simple factoring of the existing cycle by the ratio between the maximum vehicle speed each low speed category was capable of and the maximum vehicle speed required by the AMA class.
- The vehicle manufacturers association submitted a proposal for a US EPA based cycle for EU categories with a low maximum vehicle speed.
- Certain sub-categories of vehicles were identified as separate classes within the framework for durability testing and some moved categories.
- Slight revisions were made to the cycles, slightly affecting times.

The final categorisation at the time of publication for each L-category and sub-category are shown in Table 6-10.

Table 6-10: EC proposal L-category durability distances with subsequently added vehicle categories (development cycle)

Vehicle category	Vehicle category name	Durability cycle	Euro 3 durability distance (km)	Euro 4 durability distance (km)	Euro 5 durability distance (km)
L1Ae	Powered cycle	**1**	5,000	5,500	6,000
L3e-AxT (x=1, 2, 3)	Two-wheel Trial motorcycle	**3**			
L1Be	Two-wheel moped <25km/h	**2**	10,000	11,000	12,000
	Two-wheel moped <45km/h	**2**			
L2e	Three-wheel moped	**2**			
L3e-AxE (x=1, 2, 3)	Two-wheel Enduro motorcycle	**3**			
L6Ae	Light on-road quad	**2**			
L3e	Two-wheel motorcycle, (v_{max} < 130km/h)	**3**	18,000	20,000	30,000
L4e	Two-wheel motorcycle, with sidecar (v_{max}<130km/h)	**3**			
L5e	Tricycle	**3**			
L6Be	Light quadrimobile	**2**			
L7Be	All-terrain vehicles	**2**			
L7Ce	Heavy quadrimobile	**2**			
L3e	Two-wheel motorcycle, (v_{max}>130 km/h)	**4**	30,000	35,000	50,000
L4e	Two-wheel motorcycle, with sidecar (v_{max}>130 km/h)	**3**			
L7Ae	Heavy on-road quad	**3**			

Given the variation in distance covered by each cycle, it was considered that the most relevant comparison was the average vehicle speed achieved during the cycle, considering only the running time and excluding time taken servicing, undertaking emission or soak tests etc. The results are shown below.

Table 6-11: Comparison of average speed in different cycles

Category	Category Name	Average speed during cycle (km/h)			Average speed indexed to US AMA		
		US EPA AMA	SRC-LeCV 7	SRC LeCV 5	US EPA AMA	SRC-LeCV 7	SRC LeCV 5
L1Ae	Powered cycle	19.63	18.55	19.97	1.00	0.94	1.02
L3e-AxT (x=1,2,3)	Two wheel trial motorcycle	48.16	52.9	70.08	1.00	1.10	1.46
L1Be	Two wheel moped (<25 km/h)	19.63	18.55	19.97	1.00	0.94	1.02
	Two wheel moped (<45 km/h)	33.14	28.11	33.66	1.00	0.85	1.02
L2e	Three wheel moped	33.14	28.11	33.66	1.00	0.85	1.02
L3e-AxE (x=1,2,3)	Two wheel Enduro motorcycle	48.16	52.9	70.08	1.00	1.10	1.46
L6Ae	Light on-road quad	33.14	28.11	33.66	1.00	0.85	1.02
L3e	Two wheel motorcycle (Vmax<130km/h)	48.18	52.9	70.08	1.00	1.10	1.45
L4e	Two wheel motorcycle with side-car (Vmax<130km/h)	48.18	52.9	70.08	1.00	1.10	1.45
L5e	Tricycle	48.18	52.9	70.08	1.00	1.10	1.45
L6Be	Light quadri-mobile	33.14	28.11	33.66	1.00	0.85	1.02
L7Be	All terrain vehicles	33.14	28.11	33.66	1.00	0.85	1.02
L7Ce	Heavy quadri-mobile	33.14	28.11	33.66	1.00	0.85	1.02
L3e	Two wheel motorcycle (Vmax>=130km/h)	48.16	75.58	89.67	1.00	1.57	1.86
L4e	Two wheel motorcycle with side-car (Vmax>=130km/h)	48.16	52.9	70.08	1.00	1.10	1.46
L7Ae	Heavy on-road quad	48.16	52.9	70.08	1.00	1.10	1.46

It can be seen that, in comparison to the US AMA cycle, the average speed during the SRC-LeCV 7 lap cycle is 10% higher for those vehicle categories capable of moderately high vehicle speeds (group 3) and 57% higher for the highest speed vehicles. However, for the slower categories of vehicle the average speed was lower. For the proposed SRC-LeCV 5 lap cycle, the average speed was always higher than for the US AMA test. This ranged from a very small effect for low speed categories where the small differences possible have a limited overall effect, to very substantial (86%) for the highest speed categories. It should be noted that, although the vehicle manufacturer's proposal for an adaptation to the US AMA cycle for L1Be category has not been studied in detail, the same base calculations would suggest that the average speed would be 34.7 km/h, which is slightly faster (5%) than the adapted AMA cycle assumed in the process above, and also slightly higher (3%) than the SRC-LeCV 5 lap proposal.

The average speed during the test is not the only factor affecting the overall duration and cost of the test. The amount of time required for soak tests and evaporative tests has also been included and the time and cost of servicing and emissions tests have been included. Most of these factors are fixed (i.e. they are the same for each durability procedure) such that the relative change between procedures becomes less pronounced when total duration and cost are considered, rather than just considering the effects on average vehicle speed during the cycle.

For ease of comparison, the results below have been presented based on the assumption that two shifts would be run each day, the tests would be undertaken on a dynamometer using a robot rider, and the full distance would be accumulated. The time and cost associated with running 24/7 for half distance only would be substantially less while running full distances on a single shift basis on the test track would be expected to substantially increase the duration and cost. However, these variables would not be expected to have a significant influence on the difference between the different test cycles relative to one another.

Table 6-12: Duration and cost of US EPA AMA (adapted for low speed where applicable), based on 16 hour days, 7 days per week on a dynamometer with a robot rider (Method A – full durability distance)

Vehicle Category	Category name	Calendar time required for		Estimated cost of test (€)	
		Min	Max	Min	Max
L1Ae	Powered cycle	2.8	3.3	€ 16,063	€ 18,534
L3e-AxT (x=1,2,3)	Two wheel trial motorcycle	1.5	1.7	€ 9,007	€ 10,066
L1Be	Two wheel moped (<25 km/h)	5.1	6.1	€ 28,416	€ 33,858
	Two wheel moped (<45 km/h)	3.3	3.9	€ 18,723	€ 22,225
L2e	Three wheel moped	3.3	3.9	€ 18,723	€ 22,225
L3e-AxE (x=1,2,3)	Two wheel Enduro motorcycle	2.4	2.9	€ 14,304	€ 16,923
L6Ae	Light on-road quad	3.3	3.9	€ 18,723	€ 22,225
L3e	Two wheel motorcycle (Vmax<130km/h)	3.9	6.5	€ 22,779	€ 37,632
L4e	Two wheel motorcycle with sidecar (Vmax<130km/h)	3.9	6.5	€ 22,779	€ 37,632
L5e	Tricycle	3.9	6.5	€ 22,779	€ 37,632
L6Be	Light quadri-mobile	5.4	8.9	€ 30,733	€ 50,248
L7Be	All Terrain Vehicles	5.4	8.9	€ 30,733	€ 50,248
L7Ce	Heavy quadri-mobile	5.4	8.9	€ 30,733	€ 50,248
L3e	Two wheel motorcycle (Vmax>=130km/h)	6.2	10.2	€ 35,991	€ 59,178
L4e	Two wheel motorcycle with side-car (Vmax>=130km/h)	6.2	10.2	€ 35,991	€ 59,178
L7Ae	Heavy on-road quad	6.2	10.2	€ 35,991	€ 59,178

Table 6-13: Duration and cost of SRC-LeCV (7 lap), based on 16 hour days, 7 days per week on a dynamometer with a robot rider (Method A – full durability distance)

Vehicle Category	Category name	Calendar time required for test (weeks)		Estimated cost of test (€)	
		Min	Max	Min	Max
L1Ae	Powered cycle	3.0	3.5	€ 16,761	€ 19,371
L3e-AxT (x=1,2,3)	Two wheel trial motorcycle	1.4	1.6	€ 8,585	€ 9,559
L1Be	Two wheel moped (<25 km/h)	5.4	6.4	€ 29,811	€ 35,531
	Two wheel moped (<45 km/h)	3.7	4.4	€ 21,187	€ 25,182
L2e	Three wheel moped	3.7	4.4	€ 21,187	€ 25,182
L3e-AxE (x=1,2,3)	Two wheel Enduro motorcycle	2.3	2.7	€ 13,459	€ 15,908
L6Ae	Light on-road quad	3.7	4.4	€ 21,187	€ 25,182
L3e	Two wheel motorcycle	3.6	6.8	€ 21,257	€ 41,511
L4e	Two wheel motorcycle with sidecar (Vmax<130km/h)	3.6	6.8	€ 21,257	€ 41,511
L5e	Tricycle	3.6	6.8	€ 21,257	€ 41,511
L6Be	Light quadri-mobile	6.3	10.3	€ 35,168	€ 57,640
L7Be	All Terrain Vehicles	6.3	10.3	€ 35,168	€ 57,640
L7Ce	Heavy quadri-mobile	6.3	10.3	€ 35,168	€ 57,640
L3e	Two wheel motorcycle	4.2	6.8	€ 25,391	€ 41,511
L4e	Two wheel motorcycle with side-car (Vmax>=130km/h)	4.2	6.8	€ 25,391	€ 41,511
L7Ae	Heavy on-road quad	5.7	9.4	€ 33,455	€ 54,952

Table 6-14: Duration and cost of SRC-LeCV (5 lap), based on 16 hour days, 7 days per week on a dynamometer with a robot rider (Method A – full durability distance)

Vehicle Category	Category name	Calendar time required for test (weeks)		Estimated cost of test (€)	
		Min	Max	Min	Max
L1Ae	Powered cycle	2.8	3.3	€ 15,842	€ 18,269
L3e-AxT (x=1,2,3)	Two wheel trial motorcycle	1.2	1.3	€ 7,492	€ 8,249
L1Be	Two wheel moped (<25 km/h)	5.0	6.0	€ 27,974	€ 33,327
	Two wheel moped (<45 km/h)	3.2	3.8	€ 18,409	€ 21,849
L2e	Three wheel moped	3.2	3.8	€ 18,409	€ 21,849
L3e-AxE (x=1,2,3)	Two wheel Enduro motorcycle	1.8	2.2	€ 11,275	€ 13,287
L6Ae	Light on-road quad	3.2	3.8	€ 18,409	€ 21,849
L3e	Two wheel motorcycle	2.9	5.9	€ 17,326	€ 36,583
L4e	Two wheel motorcycle with sidecar (Vmax<130km/h)	2.9	5.9	€ 17,326	€ 36,583
L5e	Tricycle	2.9	5.9	€ 17,326	€ 36,583
L6Be	Light quadri-mobile	5.3	8.7	€ 30,168	€ 49,307
L7Be	All Terrain Vehicles	5.3	8.7	€ 30,168	€ 49,307
L7Ce	Heavy quadri-mobile	5.3	8.7	€ 30,168	€ 49,307
L3e	Two wheel motorcycle	3.6	5.9	€ 22,434	€ 36,583
L4e	Two wheel motorcycle with side-car (Vmax>=130km/h)	3.6	5.9	€ 22,434	€ 36,583
L7Ae	Heavy on-road quad	4.5	7.3	€ 26,903	€ 44,031

Table 6-15: Duration and cost of SRC-LeCV cycles, relative to that of the US EPA AMA (adapted to low vehicle speed where applicable) (Method A – full durability distance)

Vehicle Category	Category name	Adapted US EPA AMA		SRC-LeCV 7 lap		SRC-LeCV 5 lap	
		Calendar time	Estimated cost of test	Calendar time	Estimated cost of	Calendar time	Estimated cost of
L1Ae	Powered cycle	1.00	1.00	1.05	1.04	0.99	0.99
L3e-AxT (x=1,2,3)	Two wheel trial motorcycle	1.00	1.00	0.95	0.95	0.81	0.83
L1Be	Two wheel moped (<25 km/h)	1.00	1.00	1.05	1.05	0.98	0.98
	Two wheel moped (<45 km/h)	1.00	1.00	1.14	1.13	0.98	0.98
L2e	Three wheel moped	1.00	1.00	1.14	1.13	0.98	0.98
L3e-AxE (x=1,2,3)	Two wheel Enduro motorcycle	1.00	1.00	0.93	0.94	0.76	0.79
L6Ae	Light on-road quad	1.00	1.00	1.14	1.13	0.98	0.98
L3e	Two wheel motorcycle (Vmax<130km/h)	1.00	1.00	0.93	0.93	0.73	0.76
L4e	Two wheel motorcycle with side-car (Vmax<130km/h)	1.00	1.00	0.93	0.93	0.73	0.76
L5e	Tricycle	1.00	1.00	0.93	0.93	0.73	0.76
L6Be	Light quadri-mobile	1.00	1.00	1.16	1.14	0.98	0.98
L7Be	All terrain vehicles	1.00	1.00	1.16	1.14	0.98	0.98
L7Ce	Heavy quadri-mobile	1.00	1.00	1.16	1.14	0.98	0.98
L3e	Two wheel motorcycle (Vmax>=130km/h)	1.00	1.00	0.67	0.71	0.58	0.62
L4e	Two wheel motorcycle with side-car (Vmax>=130km/h)	1.00	1.00	0.92	0.93	0.72	0.75
L7Ae	Heavy on-road quad	1.00	1.00	0.92	0.93	0.72	0.75

7 Validation and derivation of SRC-LeCV (“phase 3”)

After the completion and publication of the phase 2 cycles, stakeholders highlighted the requirement of a validation programme before the implementation of these cycles to commercially produced vehicles.

Therefore, the EC commissioned a validation programme. The scope of the study included an experimental programme in which the feasibility of the designed test Type V durability test cycles for L-category vehicles (SRC-LeCV) developed in phase 2 of the main study was assessed.

The overall objective of the study was to validate the designed test Type V durability test. This validation included the measurement of a number of defined engine and ambient parameters during limited mileage accumulation in the emission laboratory at JRC. The aim was to check if the newly designed durability test cycles were feasible in terms of driveability, and how quickly such a durability test could be carried out by a manufacturer. This validation testing is not however intended to instruct manufacturers on how they may need to design their vehicles to pass the test. The actual validation tests and measurements were performed by JRC and the analysis of the measurement data performed by TRL. As a result of this, the SRC-LeCV durability cycles were ‘fine-tuned’.

In addition, because the outcome of this process resulted in changes to some of the cycles, the revalidation of those cycles that have changed was also considered important. This second stage of the validation programme is presented in Section 8.

7.1 Durability cycle progression

These new tests represent a fundamental shift in the way the L-category durability test is designed. The current test which has been used in some regions since the 1970's (the EPA AMA cycle) was designed by selecting the main concern of the day, namely soot and carbon build-up, the vehicle then performed actions to exacerbate this issue.

This new test takes the first steps away from this approach which is no longer relevant. Firstly, it is designed to create the conditions required to cause multiple degradation mechanisms and secondly, the frequency duration of these conditions are not exaggerated, but based on the typical occurrence in real-world use.

The consequences of this progression is that the new cycle, rather than being focussed on wear to specific vehicle parts, is also balanced with the need to simply be used as would be in the real-world (based on the WMTC test cycle shown in UN GTR No. 2).

The new cycle not only shows the effects of carbon deposits in and around the combustion chamber, as in the EPA AMA cycle, but also performs actions to wear the gaseous emission abatement parts (catalytic converter(s) and lambda sensor), and can also be shown to use actions in a manner typical of an average long journey.

An important prerequisite for any test methodology is that it can be both repeatable and reproducible. With a test based on driving a vehicle there are many variables and so for a short test (<30 minutes and <30 km) like the WMTC emissions driving cycle, the speeds, acceleration rates, deceleration rates, gear changes and pedal actions are all specified in detail to keep the vehicle to tolerances of ±1 km/h and ±1 s of the required trace.

For a mileage accumulation cycle the vehicle is expected to perform distances of tens of thousands of kilometres and therefore to reach the same level of repeatability and reproducibility tolerances do not need to be as tight, in fact such tight tolerances would be economically detrimental without providing a return - i.e. nuances of a specific vehicle do not need to be smoothed out using shallower acceleration rates and sub maximum vehicle speeds. In fact the flexibility of the cycle allows for the vehicle to be used in a manner much closer to its actual use in the real-world and consequently its true rate of degradation.

7.2 Method

To perform this validation, JRC was tasked with obtaining appropriate vehicles and performing the relevant SRC-LeCV cycle on a dynamometer. Where possible, the same vehicles which were used in the main test programme were used, allowing the use of previously performed emissions test data. If this was not possible additional testing using the WMTC cycle was performed. All of the required test data was performed and compiled before the start of the analysis phase.

To perform the analysis, software was developed in Matlab. The first step was to load all of the data into the system, this included: Vehicle speed, theoretical speed (the test trace), exhaust temperatures and oil temperature all at a resolution of 1 Hz for each of the tests. From this data the software calculated the distances, the start point of laps, the acceleration rates and deceleration rates.

Additionally basic statistics were generated such as average speeds, acceleration rates and temperatures for each of the vehicles and its emission test. This data as well as traces of the speeds and temperatures are presented in Section 7.4.

The SRC-LeCV and WMTC cycle were analysed side by side, special attention was made to ensure that the same scales, metrics and colours were used in any comparison. Note, for four vehicles only R40 emissions test data was available, which although will not provide the exact result that would have been produced by the WMTC, by analysing the results from vehicles which performed both the WMTC and R40 or R47 test it shows that running temperatures are comparable.

7.2.1 Vehicle to cycle suitability

One of the key issues raised by stakeholders was the question of whether the groupings are appropriate for the vehicles. Especially when compared to the results from the WMTC test. Therefore, it was decided that the first step in any analysis was to answer this question and if the vehicles under test were able to perform the cycle.

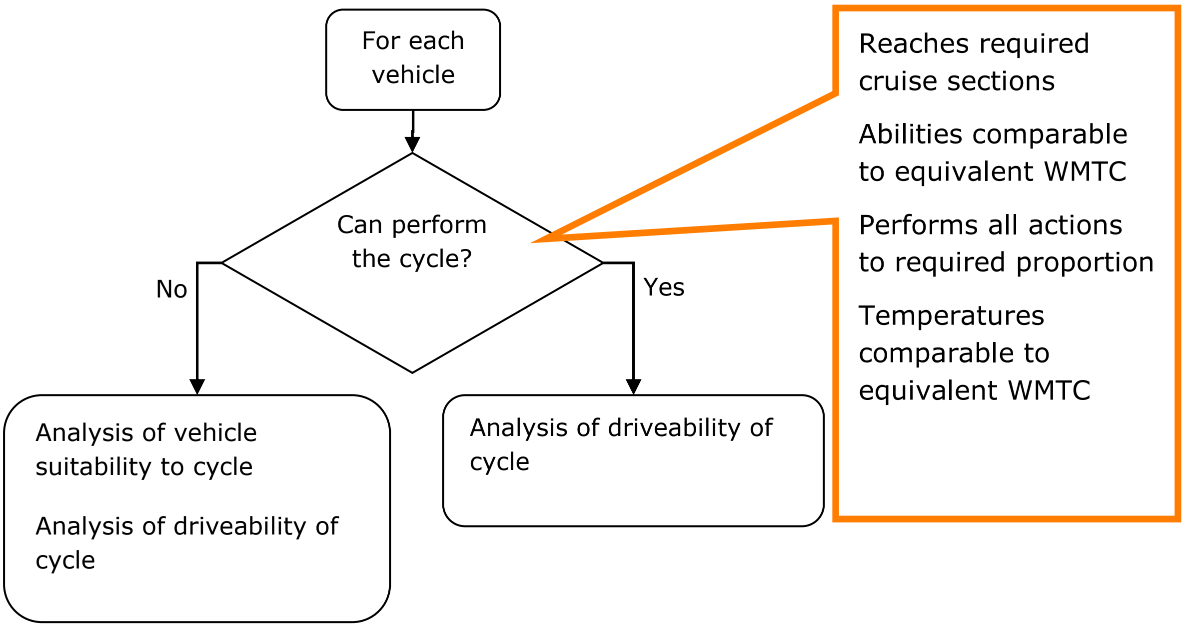


Figure 7-1: Flow chart of the assessment of vehicle to cycle suitability

The question of suitability has many facets as indicated in Figure 7-1, above. Two main overarching methods were used: comparability to the original SRC-LeCV test cycle trace and comparability to the WMTC test cycle and results.

It may be seen that a given vehicle cannot attain some of the higher speeds required, in one measure this could be considered a failure to perform the test, however the same vehicle may not be able to attain the equivalent actions in the WMTC therefore indicating that this is not a failing of the test but an inherent characteristic of the vehicle.

For the assessment based on temperatures, three changes needed be taken into account:

- The SRC-LeCV test may be significantly longer in both time and distance when compared to the vehicle's equivalent WMTC test. If available, monitoring of the oil temperature gives a good indication of where the tests can be directly compared. Once the curve of the oil temperature in the durability test results continues to increase above that seen in the emissions test the relationship is less directly comparable.
- The SRC-LeCV test has been designed without the lower speed sections and in comparison with the WMTC test; the locations of specific types of actions along the timeline are different.
- The less restrictive tolerances of a durability test allow for high speeds and sharper accelerations which had to be limited in the design of the WMTC test, this may cause marginally higher temperatures.

Over and above this, it must be remembered that the vehicles tested have not been designed for this new test. Manufactures put great effort into designing their vehicles to meet the requirements of legislation. Therefore just because a vehicle tested here displays results which may be considered disquieting doesn't mean that future design practices could either handle or prevent the occurrence of such issues.

7.2.2 Acceleration and deceleration rates

Within the SRC-LeCV durability test, changes were made to how acceleration and deceleration rates were explained in the instructions. In the EPA SRC and EPA AMA durability cycles, terms such as light, medium or WoT were used. In the EPA SRC this was supplemented with a column showing the typical rates for each action in the cycle. In the SRC-LeCV tables of approximate throttle positions were given for each of the instructions used in the cycle.

From the validation data, acceleration and deceleration rates have been taken for each of the instructions performed on a cycle. These will be compared with those used in the development of the cycle and the typical rates used in the EPA SRC (which is where the values were originally derived from).

7.2.3 Clarity of instructions

JRC, who performed the testing of the SRC, were not provided with any special instructions beyond those which were being developed for publication at the time of testing. This allowed an assessment of the clarity of the instructions themselves, as well as the ability of the test vehicles to meet the required trace.

If significant deviation from the cycle was found, a change to the instructions may be required to allow it to be performed as intended.

7.3 Type V durability cycles

There are four versions of the SRC-LeCV durability test: cycle 1 to 4 with maximum speeds of 25 km/h, 45 km/h, 100 km/h and 130 km/h respectively. Figure 4-24 shows example plots of the cycles, due to the nature of this test the actual speed/distance trace performed by a vehicle will look different due to differing acceleration and deceleration capabilities.

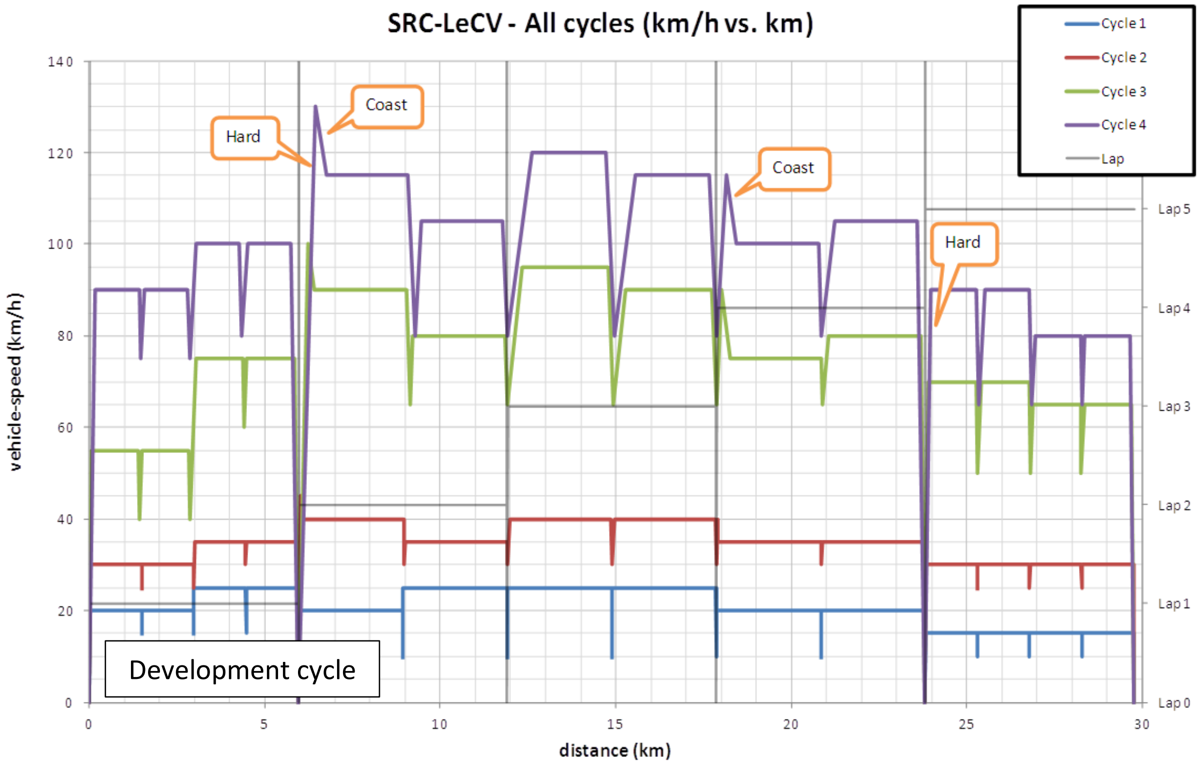


Figure 7-2: Plot of all SRC-LeCV cycles (phase 2) (development cycle)

In addition to the plots, the cycles have guidelines for throttle use during the cycle (see Table 7-1. For the majority of the cycle, the vehicles are ridden in a relaxed manner using moderate accelerations and decelerations. However, at two points a hard acceleration is performed where the full-throttle or wide-open-throttle (WoT) is used, and at another two points a coast-down is applied where the throttle is fully released and the clutch is used to disengage drive between engine and wheels.

Table 7-1: SRC-LeCV acceleration and deceleration guidelines (development cycle)

Action	Sub-action	Definition
Acceleration	Moderate	- Normal load acceleration (half throttle)
	Hard	- High load up to full throttle acceleration
Deceleration	Moderate	- Let-off of the throttle from normal load, brakes allowed as required
	Coast-down	- Fully let-off the throttle, clutch disengaged, no brakes

7.4 Test data

The test programme was performed with 13 vehicles, representing the main L-category sub-categories. For each vehicle, at least one durability and emission cycle was performed (see Table 7-2).

Table 7-2: Vehicles categorisation and test cycles performed

Vehicle #	Category	Category name	Type V Durability cycle performed (original SRC-LeCV)	Type I Emissions cycle performed (WMTC, R40, R47)
1	L1Ae	Powered cycle	1	R47
2	L1Be ≤ 25 km/h	Two-wheel mopeds	1	WMTC, R47
3	L1Be ≤ 45 km/h	Two-wheel mopeds	2	WMTC, R47
4	L3e – A1	Low performance motorcycle	3	WMTC
5	L3e – A2	Medium performance motorcycle	3	WMTC
6	L3e – A3	High performance motorcycle	4	WMTC
7	L5Ae	Tricycle	3	R40
8	L5Be	Commercial tricycle	2	R40
9	L6Ae	Light on-road quad	2	WMTC
10	L6Be	Light quadri-mobile	2	R40
11	L7Ae	Heavy on-road quad	2 3	R40
12	L7Be	All-Terrain Vehicle (ATV)	2 3	WMTC
13	L7Ce	Heavy quadri-mobiles	2	WMTC, R40

Where a vehicle was considered to be on the borderline between one group and another, testing using both of the durability Type V tests was performed. This occurred with an L7Ae and L7Be heavy quadricycle.

Where multiple emission Type I testing data was available it was used only for assessing the viability of using R40 test data on those vehicles where WMTC data was unavailable.

The following sub sections show the data for each of the vehicles as well as commentary on key characteristics considered noteworthy.

Note that both results are presented with distance in the x-axis. For the emissions test cycle, which is time not distance based, the test actions have been offset to allow easy comparison with the results.

7.4.1 Vehicle 1 - L1Ae, Cycle 1

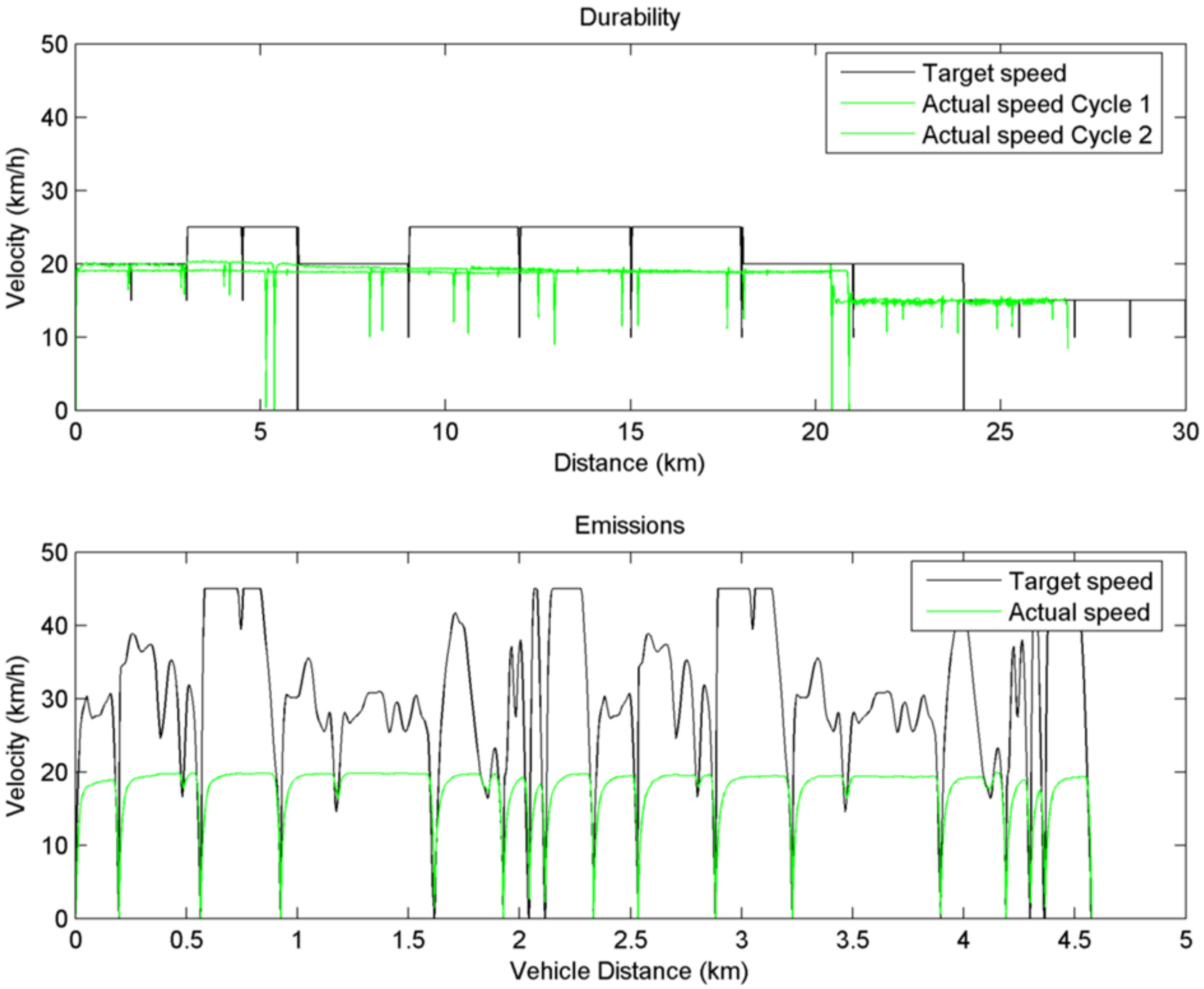


Figure 7-3: Vehicle 1 - L1Ae, Cycle 1, Type V and Type I speed traces

Table 7-3: Vehicle 1 - L1Ae, Cycle 1, overview of speed data

		Type V	Type I
General statistics	Average speed	17.8 km/h	14.5 km/h
	Max speed	20.4 km/h	19.9 km/h
	Time per cycle	90 minutes	20 minutes
	Distance per cycle	27 km	5 km
Acceleration average rate	Moderate accelerations	0.22 ms^{-2}	N/A
	Hard accelerations	0.23 ms^{-2}	N/A
Deceleration average rate	Moderate decelerations	-0.26 ms^{-2}	N/A
	Coast-downs	-0.04 ms^{-2}	N/A

This vehicle was unable to meet the required speeds for all of the higher speed points or 3/5th of the distance, with a maximum speed of approximately 20 km/h. This was much higher than its performance in the WMTC test.

The results of this durability test show a significant problem with the interpretation of the test's instructions. Although distance based, the theoretical and actual actions have become offset, shortening the total test by 3 km or 10%, spending less distance/time than required on the portions above the vehicle's maximum speed. It is known that the test house converted the test instructions to a time based format.

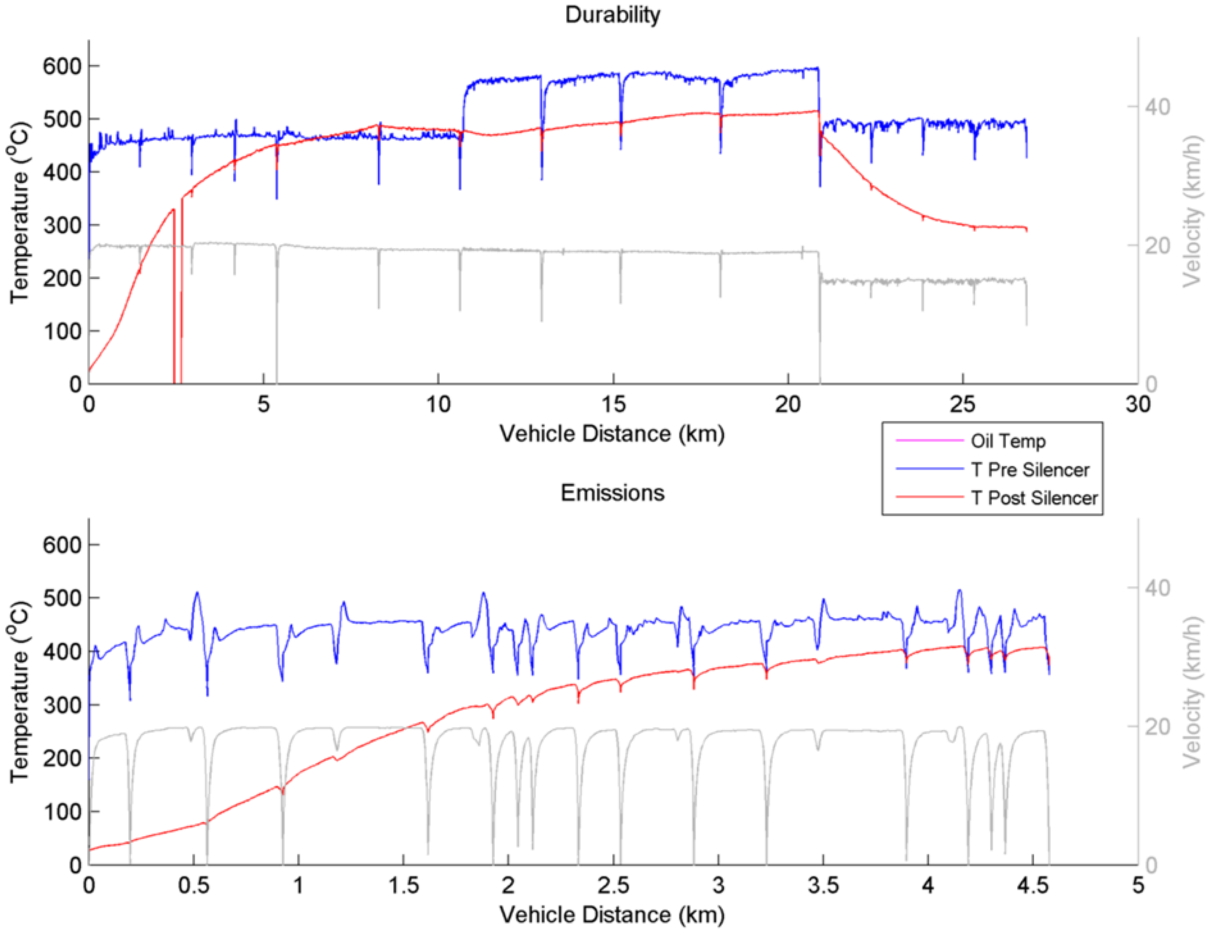


Figure 7-4: Vehicle 1 - L1Ae, Cycle 1, Type V and Type I temperature traces

Table 7-4: Vehicle 1 - L1Ae, Cycle 1, maximum temperatures

		Type V	Type I
Maximum temp. (°C)	Pre silencer	609	516
	Post silencer	530	410
	Oil	N/A	N/A

Note: As this vehicle utilises a 2 stroke engine, oil temperature could not be measured.

The pre silencer exhaust temperatures stayed at approximately the same temperatures as in the WMTC test for the first two laps, at which point they jumped by over 100°C, this continued in the second iteration of the cycle (see Appendix J). As the vehicle could only reach 20 km/h this jump is not directly caused by the cycle, and is presumably a change in fuelling regime once the vehicle had warmed (such as the deactivation of the choke). And as the vehicle performs only half of this distance in the WMTC test, this change in temperatures is not reflected in that test.

Note: Cycle 1 and 2 in the figures refers to the iteration of the SRC-LeCV cycle, not the cycle version.

7.4.2 Vehicle 2 - L1Be ≤ 25 km/h, Cycle 1

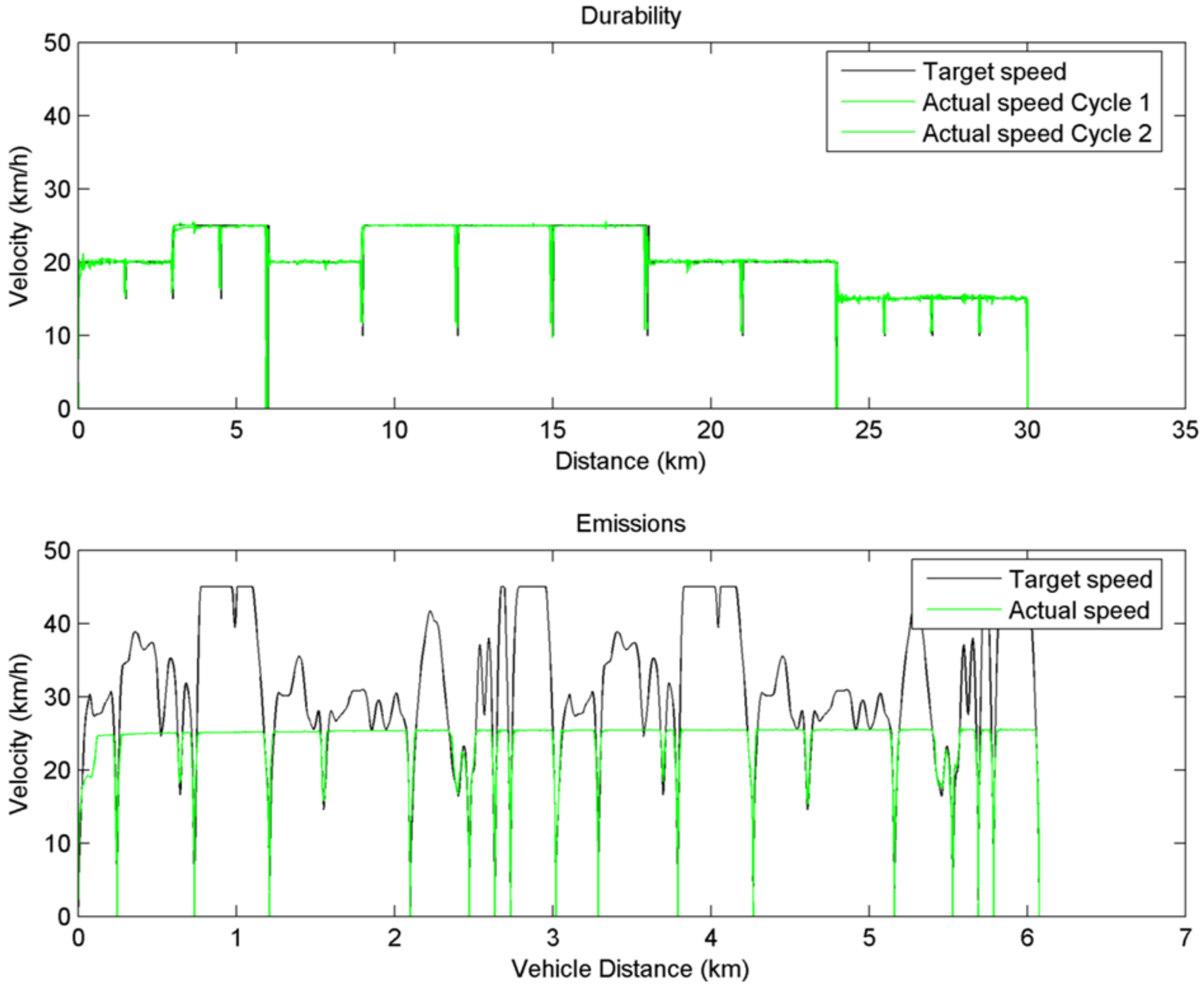


Figure 7-5: Vehicle 2 - L1Be ≤ 25 km/h, Cycle 1, Type V and Type I speed traces

Table 7-5: Vehicle 2 - L1Be ≤ 25 km/h, Cycle 1, overview of speed data

		Type V	**Type I**
General statistics	Average speed	20.1 km/h	21.4 km/h
	Max speed	25.6 km/h	25.8 km/h
	Time per cycle	90 minutes	20 minutes
	Distance per cycle	30 km	6 km
Acceleration average rate	Moderate accelerations	0.43 ms^{-2}	N/A
	Hard accelerations	0.69 ms^{-2}	N/A

		Type V	Type I
Deceleration average rate	Moderate decelerations	-0.49 ms^{-2}	N/A
	Coast-downs	-0.34 ms^{-2}	N/A

The required durability speed trace of this vehicle is reached by the vehicle for the entirety of the test, unlike the WMTC test where less than 10% is met, forcing a higher proportion of WoT to be performed.

It seems from the overview of one iteration of the cycle in Figure 7-5 that the vehicle is not decelerating as required to reach the lowest points of the cycle, the speed trace seems to protrude beyond the lowest point actually reached. Consequently this issue has been looked at further, see Section 7.5.2.

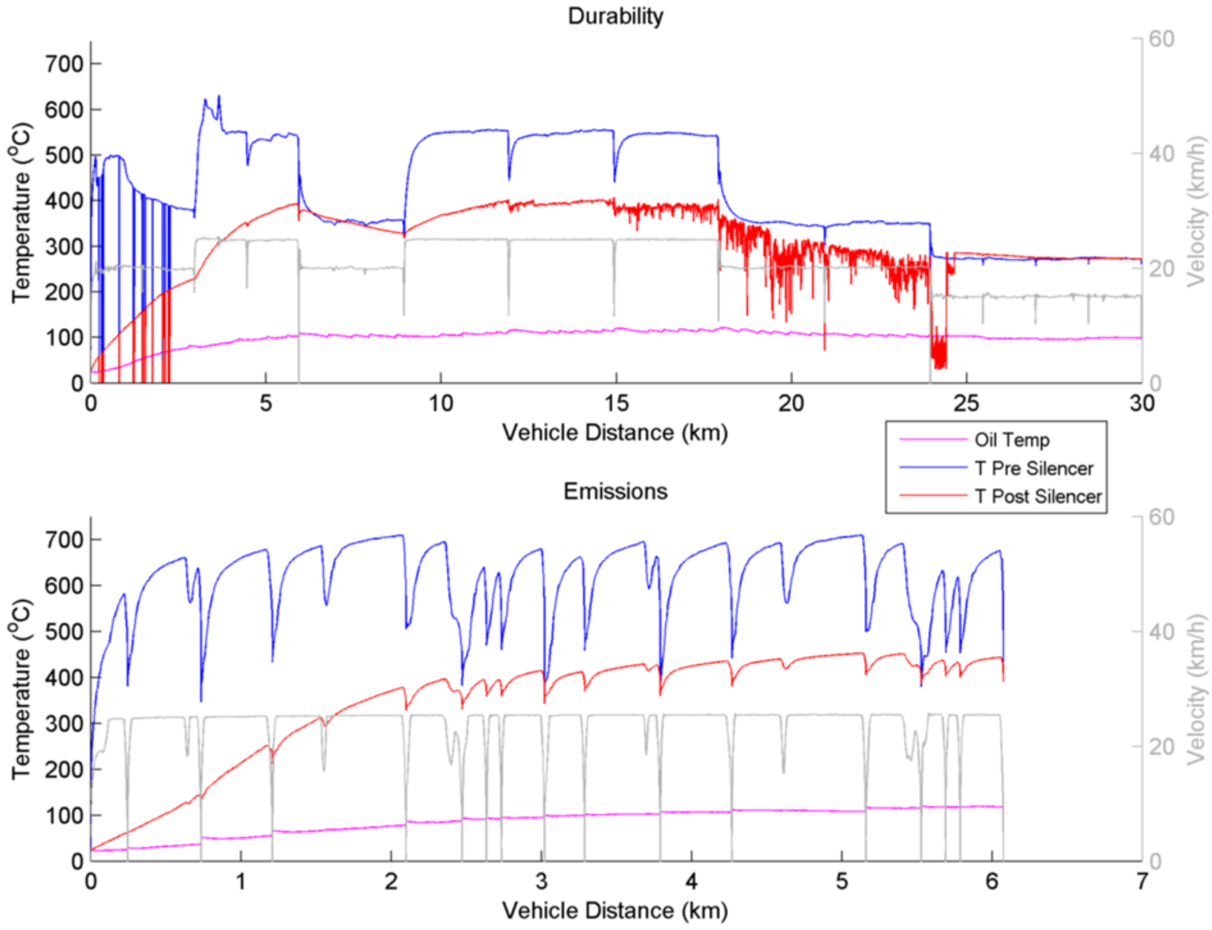


Figure 7-6: Vehicle 2 - L1Be ≤ 25 km/h, Cycle 1, Type V and Type I temperature traces

Table 7-6: Vehicle 2 - L1Be ≤ 25 km/h, Cycle 1, maximum temperatures

		Type V	Type I
Maximum temp. (°C)	Pre silencer	631	709
	Post silencer	419	452

Oil	121	120

Some anomalies were experienced when recording the temperatures from this vehicle with both pre and post silencer information dropping out at the start of lap one, and again during lap four. However, the general curve can be seen from the rest of the data recorded.

The assessment of the speed trace pre silencer exhaust temperatures continue the trend seen with the speed trace; the temperatures are high for approximately half of the proportion of distance as is seen in the WMTC test. Also, the maximum temperatures are 78°C and 33°C lower for the pre and post silencer exhaust gases, although the oil temperatures peaked at a similar value.

7.4.3 Vehicle 3 - L1Be, Cycle 2

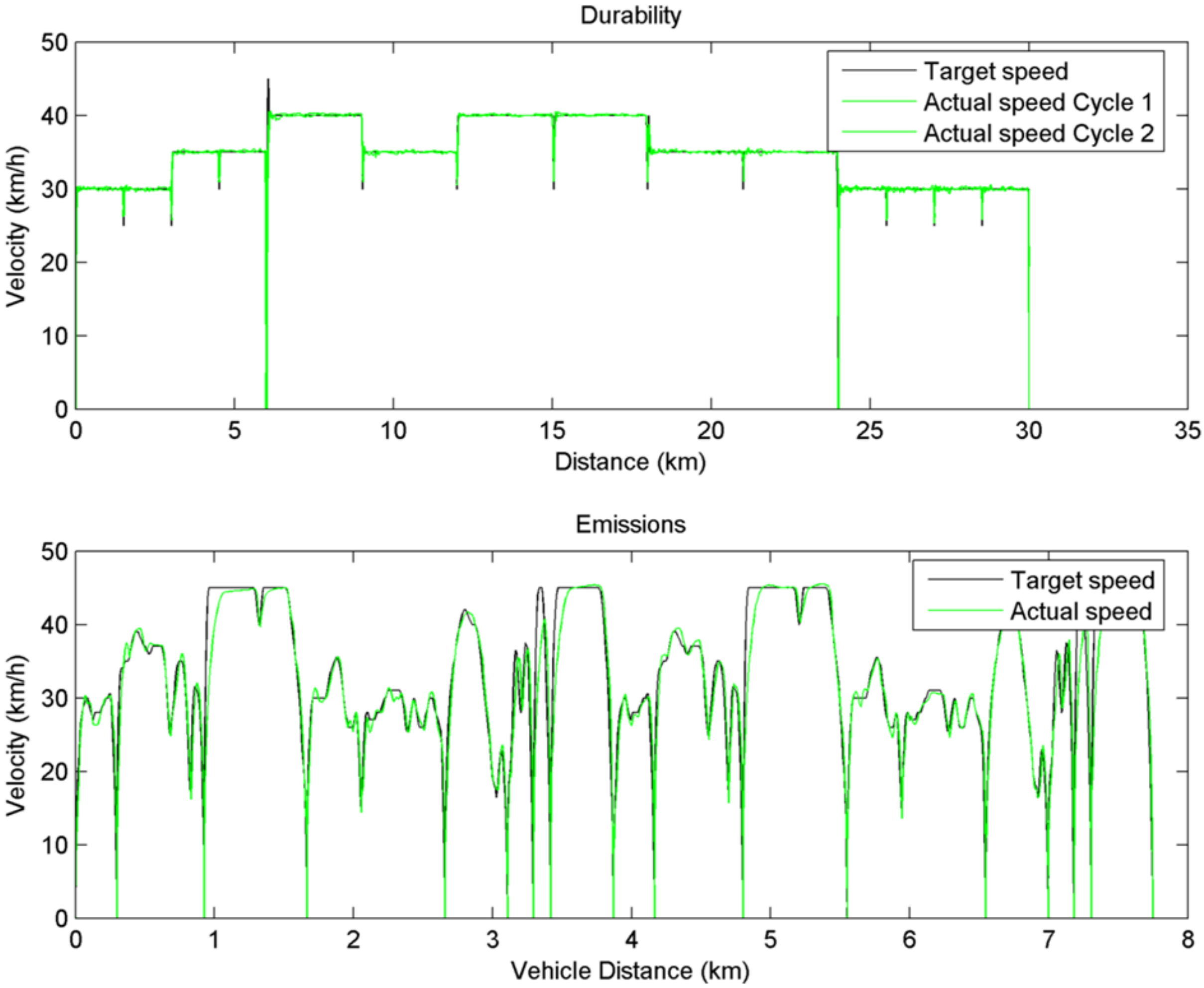


Figure 7-7: Vehicle 3 - L1Be, Cycle 2, Type V and Type I speed traces

Table 7-7: Vehicle 3 - L1Be, Cycle 2, overview of speed data

		Type V	Type I
General statistics	Average speed	34.2 km/h	27.7 km/h
	Max speed	40.7 km/h	45.5 km/h
	Time per cycle	54 minutes	20 minutes
	Distance per cycle	30 km	8 km
Acceleration average rate	Moderate accelerations	0.35 ms^{-2}	N/A
	Hard accelerations	0.71 ms^{-2}	N/A
Deceleration average rate	Moderate decelerations	-0.44 ms^{-2}	N/A
	Coast-downs	-0.28 ms^{-2}	N/A

In this test also, the vehicle did not decelerate fully as required, consistently moving onto the following step 20% or 1 km/h before the deceleration was completed.

It should be noted that the WMTC trace has been capped at 45 km/h to match the speed restrictions for mopeds (L1e). Therefore, the vehicle missed all of the peak cruising speeds, whereas for the durability test, all cruises were met, being 5 km/h below its maximum and typical riding speed for this category of vehicle.

Additionally the single 45 km/h peak was missed altogether, causing the vehicle to omit one of the two required coast-downs. This testing anomaly will be examined further in Section 7.5.3.

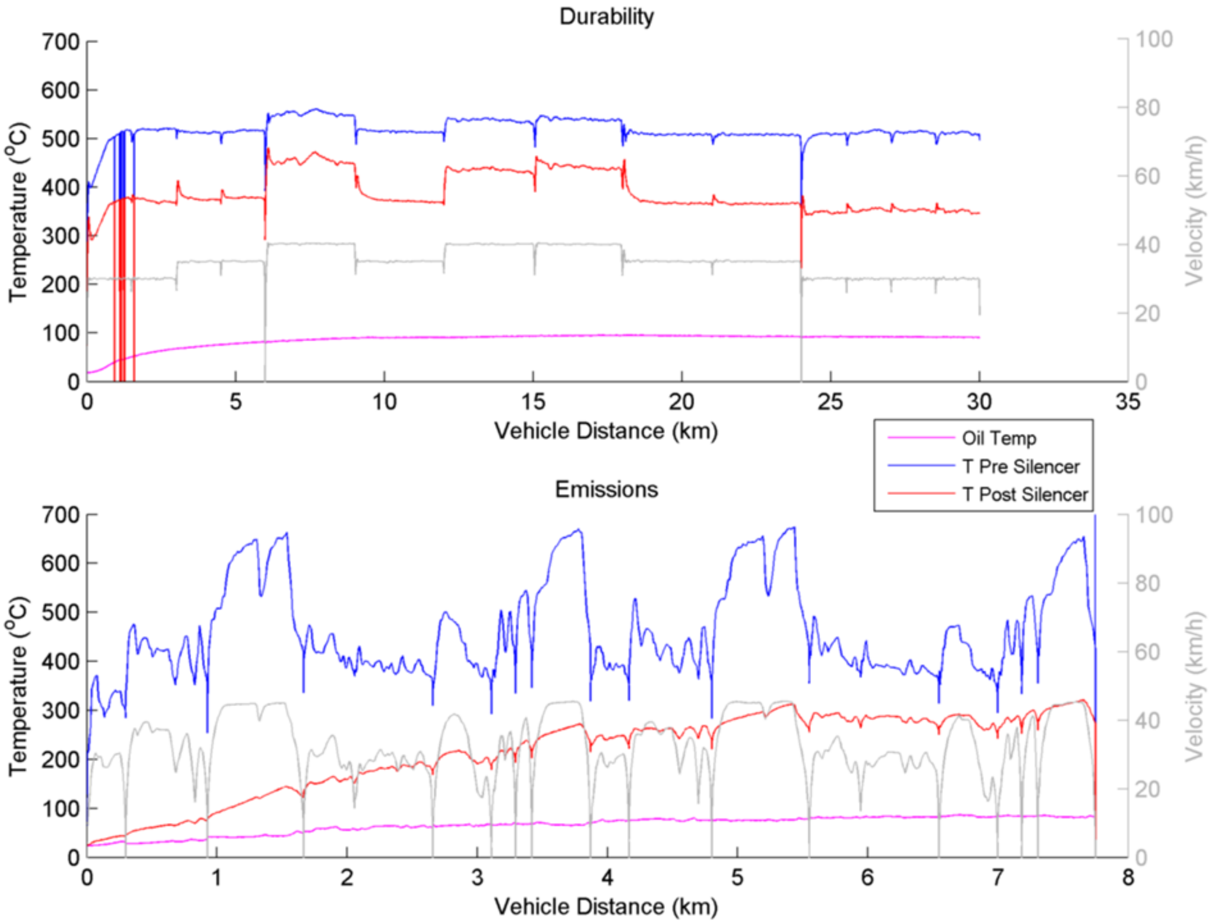


Figure 7-8: Vehicle 3 - L1Be, Cycle 2, Type V and Type I temperature traces

Table 7-8: Vehicle 3 - L1Be, Cycle 2, maximum temperatures

		Type V	Type I
Maximum temp. (°C)	Pre silencer	561	674
	Post silencer	482	313
	Oil	96	90

Due to the reduced speeds, the pre silencer exhaust temperatures in the durability test were over 100°C lower than the peaks in the WMTC test. The peak exhaust temperature was sustained for approximately one third of the distance. However, the pre silencer exhaust temperature was ~50°C above those of the moderate speed sections in the WMTC emission test.

7.4.4 Vehicle 4 – L3e A1, Cycle 3

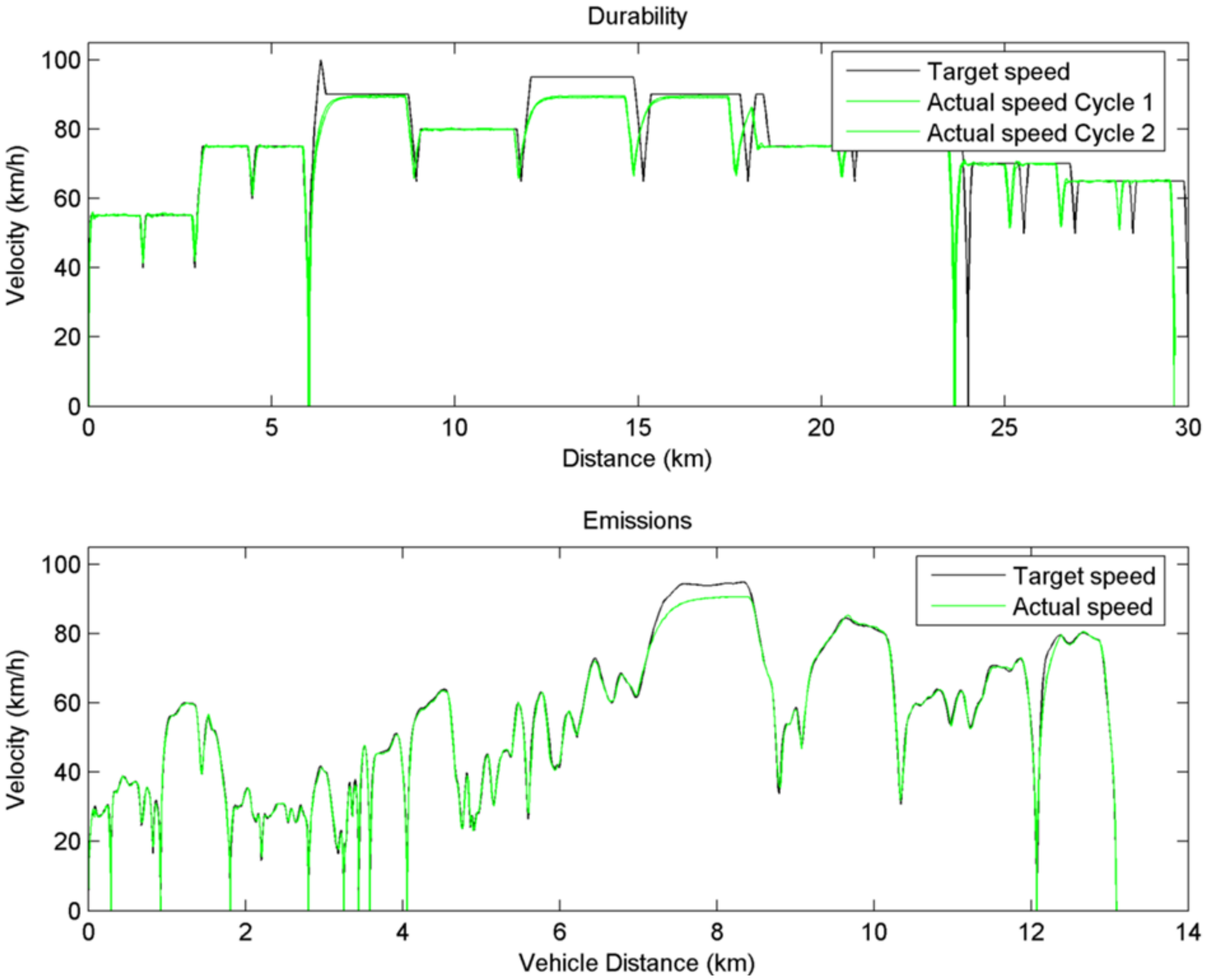


Figure 7-9: Vehicle 4 – L3e A1, Cycle 3, Type V and Type I speed traces

Table 7-9: Vehicle 4 – L3e A1, Cycle 3, overview of speed data

		Type V	Type I
General statistics	Average speed	71.6 km/h	43.9 km/h
	Max speed	89.8 km/h	90.6 km/h
	Time per cycle	26 minutes	20 minutes
	Distance per cycle	30 km	13 km
Acceleration average rate	Moderate accelerations	0.38 ms^{-2}	N/A
	Hard accelerations	1.00 ms^{-2}	N/A
Deceleration average rate	Moderate decelerations	-0.61 ms^{-2}	N/A
	Coast-downs	-0.39 ms^{-2}	N/A

The vehicle was unable to perform the first high acceleration peak due to its limitations. However, an error was also made in the execution of the second hard acceleration to a peak in the fourth lap. In this case, the action was abandoned before both the required speed and vehicle's maximum speed and occurred on both iterations of the cycle.

As with vehicle 1, the misinterpretation of the instructions for the durability cycle caused the vehicle to perform a shorter distance at high speed in the third lap.

The proportions of medium and high vehicle speed cruises in the emissions cycle occur in approximately equal amounts in the durability test.

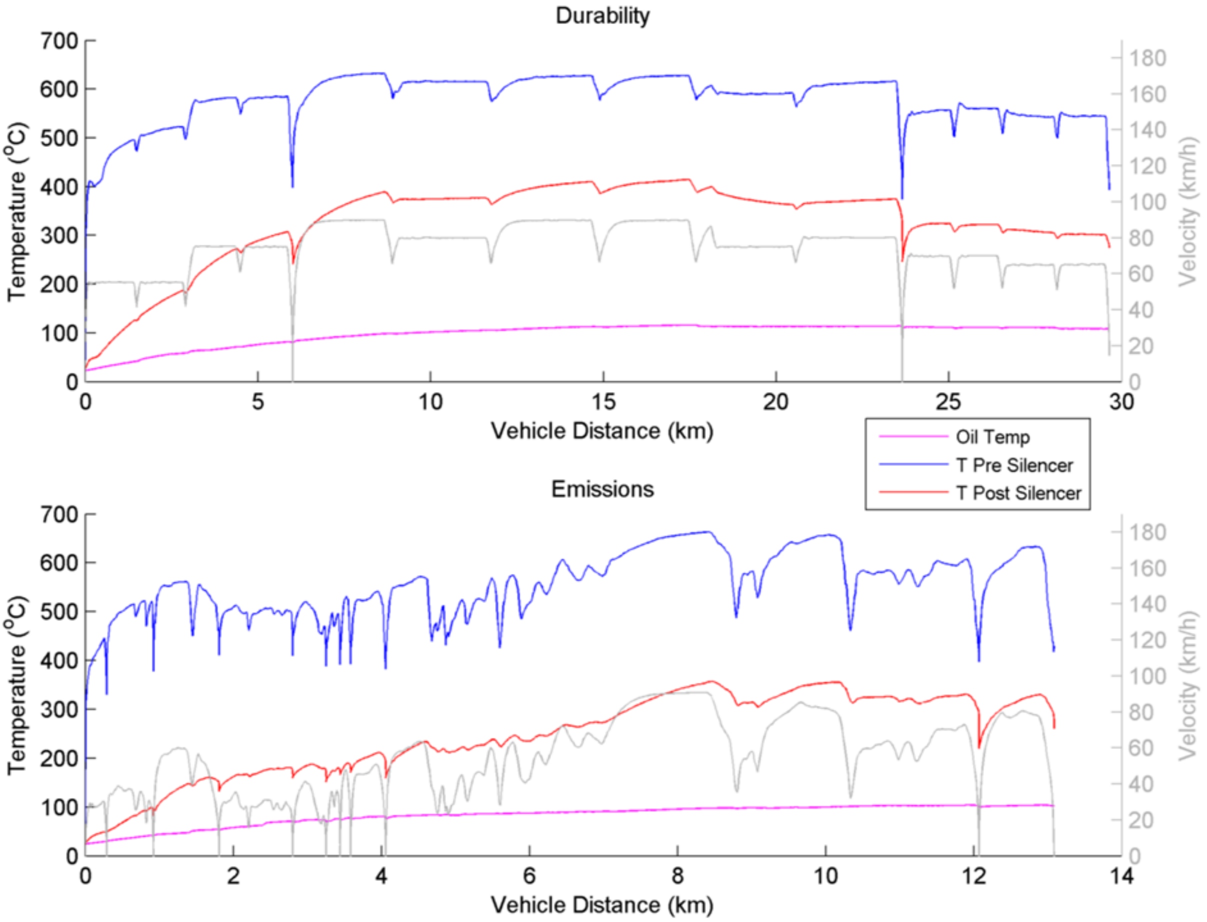


Figure 7-10: Vehicle 4 – L3e A1, Cycle 3, Type V and Type I temperature traces

Table 7-10: Vehicle 4 – L3e A1, Cycle 3, maximum temperatures

		Type V	Type I
Maximum temp. (°C)	Pre silencer	632	663
	Post silencer	527	357
	Oil	119	104

The pre silencer, post silencer and oil temperatures correlate between both test cycles.

7.4.5 Vehicle 5 – L3e A2, Cycle 3

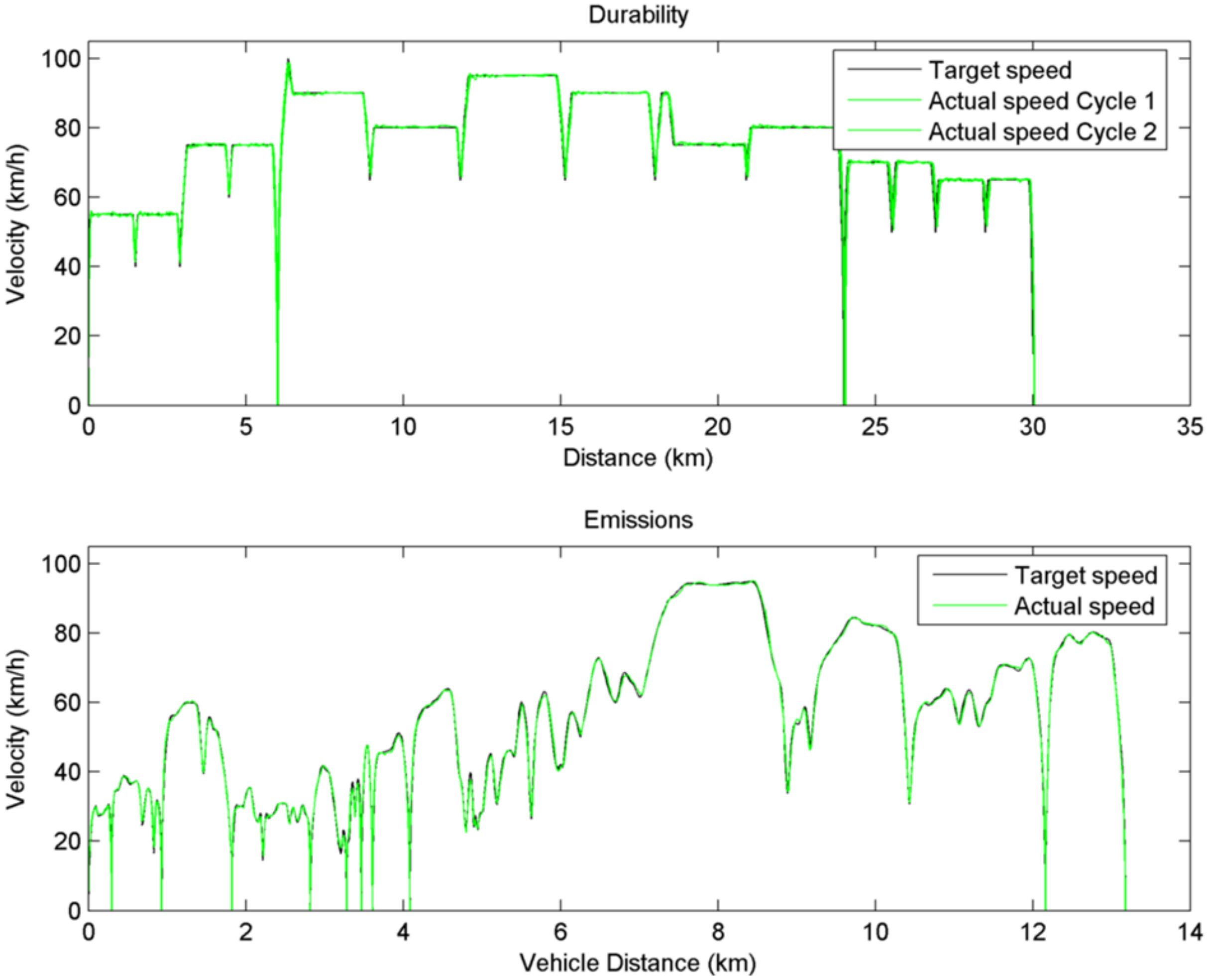


Figure 7-11: Vehicle 5 – L3e A2, Cycle 3, Type V and Type I speed traces

Table 7-11: Vehicle 5 – L3e A2, Cycle 3, overview of speed data

		Type V	Type I
General statistics	Average speed	72.7 km/h	44.8 km/h
	Max speed	98.9 km/h	95.1 km/h
	Time per cycle	26 minutes	20 minutes
	Distance per cycle	30 km	13 km
Acceleration average rate	Moderate accelerations	0.51 ms^{-2}	N/A
	Hard accelerations	1.34 ms^{-2}	N/A
Deceleration average rate	Moderate decelerations	-0.62 ms^{-2}	N/A
	Coast-downs	-0.38 ms^{-2}	N/A

This vehicle is able to match the trace in both the durability and emission cycle.

An error in testing occurred during the execution of the second peak at the start of lap four. After the required speed was reached, rather than continuing to the next action, the vehicle continued on an additional cruise section for 10 seconds. This will be examined further in Section 7.5.4.

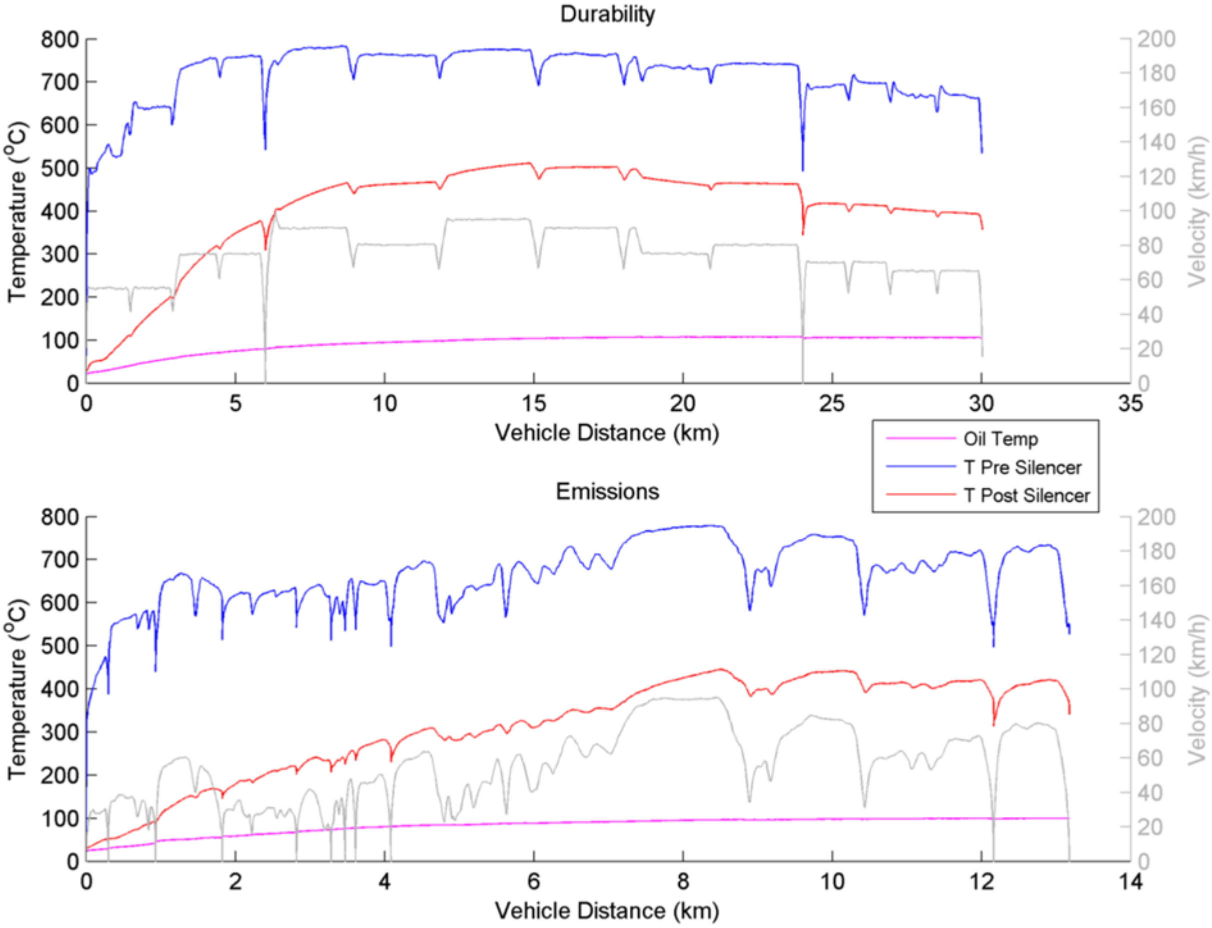


Figure 7-12: Vehicle 5 – L3e A2, Cycle 3, Type V and Type I temperature traces

Table 7-12: Vehicle 5 – L3e A2, Cycle 3, maximum temperatures

		Type V	Type I
Maximum temp. (°C)	Pre silencer	784	779
	Post silencer	654	445
	Oil	111	100

As with vehicle 4 the pre silencer, post silencer and oil temperatures are comparable for the same vehicle speed section in both test cycles.

7.4.6 Vehicle 6 – L3e A3, Cycle 4

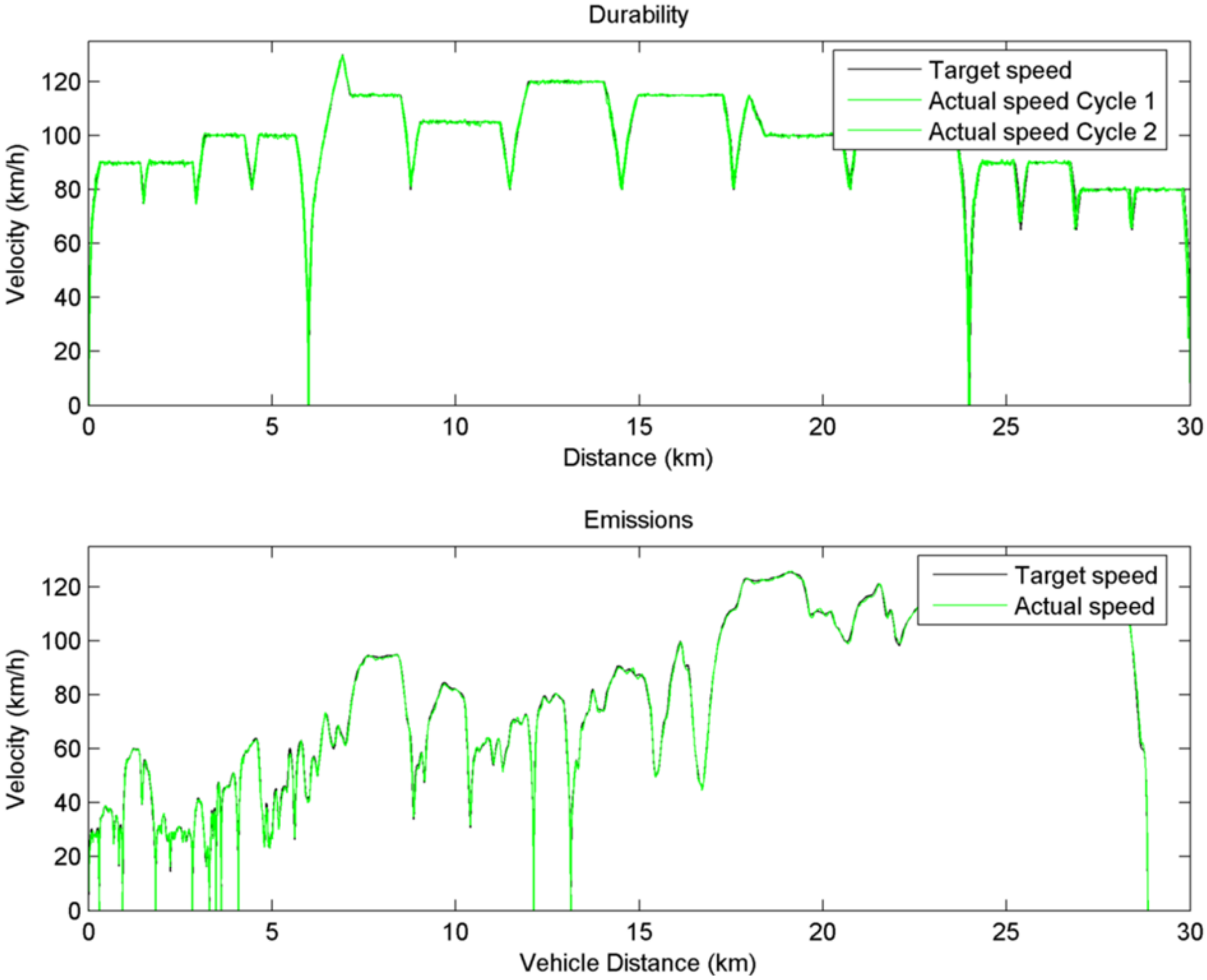


Figure 7-13: Vehicle 6 – L3e A3, Cycle 4, Type V and Type I speed traces

Table 7-13: Vehicle 6 – L3e A3, Cycle 4, overview of speed data

		Type V	Type I
General statistics	Average speed	93.1 km/h	63.2 km/h
	Max speed	129.9 km/h	125.8 km/h
	Time per cycle	20 minutes	30 minutes
	Distance per cycle	30 km	29 km
Acceleration average rate	Moderate accelerations	0.62 ms^{-2}	N/A
	Hard accelerations	1.21 ms^{-2}	N/A
Deceleration average rate	Moderate decelerations	-0.78 ms^{-2}	N/A
	Coast-downs	-0.42 ms^{-2}	N/A

This vehicle was able to match the trace in both the durability and emission cycle.

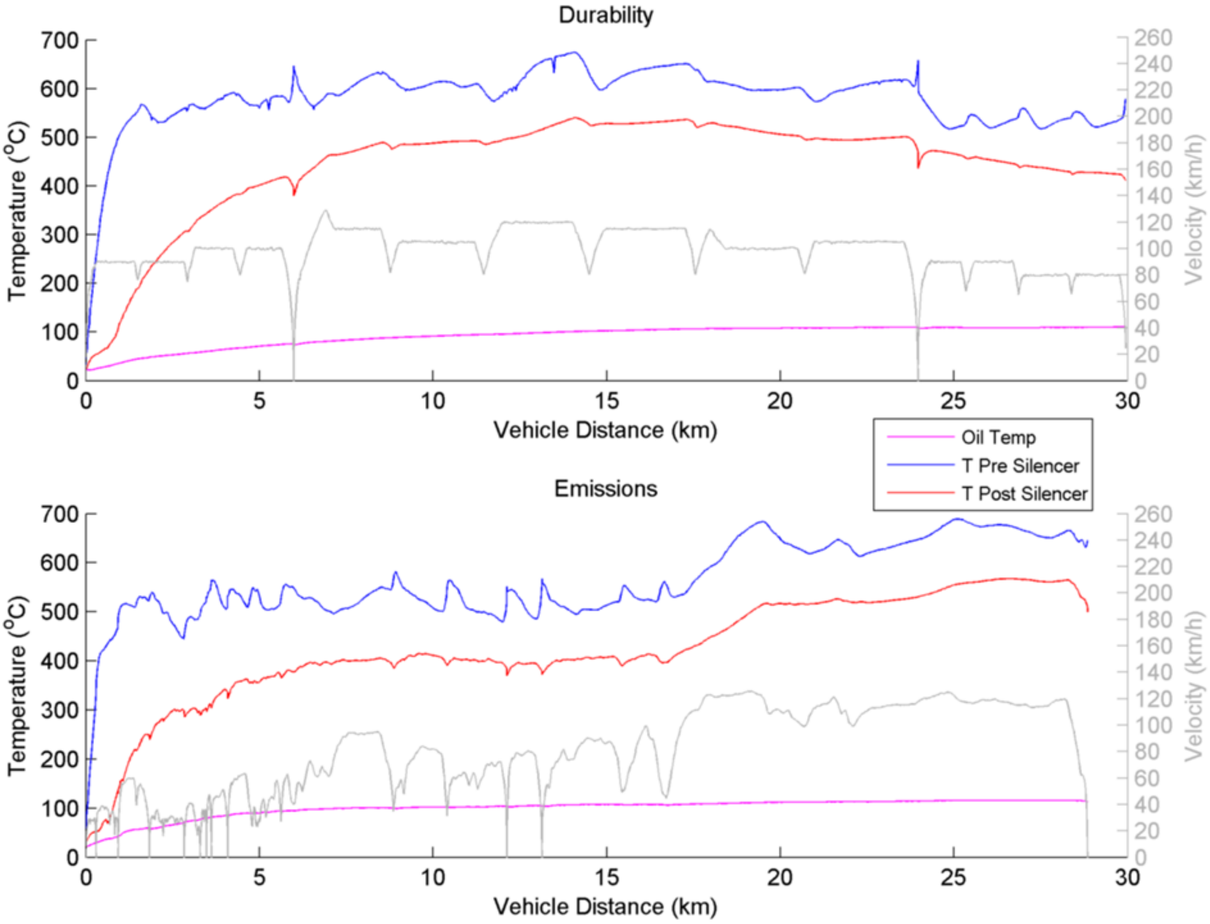


Figure 7-14: Vehicle 6 – L3e A3, Cycle 4, Type V and Type I temperature traces

Table 7-14: Vehicle 6 – L3e A3, Cycle 4, maximum temperatures

		Type V	Type I
Maximum temp. (°C)	Pre silencer	675	689
	Post silencer	625	568
	Oil	116	116

For this vehicle the exhaust and oil temperatures were comparable for similar cruising speeds in both tests.

In the pre silencer temperature data for both test cycles there is an anomaly where the temperature increases rather than drops when the vehicle decelerates to a stop. This is present at the transition from laps 1 to 2 and 4 to 5 in the durability cycle, and between 10 and 15 km in the emissions test. This anomaly will be investigated further in Section 7.6.1.3.

7.4.7 Vehicle 7 – L5Ae, Cycle 3

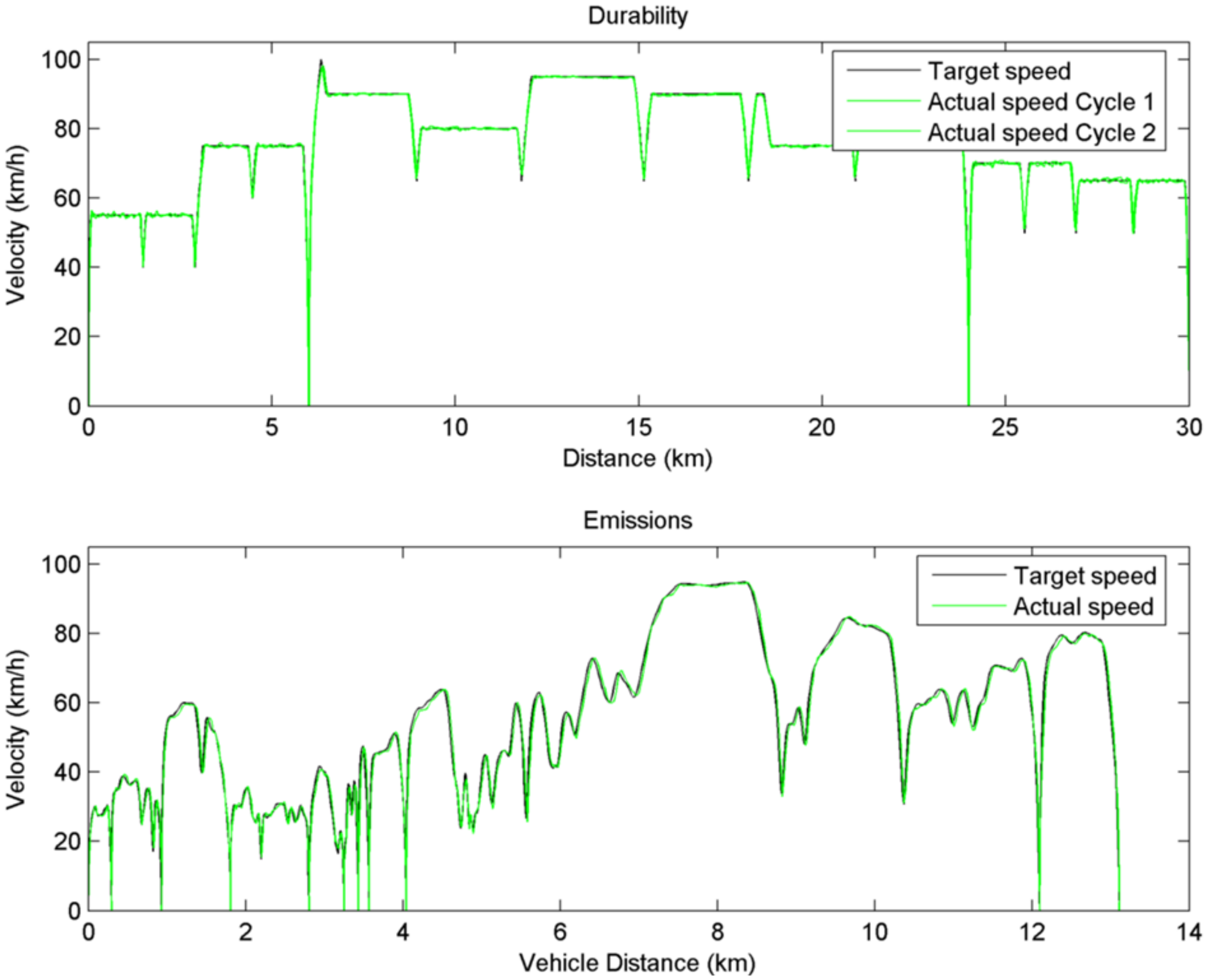


Figure 7-15: Vehicle 7 – L5Ae, Cycle 3, Type V and Type I speed traces

Table 7-15: Vehicle 7 – L5Ae, Cycle 3, overview of speed data

		Type V	Type I
General statistics	Average speed	72.4 km/h	44.2 km/h
	Max speed	98.2 km/h	94.6 km/h
	Time per cycle	26 minutes	20 minutes
	Distance per cycle	30 km	13 km
Acceleration average rate	Moderate accelerations	0.53 ms^{-2}	N/A
	Hard accelerations	1.25 ms^{-2}	N/A
Deceleration average rate	Moderate decelerations	-0.64 ms^{-2}	N/A
	Coast-downs	-0.35 ms^{-2}	N/A

This vehicle was able to match the trace in both the durability and emission cycle.

As with vehicle 5, an error with the testing occurred during the execution of the second peak at the start of lap 4. This anomaly will be looked at further in Section 7.5.4.

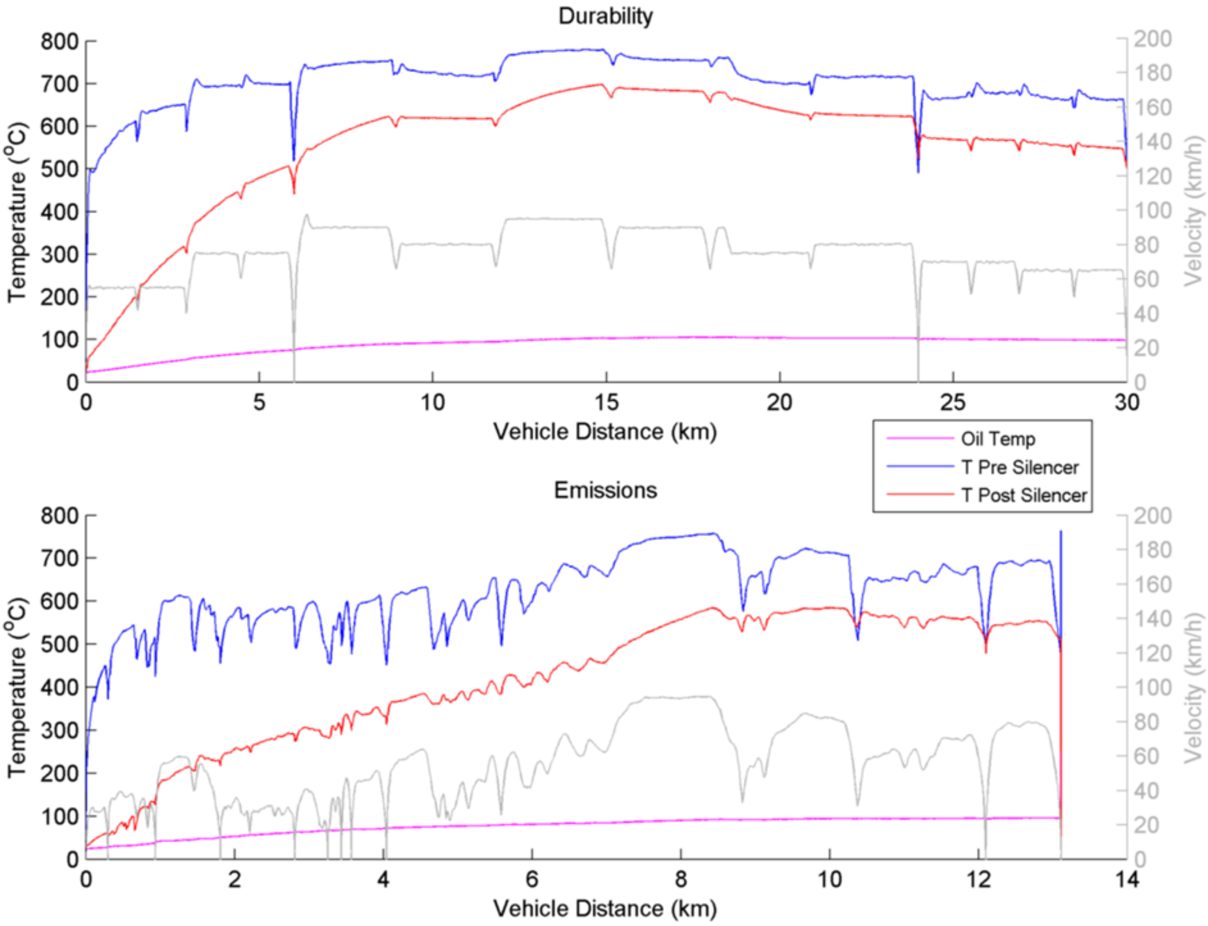


Figure 7-16: Vehicle 7 – L5Ae, Cycle 3, Type V and Type I temperature traces

Table 7-16: Vehicle 7 – L5Ae, Cycle 3, maximum temperatures

		Type V	Type I
Maximum temp. (°C)	Pre silencer	786	764
	Post silencer	711	585
	Oil	111	95

For this vehicle the exhaust and oil temperatures were comparable for similar cruising speeds in both tests. During the period in the durability cycle where the vehicle reaches 10 km/h more than the highest point in the emissions cycle, there is an increase of ~50°C and ~100°C for the pre and post silencer exhaust temperatures respectively.

7.4.8 Vehicle 8 – L5Be, Cycle 2

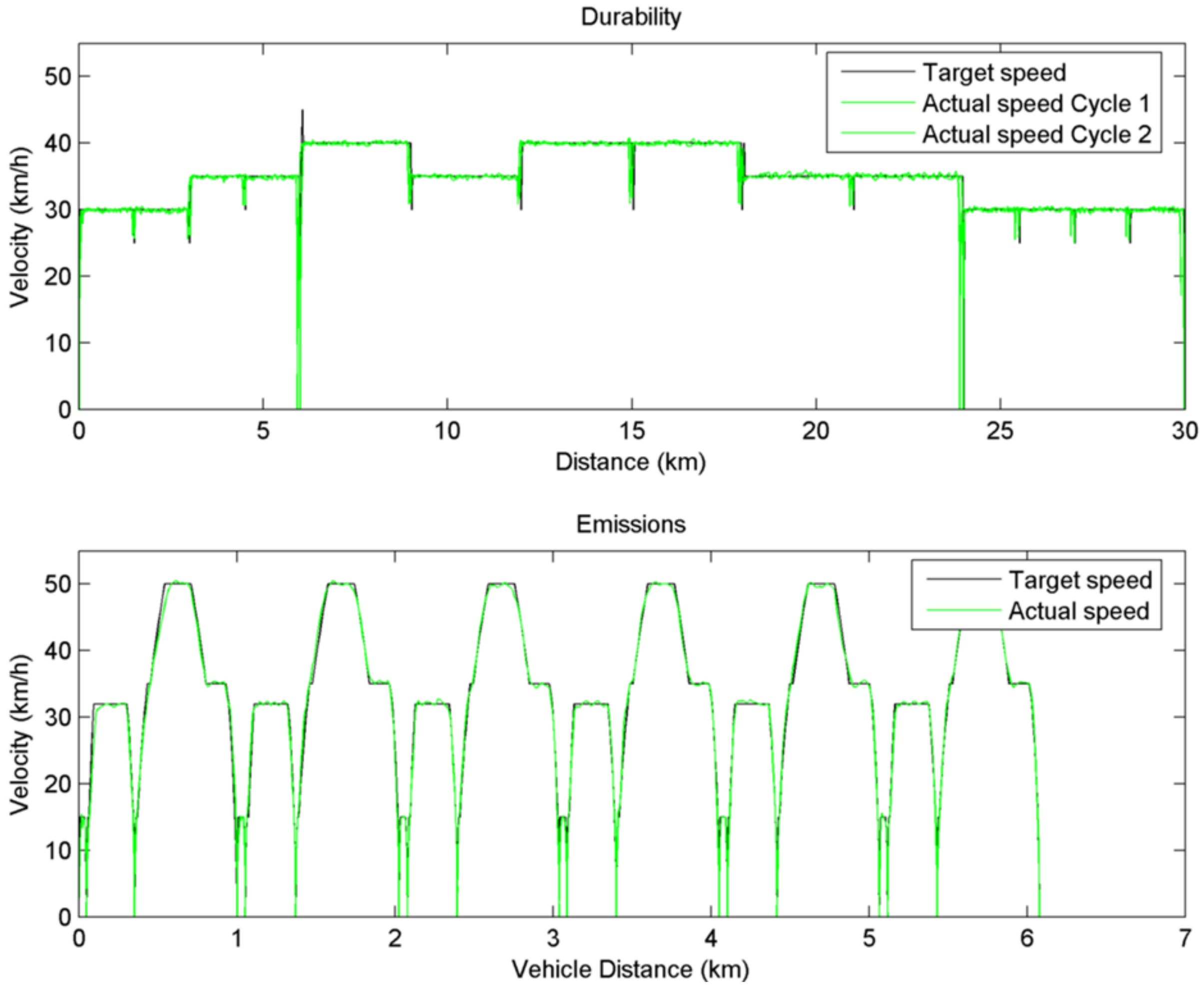


Figure 7-17: Vehicle 8 – L5Be, Cycle 2, Type V and Type I speed traces

Table 7-17: Vehicle 8 – L5Be, Cycle 2, overview of speed data

		Type V	Type I
General statistics	Average speed	34.1 km/h	25.3 km/h
	Max speed	40.8 km/h	50.5 km/h
	Time per cycle	54 minutes	20 minutes
	Distance per cycle	30 km	6 km
Acceleration average rate	Moderate accelerations	0.32 ms^{-2}	N/A
	Hard accelerations	0.59 ms^{-2}	N/A
Deceleration average rate	Moderate decelerations	-0.40 ms^{-2}	N/A
	Coast-downs	-0.25 ms^{-2}	N/A

For this vehicle's emission test, the UN regulation 40 was used rather than the WMTC.

Although the vehicle could perform a speed of at least 50 km/h, as seen in the emissions test, the required peak to 45 km/h was skipped when performing both repeats of the durability cycle, reaching a maximum speed of 40.8 km/h during the test. This error in the testing will be looked at further in Section 7.5.3.

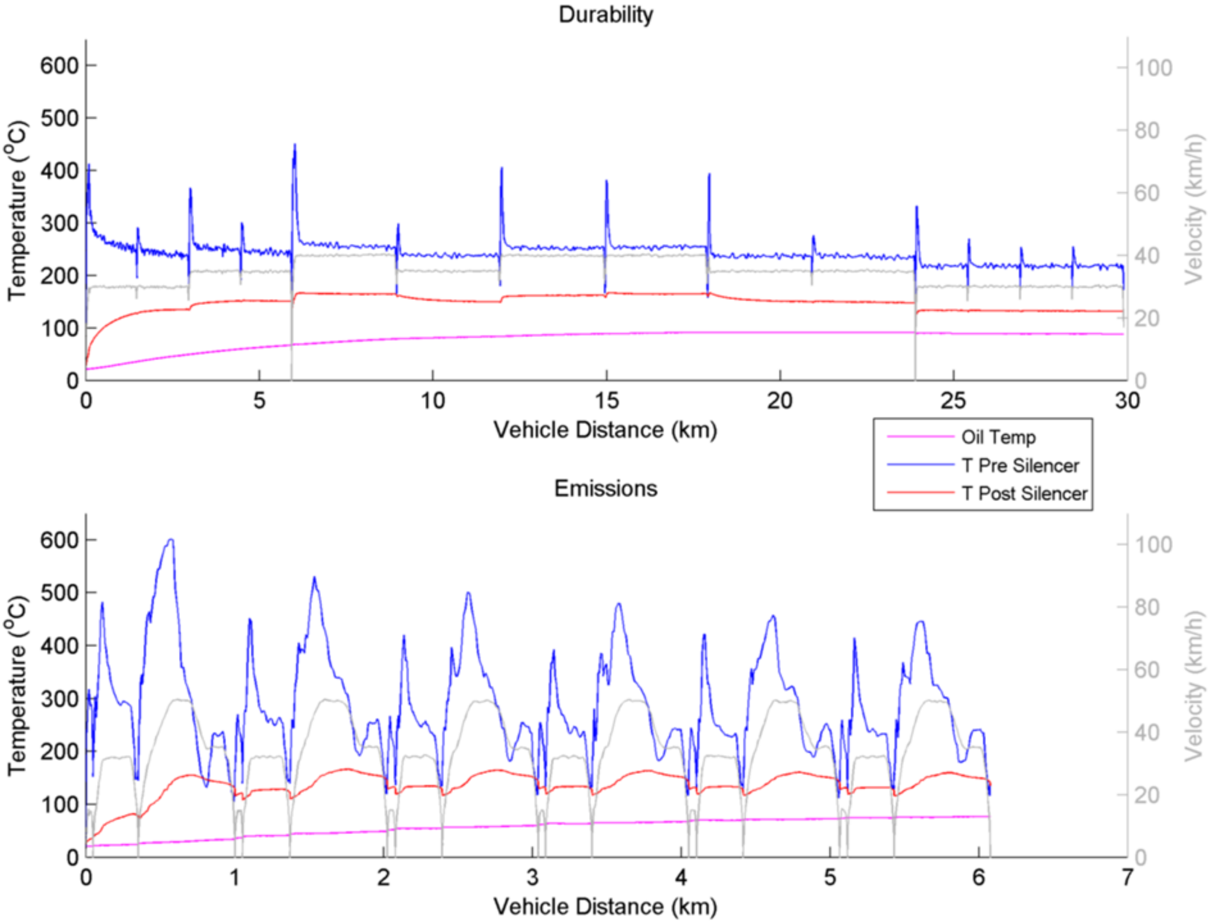


Figure 7-18: Vehicle 8 – L5Be, Cycle 2, Type V and Type I temperature traces

Table 7-18: Vehicle 8 – L5Be, Cycle 2, maximum temperatures

		Type V	Type I
Maximum temp. (°C)	Pre silencer	466	601
	Post silencer	168	166
	Oil	95	75

The L5Be vehicle tested using the UN Regulation 40 test resulted in 12 WoT accelerations to medium and high vehicle speeds. This produces higher (+135°C) pre silencer exhaust temperatures during the emissions test and they are held at these higher levels for sustained periods.

The post silencer exhaust temperatures stay comparable. The oil temperature in the emission test does not level off before the end of the emissions test, but stays comparable with the SRC-LeCV up to an equal distance in the durability test, being 69°C and 77°C for the durability and emissions cycles respectively at 6 km into both tests.

7.4.9 Vehicle 9 – L6Ae, Cycle 2

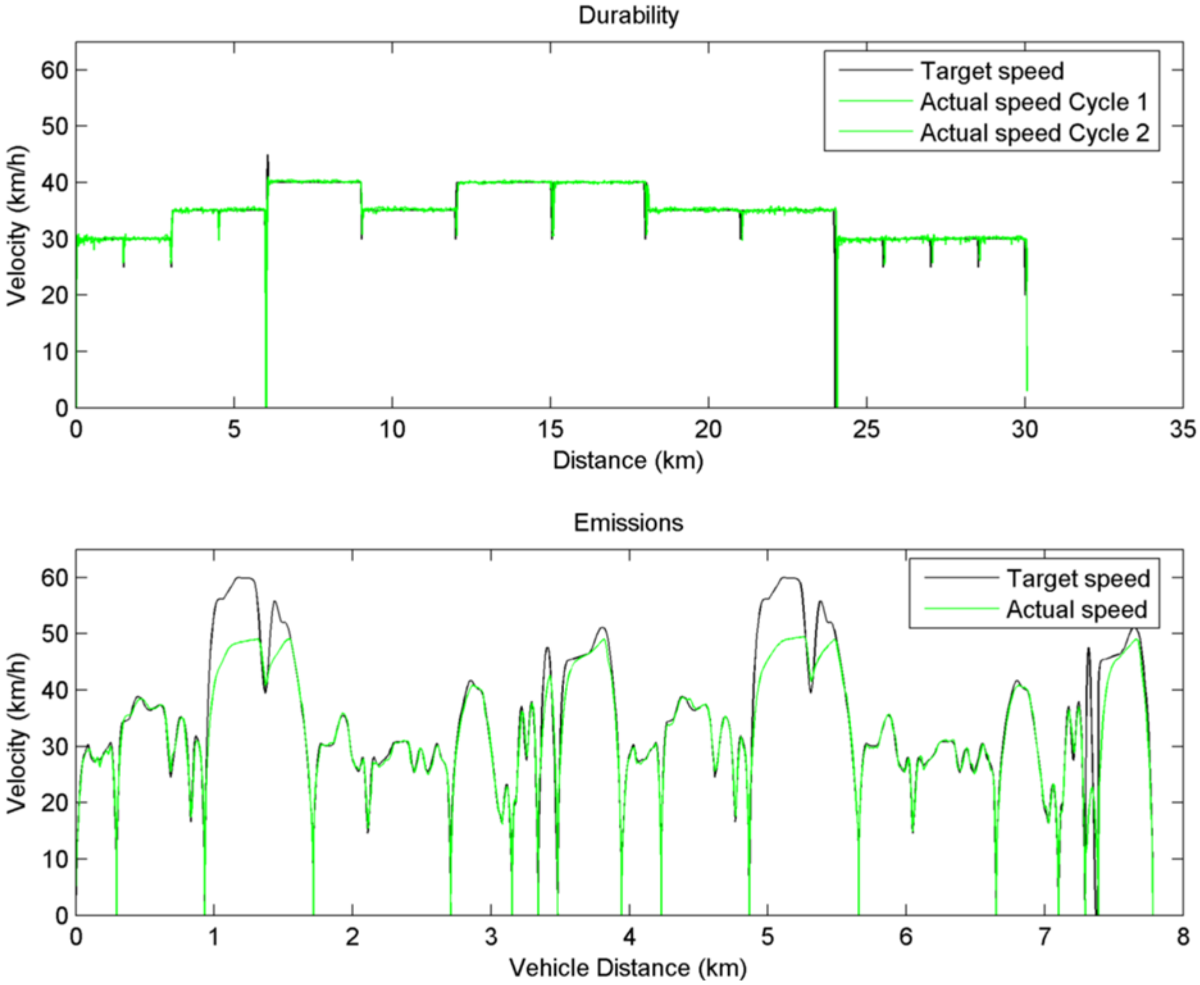


Figure 7-19: Vehicle 9 – L6Ae, Cycle 2, Type V and Type I speed traces

Table 7-19: Vehicle 9 – L6Ae, Cycle 2, overview of speed data

		Type V	Type I
General statistics	Average speed	34 km/h	26.6 km/h
	Max speed	41 km/h	49.5 km/h
	Time per cycle	54 minutes	20 minutes
	Distance per cycle	30 km	8 km
Acceleration average rate	Moderate accelerations	0.34 ms^{-2}	N/A
	Hard accelerations	0.93 ms^{-2}	N/A
Deceleration average rate	Moderate decelerations	-0.42 ms^{-2}	N/A
	Coast-downs	-0.22 ms^{-2}	N/A

Although this vehicle should be limited to 45 km/h, it travelled at 49.5 km/h during the emissions test.

This vehicle was unable to match the required speeds and acceleration rates in the two high and two medium vehicle speed sections of the emissions test. However, in the emissions test it was able to match all of the required speeds.

Given a maximum speed in excess of its legislated limit, the vehicle was still unable to perform the 45 km/h peak required in the durability test (see Section 7.5.3).

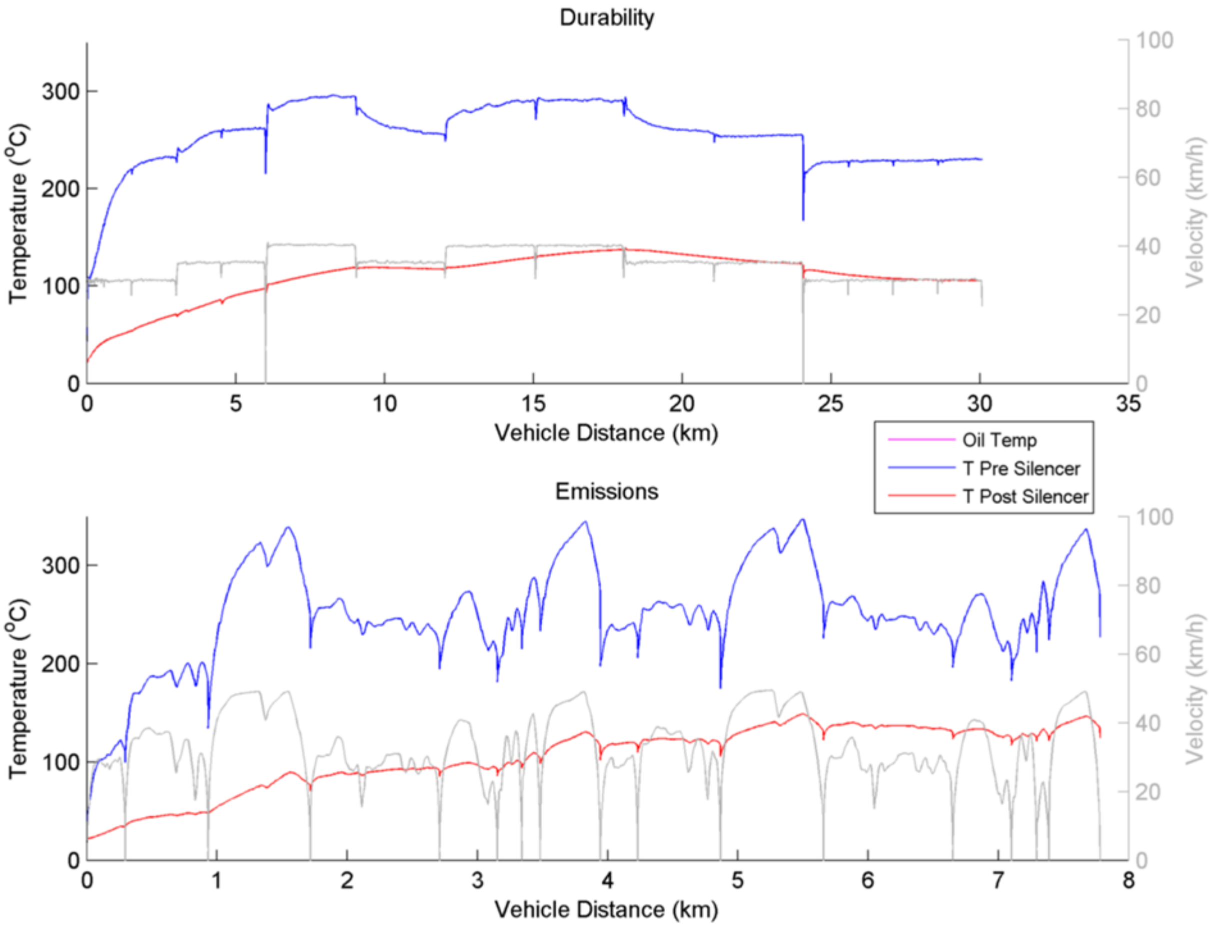


Figure 7-20: Vehicle 9 – L6Ae, Cycle 2, Type V and Type I temperature traces

Table 7-20: Vehicle 9 – L6Ae, Cycle 2, maximum temperatures

		Type V	Type I
Maximum temp. (°C)	Pre silencer	294	347
	Post silencer	138	149
	Oil	N/A	N/A

Note: As this vehicle utilises a 2 stroke engine, oil temperature could not be measured.

Higher speeds achieved in the emissions test are reflected in the higher pre silencer exhaust temperatures, with peaks 50°C higher. The post silencer temperature however stayed comparable.

In general, these temperatures are low. If a catalytic converter was fitted it may need to be placed close to the engine-out to allow it to attain the required conditions to function.

7.4.10 Vehicle 10 – L6Be, Cycle 2

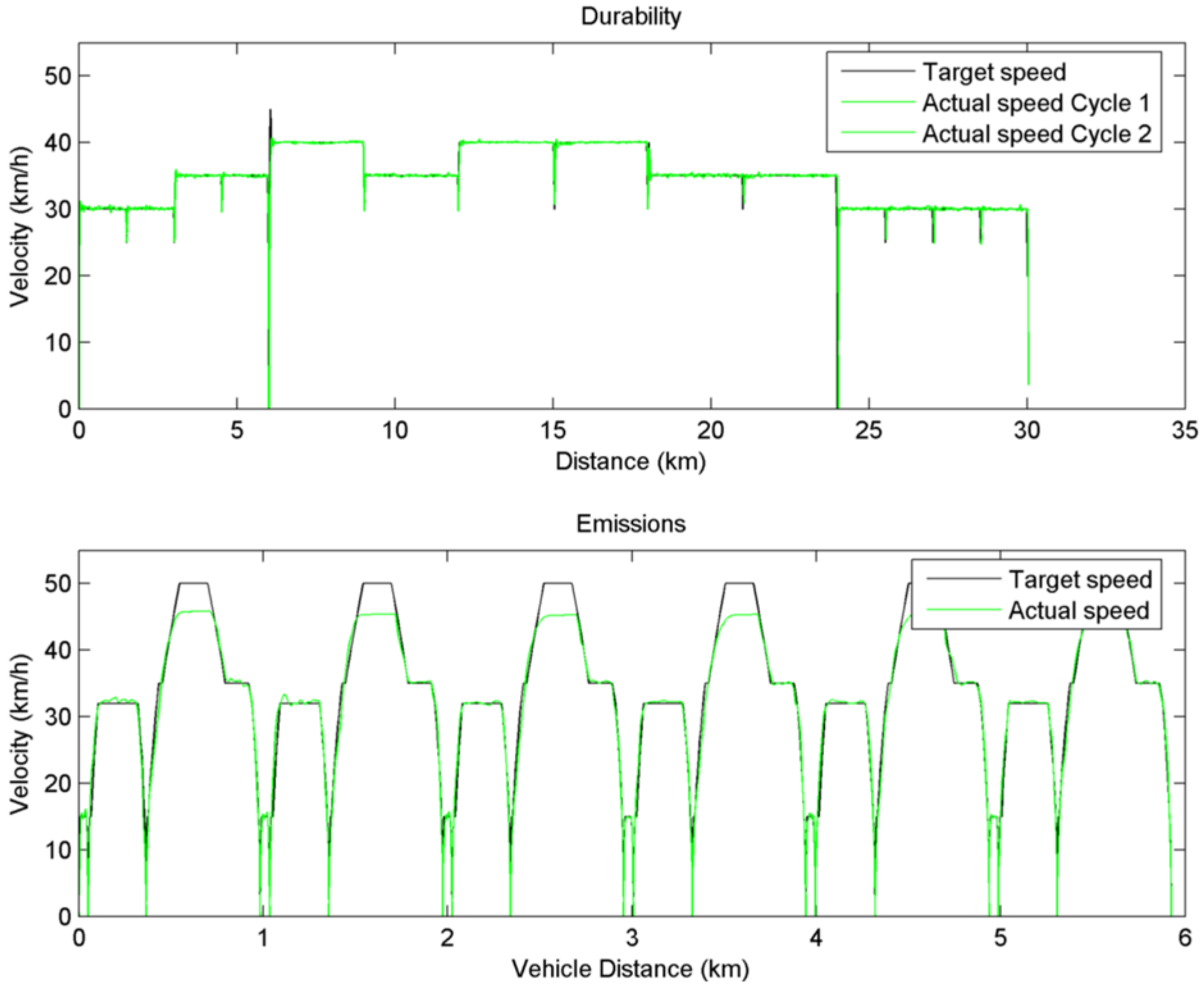


Figure 7-21: Vehicle 10 – L6Be, Cycle 2, Type V and Type I speed traces

Table 7-21: Vehicle 10 – L6Be, Cycle 2, overview of speed data

		Type V	Type I
General statistics	Average speed	34.3 km/h	25.4 km/h
	Max speed	40.7 km/h	45.8 km/h
	Time per cycle	54 minutes	20 minutes
	Distance per cycle	30 km	6 km
Acceleration average rate	Moderate accelerations	0.40 ms^{-2}	N/A
	Hard accelerations	0.94 ms^{-2}	N/A
Deceleration average rate	Moderate decelerations	-0.42 ms^{-2}	N/A
	Coast-downs	-0.36 ms^{-2}	N/A

The required durability speed trace of this vehicle was reached by the vehicle for the entirety of the test, unlike the UN R40 test where none of the higher speed peaks were met, forcing a higher proportion of WoT to be performed. Given this vehicle's maximum speed, this would equate to missing two long and two shorter high speed sections. This is a similar behaviour to vehicle 3, which has the same maximum vehicle speed restriction.

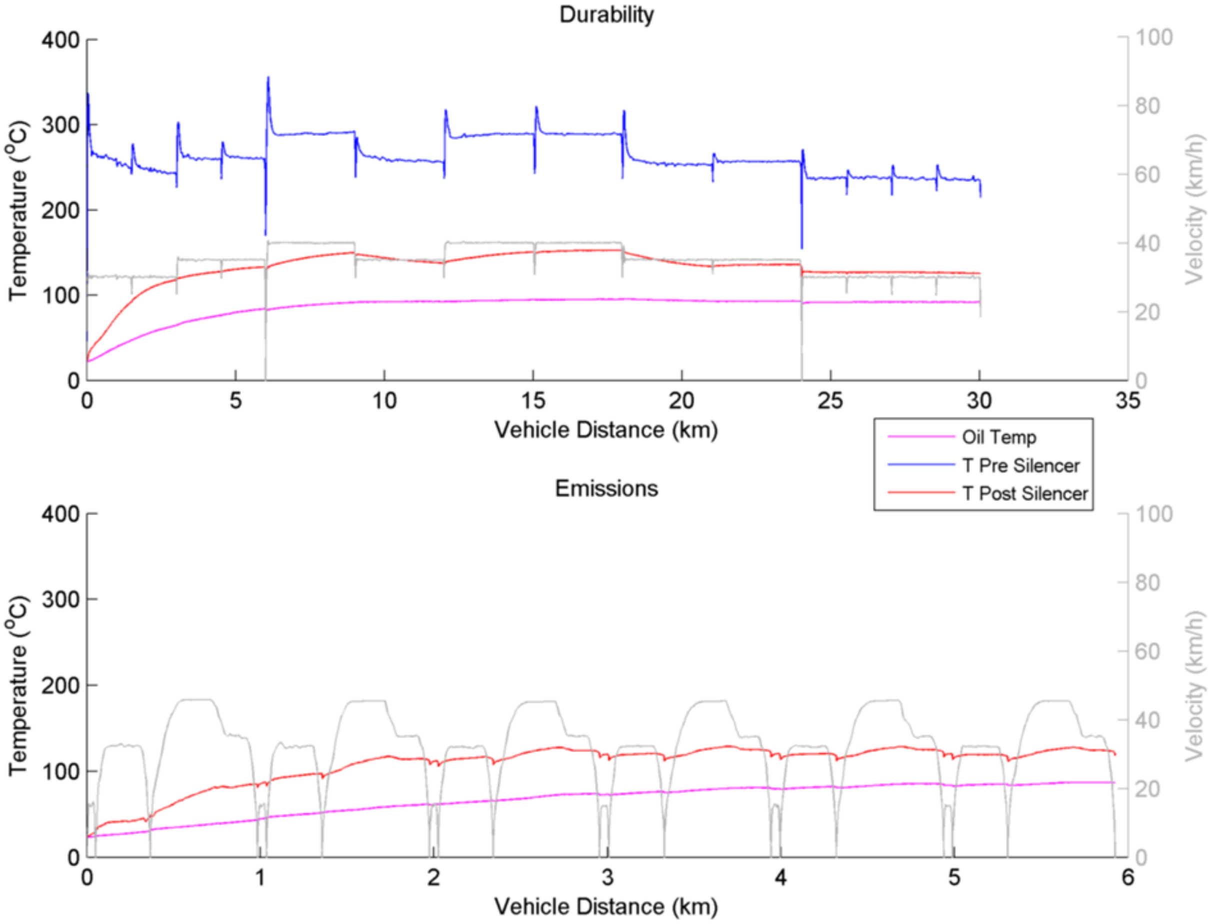


Figure 7-22: Vehicle 10 – L6Be, Cycle 2, Type V and Type I temperature traces

Table 7-22: Vehicle 10 – L6Be, Cycle 2, maximum temperatures

		Type V	Type I
Maximum temp. (°C)	Pre silencer	356	N/A
	Post silencer	153	129
	Oil	96	85

Unfortunately, the temperature before the silencer was not measured for this vehicle during the emissions test due to the intricacy of the exhaust system in the engine bay. If the data from vehicle 9 on the pre silencer temperature can be taken as a probable outcome, the high cruising speed sections are likely to cause continuous higher temperatures at least equal to the peaks of ~400°C seen in the durability test.

In general, these temperatures are low. If a catalytic converter was fitted it may need to be placed close to the engine-out to allow it to attain the required conditions to function.

7.4.11 Vehicle 11 – L7Ae, Cycle 3 & 2

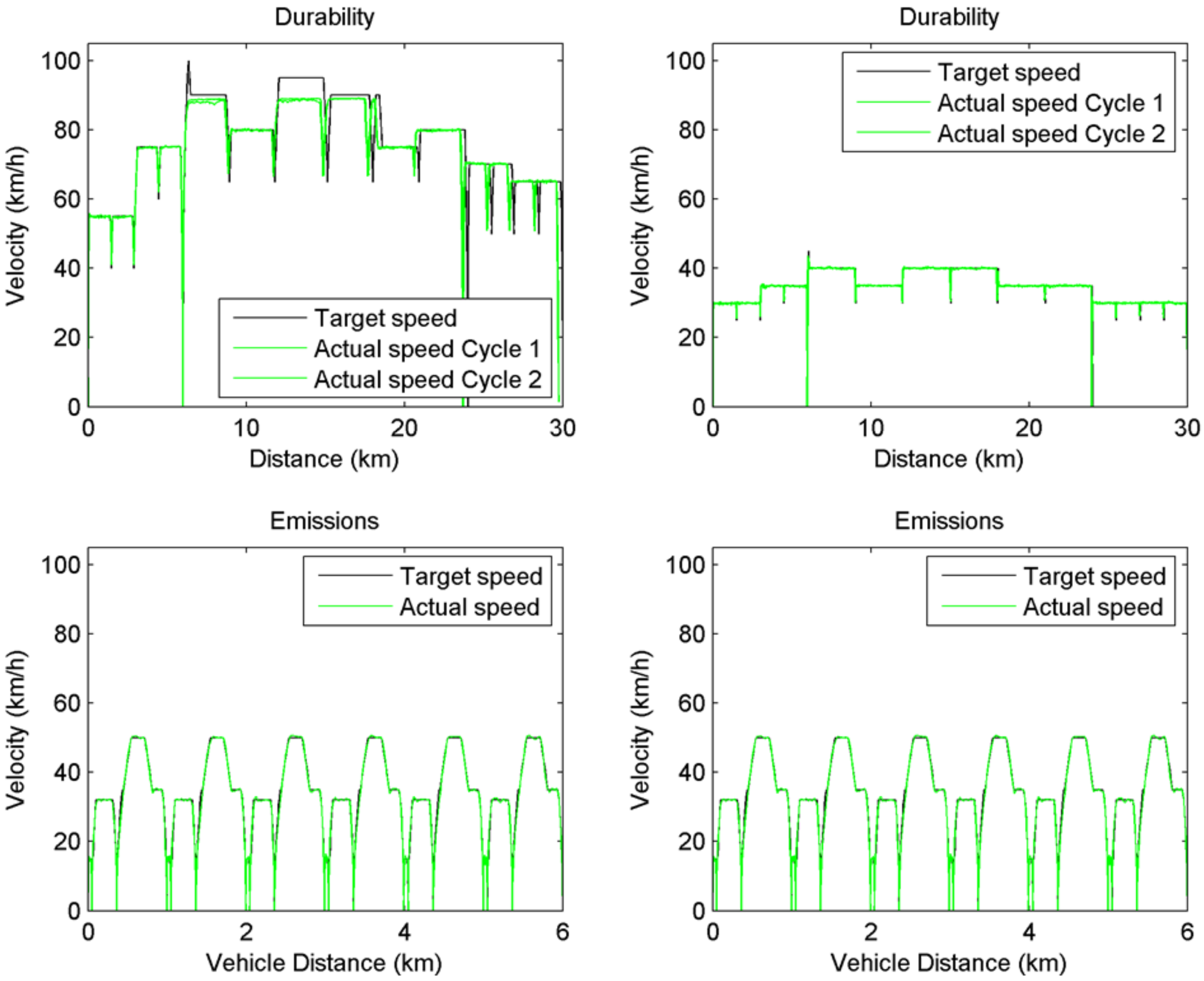


Figure 7-23: Vehicle 11 – L7Ae, Cycle 3 & 2, Type V and Type I speed traces

Table 7-23: Vehicle 11 – L7Ae, Cycle 3 & 2, overview of speed data

		Type V	Type I
General statistics	Average speed	72/34 km/h	25.2 km/h
	Max speed	89/44 km/h	50.7 km/h
	Time per cycle	26/54 minutes	20 minutes
	Distance per cycle	30 km	6 km
Acceleration average rate	Moderate accelerations	0.48/0.30 ms^{-2}	N/A
	Hard accelerations	1.25/0.96 ms^{-2}	N/A
Deceleration average rate	Moderate decelerations	-0.56/-0.37 ms^{-2}	N/A
	Coast-downs	-0.18/-0.26 ms^{-2}	N/A

This vehicle had a maximum speed of ~90 km/h and was considered on the borderline between two categories. Therefore, it was tested using both cycle 3 and 2 (maximum speeds of 100 and 45 km/h respectively).

Under cycle 3 (see top left of Figure 7-23), the vehicle was not able to attain all of the cruising speeds, in contrast to the emissions test, where it was only required to reach 50 km/h, or 55% of its maximum speed, and attained all of the required points.

In the cycle 2 test the vehicle was able to match all of the cruising speeds. Even though its capabilities far exceed the requirements of the cycle, the first peak of 45 km/h was missed by ~2 km/h, although the second peak was only missed by ~1 km/h.

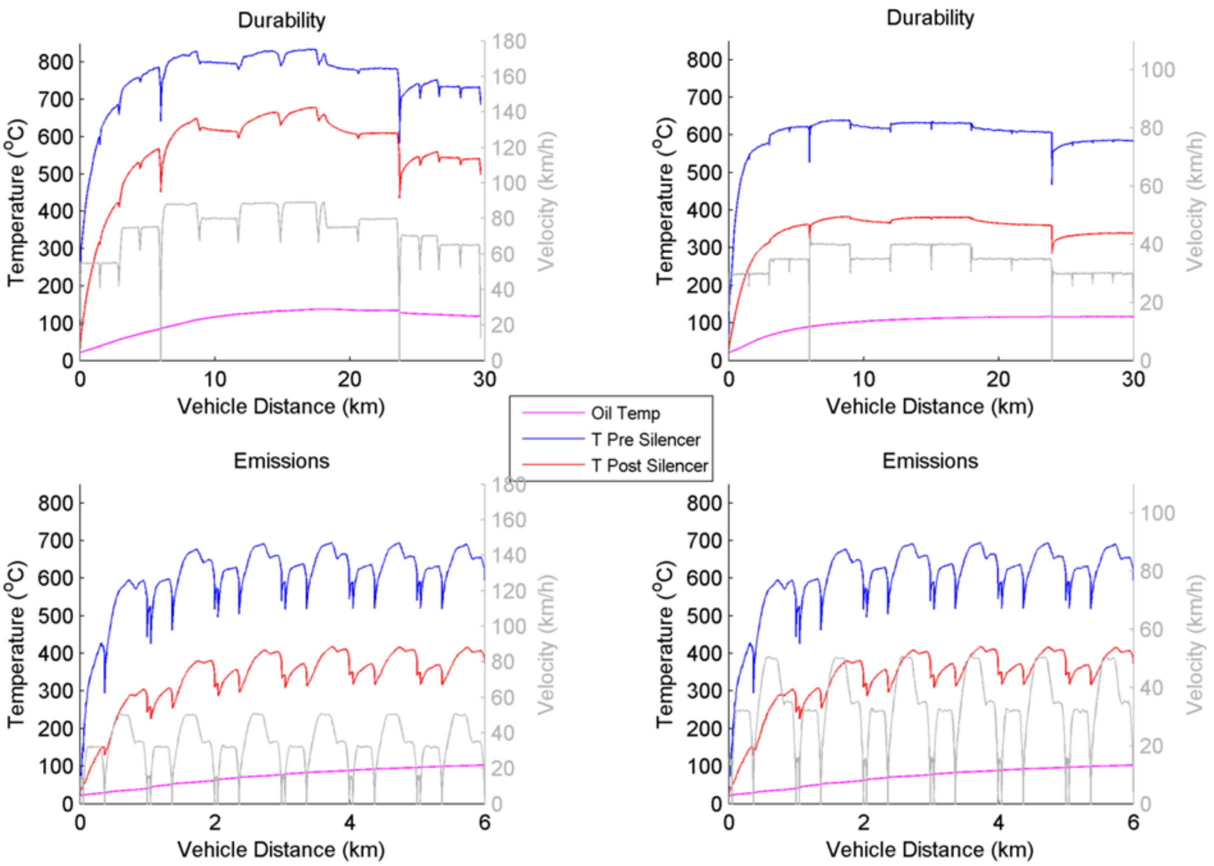


Figure 7-24: Vehicle 11 – L7Ae, Cycle 3 & 2, Type V and Type I temperature traces

Table 7-24: Vehicle 11 – L7Ae, Cycle 3 & 2, maximum temperatures

		Type V	Type I
Maximum temp. (°C)	Pre silencer	835/640	694
	Post silencer	693/383	418
	Oil	140/118	99

The vehicle's exhaust temperatures show a similar story. For cycle 3, the maximum temperatures were 140°C and 275°C higher pre and post the silencer respectively, while for cycle 2 they were 54°C and 35 °C cooler.

The oil temperature, however, continued to rise for both durability cycles due to the substantially increased distance travelled of approximately double the emissions cycle.

7.4.12 Vehicle 12 – L7Be, Cycle 3 & 2

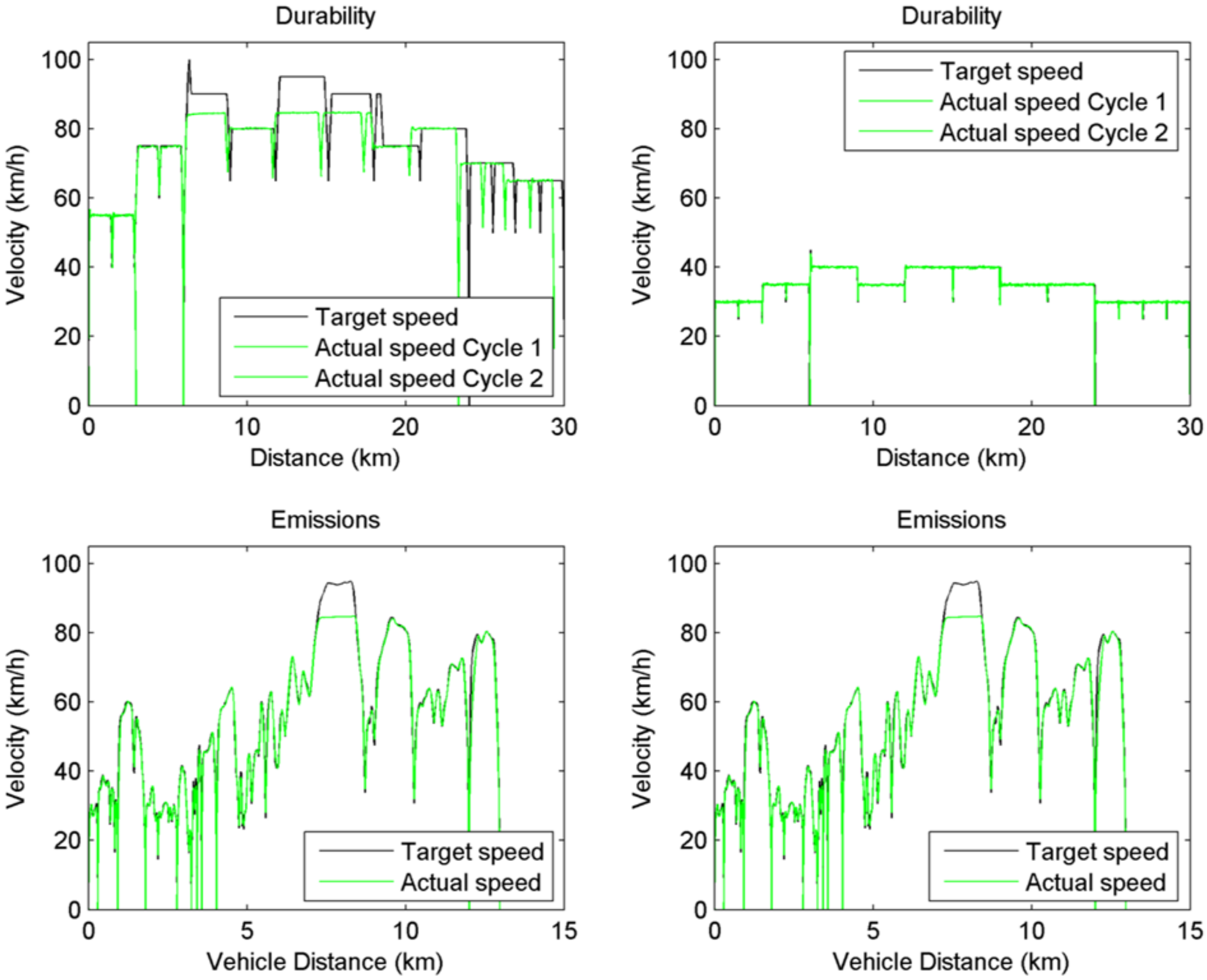


Figure 7-25: Vehicle 12 – L7Be, Cycle 3 & 2, Type V and Type I speed traces

Table 7-25: Vehicle 12 – L7Be, Cycle 3 & 2, overview of speed data

		Type V	**Type I**
General statistics	Average speed	68/34 km/h	43.8 km/h
	Max speed	85/44 km/h	84.7 km/h
	Time per cycle	26/54 minutes	20 minutes
	Distance per cycle	30 km	13 km
Acceleration average rate	Moderate accelerations	0.51/0.43 ms^{-2}	N/A
	Hard accelerations	1.33/0.91 ms^{-2}	N/A
Deceleration average rate	Moderate decelerations	-0.57/-0.47 ms^{-2}	N/A
	Coast-downs	-0.48/-0.37 ms^{-2}	N/A

For this vehicle (with a maximum speed of 85 km/h) a similar situation as for vehicle 11 occurred. However, in this case the WMTC emissions test data was available, which required speeds closer to its maximum.

In the emissions test only the largest peak or 10% of the required speeds weren't reached. However, 33% of the durability cycle could not be reached, forcing the use of WoT for an extended period.

As with previous vehicles, the inability to reach the required speeds of some laps in cycle 3 has caused a reduction in the distance travelled during the cycle (see top left of Figure 7-25). This was not an issue with the test using cycle 2.

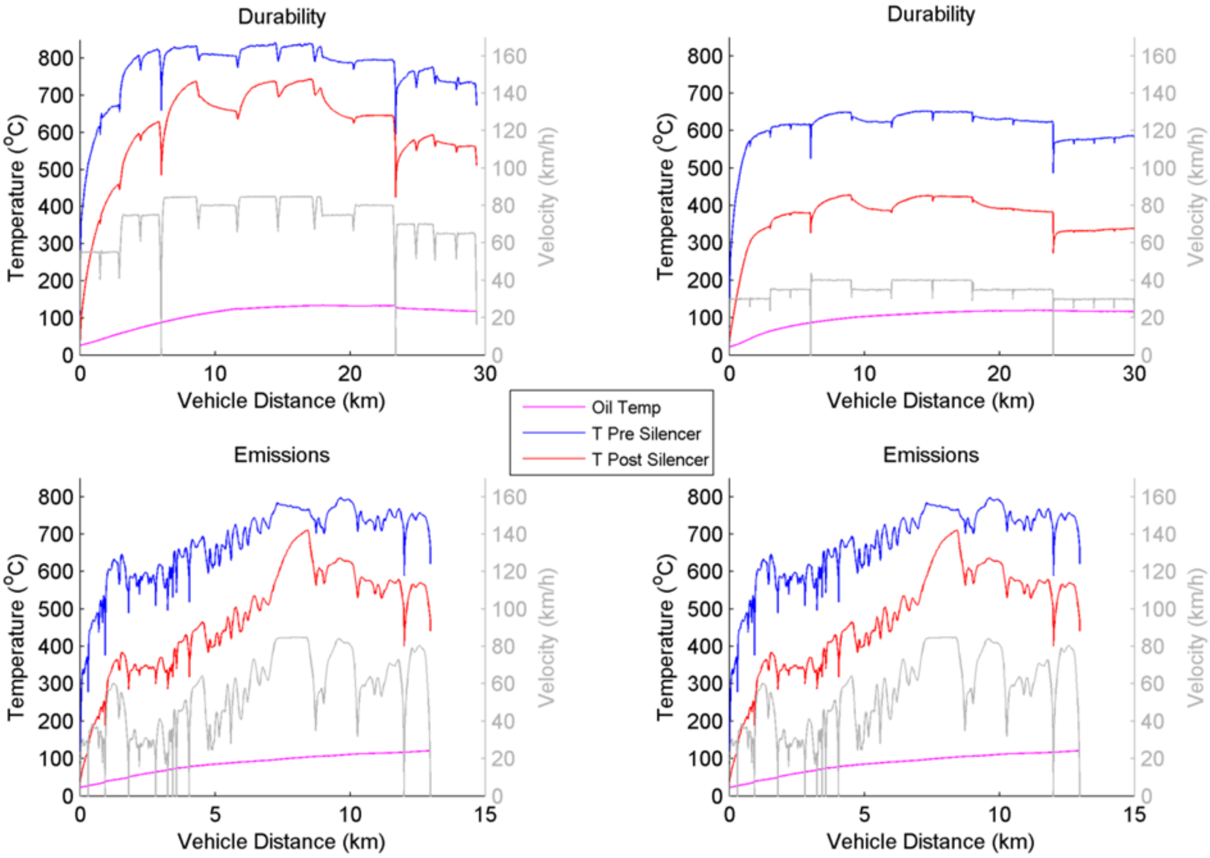


Figure 7-26: Vehicle 12 – L7Be, Cycle 3 & 2, Type V and Type I temperature traces

Table 7-26: Vehicle 12 – L7Be, Cycle 3 & 2, maximum temperatures

		Type V	Type I
Maximum temp. (°C)	Pre silencer	842/654	797
	Post silencer	743/428	710
	Oil	134/123	117

The temperatures exhibited by this vehicle were the highest found during the testing programme, both in the cycle 3 durability and WMTC emissions test. The pre silencer exhaust temperature reached well over 800°C and stayed at this level for ~50% of the test, whereas this test point was approximately 100°C lower for the same proportion of test in the WMTC emissions test cycle.

This high exhaust temperatures manifested in the exposed exhaust pipe becoming hot enough to be considered a safety hazard, as well as damaging to some of the sensors used in the experiment. Therefore, it was decided to halt the execution of the second iteration of the cycle (see Figure 16-88).

7.4.13 Vehicle 13 – L7Ce, Cycle 2

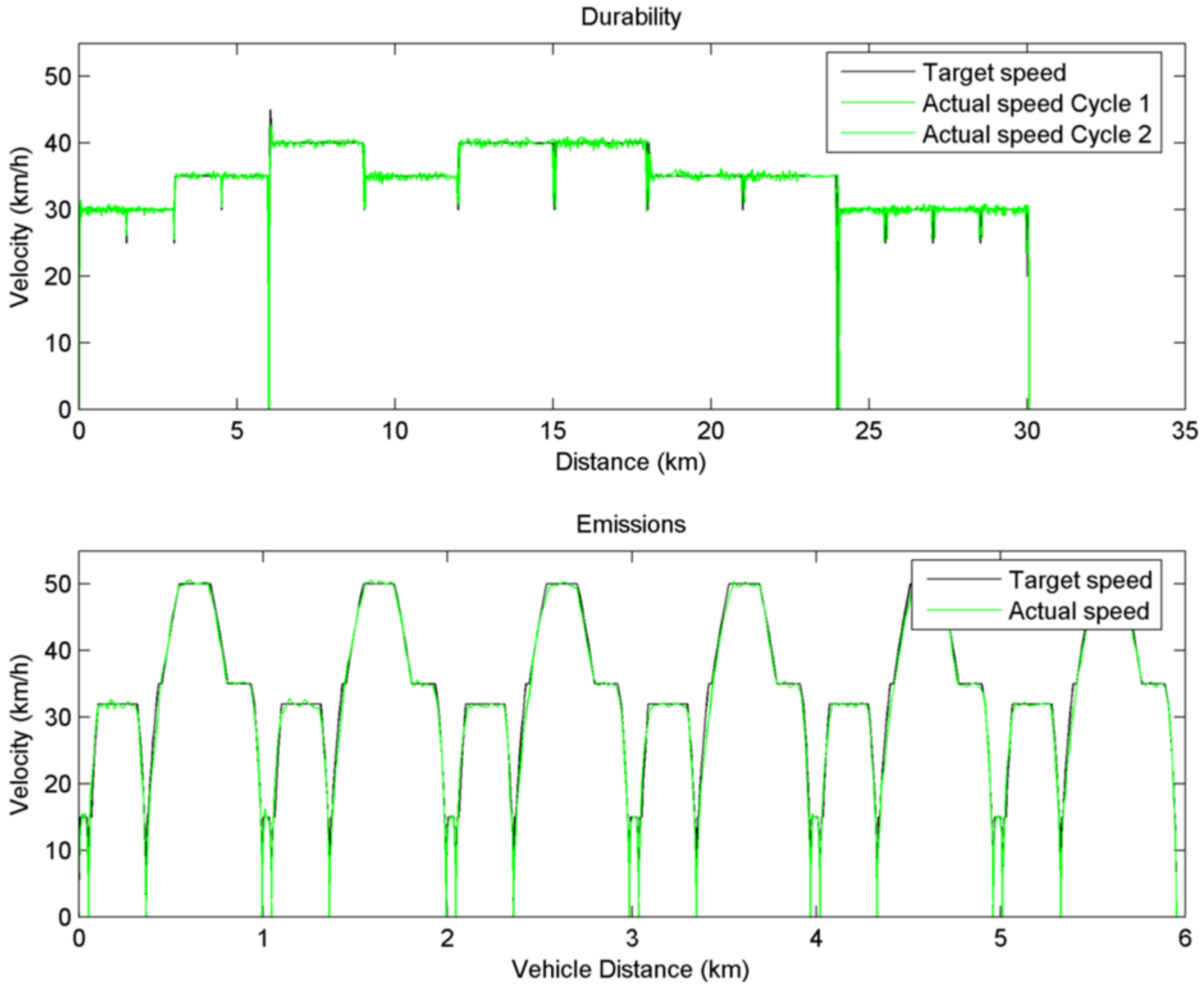


Figure 7-27: Vehicle 13 – L7Ce, Cycle 2, Type V and Type I speed traces

Table 7-27: Vehicle 13 – L7Ce, Cycle 2, overview of speed data

		Type V	Type I
General statistics	Average speed	34.3 km/h	25.5 km/h
	Max speed	42.8 km/h	50.6 km/h
	Time per cycle	54 minutes	20 minutes
	Distance per cycle	30 km	6 km
Acceleration average rate	Moderate accelerations	0.38 ms^{-2}	N/A
	Hard accelerations	0.89 ms^{-2}	N/A
Deceleration average rate	Moderate decelerations	-0.45 ms^{-2}	N/A
	Coast-downs	-0.29 ms^{-2}	N/A

Vehicle 13 performed the durability cycle 2 and was able to achieve all of the cruise and deceleration points. However, it under ran the first peak by 2 km/h. It was able to reach all of the required speed points in the UN R40 emissions test, which reaches speeds of 50 km/h.

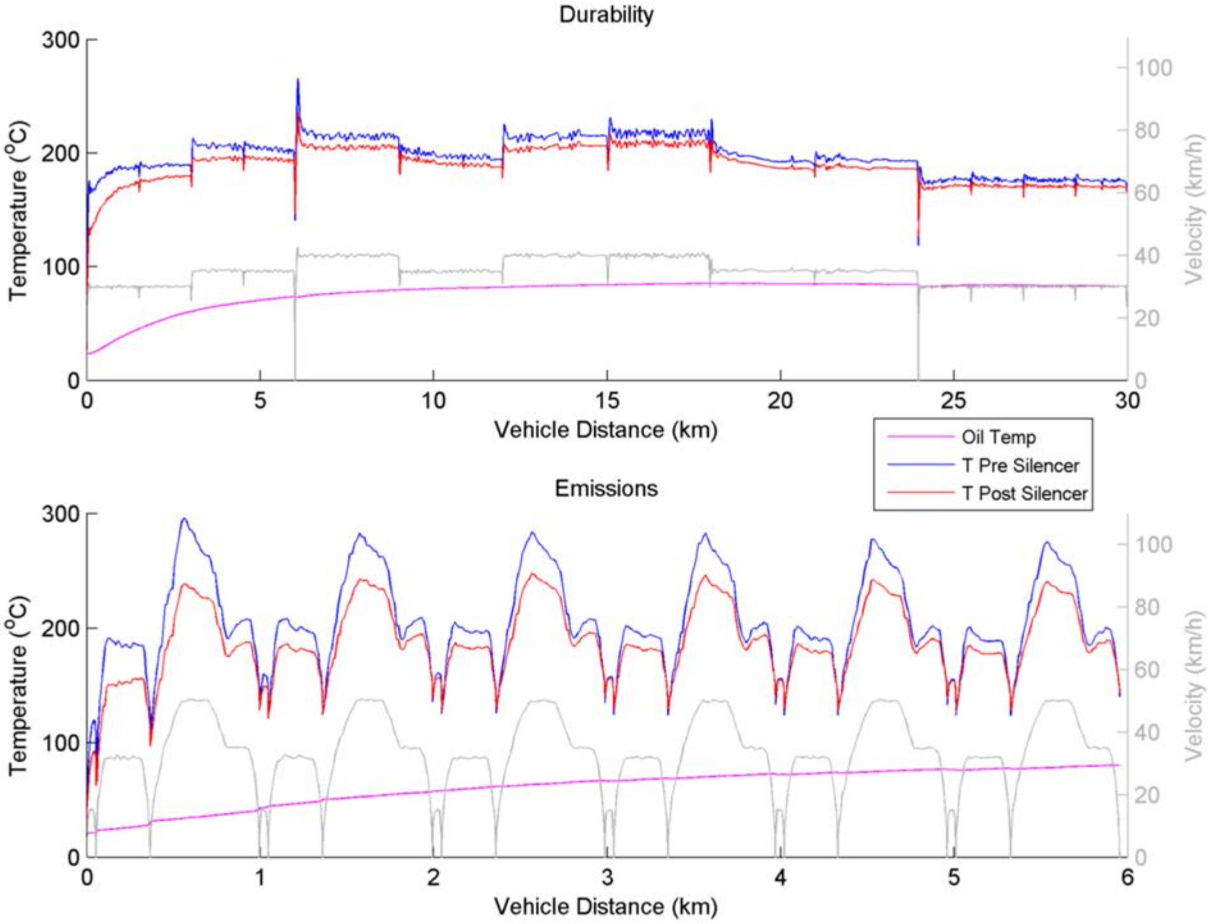


Figure 7-28: Vehicle 13 – L7Ce, Cycle 2, Type V and Type I temperature traces

Table 7-28: Vehicle 13 – L7Ce, Cycle 2, maximum temperatures

		Type V	**Type I**
Maximum temp. (°C)	Pre silencer	266	296
	Post silencer	236	248
	Oil	86	78

In this vehicle, pre and post silencer test points were very close due to the configuration of the exhaust system and consequently their temperatures were also similar.

As would be expected by travelling 10 km/h less than required in the emissions test, the exhaust temperatures were significantly lower in the durability cycle. For the durability test, the exhaust gasses were constant at around 200°C for the duration of the test. However, for the emissions test, they rose by a further 100°C during the 50 km/h sections.

7.5 Test analysis

As stated in the methodology, it was the initial intention of this analysis to separate those vehicles which were deemed to be able to perform the cycle and those which could not. Results from vehicles that were able to follow the cycles were used to adjust the cycles, whereas vehicles that could not follow the cycles would be used to decide on changes to the vehicle groupings and which cycle they should perform.

Two key areas were looked at: comparability of cruise vehicle speeds and temperatures between the Type V SRC-LeCV durability test cycle and the WMTC emissions cycle. Seven of the thirteen vehicles showed some discrepancy in the cruise speeds and seven vehicles were highlighted in regards to exhaust temperatures (see Table 7-29).

Table 7-29: Approximate proportion of lap where cruise speed could be attained and continuous periods of high temperatures and their proportions (noteworthy divergences in bold)

Vehicle	Category	Cycle	Cruise sections		Peak temperatures [°C]	
			Type V	Type I	Type V	Type I
1	L1Ae	1	**60%**	**<10%**	**600, 40%**	**550, 100%**
2	L1Be ≤ 25 km/h	1	**100%**	**<20%**	**550, 40%**	**650, 100%**
3	L1Be ≤ 45 km/h	2	100%	90%	**525, 100%**	**650, 20%**
4	L3e – A1	3	**70%**	**90%**	625, 60%	650, 20%
5	L3e – A2	3	100%	100%	650, 70%	650, 20%
6	L3e – A3	4	100%	100%	600, 80%	675, 40%
7	L5Ae	3	100%	100%	650, 60%	700, 40%
8	L5Be	2	100%	100%	**250, 100%**	**400, 50%**
9	L6Ae	2	**100%**	**75%**	275, 30%	325, 40%
10	L6Be	2	**100%**	**75%**	300, 30%	*325, 40%*
11	L7Ae	3 / 2	**70%** / 100%	**100%**	**800, 80%** / 625, 80%	**650, 80%**
12	L7Be	3 / 2	**70%** / 100%	**90%**	**850, 60% / 650, 80%**	**750, 40%**
13	L7Ce	2	100%	100%	**200, 60%**	**275, 50%**

Of the vehicles identified in each area, only four were shown to have large discrepancies in both groups: vehicles 1, 2, 11 and 12. However, it could be seen that the speed and temperature discrepancies did not interfere with other key issues found with the test. Therefore, rather than discarding them from the main cycle analysis, the information obtained from these tests can be used alongside the other vehicles.

With this in mind, the full analysis of the cycle design was performed first, then taking into account any likely changes to the design, the assessment of possible changes to the vehicle groupings was considered.

7.5.1 Cycle design

In Section 7.4, the following areas were identified to require further analysis:

- Speed points met during decelerations
- Highest speed first peaks met
- Lower speed second peaks met

- Actions missed or foreshortened

Also, a single vehicle exhibited an anomaly in the exhaust temperatures during deceleration, which was suspected to be caused by a protection mechanism for the vehicles catalytic converter.

In order to asses an area involving speed discrepancies, a tolerance was required to judge it against. Although no tolerances are explicitly expressed in the draft legislative text of the SRC-LeCV cycle (as is the practice in durability tests), it was useful to have some guidelines to use during the analysis. One of the areas already identified is the error caused by using the vehicle's speedometer rather than more accurate supplementary telemetry.

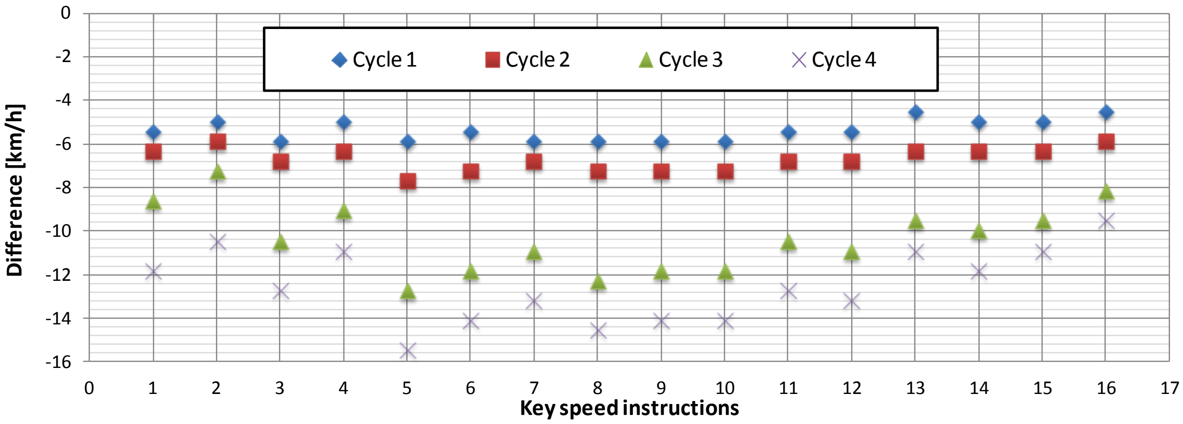


Figure 7-29: Difference between instruction and true speed given worst case scenario

Figure 7-29, above shows the speed instructions for the key points during the four cycles. For each point the worst case scenario as allowed by UN Regulation 39 was applied and the difference found.

$$0 \leq (V1 - V2) \leq 0.1\,V2 + 4\,km/h$$

Figure 7-30: UN Regulation 39 article 5.3, equation to calculate allowable discrepancy in speedometers, where: V1 is the speed displayed and V2 is the true speed in km/h

This shows that the actual speed performed could be between 4 and 16 km/h less than required. However it should be noted that it is highly unlikely that a vehicle's speedometer is designed up to the limit in this manner or that this discrepancy is felt through the entire speed range of the vehicle. Therefore, a smaller discrepancy could be caused by this mechanism.

It should also be noted that all of the testing has been performed on a dynamometer, where an accurate speed based on the rotation of the roller is clearly presented to the test rider.

7.5.2 Decelerations

In every lap and also in the transition from lap 2-3 and 3-4, the vehicle is required to decelerate from a cruising speed to specific speed at which point it should then accelerate to meet a second cruising speed, this is done without stopping the vehicle.

It was seen from the test data that this action was not always performed as intended, and so a detail of four points during the cycle (from left to right, first then second row:

the middle of lap 1, the transition from lap 2-3, the middle of lap 4 and the middle of lap 5) are presented below in Figure 7-31 to Figure 7-34. This has been done for a vehicle performing each of the four cycles.

Vehicle 1 (see below), performing cycle 1, is a category L1Ae power assisted bicycle with a maximum vehicle speed of ~19 km/h. In the top left plot it was ~1 km/h below the cruising speed of 20 km/h, it was then required to decelerate by 5 km/h to 15 km/h but only decelerated to 16 km/h, it was then unable to accelerate the required 10 km/h to the next cruise of 25 km/h, instead only achieving a change of 3-4 km/h.

The following figures show the performance of the action for both iterations of the SRC-LeCV cycles superimposed on top of each other.

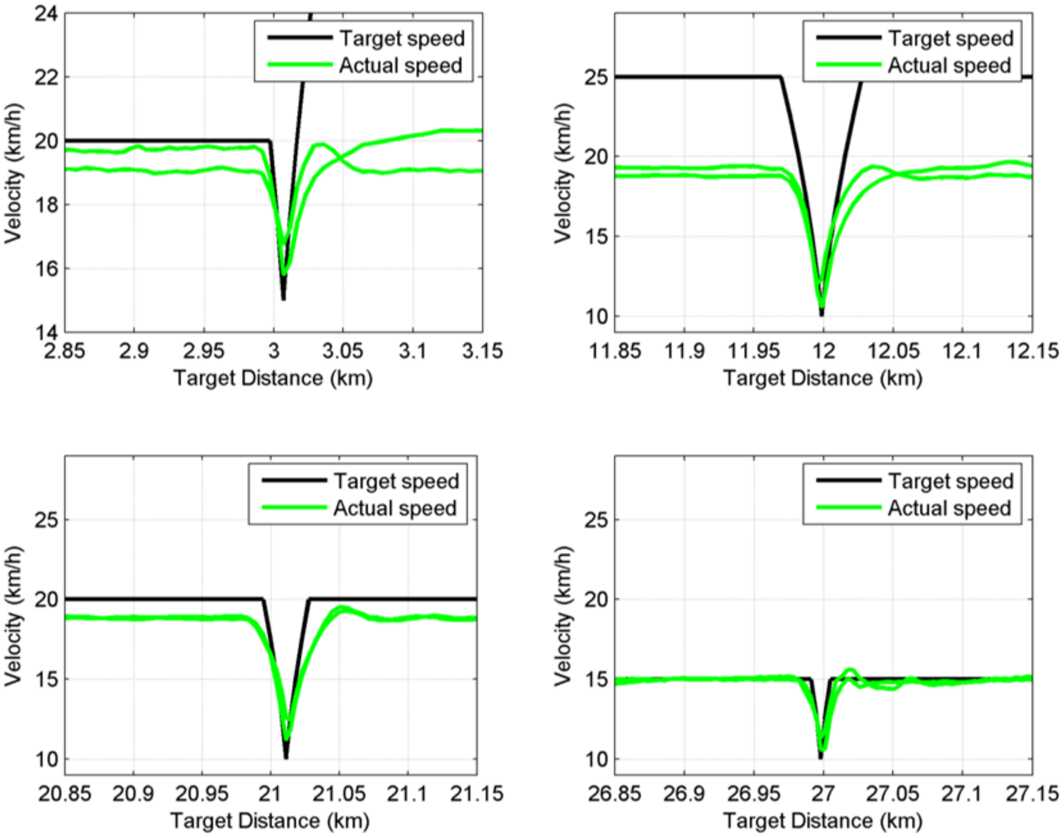


Figure 7-31: Vehicle 1, deceleration points performed vs instruction

In the second plot, the larger speed changes meant that the trace was designed with more time to perform the speed change, and so the deceleration point of 10km/h was met, however the entire action was a 10 km/h deceleration and acceleration rather than the required 15 km/h change.

In the third plot (bottom left), the smaller required speed change again causes the final speed of the deceleration to be missed by a small margin. But for the final plot the very small required speed change of just 5 km/h forced the rider to start the deceleration before the plot indicated and accelerate for longer afterwards.

Vehicle 3 is an L1Be moped and performed cycle 2, this vehicle had no issues with meeting the required cruise speeds (see Figure 7-32). The test rider in this instance allowed the vehicle to start decelerating slightly earlier than indicated in the trace they had generated for this vehicle, however it still did not decelerate the full amount, again missing the final vehicle speed by ~1-2 km/h.

As this vehicle could reach the preceding and following vehicle cruise speeds, the majority of the required actions were performed.

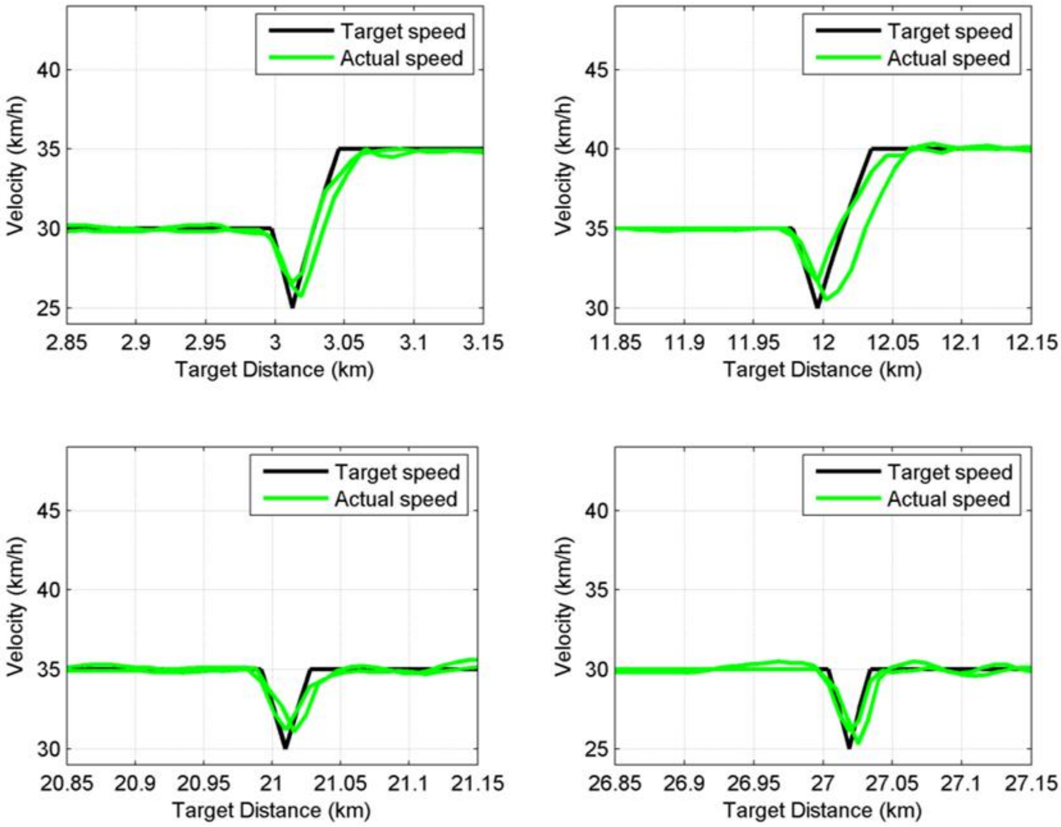


Figure 7-32: Vehicle 3, deceleration points performed vs instruction

Vehicle 4 is an L3e-A1 low performance motorcycle (a 125 cm^3) and performed cycle 3 (see Figure 7-33). This vehicle could also reach the required cruise speeds, however with the high speeds and larger speed changes the size of the missed action has increased, foreshortening the decelerations by 2-3 km/h.

It can also be seen in the second and third plot that with high starting vehicle speeds the vehicle takes a longer distance to both decelerate and accelerate. This causes them to miss the point defined to start the following action, this occurred even with the steeper of change defined in the pre-planned cycle 3 trace.

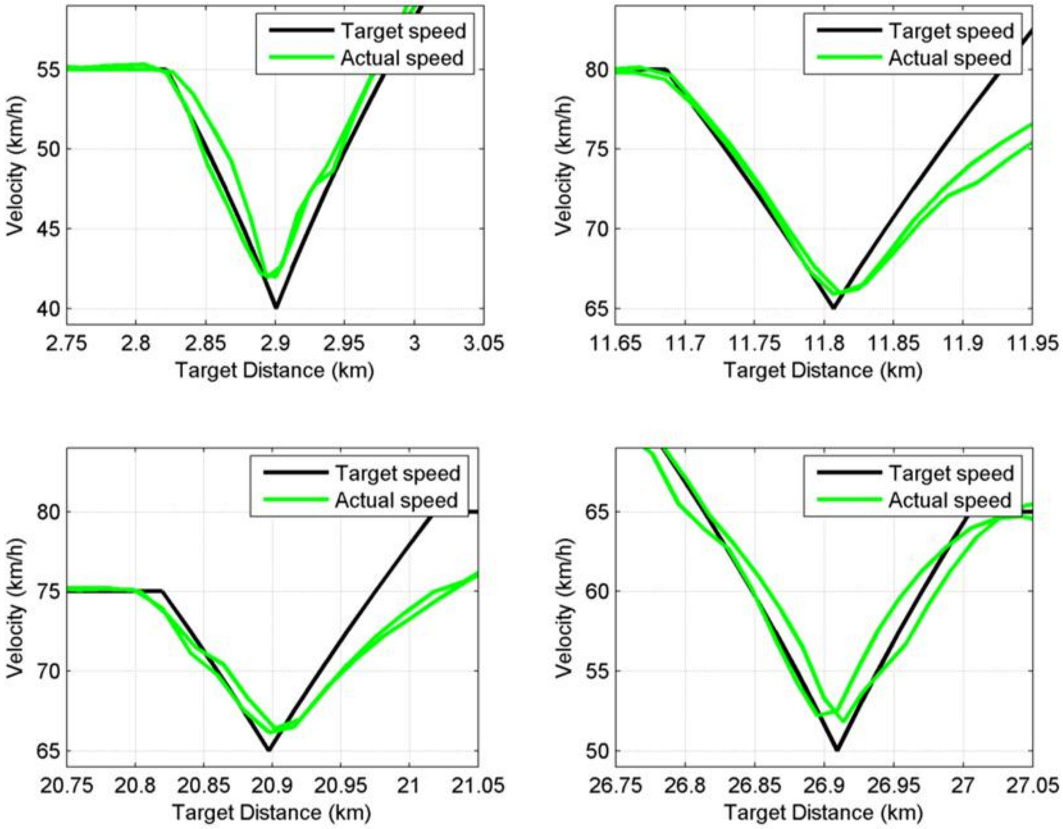


Figure 7-33: Vehicle 4, deceleration points performed vs instruction

Vehicle 6 performed cycle 4 and is an L3e-A3 high speed motorcycle (see Figure 7-34). This vehicle could follow all of the rates of change prescribed by the pre-planned cycle 4 trace, however it did not follow them in a smooth manner. This vehicle had a manual gearbox (transmission) and the let-offs required by changing gear are at least partially the cause. In all four plots it can be seen that the gear changes occur at similar points in the accelerations for both iterations of the cycle.

Another possible cause of this non-smooth acceleration could be caused by the test rider following the trace rather than the instructions prescribed by the cycle, which are written in the form "perform a moderate acceleration to the final vehicle speed of ##km/h".

This vehicle however had no issues with decelerating to the required speed points, likely due to the higher speeds it slowed easily. At some points it decelerated beyond the required points, these extra decelerations mean that on average the vehicle performed closer to the required proportion of deceleration and accelerations as found to be required by the original cycle design.

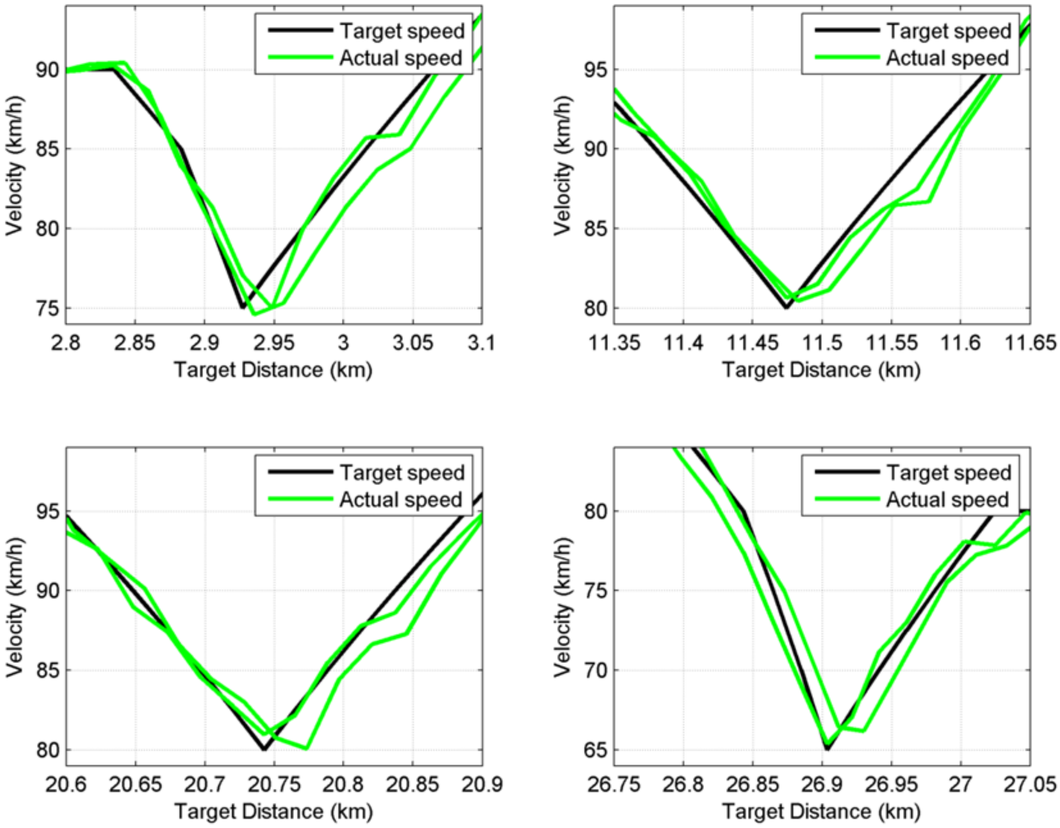


Figure 7-34: Vehicle 6, deceleration points performed vs instruction

These results have brought to light that in order to cause the required degradation factors that were intended by the prescribed deceleration points, a minimum deviation from the prescribed deceleration points could be prescribed in the technical requirements. Secondly, to ease the transition from one action to another, the point at which a complex set of actions commences needs to be shown in a clearer manner.

7.5.3 Missed first peak

In the SRC-LeCV durability cycle there are two points where the vehicle is required to perform a hard acceleration from stop using WoT to a peak, followed by a coast-down, before continuing to a cruise section. The first of which takes the vehicle to the highest point in the cycle, after which the vehicle will travel at most 5-10 km/h below this. This sequence of actions may be difficult to perform for some vehicles.

Nine of the vehicles did not perform the first peak and one only partially performed it. However of these nine vehicles, only four could not perform the action due to the capabilities of the vehicle, the other five simply had the test cycle applied incorrectly.

The four vehicles whose capabilities were below the requirements of the cycle will be considered first: vehicles 1, 4, 11 and 12, followed by the five which should have been able to follow the cycle: vehicles 3, 8, 9, 10 and 13. All of the plots in these sections show a change of 30 km/h in the y-axis and a period of 1 km/h in the x-axis.

A detail of vehicle 11’s first peak is shown in Figure 7-35. As the vehicle could not reach the required speed, the peak was not performed. The first consequence of this is the time and distance spent performing the acceleration seems to be reduced. However, as the vehicle would have used WoT to reach its maximum vehicle speed, and the reduced acceleration rate it exhibited to reach its maximum vehicle speed, the time and distance spent in this high load situation has in fact not been reduced.

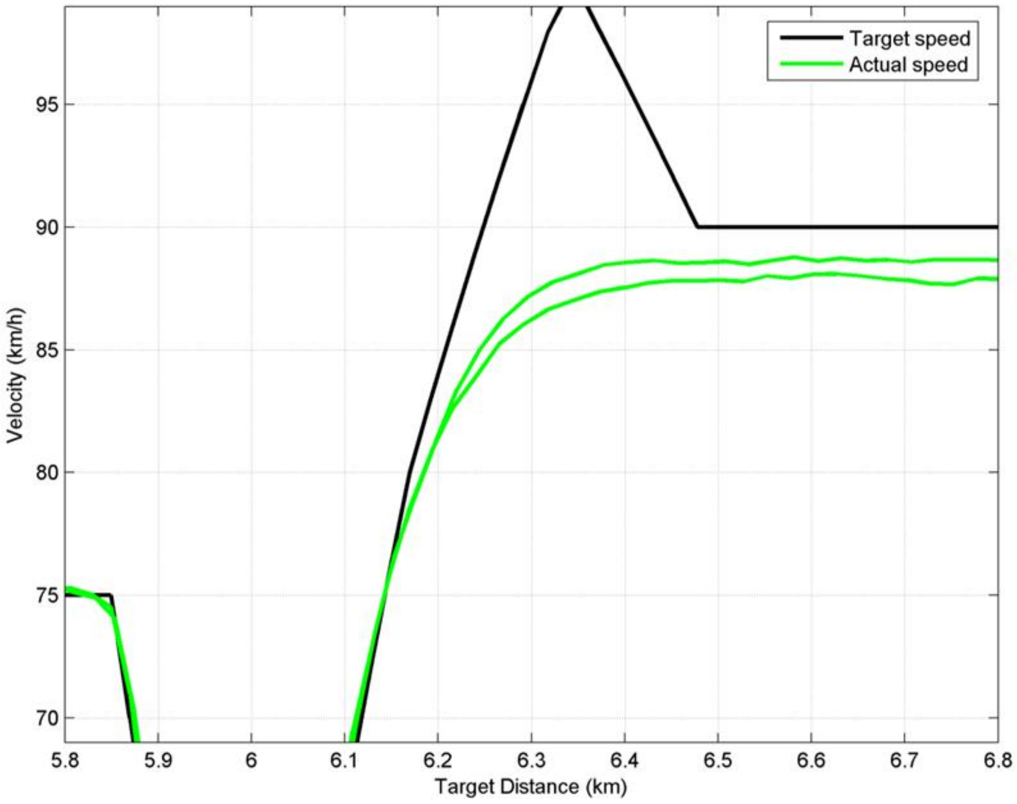


Figure 7-35: Vehicle 11, first peak at transition from lap 1-2

A second consequence is that the deceleration following the peak should be performed using a coast-down; not performing this action is a concern since the coast-down is a key part in process to cause a specific degradation mechanism (see Section 7.6.1).

Figure 7-36 shows the plots of the vehicles, which, according to the capabilities seen from their respective emission cycle tests, should have been able to reach the speed requested.

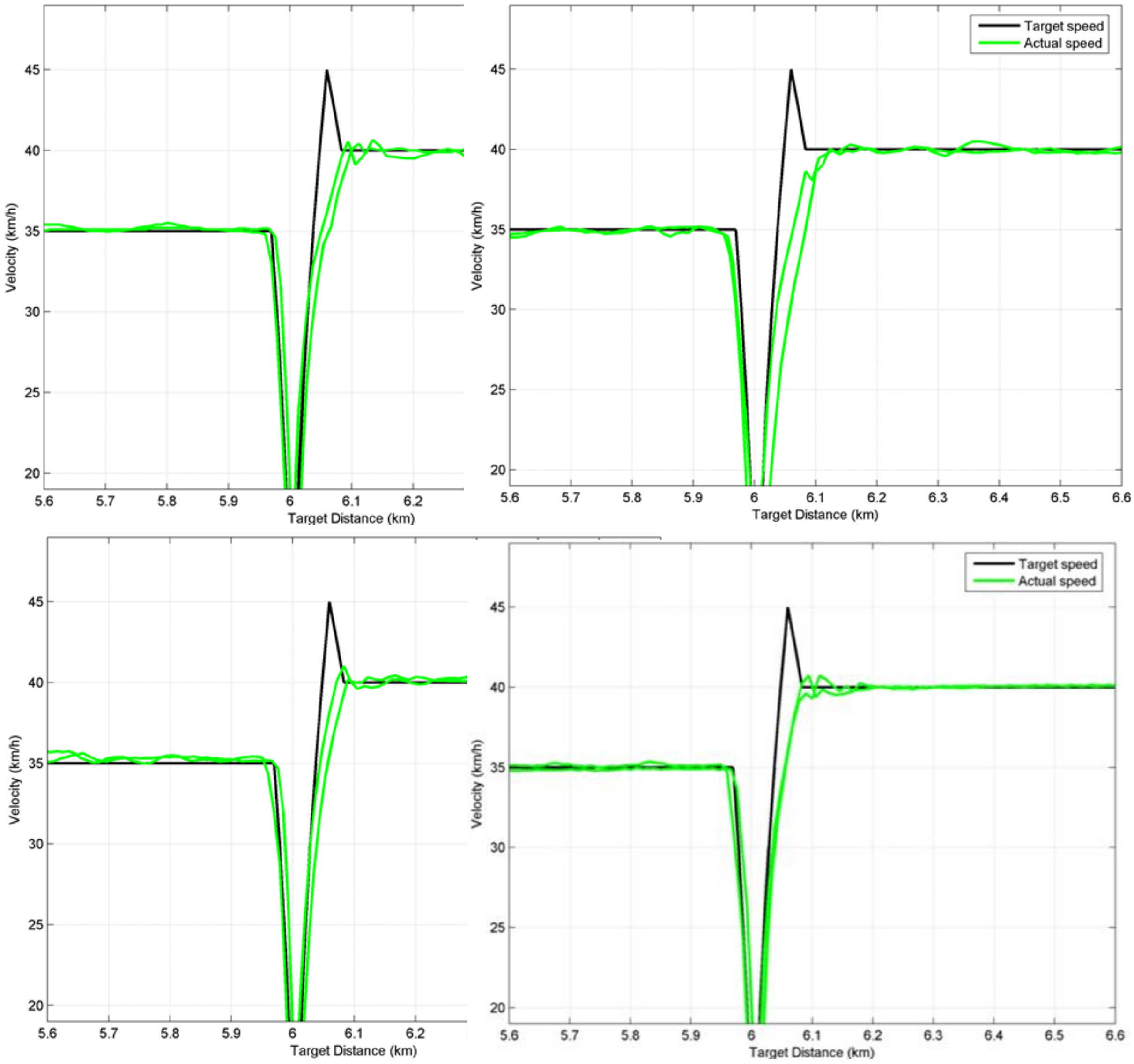


Figure 7-36: Vehicle 3, 8, 9 and 10, first peak at transition from lap 1-2

From left to right in Figure 7-36, maximum vehicle speeds of 45.5 km/h, 50.5 km/h, 49.5 km/h and 45.8 km/h had been observed for these four vehicles, and vehicle 8 may have been capable of higher speeds than required by its emissions test. Nevertheless, when performed, the test rider again followed the trace rather than the instructions for the cycle. As the vehicle had taken a steeper approach as it reached its maximum vehicle speed, the vehicles were at or just reaching the third instruction in the sequence, to perform a cruise, and therefore the first two instructions of accelerating to a speed and then decelerating were bypassed.

Figure 7-37 below shows the results of vehicle 13, an L7Ce Heavy quadri-mobile (i.e. a mini-car). This vehicle had a slightly higher acceleration rate and so began the peak. However, even this action and subsequent coast-down was cut short as the vehicle was shown to be able to achieve at least 50 km/h in the emissions test cycle, so should have reached the 45 km/h peak as required by the test.

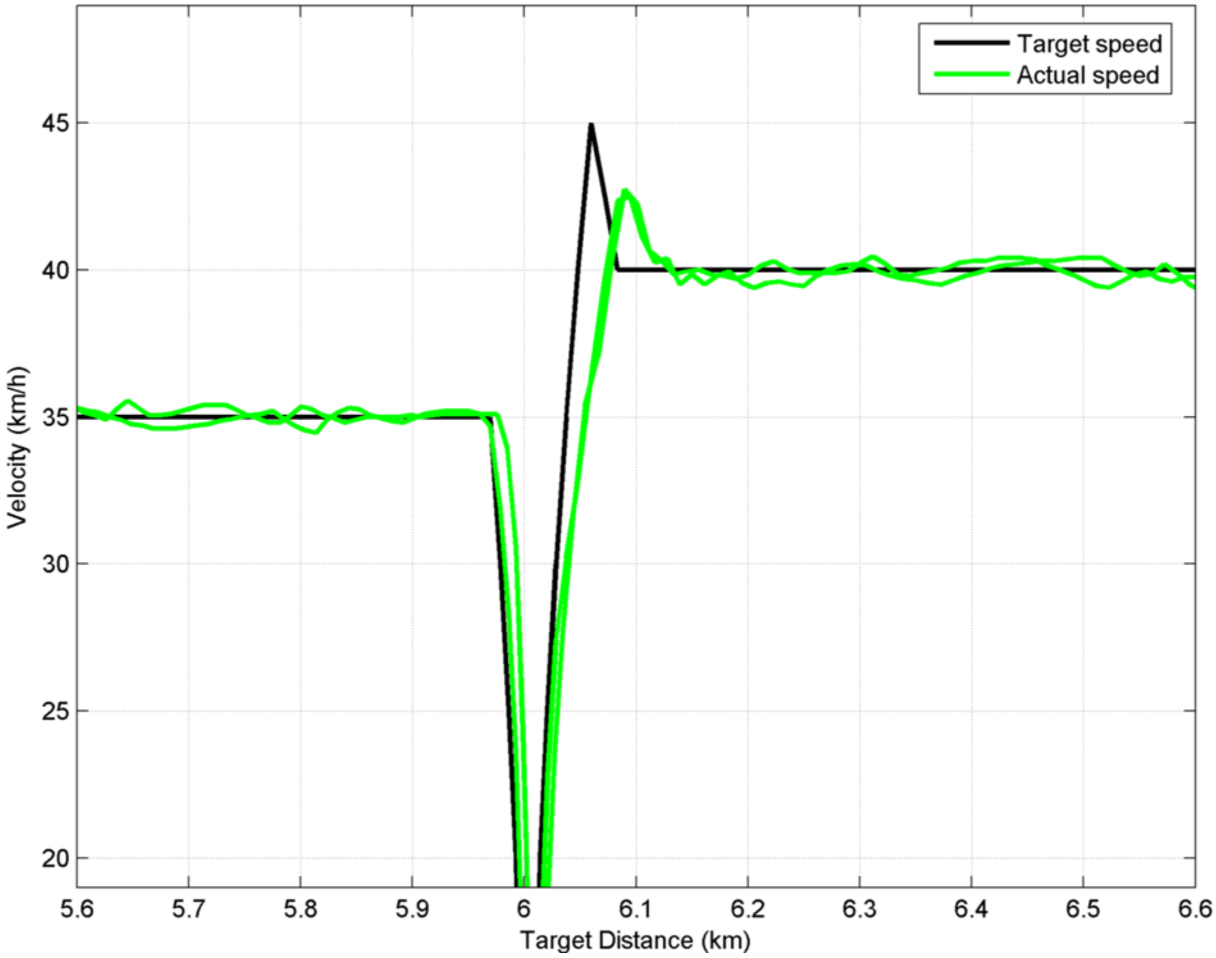


Figure 7-37: Vehicle 13, first peak at transition from lap 1-2

These results again highlight the same issues with clarity of the instructions as seen in Section 7.5.2, but also that if a vehicle is incapable of one action that can have significant consequences to other actions, in this case even missing them entirely.

7.5.4 Missed second peak

The second peak in the SRC-LeCV durability test cycle occurs at the start of lap 4. In contrast to the first peak this one is not started from idle but after a deceleration at the end of lap 3 to 10 km/h, 30 km/h, 65 km/h or 80 km/h in cycles 1-4 respectively and the peak does not require a hard acceleration to a high vehicle speed above the rest of the cycle, but equal to the cruise speeds in laps 2 and 3.

The details from three vehicles have been selected to indicate different issues which arose when performing this part of the test cycle.

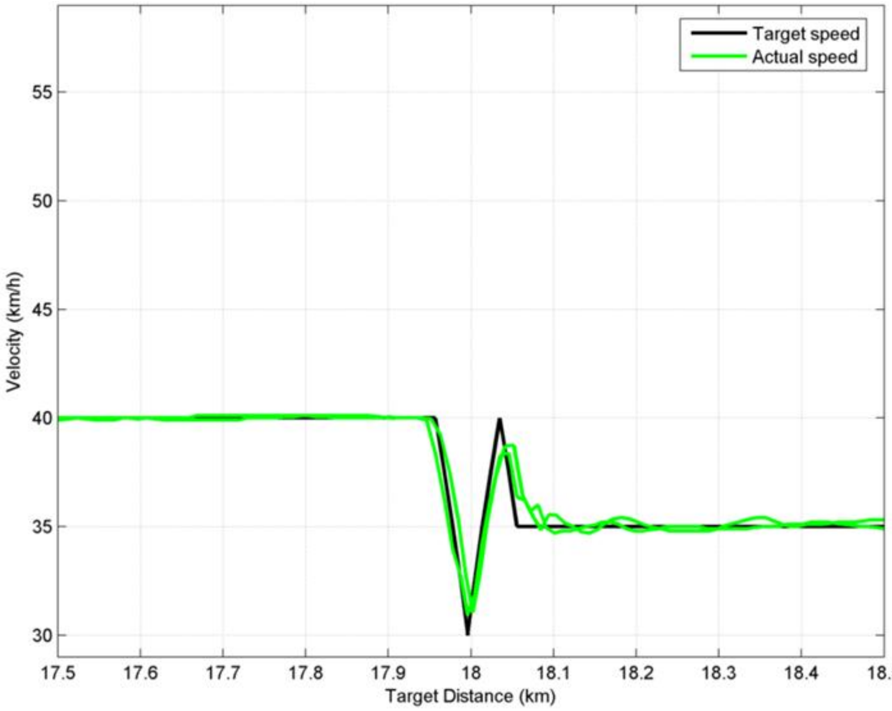


Figure 7-38: Vehicle 3, second peak at transition from lap 3-4

Vehicle 3 (see Figure 7-38), a L1Be moped, and vehicle 9, a L6Ae light on-road quad, both capable of the 40 km/h required by the action, showed similar deviations from the cycle as were indicated in Section 7.5.2 on missed deceleration final speed points. They missed both the lowest point in the deceleration from lap 3 by 1-2 km/h and also clipped the top of the peak by a further 1-2 km/h. This reduced the effect of the acceleration by 20% and the deceleration by 40%.

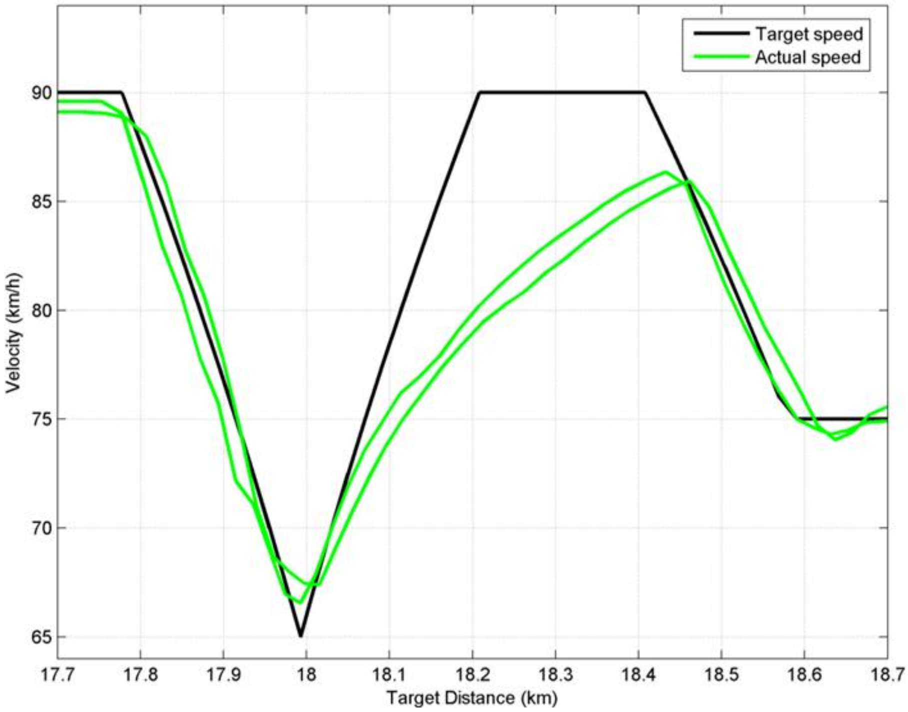


Figure 7-39: Vehicle 4, second peak at transition from lap 3-4

Vehicle 4 (see Figure 7-39), a L3e-A1 low performance motorcycle, had a low acceleration rate due to the high starting vehicle speed and the instruction to use medium acceleration rather than hard. This caused the vehicle to not reach the required vehicle speed before hitting, albeit the extended, point to start the coast-down, and so the test rider started the next action before completing the acceleration.

It should be noted that even if the rider had continued to the required vehicle speed and performed the coast-down the vehicle would have likely travelled 1 km and not exceeded the 3 km in distance before the following sequence of actions.

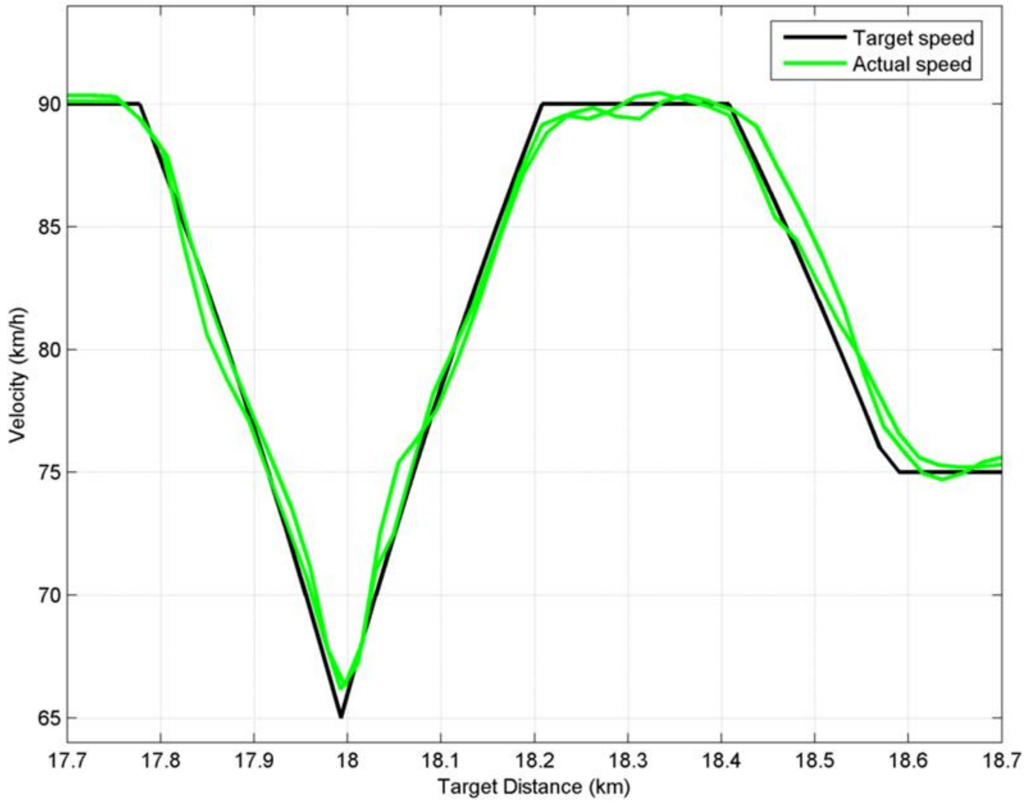


Figure 7-40: Vehicle 5, second peak at transition from lap 3-4

Vehicle 5 (see Figure 7-40), a L3e-A2 medium performance motorcycle, and vehicle 7, a L5Ae tricycle, had greater acceleration capabilities than vehicle 4, yet used the same pre-generated time based speed trace. As such, the test rider was able to follow the acceleration line but then mistakenly followed the additional cruise section before decelerating down to the actual cruise section defined in the cycle.

These results highlight an issue with the clarity of the instructions. In the current state they are only explained by means of a table of final speeds, this may not be the best presentation method to ensure the intentions of the cycle are fully conveyed to a tester.

7.5.5 Duration of action foreshortened

An issue mentioned in the previous sections is that due to a mistake or misinterpretation, the duration of an action has been reduced. Another cause of this is following the cycle exactly as presented, when the vehicle was unable to meet a vehicle speed point due to its capabilities.

Figure 7-41 shows the Type V durability speed trace of vehicle 1, a L1Ae moped. As this vehicle is in a category requiring a maximum speed of 25 km/h, the cycle has been designed with this in mind, with peaks and cruise sections at this speed.

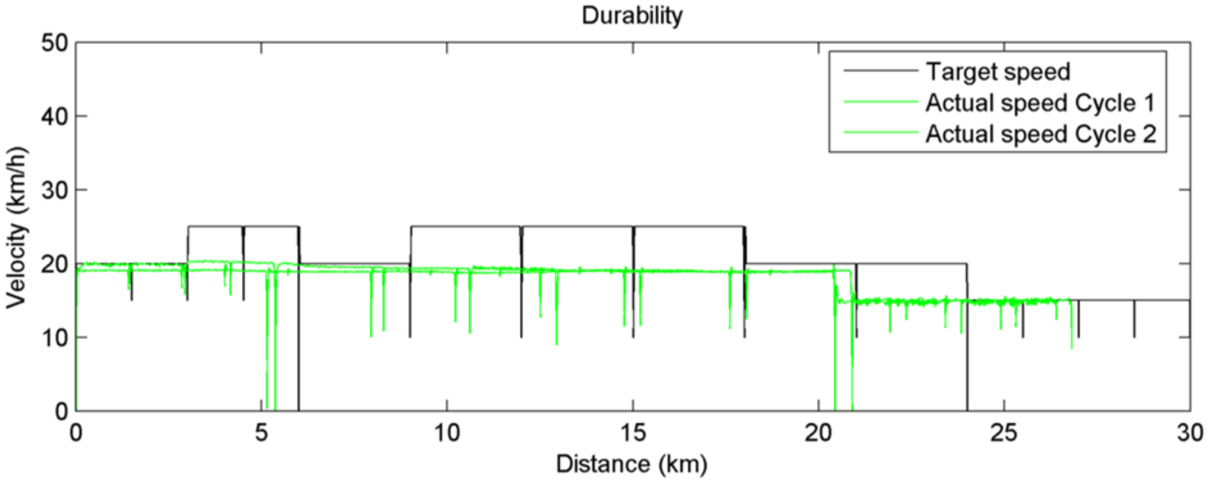


Figure 7-41: Vehicle 1 Type V speed trace

However, this vehicle has a maximum design speed of just below 20 km/h, therefore the deceleration and acceleration peaks and troughs have been performed for reduced proportions of the cycle as required, i.e. the proportions of actions designed to cause some key degradation mechanisms are not being fully carried out. And therefore the vehicle is not experiencing the correct amount of wear as defined by the WMTC emissions test cycle to occur in real-world riding.

A change of the final vehicle speeds is a probable solution, however this would also effect those vehicles, which are able to follow the speed trace. For instance vehicle 2, which is an L1Be with maximum design speed of 25 km/h, is able to follow the speeds as required in the cycle (see Figure 7-5).

7.6 Stakeholder information

In addition to the results of the validation testing, since the presentation of the phase 2 SRC-LeCV durability test cycle and legislative text, stakeholders have provided information regarding possible shortcomings (see ACEM, 2012). Chief amongst these is the recognition of thermal shock from oxygen showers, where an advanced vehicle under specific conditions would shut the flow of fuel into the combustion chamber and a flush of cold air would be pumped through the engine.

Another is the reduced proportions of low speeds and temperatures, which is desired when wanting to cause high levels of catalytic converter poisoning and the coating of this and other parts (such as the combustion chamber and lambda sensor) with soot and oil.

7.6.1 Thermal shock

A practical limitation in the development of a new durability cycle was the absence of test data throughout full distance accumulation. Instead, vehicles that had already been used on the road were tested using the WMTC Type I emissions test (as would be used during the Type V durability test) and real time data from these tests were used to ascertain the causes of degradation mechanisms.

The literature review identified a selection of key mechanisms of ageing. These features could be matched against changes seen in the real-time plots for emissions and temperature on a range of L-category vehicles. However, this methodology was not suited for identifying the degradation mechanism of thermal shock on a catalytic converter and this shortcoming was pointed out by stakeholder feedback from MCWG meetings.

The literature review revealed that catalytic converters are designed into the vehicle in such a way that they can heat up to their optimal operating temperature (in excess of ~500°C to ~950°C) and remain at this level. Over time and at temperatures materials and structures used in their construction are susceptible to rapid changes in temperature, which can cause slight, or for prolonged exposures, catastrophic failure. For instance, a sudden blast of relatively hot air on engine start or cold air on fuel cut-off can cause the device to crack or warp restricting the airflow through the exhaust system.

In the initial "phase 1" of the test programme only one of the two mechanisms (i.e. thermal shock from hot gasses striking the cold catalyst and lambda sensor at engine start) could be seen in the test data to be a significant issue for the majority of the L-category fleet. However, after stakeholder feedback, later test data was analysed with specific consideration of these issues and this mechanism was identified in the test data. As a result, relevant features were added to the proposed durability cycles to represent this ageing mechanism.

7.6.1.1 *Thermal shock due to cold vehicle*

When a vehicle is started, all of the components need to heat up before they can perform optimally. This temperature varies massively between parts and also vehicles. In real-world use this is likely to happen a few times a day, however in a durability test, time is a factor and a cooling period of typically 6 hours (as stipulated in the Type I emissions test) would have serious cost implications. Neither the EPA AMA, EPA SRC or UN and EC versions of those cycles stipulates any additional testing to try and factor in this type of degradation mechanism.

In the SRC-LeCV it was seen that, with the prediction of greater catalytic converter use in the future, this type of mechanism should be included. It was for that reason that together with the initial start from cold, additional cooling regimes were added alongside the minimum stipulated stops for emissions tests. In the initial published draft of the legislated text this was established as a minimum of four stops.

It should be highlighted that, although five starts (start of testing plus four stipulated) from cold are required as a minimum, there is by no means a fixed maximum. The flexibility of the test cycle allows the manufacturer to have a break in testing at the end of a complete cycle as and when they require. Some of these will be short for refuelling but others may be longer overnight breaks in testing shifts.

It is stipulated that before the start and after the end of any testing period, i.e. to travel to and from the test track, that high loads and speeds are not permitted (medium acceleration only). Therefore, the start of any testing period is likely to cause thermal shock. Some manufactures may choose to perform intensive testing with minimal breaks, such as three shifts a day with short breaks in-between or even 24/7 using a robot rider on a dynamometer. If performed on a dynamometer, the manufacturer could choose to use automatic refuelling, negating the requirement to stop at all.

It was felt that, although it would be beneficial to have some required cooling periods, improving upon all current durability testing methods, without data on such items as how often these occur in the real-world, asking for additional stoppages beyond those already called for in emission testing could not be justified.

7.6.1.2 *Thermal shock due to fuel cut-off*

In certain vehicles equipped with an engine management system, particular conditions trigger the supply of fuel to be cut off when not stationary and without disabling the engine.

One of the key reasoning with the initial discounting of this mode of degradation was the fact that it was only present in some of the assessed vehicles. The entire exercise by the EC is to update the legislation in a way suitable for the entire L-category fleet. However, another aim of the legislation was to update it to cover newer technologies. In the future, a greater proportion of new vehicles are anticipated to be equipped with advanced emission abatement systems, easily implementing techniques like deceleration fuel cut-off. This not only reduces vehicles' impact on the environment, but also reduces fuel use and decrease the cost of manufacture.

The deceleration fuel cut-off (DFCO) regime can be engaged when the vehicle is:

- At high engine speed
- At low engine load
- Not at low vehicle speed
- Decelerating
- Throttle off (or low)

The engine management system recognises that fuel is not required by the engine and that cutting it will not cause the engine to stall or vehicle to stop. It then simply stops the fuel injector from supplying fuel and, as the engine is still going through the required motions, it pumps air through from the intake to exhaust system. This technique saves fuel and consequently emissions.

The possible hazard with this technique is that the cold air causes a large and sudden temperature differential to the engine, exhaust and emission abatement parts such as the catalytic converter and lambda sensor. The engine itself is designed to withstand such changes, however the catalytic converter and lambda sensor are fragile and particularly sensitive to the rate at which they change temperature.

How the vehicle enters into DFCO is very much dependent on engine calibration. Even if the frequency of occurrence is low the resulting effect could be very damaging on the ageing of the catalyst.

Due to the renewed concerns by stakeholders of this degradation mechanism, this mechanism will be added to the current four used in updating the cycle together with the other findings of the validation programme. Therefore, to keep in line with the current design methodology, the proportions of occurrences by time will be looked for in the WMTC cycle for each of the category groupings and this will be balanced with the requirements of other mechanisms.

7.6.1.3 *Anomalies*

In the temperature data from vehicle 6, an anomaly was spotted in both the durability and emissions cycle. During some of the decelerations, especially where the vehicle decelerated to a stop, the pre silencer exhaust temperature increased, while the post silencer temperature decreased (see Figure 7-42).

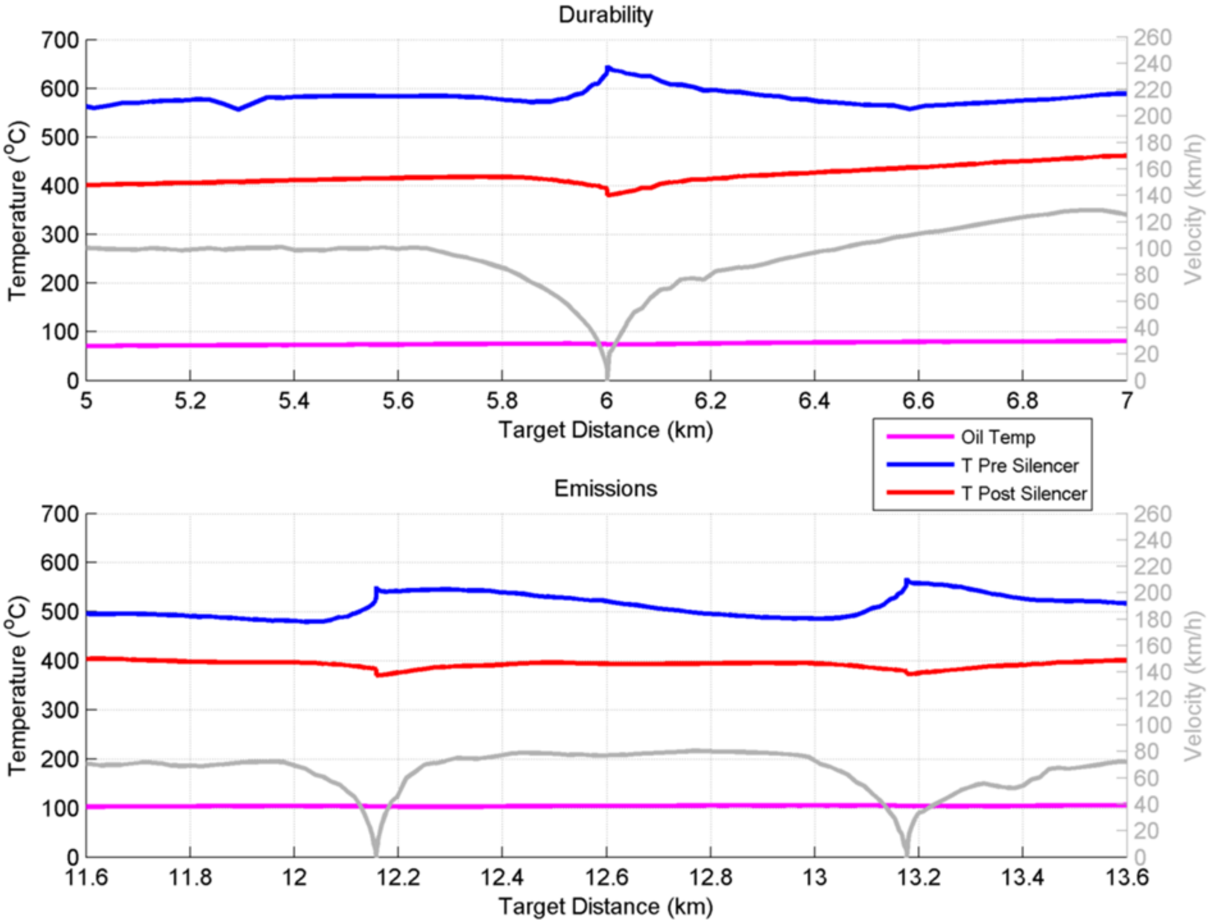


Figure 7-42: Vehicle 6, change in air/fuel ratio as catalytic converter protection mechanism

7.6.2 Low loads

7.6.2.1 *Low loads: Catalyst ageing*

A further concern raised by the stakeholders was the lack of slow laps, and consequently a high average speed, which on its own seems to indicate a deviation from real-world use. The degradation mechanisms (see ACEM, 2012) associated with low vehicle speed and load are listed below.

- Catalyst poisoning
    - Fuel
    - Oil
- Catalyst fouling
    - Soot

  - Carbon (coke) build-up

Poisoning of the catalyst results from the many additives and unwanted elements present in the fuel, oil and even the metals from the engine and exhaust. These chemicals directly bond with the catalysts disabling them in a reversible or irreversible manner, depending on the specific poisoning compound. High or low temperatures may assist in accelerating any ageing process (see Lassi, 2003).

At low temperatures the fouling from fuel, oil and soot build-up on the catalyst does not burn off. This could mean that if the contaminants contain these unwanted chemicals, the catalysts will be exposed to them for a longer period. If there are low amounts of these contaminants in the fouling this prevents the catalyst from being exposed to the exhaust flow, thereby preventing it from performing its purpose.

As loads and vehicle speeds increase, temperatures rise and the majority of the build-up is removed and some of the degradation is reversed. Even so, some soot and/or carbon deposition will remain and chemical deactivation of the catalyst by some chemicals will not.

Since catalytic converters were first implemented in motor vehicles in the 1950's the issue of poisoning has be regarded as a significant issue. As such, there have been many studies and subsequent changes to the quality of fuel and oil to remove elements such as lead, sulphur, phosphorous and silicon in order to limit possible damage. In addition, the designs of engines, fuel injection systems and combustion chambers have reduced the formation of soot in the exhaust gasses.

It was for these reasons that the significance of these degradation mechanisms were lowered in priority compared to circumstances such as high temperatures, which are cited as a larger concern with the need for catalysts to reach their operating temperature and start functioning quicker (light-off times), which may be required to attain the stricter tailpipe emission limits. This is because one method to decrease the light-off time is to position the catalytic converter closer to the exhaust valves on the engine and therefore expose it to higher exhaust temperatures.

For this reason, the two low speed laps, that kept the vehicle at low loads and engine speeds at or below their peak torque point, were removed. However, this does not remove all situations which cause low loads and temperatures:

1. A significant constituent in the design of the test cycles was the inclusion of carefully proportioned decelerations, which prevents deposits being properly burned off, although it can be seen that the catalytic converter will have reached its running temperature for the majority of the distance accumulated.
2. With the removal of the low speed laps it was felt that some causes of soot creation would not task diesel particulate filters, which might also be used in future petrol vehicles if proven cost effective. To tackle this, an idling period was added that four times during the distance accumulation the vehicle will be required to be left idling for 1 hour. This situation has been described as the ultimate low engine load and engine speed.
3. During the testing the vehicle will be required to perform emissions tests a minimum of 5 times, and one emission test could consist of 2-3 reiterations of the WMTC cycle and if required for other testing authorities, the FTP and UN R40 or

R47 tests. All of these have low load sections which will add to the degradation of the emission relevant components.

7.6.2.2 *Low loads: Heat damage*

A concern raised by stakeholders is the removal of the low speed sections consequently removing a rest for the engine and parts. Theoretically at high temperatures parts wear faster than if allowed to cool. As L-category vehicles are by definition light, excessive factors of safety cannot be used in the choice of material thickness.

It can be seen, however, that this is not a concern of all vehicles and all categories. For instance some quadricycles are designed for travelling over rough terrain and therefore are rugged. Secondly, there is no requirement for a vehicle to perform every iteration of the cycle back-to-back.

Therefore, it has been left open for a manufacturer to decide whether they sacrifice time to allow a vehicle to rest, or to minimise breaks to decrease the total testing duration.

7.7 Proposed changes to cycles

From the analysis of the data obtained while assessing the cycles with the limited amount of vehicles available for testing in this validation programme it can be said that the cycles 3 and 4 are validated. However, the second two, cycle 1 and 2, were not. The reason for these cycles not being validated arises from the wide variety of vehicles in the L-category, and the false assumption that a vehicle’s (category-stipulated) maximum vehicle speed or motive power limit denotes that the vehicle can obtain that level of performance. For the higher performance vehicles performing cycles 3 and 4 there was no issue in attaining the required speeds, whereas in the lower vehicle speed categories, performing cycle 1 and 2, the vehicle’s actual performance capabilities could in an effort to not exceed a limit (such as that of their category’s or a desired target vehicle speed in the test) be far below it. Even for the higher speed vehicles performing cycles 3 and 4 there were some issues where the cycles could not be followed, however this is seen to be an issue with how the cycle had been implemented in the tests and not with the capabilities of the vehicles.

Therefore to rectify these issues, the cycles must be adjusted to have a greater level of flexibility, ensuring that the intended outcomes are achieved.

7.7.1 Decelerations

In addition to the requirement of redesigning cycles 1 and 2 with a greater understanding the actual capabilities of these categories, the following change to their instructions is proposed:

- Rather than providing all of the instructions in terms of final vehicle speed, a required speed change should be given for some instructions. This should only be required for decelerations and to reach a following cruise speed the test rider will be permitted to perform an additional action to accelerate back to the required speed.

For vehicles that can currently perform the cycles as required, this modification will constitute no change. However, for those who can’t it will ensure that a greater proportion of the required decelerations are performed.

It can be seen that this modification could cause some vehicles to reach 0 km/h. Rather than requiring a stop, the vehicle could be permitted to continue on to the next action just before the vehicle speed at which a two-wheeler might require additional stability. However, it is important that the deceleration and acceleration is carried out as fully as possible. Therefore, a stop will be required, but no additional idling period beyond what is required to prepare for moving off.

7.7.2 Alignment of actions

In order to assist the test rider as well as ensuring that actions are performed in the correct manner, a second change is proposed for the test:

- Rather than actions leading up to a fixed distance on the track, possibly causing the action to not be performed correctly, the start of a string of complex actions will always be started once passed a fixed distance.

For instance, instead of decelerating to meet the idling point precisely at the start/stop point on the track, the rider will start decelerating when passing this point and perform the subsequent deceleration, idling and acceleration as and when the vehicle has completed performing each instruction in the sequence of actions.

This will have the effect of offsetting the speed trace, but time and distance gained at one point will then be lost in the transition to another. If the vehicle is required to stop performing the test, when requiring a refuel for instance, the rider could then pre-empt the start of a deceleration to meet the track exit point as usual and would mean that on average there would be no effect on the actual distance ridden.

7.7.3 Trace

In addition, the use of a pre-generated time based trace is unadvisable. If it is used the trace should be made in conjunction with testing of the characteristics of the actual vehicle under test and if seen to be necessary the trace should be adjusted at appropriate points during the distance accumulation as the characteristics of the aged vehicle change.

7.7.4 Rates of change

The test data has also provided more accurate information of accelerations and decelerations (see Table 7-30). This data will be used in the generation of the modified cycles to provide more accurate proportions of the key characteristics of degradation factors.

Table 7-30: Average values of acceleration and deceleration

	Cycle 1	Cycle 2	Cycle 3	Cycle 4
Moderate acceleration (ms^{-2})	0.33	0.36	0.48	0.62
Hard acceleration (ms^{-2})	0.46	0.85	1.23	1.21
Moderate decelerations (ms^{-2})	-0.38	-0.47	-0.54	-0.78
Coast-downs (ms^{-2})	-0.19	-0.29	-0.35	-0.42

7.7.5 Speed changes

From early on in the development of the cycles it was noted that some of the speed changes were too precise and too small to be practical, i.e. a resolution of 1 km/h and changes below 5 km/h. There is a need to find a balance between practicality and scientific accuracy. Therefore, a resolution of 5 km/h was set, with speed changes of at least 5 km/h in the slower cycles and 10 km/h in the faster ones.

During the validation programme, JRC noted that attempting these small changes was very difficult (see Appendix O), and therefore errors were caused, deviating from the requirements to a larger degree.

Fortunately however, the other changes required due to the addition of certain fuelling regimes to the cycle development criteria have shown a greater requirement for long decelerations. When combined this should allow a reduction in difficulty and errors from small speed changes without the loss of scientific integrity of the test.

7.8 Evaporative tests

From initial information obtained from stakeholders it was seen that evaporative testing (Type IV test) was connected with durability testing. In that case the evaporative testing was initially linked with the minimum of four tests required for partial distance testing, together with emissions test, cold soaks and the idling period.

The reasoning for this was to find the durability of the parts key to preventing evaporative emissions. However, stakeholders have since provided information to state that this is not necessary: Firstly, the general tubing and connections in the fuelling system will become loose due to vibration. This is not likely to be greatly affected by different test cycles.

Secondly, the degradation of carbon canisters, used in the scrubbing of fuel from the air leaving the fuel tank, are deemed by stakeholders not to be effected by distance travelled but rather time, and so it has been suggested that some evaporative emission control components would be better tasked through a separate accelerated test. Other industry stakeholders may be of a different opinion and have alternative evidence to show that for instance the carbon in the carbon canister may deteriorate when the evaporative emission control system is not sufficiently well designed or calibrated for the specific vehicle under test.

For these reasons, the evaporative emission test may only need to be performed once, using for example a vehicle which has performed the durability test combined with a carbon canister which has been aged separately or as a golden part.

7.9 Proposed changes to legislation

A significant worry from some manufacturers is that the EU requires one test while other regions another, specifically the US which requires the EPA AMA Type V durability test together with the FTP Type I emissions test. Given that there is currently no durability test for L-category vehicles in the EU, if they chose to market a given vehicle in multiple regions in addition to the EU the development costs would be higher.

On one hand this additional cost is offset by the manufacturers ability to sell in another market and this additional cost is the same as would need to be invested by companies which currently only market their vehicles in the EU and other places which do not require the test.

However, the key reasoning for the development of new L-category legislation was for the opening up of trade, reduction of costs and the harmonisation between regions. Although, for scientific reasons, the harmonisation of test cycles has not been seen to be beneficial, other measures could be put forward to allow partial harmonisation.

It has been seen that the testing procedure and legislation surrounding both the US EPA AMA and SRC have been well thought out and logical, and therefore as far as possible the same rules have been used.

However, one key advantage in the US legislative system is the permission of choice, for instance, light duty vehicles and trucks (i.e. cars and vans) are permitted to use either the SRC or class 3 AMA test. If a test cycle can be shown to be as stringent as or more stringent than the current requirements it could be accepted as an alternative.

However, although some rules are similar not all are and key amongst these is the Type I test. For US testing the FTP test is used, but in the EU the WMTC is used. To fix this and any other deviations an additional article is proposed, which would allow additional restrictions to be placed on the test by the manufacturer so that it can be made compatible with the testing of another region.

So for instance if required, the manufacturer could follow the WMTC emission test with the FTP and UN R40 tests if required. They could also perform multiple tests of each one if required. This would, however, not allow the manufacturer to perform processes which would lower the scientific integrity of the test for the EU's requirements by performing shorter soak periods or stopping the mileage accumulation mid cycle for instance.

In addition, due to the possible cost implications of a manufacturer performing so many additional tests, this distance accumulated could be allowed to be counted amongst the total durability distance.

7.10 Categories

In response to the publication of the test cycle and draft legislative text, a stakeholder performed two of the test cycles and published the results at the MCWG meeting on 17th April (ACEM, 2012). One vehicle performed the SRC-LeCV cycle 4 (phase 2) for L3e vehicles capable of >130 km/h and the EPA AMA class III cycle for vehicles with engine capacities of ≥280 cm^3 (see Appendix N).

The second vehicle performed: the SRC-LeCV cycle 3 for L3e capable of <130 km/h, L4e, L5e and endure and trial L3e motorcycles, the EPA AMA class I for vehicles with engine capacities of ≥170 cm^3, and the WMTC sub-class 1-3 emissions cycle for vehicles with engine capacities of <150 cm^3 and capable of 50 km/h$\leq v_{max}<$100 km/h.

In the tests, the temperature of the catalytic converter is measured and compared between the cycles. As it is shown that the temperatures generated by the SRC-LeCV are comparable to the high speed lap 11 for high performance L3e motorcycles (EPA AMA: ~600°C, SRC-LeCV: ~600-650°C), but exceed the design capabilities of the vehicle performing the cycle 3 test (EPA AMA: ~725°C, SRC-LeCV: ~800-900°C), the WMTC test for this vehicle showed temperatures of ~600°C however this test only reached 2/3 of the vehicle's maximum vehicle speed for short periods of time.

Based purely on the stakeholder's data it was initially suspected that there may be an issue with cycle 3, this was later backed up with the results from vehicles 11 and 12, which were performed early in the testing programme. Conversely, later results from vehicles 4, 5 and 7 showed no issue. It was for these reasons that it is now suspected that the issue is with the categorisation methodology and not the cycle design.

7.10.1 Phase 1 and 2 category development

In the development of the cycles the importance of vehicle variations between categories was recognised, and in the development of phase 1 (the 7 lap first iteration of the development process), the cycles were designed in line with the EC's data on average distance travelled per category as shown in Table 7-31.

Table 7-31: Proposed durability mileages for L-category vehicles EC, 2010 (development cycle)

Vehicle category	Vehicle category name	SRC-LeCV cycle	Durability mileage (km)		
			Euro 3	Euro 4	Euro 5
L1Ae	- Powered cycle	1	5,000	5,500	6,000
L1Be	- Two-wheel moped	2	10,000	11,000	12,000
L2e	- Three-wheel moped				
L6Ae	- Light on-road quad				
L3e **L4e**	-Two-wheel motorcycle, with and without sidecar (v_{max}<130 km/h)	3	18,000	20,000	30,000
L5e	- Tricycle				
L6Be	- Light quadri-mobile				
L7Be	- Heavy quadri-mobile				
L3e **L4e**	-Two-wheel motorcycle, with and without sidecar (v_{max}>130 km/h)	4	30,000	35,000	50,000
L7Ae	- Heavy on-road quad				

With the assessment of the efficiency of the first phase in the design, the alignment of vehicles to cycles was reassessed. The realignment was done in view of changes to the categories themselves, which were also being revised as part of the revision of L-category legislation by other parties.

This second categorisation (see Table 7-32) was presented in the draft legislation and used for the selection of vehicles for the validation project.

Table 7-32: EC proposal L-category durability distances with subsequently added vehicle categories EC, 2010 (development cycle)

Vehicle category	Vehicle category name	SRC-LeCV cycle	Durability mileage (km)		
			Euro 3	Euro 4	Euro 5
L1Ae	Powered cycle	1	5,000	5,500	6,000
L3e-AxT (x=1, 2, 3)	Two-wheel trial motorcycle	3			
L1Be	Two-wheel moped <25 km/h	2	10,000	11,000	12,000
	Two-wheel moped <45 km/h	2			
L2e	Three-wheel moped	2			
L3e-AxE (x=1, 2, 3)	Two-wheel Enduro motorcycle	3			
L6Ae	Light on-road quad	2			
L3e	Two-wheel motorcycle (v_{max}<130 km/h)	3	18,000	20,000	30,000
L4e	Two-wheel motorcycle with sidecar (v_{max}<130 km/h)	3			
L5e	Tricycle	3			
L6Be	Light quadri-mobile	2			
L7Be	All-terrain vehicles	2			
L7Ce	Heavy quadri-mobile	2			
L3e	Two-wheel motorcycle (v_{max}>130 km/h)	4	30,000	35,000	50,000
L4e	Two-wheel motorcycle with sidecar (v_{max}>130 km/h)	3			
L7Ae	Heavy on-road quad	3			

There was a concern raised by stakeholders that vehicles that are typically used at slower vehicle speeds than their characteristics or category classification are being required to perform a cycle not consistent with real-world use. Therefore, the phase 2 categories were designed to allow these slower vehicles to run in different cycles.

However, as shown with the test data from ACEM and the results from vehicles 11 and 12, this adjustment was not successful. The categories are sometimes based on vehicle speed or do not fully encapsulate the performance capabilities of a vehicle and so cannot be used to select the correct testing methodology. Therefore, it is proposed to select a new methodology that would disconnect the cycle from the durability mileage accumulation full distances.

7.10.2 SRC-LeCV phase 3 category development

The SRC-LeCV durability cycles have been developed using the WMTC emission cycles as a base, using its categorisation system to select the cycles to perform. Therefore, rather than creating another categorisation system it is proposed to use its system.

The WMTC categorisation system is documented in UN GTR No. 2 (see Table 16-6). In the stage 2 and 3 (revised) versions of the WMTC it has 5 sub-classes collected into 3 classes (stage 1 had 7 sub-classes and 3 classes). The divisions are based on engine capacity and maximum vehicle speed.

It has been proposed by the EC that <50 cm³ and <45 km/h vehicles (i.e. mopeds, powered cycles >1,000 W and light quadricycles) will use the WMTC emissions test in the future. They would be included as Class I vehicles which was why this test was used for the vehicle testing programme for both the main durability report and validation project, this can be seen with the results from vehicles 1, 2, 3 and 9.

When comparing the WMTC system with the categorisation system used in phase 1 of the durability cycle design, class 1 aligns well with cycle 4 and class 2 with cycle 3. Cycles 1 and 2 however do not fit with any class; rather they are both excluded by both the lower engine capacity and vehicle speed limits. Moreover, there is no SRC-LeCV cycle which matches class 1 of the WMTC.

The results from vehicles 1 and 2 show that a cycle to match their vehicle’s precise limits does not help it match real-world use, but rather makes the vehicle speeds and loads below what would be expected. For example if a vehicle with a maximum design vehicle speed of 20 km/h is required to travel at 20 km/h, then it will require WoT to reach the required vehicle speed, but less than that in order to maintain it. If however the vehicle is required to travel at 25 km/h the vehicle will need to use WoT continuously.

Although highly unlikely for larger vehicles, <45 km/h vehicles are considered to spend a large proportion of their use at their maximum speed, and for slower <25 km/h vehicles it is practically a requirement that they will be under maximum load and/or at maximum vehicle speed for the majority of the time.

It is therefore proposed that all vehicles such as these use the same cycle, it will be designed for the higher capability mopeds and light quadricycles, and when combined with the additional rules proposed in Section 7.7.1, slower vehicles will automatically perform a larger proportion at maximum vehicle speed.

Keeping in line with the proposal for cycles 3 and 4 to follow the WMTC classes, the new cycles should also. But as two cycles are required but only one class, a split will be required. This split could follow the classes, sub-classes or additional sub-divisions used in the criteria for WMTC stages 1, 2 or 3 (see Table 7-33).

Table 7-33: Possible criteria for selecting cycle based on WMTC method

Cycle	Class	Option 1	Option 2	Option 3
		Split by in- and outside of class 1	Split by sub-division of class 1, stage 3	Split by sub-classes of class 1, stage 1
1	**1**	Vd≤50 cm³	Vd≤50 cm³ v_{max}≤50 km/h	Vd≤50 cm³ v_{max}≤60 km/h
2		50 cm³<Vd<150 cm³ v_{max}<100 km/h	50 cm³<Vd<150 cm³ 50 km/h<v_{max}<100 km/h	50 cm³<Vd<150 cm³ 60 km/h<v_{max}<100 km/h
3	**2**	Vd≥150 cm³ 100 km/h≤v_{max}<130 km/h		
4	**3**	v_{max}≥130 km/h		

Where: Vd = engine displacement volume and v_{max} = maximum design speed (velocity)

Note that the current GTR No. 2 (containing the revised or stage 3 WMTC) only separates vehicles by engine capacity and maximum vehicle design speed. It will be necessary in the future to supplement this with a propulsive power limit (i.e. kW net power). In the EC proposal COM(2010) 542 the values of 4 kW for 50 cm³ vehicles and 11 kW for 125 cm³ vehicles are used, assuming a linear relationship this makes 150 cm³ equivalent to ~13 kW (or 18 BHP). However as these are based on limits, the true value may be higher.

Without a power rating equivalent it would be preferable to use a sub-division criteria which contains a maximum vehicle speed, therefore options 2 or 3 (see Table 7-33). Additionally, it is preferable to base any classification on the most current version of the legislation (i.e. stage 3) rather than outdated divisions from the WMTC stage 1 and 2, it is therefore preferable to use option 2.

7.11 Cycle redesign phase 3

To design the new cycles 1 and 2 the same tool was used as for phase 1 and 2 (see Section 4.5), however the following changes were made:

1. The test data was used for deceleration and acceleration rates rather than the US EPA SRC typical rates.
2. Decelerations will be explained in terms of difference from previous vehicle speed.
3. The start of instruction groups will be aligned to the start or sub-division of a lap, rather than straddling a sub-division.
4. Proportions of low vehicle speed or engine load will be removed (i.e. one of the causes of carbon deposits).
5. Proportions of low load at high vehicle speed will be added (i.e. the trigger for DFCO).

The items 1, 2 and 3 have been directly added to the tool by changing the formulae, and an additional variable of maximum vehicle speed has been added to allow the effect of vehicle characteristics to be seen. The items 4 and 5 will require a re-assessment of the WMTC cycle and modification of the tool to accept the change to criteria.

7.11.1 Analysis of WMTC emissions cycle for identification of DFCO and mixture enrichment

The emissions test data (using the WMTC emissions test) from five vehicles were assessed to look for instances of two special fuelling regimes: DFCO using the criteria in Section 7.6.1.2 and catalytic converter air/fuel enrichment using the indicator identified with vehicle 6 (see Section 7.6.1.3). The vehicles chosen for this were all category L3e-A3 (high-performance motorcycles) as they are more likely to use these advanced methods.

Of the five vehicles assessed, the pronounced indicator of DFCO was found with one vehicle and air/fuel mixture enrichment with two. Both fuelling techniques are not implemented in the same vehicle (see Table 7-34).

Table 7-34: L3e-A3 high performance motorcycles fuelling regimes

Vehicle		DFCO	Rich
Vehicle 6	(6)	No	**Yes**
Durability project vehicle 6	(D6)	No	No
Anti-tampering project vehicle 11	(T11)	**Yes**	No
Anti-tampering project vehicle 12	(T12)	No	**Yes (small)**
Anti-tampering project vehicle 13	(T13)	No	No

Note: Vehicle 6 was tested for the validation, vehicle D6 is a different vehicle tested in Section 2.2, vehicles T11-T13 were tested as part of Tampering prevention in L-category vehicle approval legislation, 2012.

7.11.1.1 *Deceleration Fuel Cut-Off (DFCO)*

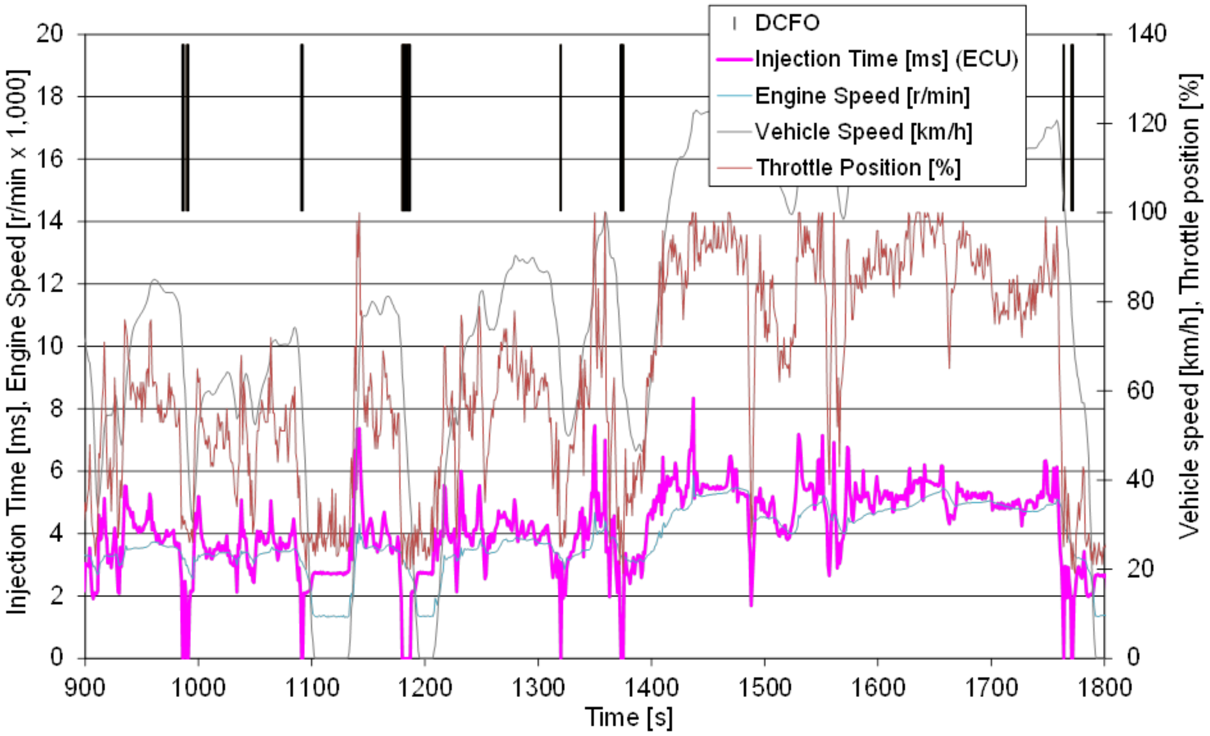


Figure 7-43: Vehicle T11, L3e-A3, DFCO, WMTC stage 1 (Parts 2 & 3, normal speed)

Figure 7-43 shows an excerpt from the WMTC test on vehicle T11. DFCO was in effect for 21 data points 7 instances in the test cycle: none were in part 1 of the WMTC test (0-600 s), 3 in part 2 (600-1,200 s) and 4 in part 3 (1,200-1,800 s). Next the values of key measures were taken for just those instances of DFCO (filtered from the raw data, see Appendix O) and were used to find the key criteria used by the vehicle to decide if fuel can be cut off. The ranges presented for the whole test are presented alongside for comparison (see Table 7-35).

Table 7-35: Vehicle T11, criteria at DFCO

	At DFCO		Ranges whole test	
	Min.	Max.	Min.	Max.
Rate of change [ms^{-2}]	-1.847	-0.792	-2.875	3.319
Vehicle speed [km/h]	34.7	102.7	-0.3	126.1
Engine speed [r/min]	2,662	4,432	1,215	5,854
Throttle position [%]	19	32	0	100

The vehicle only implemented the fuel cut-off at vehicle speeds >35 km/h and engine speeds >2,662 r/min, which is more than double the idling speed.

Interestingly the vehicle was always decelerating at a high rate of at least -0.792 ms^{-2}, however the use of DFCO may itself increase the deceleration rate due to additional engine losses incurred by pumping air through the engine. DFCO should still engage regardless of the vehicles actual deceleration, for example while a vehicle rolls downhill and possibly accelerates, therefore deceleration rate is unlikely to be a criteria used by the system.

Another key point is that the fuelling cut-off regime was implemented even when the throttle was engaged up to 32%.

When applied to the SRC-LeCV test cycle, the simulated DFCO points are primarily positioned on the three long decelerations to 0 km/h (see Figure 7-44).

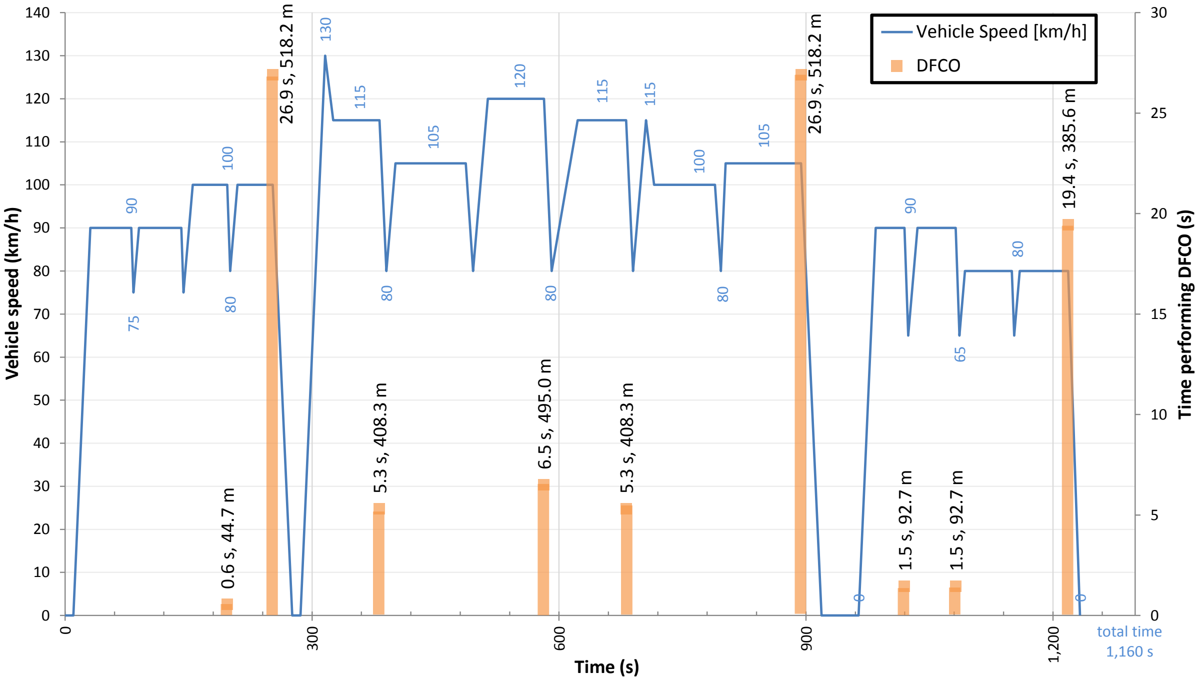


Figure 7-44: SRC-LeCV (Cycle 4) – highlighting DFCO phases

For this one test vehicle, DFCO was triggered during these decelerations using instructions to decelerate and change gear according to the WMTC stage 2 cycle guidelines. However, it is acknowledged that with a sample size of only one vehicle, the finding that DFCO would be triggered in these circumstances for all L-category vehicles cannot be presented with certainty. The activation criteria for DFCO will be highly dependent on such parameters as: vehicle mass, drag coefficient, internal transmission losses and engine type and may therefore vary between vehicles. The technique of DFCO may also be used to a greater degree in the future, both in terms of prevalence in the fleet and the range of riding situations which will activate it. However, within the scope, time and budget of the study, these metrics could not be obtained.

7.11.1.2 *Rich engine operation*

The instances of enriched fuelling in vehicle 6 were identified by looking for points, at which the air/fuel ratio was rich, the vehicle was decelerating and it experienced a reduction of post silencer exhaust temperature, but an increase in pre silencer exhaust temperature. This occurred in 55 data points (out of 1,800 in the test) in 15 instances (see Figure 7-45).

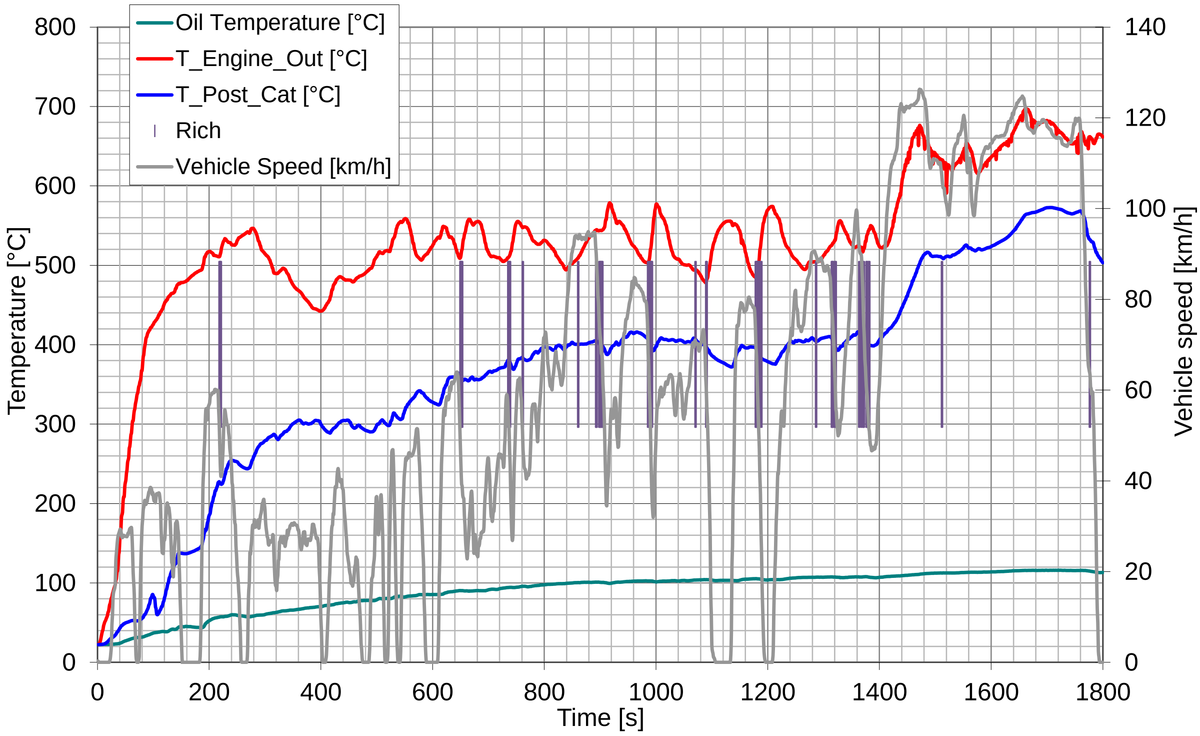


Figure 7-45: Vehicle 6, deceleration mixture enrichment

The rich fuelling regime occurred over a wider proportion of the WMTC cycle than DFCO, with 1 instance in part 1, 9 in part 2 and 5 in part 3.

Table 7-36: Vehicle 6, criteria for deceleration mixture enrichment

	Rich		Ranges whole test	
	Min.	Max.	Min.	Max.
Lambda	0.83	0.99	0.76	1.46
Rate of change [ms^{-2}]	-1.86	-0.04	-3.51	4.07
Vehicle Speed [km/h]	24.15	106.8	0	126.3
T pre silencer [°C]	479	662	23	698
T post silencer [°C]	225	532	22	573
Rate of change T pre silencer [°C/s]	0.05	10.18	-37.25	22.67
Rate of change T post silencer [°C/s]	-2.76	-0.10	-8.28	5.52

The criteria for this fuelling regime (see Table 7-36) seem to be related to the action of decelerating from speeds >25 km/h, pre silencer exhaust temperatures >~500°C and long decelerations.

Given that there are 16 deceleration instances during the SRC-LeCV test, a similar number to those found in the analysis, all of which from moderate to high vehicle speeds, it is likely that the correct proportion of deceleration mixture enrichment is already occurring. Furthermore, from the trace of durability and emissions testing from vehicle 6 it can be seen that the mixture of long and short periods of enrichment is also already covered by the current testing method.

7.11.1.3 *Analysis of WMTC instructions*

In order to assess the proportions of DFCO and deceleration mixture enrichment, criteria based on the limited metrics available in the WMTC and SRC-LeCV plots must be devised. The metrics available include vehicle speed, distance, time and acceleration rates as well as if the vehicle is in a stop, accelerating, cruising or decelerating phase.

Taking the DFCO rules as: decelerating, deceleration rate <-0.8 ms^{-2} and speed >35 km/h, 82 data points are seen to meet the criteria, which is far in excess of the 21 in the actual vehicle. Additionally, the occurrences of DFCO were spread over the whole test including part 1 of the WMTC test.

An ECU may also be obtaining information on the engine speed and coolant temperature. However this data is not available, in order to estimate an initial high engine speed the speed of the peak before the deceleration will be taken into account. For vehicle T11 this was at 70 km/h, although the vehicle was decelerating for over 3 seconds it was travelling at 60 km/h before DFCO engaged. This additional time may be to prevent the system engaging when power may be required again, while changing gear for instance, and to ensure a smooth transition from positive to negative torque delivery for driveability.

With the additional DFCO rules of: decelerating for 3 seconds previous and peak of over 70 km/h in the past (a time of 20 seconds was used), the analysis provides 22 data points at DFCO grouped into 10 instances with all but one occurring in the same locations as seen in the results from vehicle 6.

It should be noted that an assumption made in the development of the cycles is that the engine is engaged with the wheels for the majority of the cycle, this was both based on general correct driving practice as well as to prevent over-complexity of the model. However, without specific instructions on the deceleration phase a rider could in practice part clutch or use the clutch for long periods when downshifting and coast (i.e. disengage the drive from the wheels).

Therefore, an additional type of instruction is proposed, where the vehicle is required to limit the coasting periods in gear changing and to extend the time that the action takes place over. This will be termed a ‘coast-through’ deceleration and will be used in addition to the current moderate and coast-down decelerations.

Furthermore, specific rules should be required to both ensure the moderate and coast-through decelerations are performed as intended and ensure that they reflect realistic real-world use. Bearing in mind the large range of vehicles included in the L-category, this might or might not be achieved. However, the gear shift prescriptions developed for the UN GTR No. 2 are already designed to represent real-world use and could be used as a base; it is therefore suggested to use those procedures, as laid down in paragraph 4.5.5. to Annex I of the forthcoming regulation on the environmental and propulsion performance requirements for the approval and market surveillance of two- or three-wheel vehicles and quadricycles (REPPR), this will hence forth be referred to as Regulation (EU) No [xxx/2012], with the caveat to permit vehicle manufacturers to adapt them at the agreement of the approval authority. This will strengthen repeatability of the Type V test cycle, while allowing freedom for differing technologies in the full range of L-category vehicles. The specific instructions to be followed in all three types of decelerations (moderate, coast-through and coast-down) are set out in Section 9.1.3.

7.11.2 New cycle 1

The new cycle 1 is not a modification of the phase 2 cycle 1, but instead a combination of the original cycle 1 and 2. The redesign of the trace is founded on the new vehicle groups and emission abatement part degradation criteria, these include the removal of low vehicle speeds and the addition of a specific deceleration action designed to encourage DFCO. Together with the new test methodology to ensure decelerations are fully performed (see Section 7.7.1), it is designed to be used with all vehicles with maximum vehicle speeds ≤50 km/h, engine capacity ≤50 cm^3 and/or net power ≤4 kW, i.e. all vehicles on the lower extremities of the UN GTR No. 2 classing system.

This cycle is able to function for all vehicles originally covered by two cycles due to changes to the instructions, in that it has been designed in a manner that takes into account the changes that occur when a vehicle of lower performance performs it. Going from fully capable vehicles through to ≤45 km/h mopeds, ≤25 km/h light mopeds or ≤15 km/h powered cycles the proportion of maximum velocity full throttle riding increases. This change is in line with that which the vehicle experiences when performing the WMTC (stage 3) class I emissions driving test, which is the class that all of the vehicles performing this durability cycle use (see vehicles 1, 2, 3, 9 and 10).

The balance of likely degradation causing actions is presented below in Figure 7-46 which compares the proportions in both a time and distance base for the new cycle which was being worked on and the appropriate WMTC cycle. Note the addition of a measure of DFCO and the removal of significance to low load below peak torque (taken from the average of results from the vehicles under test in the main durability project testing programme).

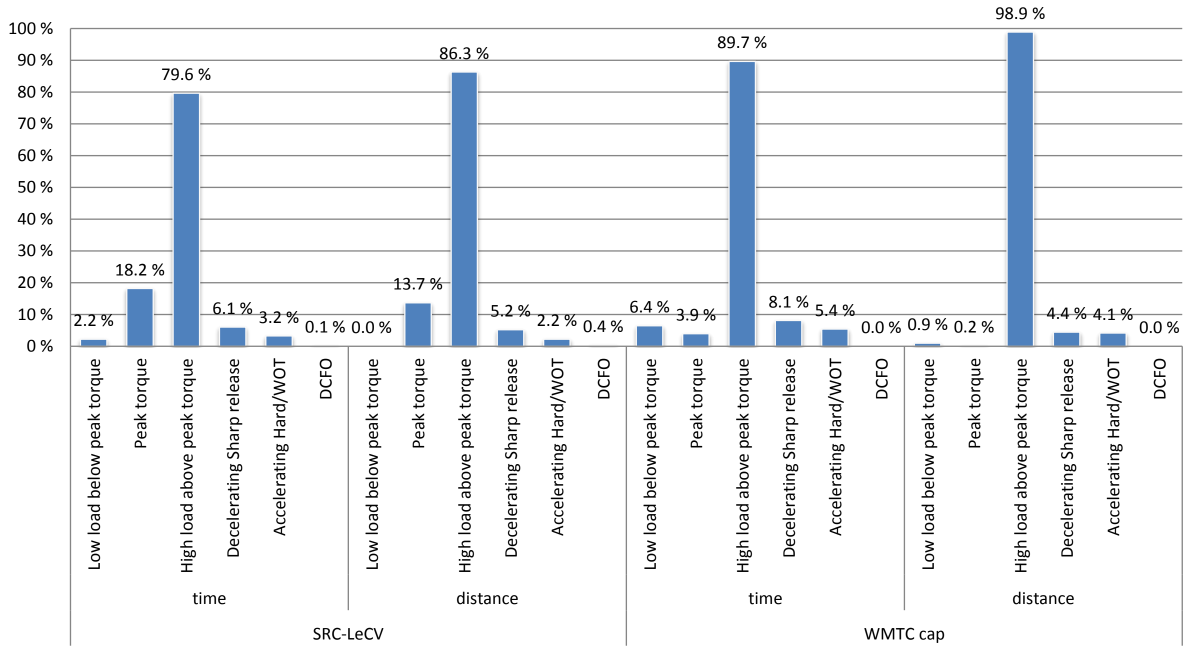


Figure 7-46: Proportions of key actions in phase 3 cycle 1

A graphical representation of the SRC-LeCV phase 3 cycle 1 speed trace is presented in Figure 7-47 (note it is presented against distance and therefore the stops for idling are not shown).

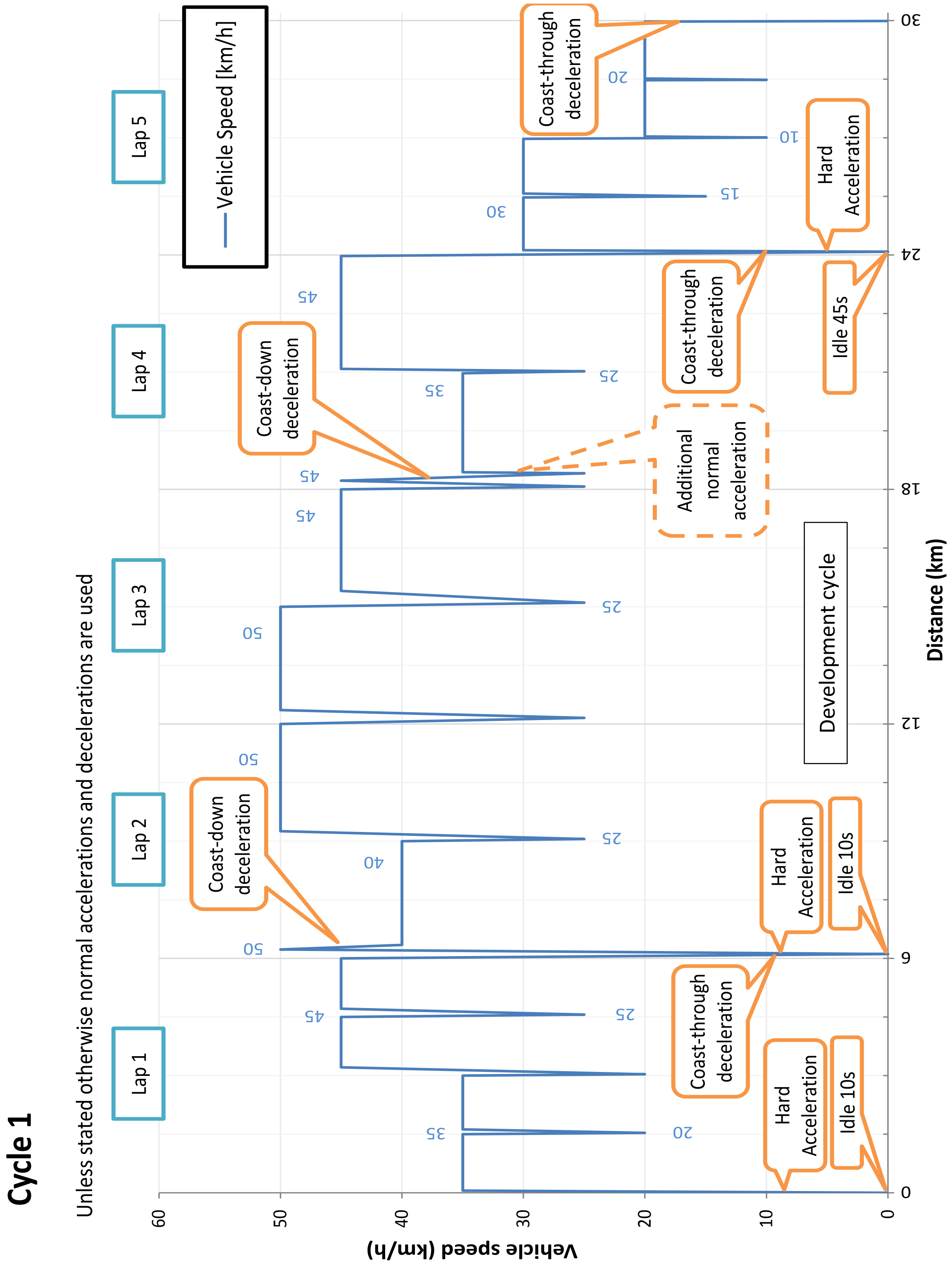


Figure 7-47: SRC-LeCV cycle 1 (phase 3) (development cycle)

7.11.3 New cycle 2

For the development of cycle 2, due attention was paid the issues with vehicles 11, 12 and 13 in addition to the test data provided by a stakeholder (see Appendix N). As the phase 3 cycle 2 is now able to be used for all vehicles previously covered by two it was possible to develop a cycle which fitted in the gap between mopeds and high performance vehicles without adding greater complexity to the system by adding a fifth cycle.

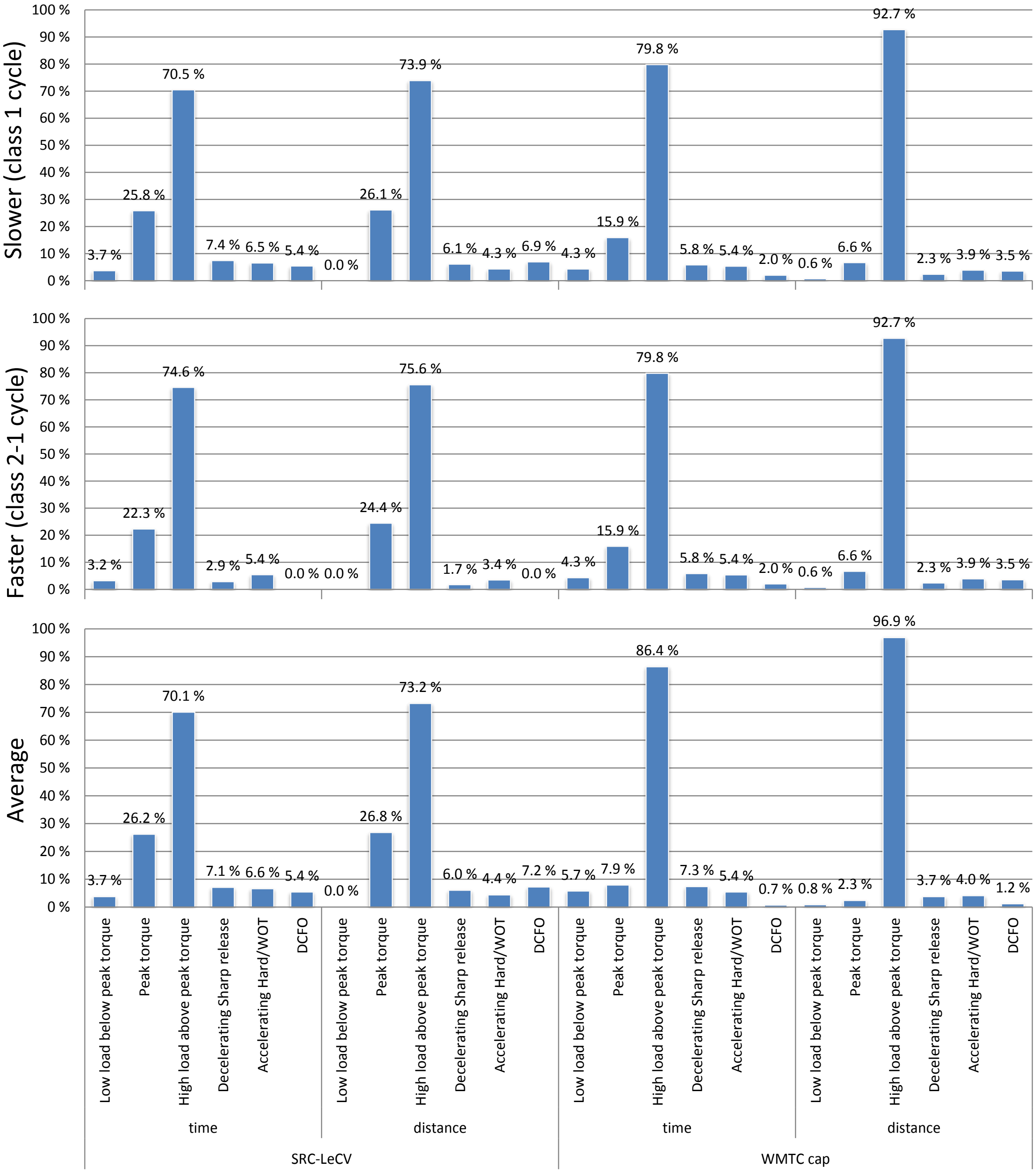


Figure 7-48: Proportions of key actions in phase 3 cycle 2, using range of WMTC cycles

With previous cycle development it was possible to select a single WMTC cycle to compare the SRC-LeCV cycle against. However as this group contains such a wide range of vehicles, instead two cycles were used to represent the two extremes of the vehicles contained within (see Figure 7-48). The first of these was the WMTC class 1 cycle which has a maximum speed of 50 km/h and second was WMTC class 2-1 cycle with a maximum speed of 80 km/h (cycle 3 being developed against the WMTC class 2-2 cycle with a maximum speed of 95 km/h).

As with the transition from phase 1 to phase 2 after the proportions were brought into alignment, an engineering assessment was brought into play. It was seen that even with this combination of WMTC cycles to compare against, the new cycle was biased towards higher velocities making it similar to the SRC-LeCV cycle 3. Yet this cycle was developed to prevent the issues seen with some of the lower performance or lower geared vehicles commonly found within this group.

Therefore, the common riding speeds, European urban road speeds and uses found with these types of vehicles were assessed and some of the speed points were brought down to match these. However, this was not performed at the expense of accurately tasking the high vehicle speeds also found in the group. Therefore, two higher speed areas were added: The main hard acceleration peak at the start of lap 2 was placed at 100 km/h (the same vehicle speed as with cycle 3) and the highest speed cruise found in lap 3 was kept at 90 km/h.

A graphical representation of the SRC-LeCV phase 3 cycle 2 speed trace is presented in Figure 7-49 (note it is presented against distance and therefore the stops for idling are not shown).

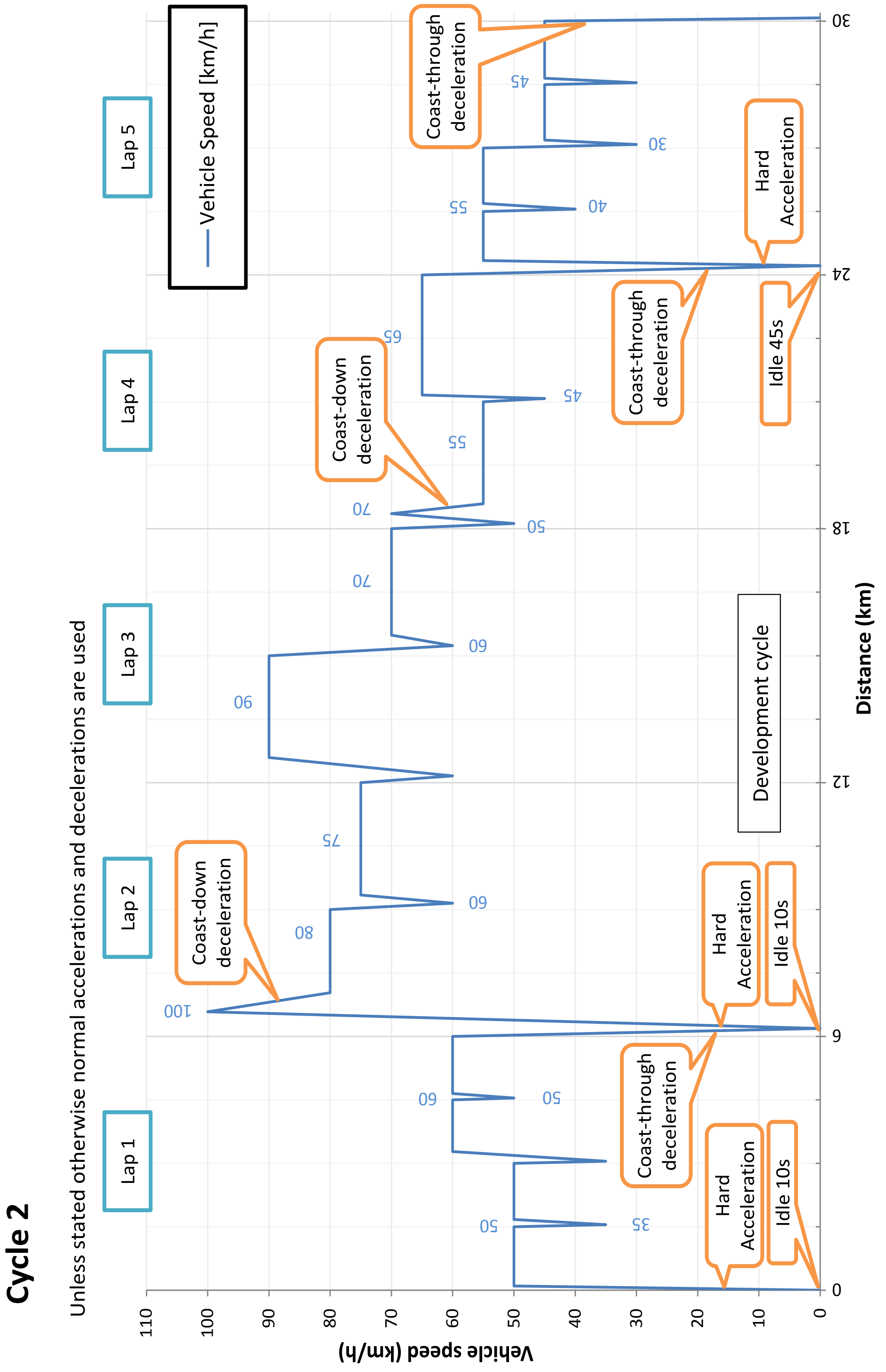


Figure 7-49: SRC-LeCV cycle 2 (phase 3) (development cycle)

8 Revalidation of SRC-LeCV - Phase 3 testing

This Section presents the findings from the testing of the phase 3 version of the SRC-LeCV durability distance accumulation cycle developed (See Section 7).

The phase 2 version of the SRC-LeCV (see Section 4) was previously presented to stakeholders and assessed via a validation programme on a select range of L-category vehicles. The comments from stakeholders and results from these tests informed changes that were fed into a third phase of the cycle development where the cycle and guidelines were adjusted accordingly.

Phase 3 (see Section 7.11) concluded that some issues did need to be resolved, specifically for the lower maximum speed vehicles. The following changes were made:

- The classification criteria was changed from category-based to vehicle characteristic-based, in line with the system in UN GTR No. 2 (WMTC)
- The expansion of the range of vehicles covered by cycles 1 and 2, and reduction of vehicles covered by cycle 3
- Adjustments to the acceleration and deceleration instructions
- The addition of a system of adjusting the deceleration periods for vehicles with relatively low maximum vehicle speeds
- Simplifying the execution of the cycle by initiating speed changes at specified points, rather than requiring the vehicle to be at a specific speed at fixed points
- The redesign of cycles 1 and 2 to account for the change in the vehicles to which it applies, and to encompass the added capabilities of the deceleration action readjustment system

The redesigned cycles are presented below in Figure 8.1 and Figure 8.2:

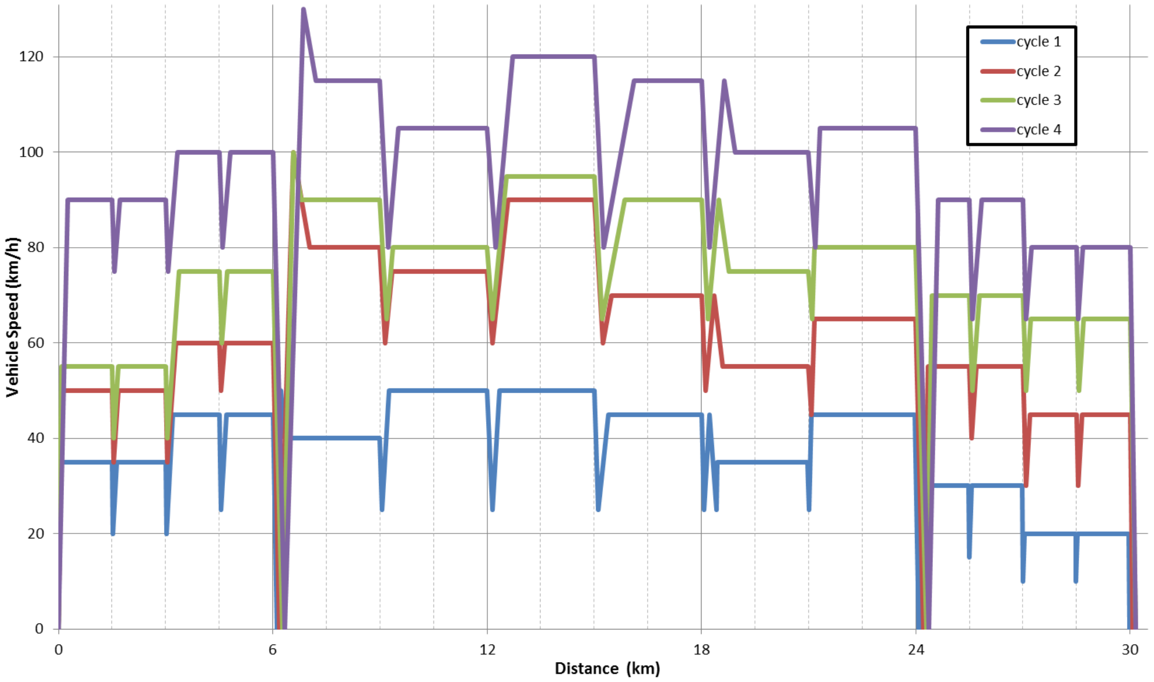


Figure 8.1: Example of SRC-LeCV Phase 3 cycles, vehicle speed vs. distance. The actual trace will depend on the capabilities of the vehicle under test

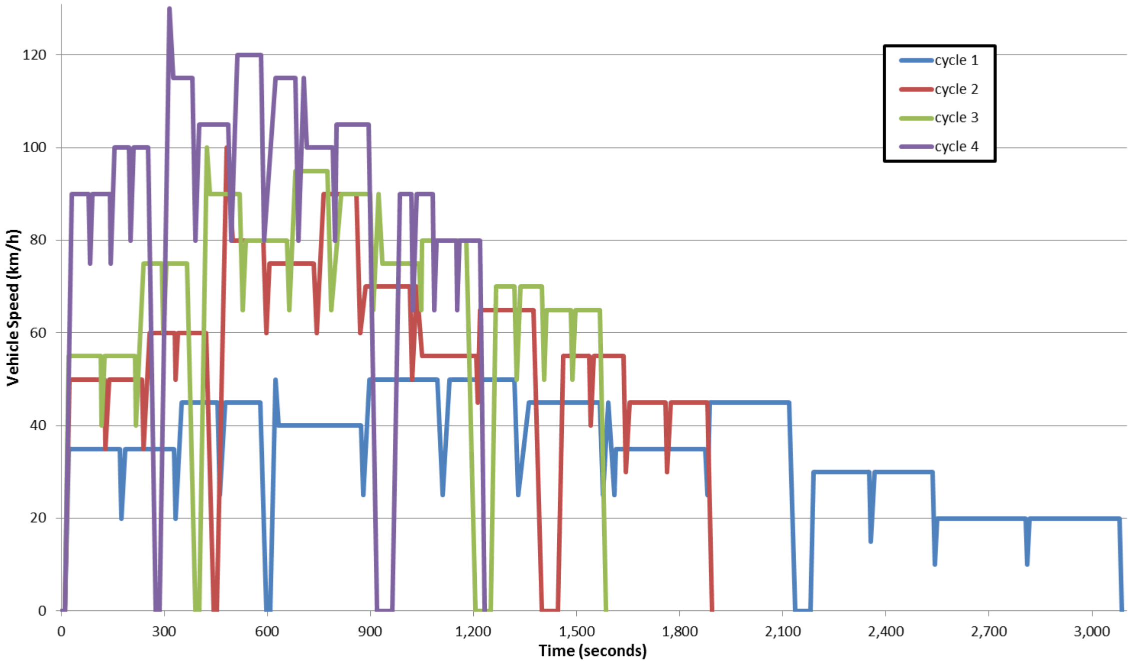


Figure 8.2: Example of SRC-LeCV Phase 3 cycles, vehicle speed vs. time. The actual trace and time will depend on the capabilities of the vehicle under test

As with phase 2, the cycles and guidelines developed in phase 3 were put through a validation process. This involved the test house (JRC) taking key vehicles, together with the updated test cycles and guidelines, and performing two iterations of the appropriate cycle. Other additional information was not provided. This was to ensure that the interpretation of the test was also evaluated and any mistakes in the execution of the cycles should be interpreted as a shortcoming of the guidelines.

Three vehicles previously used in the testing of the phase 2 validation (see Table 7-2 on p97) were chosen to assess whether changes to the cycles would rectify the issues identified in the phase 2 validation, and to check whether any other problems arose. These vehicles were: Vehicle 2 an L1Be moped restricted to ≤25 km/h, vehicle 3 an L1Be moped restricted to ≤45 km/h and vehicle 4 an L3e-A1 low-powered motorcycle (i.e. a 125cm^3).

The vehicles used the cycles allocated by the updated categorisation system. This meant that both mopeds performed the same cycle 1, but that the cycle now had a higher top vehicle speed of 50 km/h and a system to ensure deceleration duration stayed equal irrespective of the vehicle’s actual maximum vehicle speed. Additionally, the low-powered motorcycle now performed the new cycle 2, which has the same peak vehicle speed as the cycle 3, but with a lower vehicle speed bias to account for the higher proportion of lower speed riding while still utilising the vehicle’s full capabilities for a short period.

The validation process remained the same as it was for the phase 2 testing:

- To see if the cycles are driveable with respect to the ability of a tester to interpret and carry out the instructions
- To see if the cycles are feasible in regards to the types of use the vehicle’s would likely experience in the real-world

- This validation testing is not intended to instruct manufacturers on how they may need to design their vehicles to pass the test

Note: the vehicle numbering was the same as that for the validation of the phase 2 testing to aid comparison.

8.1 Test data

8.1.1 Vehicle 2 - L1Be ≤ 25 km/h, Phase 3 cycle 1

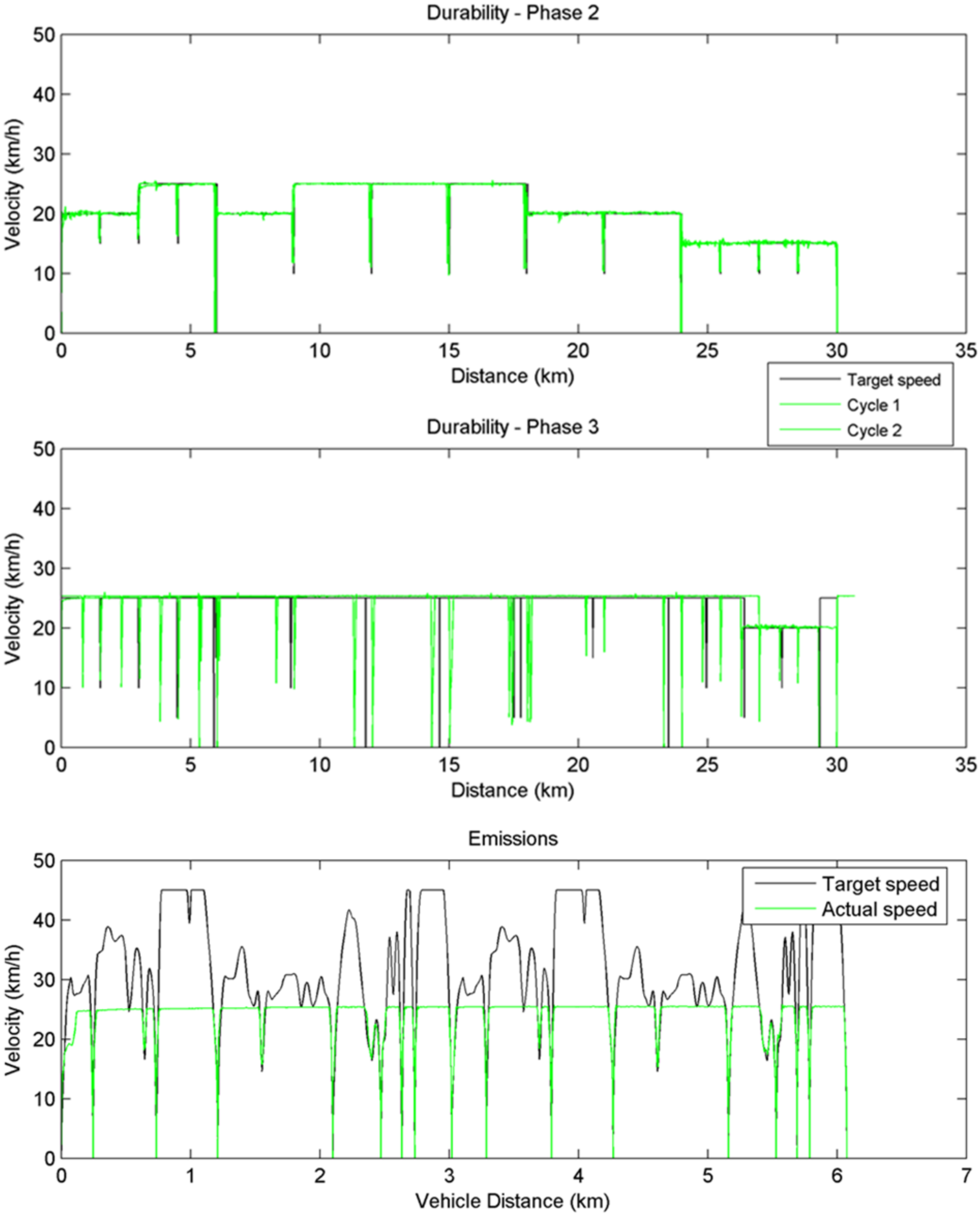


Figure 8.3: Vehicle 2 - L1Be ≤ 25 km/h, Phase 3 cycle 1, Type V phase 2, Type V phase 3 and Type I speed traces

Table 8.1: Vehicle 2 - L1Be ≤ 25 km/h, Phase 3 cycle 1, overview of speed data

		Type V phase 2	Type V phase 3	Type I
General stats	Average speed	20.1 km/h	23.3 km/h	21.4 km/h
	Max speed	25.6 km/h	26 km/h	25.8 km/h
	Time per cycle	90 minutes	79 minutes	20 minutes
	Distance per cycle	30 km	30 km	6 km

In Figure 8.3, the results from both the phase 2 and 3 durability distance accumulation tests as well as the UN GTR No. 2 WMTC emissions test are compared. Vehicle 2 is a low-powered moped limited to ≤25 km/h, therefore the cycle trace was adjusted to the vehicle’s capabilities in line with the updated phase 3 guidelines.

The vehicle capability based adjustment requires that the speed difference in decelerations and subsequent accelerations remains the same, irrespective of the maximum speed capabilities of the vehicle. This change allowed the phase 3 cycle 1 test on vehicle 2 to exhibit a speed trace which matched the actual speed trace seen in the WMTC much closer than the previous phase 2 cycle.

Regarding the driveability, the actual speed performed did still clip or exceed the target speed on occasion, especially during the decelerations. However, over the course of the test these variations averaged out. Variability of this form, deviating above and below the target speed in equal proportions is the preferred approach for durability distance accumulation, in contrast to an emission test where it is preferred to err on the side of caution in keeping to the target speed.

The temperature data (see Figure 8.4) also shows that the vehicle responded to the phase 3 cycle in a more similar way to the WMTC type I test compared to the phase 2 cycle. The peak pre-silencer temperatures of the phase 3 cycle and Type I test were only ±10°C apart. Disregarding the period where the vehicle was still warming, the post-silencer temperature in the durability cycle was ~50°C hotter for the majority of the test. Although this is a small margin, it does show that the Type V test exerts greater load onto the vehicle. Since the speeds are similar, this difference is likely to be the result of using an ‘instruction based procedure’, rather than a ‘trace following procedure’ as used in the Type I tests. This allowed the engine to be kept at a fixed throttle for an entire action, where a ‘trace following procedure’ would require some vehicles to let off the throttle to match a speed profile.

Table 8.2: Vehicle 2 - L1Be ≤ 25 km/h, Phase 3 cycle 1, maximum temperatures

		Type V phase 2	Type V phase 3	Type I
Maximum temp °C	Pre silencer	631	694	709
	Post silencer	419	509	452
	Oil	121	137	120

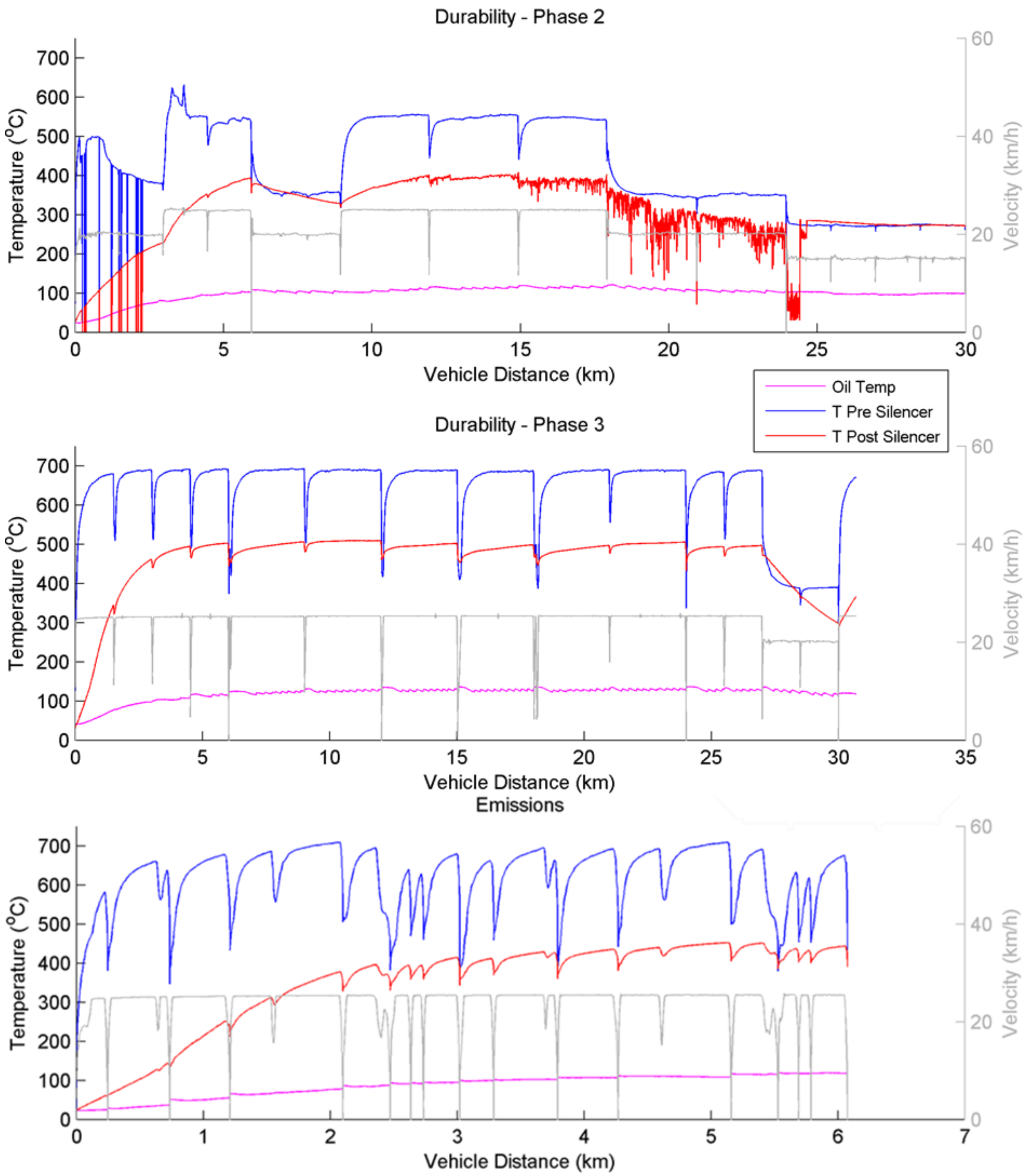


Figure 8.4: Vehicle 2 - L1Be ≤ 25 km/h, Phase 3 cycle 1, Type V phase 2, Type V phase 3 and Type I temperature traces

8.1.2 Vehicle 3 - L1Be, Phase 3 cycle 1

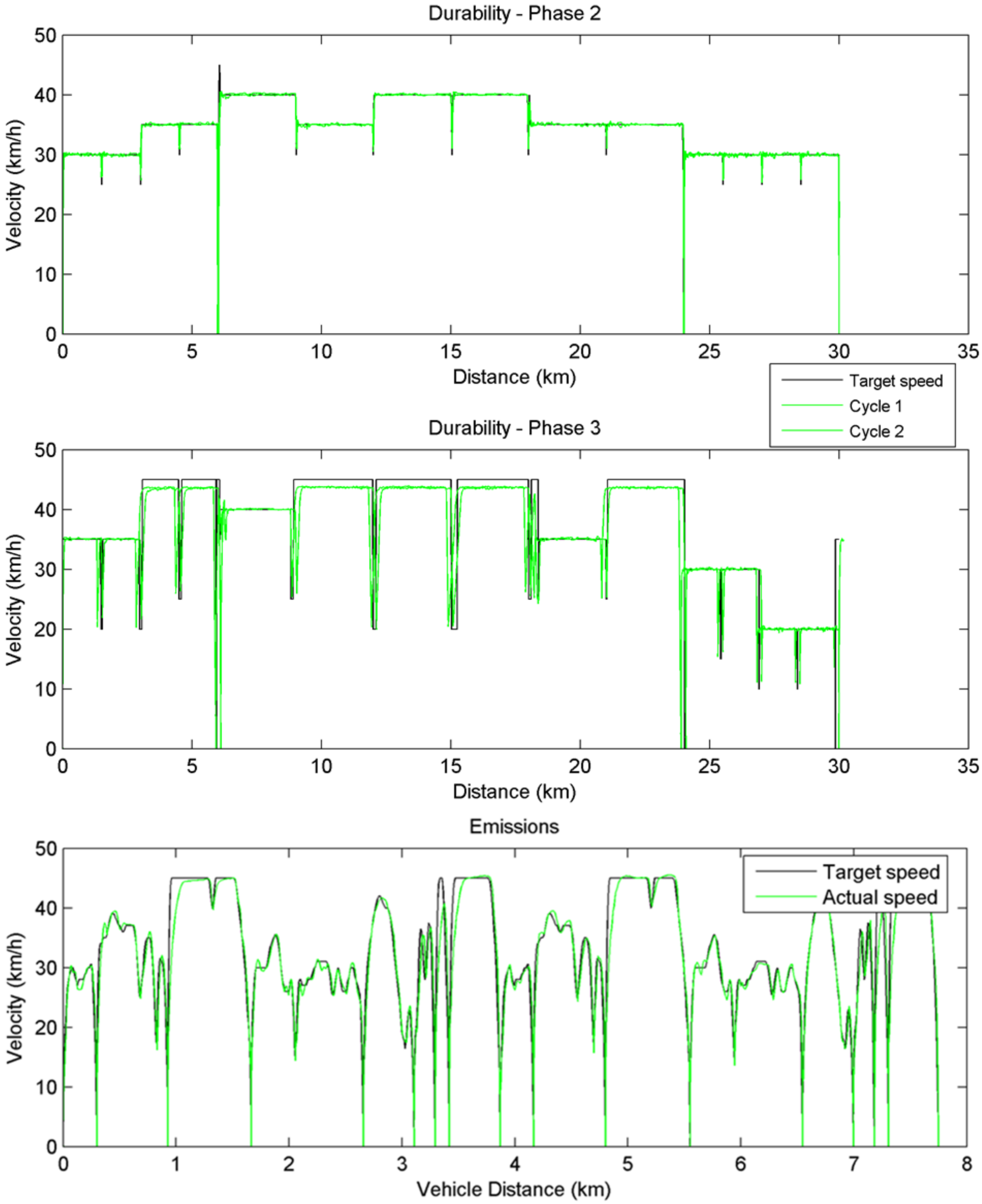


Figure 8.5: Vehicle 3 - L1Be, Phase 3 cycle 1, Type V phase 2, Type V phase 3 and Type I speed traces

Table 8.3: Vehicle 3 - L1Be, Phase 3 cycle 1, overview of speed data

		Type V phase 2	Type V phase 3	Type I
General stats	Average speed	34.2 km/h	34 km/h	27.7 km/h
	Max speed	40.7 km/h	44 km/h	45.5 km/h
	Time per cycle	54 minutes	56 minutes	20 minutes
	Distance per cycle	30 km	30 km	8 km

Vehicle 3 is a moped restricted to ≤45 km/h, and performed the same cycle 1 durability Type V test as vehicle 2. However, because it had a higher maximum vehicle speed, only 5 km/h needed to be taken of one peak and the two high vehicle speed cruising sections. This adjustment can be seen, with the additional acceleration bump at the 6 km point, as well as the slightly elongated decelerations at the 12 km and 15 km on the x axis on Figure 8.6.

In this case the vehicle performed more of the cycle at the vehicle's maximum speed than the WMTC Type I test, approximately 50% and 20% respectively. In the phase 2 test, the vehicle only reached its maximum vehicle speed for ~1% of the cycle. This difference shows the differing priorities of the two tests: the WMTC it is trying to obtain the emissions for the entire range of driving speeds and vehicle loads, whereas in the durability test higher vehicle speeds correspond to the higher loads and temperatures necessary to wear to emission-critical parts.

In the temperature data, the change to the cycle in phase 3 produced a response from the engine much closer to the type I test than the trace would suggest. Maximum temperatures for the pre and post silencer and oil were ~50°C apart between the type I and phase 3 type V tests (see Table 8.4 below).

Table 8.4: Vehicle 3 - L1Be, Phase 3 cycle 1, maximum temperatures

		Type V phase 2	Type V phase 3	Type I
Maximum temp °C	Pre silencer	561	708	674
	Post silencer	482	364	313
	Oil	96	115	90

Taking the full temperature plots in Figure 8.6, the similarities are seen to be even closer. Even with the differing proportions of maximum vehicle speed in the Type V test, the proportions of temperatures in the 700° area are only slightly more pronounced in the phase 3 cycle. Figure 8.6 shows that whenever the vehicle was not under full load, the pre silencer exhaust temperature dropped by 200-300°C, even if this was only a 5 km/h speed difference.

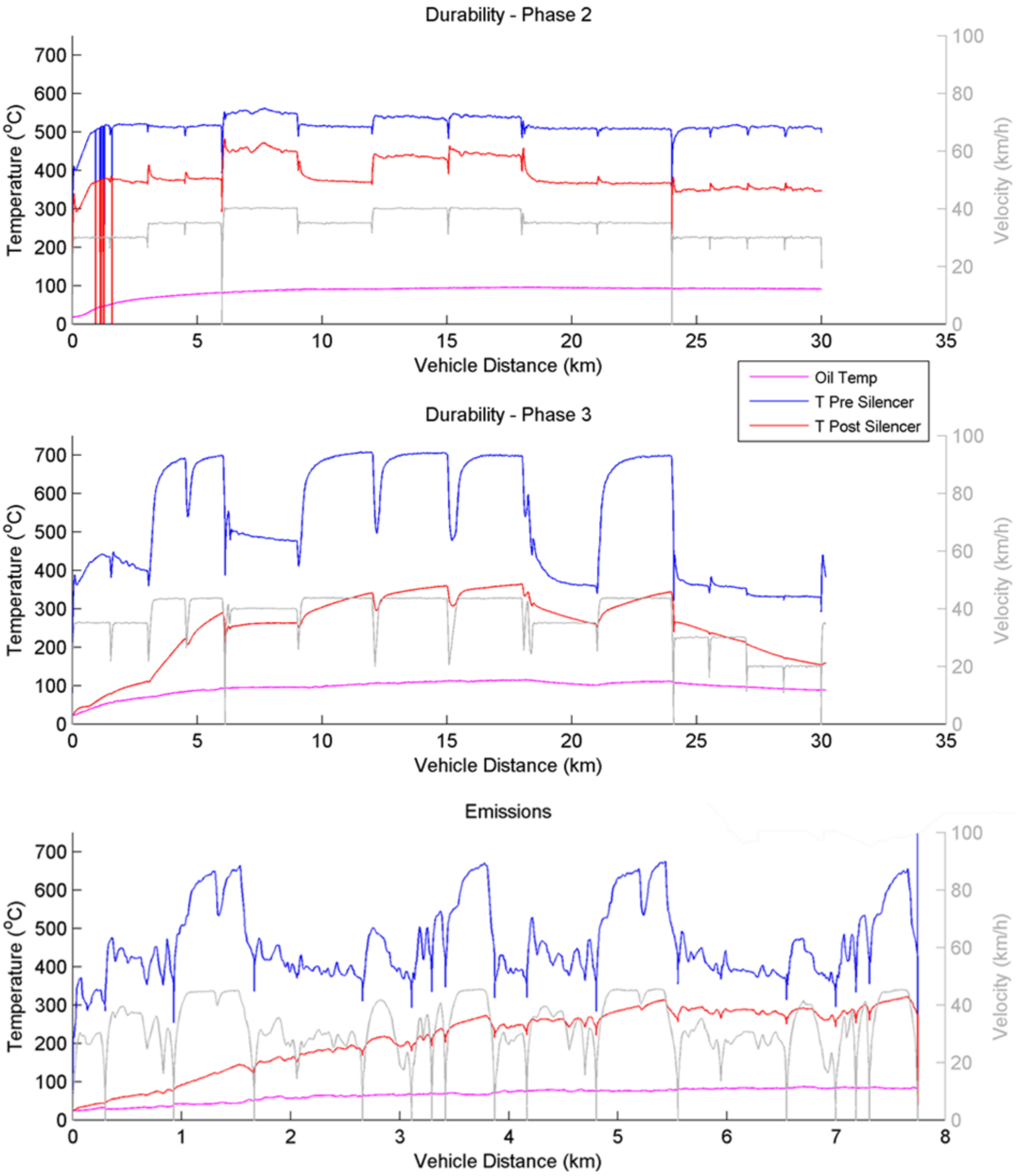


Figure 8.6: Vehicle 3 - L1Be, Phase 3 cycle 1, Type V phase 2, Type V phase 3 and Type I temperature traces

8.1.3 Vehicle 4 – L3e A1, Phase 3 cycle 2

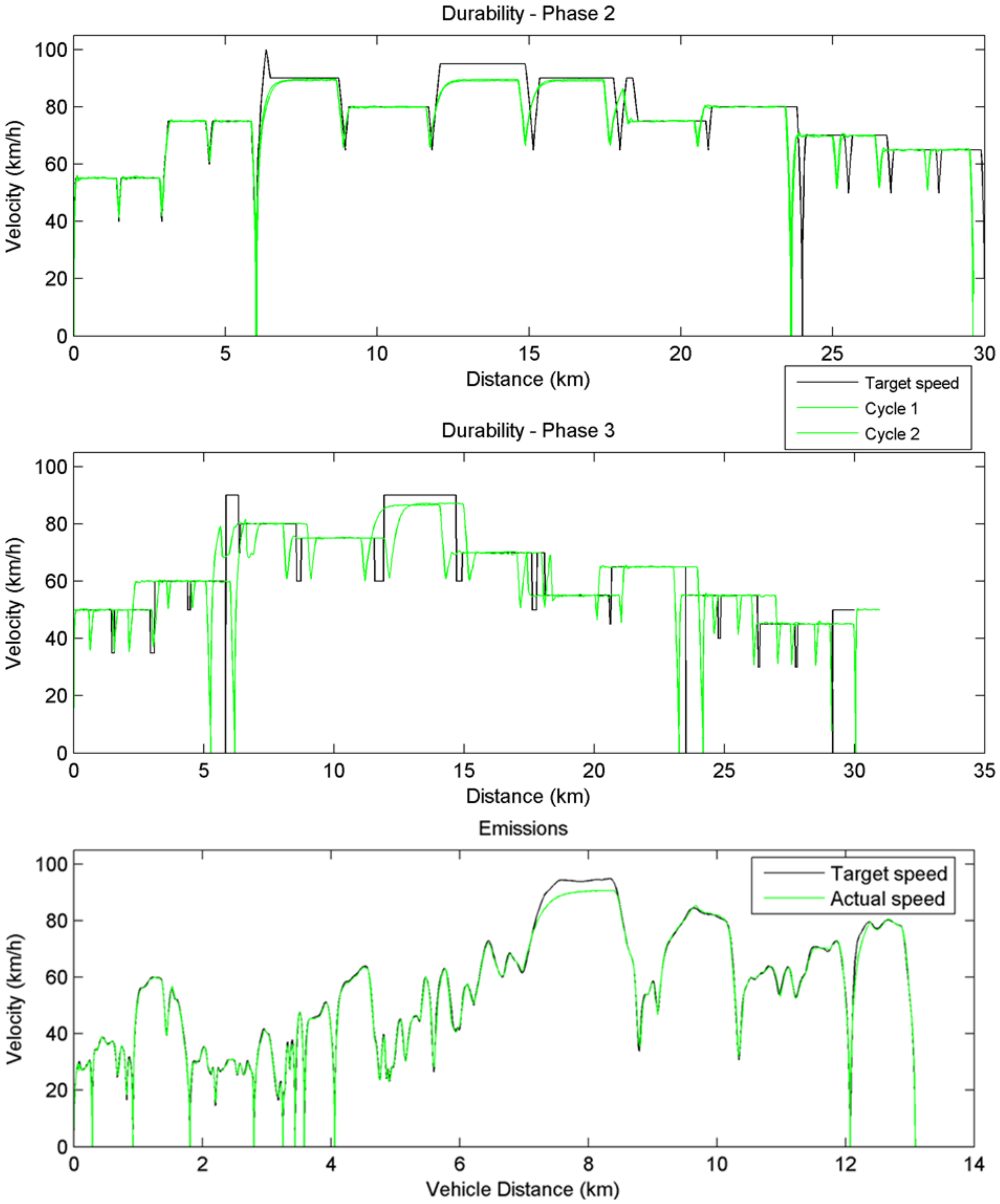


Figure 8.7: Vehicle 4 – L3e A1, Phase 3 cycle 2, Type V phase 2, Type V phase 3 and Type I speed traces

Table 8.5: Vehicle 4 – L3e A1, Phase 3 cycle 2, overview of speed data

		Type V phase 2	Type V phase 3	Type I
General stats	Average speed	71.6 km/h	57 km/h	43.9 km/h
	Max speed	89.8 km/h	87 km/h	90.6 km/h
	Time per cycle	26 minutes	33 minutes	20 minutes
	Distance per cycle	30 km	30 km	13 km

Vehicle 4 is a low powered motorcycle, colloquially referred to as a 125 in reference to its maximum engine capacity. It was with a vehicle of this type which was shown by a stakeholder to have issues with cycle 3. This type of vehicle was originally assigned to cycle 3 under the phase 2 rules based on category and not performance, however under the phase 3 rules (based on the UN GTR No. 2 classification system) having an engine capacity <150 cm^3 and maximum vehicle speed <100 km/h require the vehicle to instead perform the cycle 2.

As vehicle 4 has a maximum vehicle speed of ~90 km/h, only one point in the test needed to be scaled down; a peak following a full throttle acceleration to 100 km/h at the start of lap 2 (6km).

Examination of the data showed that at the peak in lap 2 there was an error in execution, where the acceleration was not performed to the maximum of the vehicle’s capability. The distance covered during the deceleration to 0 km/h at the end of lap 1 and subsequent acceleration, meant that the time based instruction system became out of synchronisation with the distance-based instructions. Consequently, the test rider did not see the instruction and mistakenly failed to accelerate to the maximum vehicle speed. In addition, the following instruction of decelerating by 20 km/h was not performed; instead the test rider decelerated “to” 70 km/h.

This error in the first peak was repeated in the second iteration of the cycle; however all other instructions in the experiment were performed correctly, even when the instructions became out of synchronisation. It can therefore be assumed that there was a misinterpretation of the instructions. This will be examined further in Section 8.2.

The temperature measurements on this vehicle indicates a closer match between the phase 3 Type V and Type I tests. When taking into account the warming up period in the Type I test, which is more noticeable with the differing x-axis scale, not only are the maximum temperatures comparable (see Table 8.6), the proportions of temperatures and seem to be also (see Figure 8.8). The temperature changes are not as pronounced in the Type V test except during the full decelerations to idle. However, it should be remembered that the vehicle will repeat these actions multiple times and should therefore provide the required thermal shock proportions for this situation.

Table 8.6: Vehicle 4 – L3e A1, Phase 3 cycle 2, maximum temperatures

		Type V phase 2	Type V phase 3	Type I
Maximum temp °C	Pre silencer	632	620	663
	Post silencer	527	520	357
	Oil	119	115	104

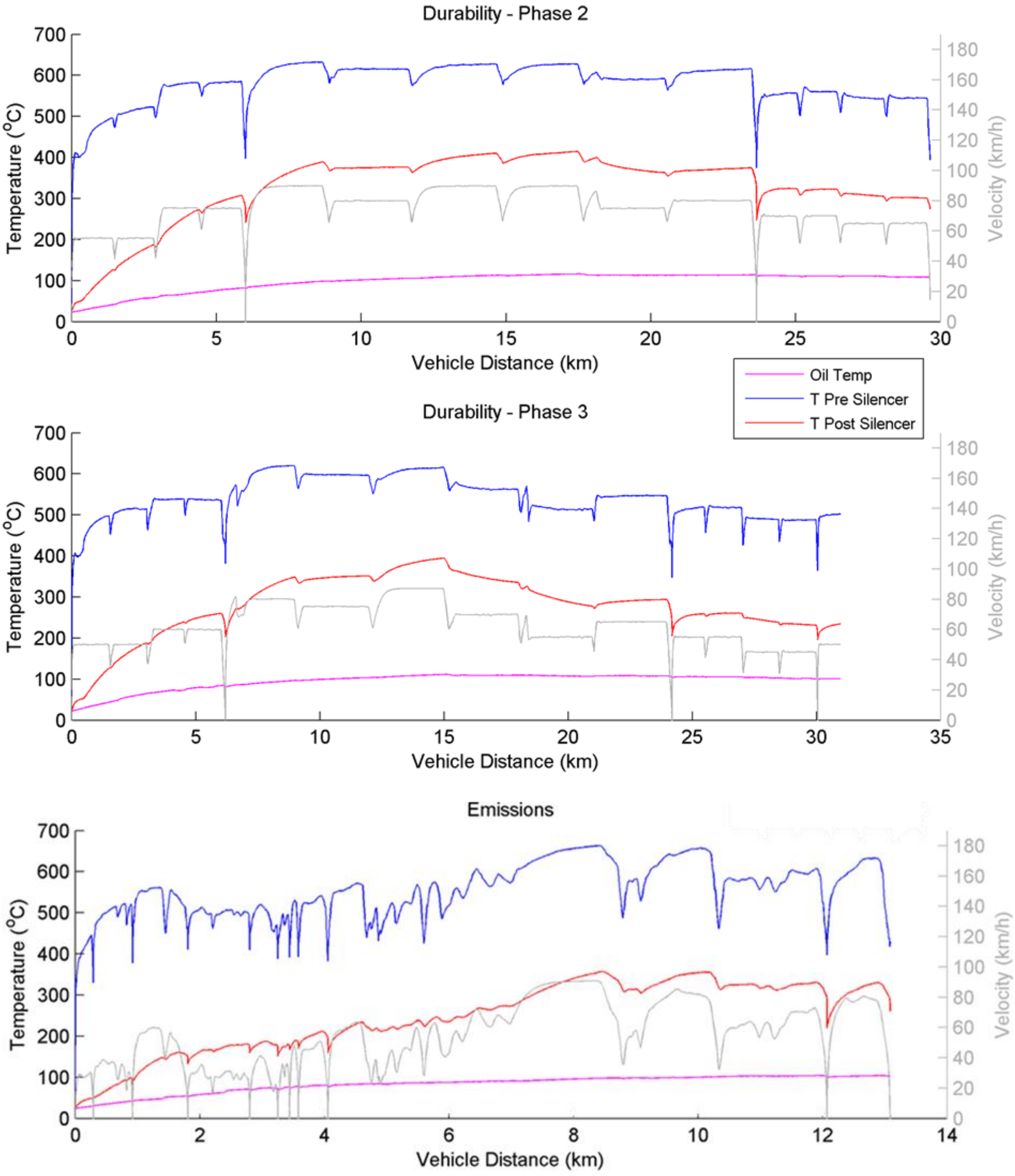


Figure 8.8: Vehicle 4 – L3e A1, Phase 3 cycle 2, Type V phase 2, Type V phase 3 and Type I temperature traces

8.2 Test analysis

8.2.1 Deceleration instructions

The new deceleration methodology used in phase 3 required that the vehicle be decelerated “by” a certain speed from the “actual” speed attained in the previous action. This was shown to be a much more practical way to implement the declarations into the cycle.

For the validation process this was done in the rider instruction display software, based on the maximum vehicle speed and did not take into account the actual point by point capabilities of the vehicle. For instance, while the vehicle was warming up, the vehicle is likely to have had a slightly lower maximum speed. This reduced performance may even occur at other points, as a protection mechanism when the vehicle is very hot.

It can be seen that trying to calculate the required change in speed while riding is a difficult proposition to request of the test rider.

No other issues were seen with the cycles and guidelines as part of this min-validation programme.

8.3 Proposed changes to cycles

This validation programme has validated the phase 3 versions of the SRC-LeCV cycles 1 and 2 and shown that the changes made to the cycle, together with the changes to the instructions and the specific cycle followed by different L-category vehicles are technically feasible and achieve the technical aims.

The only area of concern, deceleration speed changes (see Section 8.2), is an area that has already been highlighted in the ‘phase 2 validation’ - that of using a time-based set of instructions used by the test rider. However, this also highlights the difficulties for the test rider to calculate deceleration rates based on previous actions while executing the test. If this is the case, it should be highlighted that, with the approval of the test authority, manufacturers may tune the test rider’s instructions during the test if they find the actual performance of the vehicle deviates significantly from that demanded by the cycle.

8.4 Time duration required for new cycles

To estimate the time that would be required to run the new cycles, calculations were made to provide some initial estimates (see Table **8-7**). These estimates assumed that the cycles were run 24 hours a day, seven days a week and therefore took no account of maintenance or rest periods. In addition distance accumulated during emission testing has not been subtracted. However, this analysis provides an indication of the cycle time required to complete the full distance durability cycles. Of course, the manufacturer may choose to perform a partial distance. In this case, the time required would be 50% of that in this example.

Table **8-7** shows that, as well as the applicable durability distance, the time taken to complete the durability distance is strongly dependent on the maximum speed of the vehicle under test. The table provides some comparisons between vehicles in the same sub-category, but which have different speed capabilities.

Table 8-7: Estimated time durations required for full durability distance

Vehicle category	Vehicle category name	Durability distance (km) Euro 4	Sub-cycles [#]	Est V_{max} [km/h]	Cycle	Time/sub-cycle [h:m]	Total time [d, h:m]
L1Ae	Powered cycle	5,500	182	15	1	2:04	15, 16:26
L1Ae	Powered cycle	5,500	182	25	1	1:16	09, 17:12
L1Be	Two-wheel moped <25 km/h	11,000	365	15	1	2:04	31, 10:56
L1Be	Two-wheel moped <25 km/h	11,000	365	25	1	1:16	19, 11:42
L1Be	Two-wheel moped <45 km/h	11,000	365	30	1	1:05	16, 16:29
L1Be	Two-wheel moped <45 km/h	11,000	365	45	1	0:52	13, 06:09
L2e	Three-wheel moped	11,000	365	30	1	1:05	16, 16:29
L2e	Three-wheel moped	11,000	365	45	1	0:52	13, 06:09
L3e	Two-wheel motorcycle (v_{max}<130 km/h)	20,000	664	90	2	0:31	14, 13:09
L3e	Two-wheel motorcycle (v_{max}<130 km/h)	20,000	664	100	3	0:26	12, 04:09
L3e	Two-wheel motorcycle (v_{max}>130 km/h)	35,000	1,162	130	4	0:20	16, 13:39
L3e-AxE	Two-wheel Enduro motorcycle (x=1, 2, 3)	11,000	365	90	2	0:31	07, 23:55
L3e-AxE	Two-wheel Enduro motorcycle (x=1, 2, 3)	11,000	365	100	3	0:26	06, 16:36
L3e-AxE	Two-wheel Enduro motorcycle (x=1, 2, 3)	11,000	365	130	4	0:20	05, 04:54
L3e-AxT	Two-wheel trial motorcycle (x=1, 2, 3)	5,500	182	90	2	0:31	03, 23:42
L3e-AxT	Two-wheel trial motorcycle (x=1, 2, 3)	5,500	182	100	3	0:26	03, 08:04
L3e-AxT	Two-wheel trial motorcycle (x=1, 2, 3)	5,500	182	130	4	0:20	02, 14:17
L4e	Two-wheel motorcycle with sidecar (v_{max}<130 km/h)	20,000	664	90	2	0:31	14, 13:09
L4e	Two-wheel motorcycle with sidecar (v_{max}<130 km/h)	35,000	1,162	100	3	0:26	21, 07:16
L4e	Two-wheel motorcycle with sidecar (v_{max}>130 km/h)	35,000	1,162	130	4	0:20	16, 13:39
L5e	Tricycle	20,000	664	90	2	0:31	14, 13:09
L5e	Tricycle	20,000	664	100	3	0:26	12, 04:09
L5e	Tricycle	20,000	664	130	4	0:20	09, 11:14
L6Ae	Light on-road quad	11,000	365	30	1	1:05	16, 16:29
L6Ae	Light on-road quad	11,000	365	45	1	0:52	13, 06:09
L6Be	Light quadri-mobile	20,000	664	30	1	1:05	30, 08:33
L6Be	Light quadri-mobile	20,000	664	45	1	0:52	24, 02:47
L7Ae	Heavy on-road quad	35,000	1,162	70	2	0:32	26, 09:56
L7Ae	Heavy on-road quad	35,000	1,162	90	2	0:31	25, 11:01
L7Ae	Heavy on-road quad	35,000	1,162	130	4	0:20	16, 13:39
L7Be	All-terrain vehicles	20,000	664	70	2	0:32	15, 02:14
L7Be	All-terrain vehicles	20,000	664	90	2	0:31	14, 13:09
L7Ce	Heavy quadri-mobile	20,000	664	70	2	0:32	15, 02:14
L7Ce	Heavy quadri-mobile	20,000	664	90	2	0:31	14, 13:09

9 Durability of pollution control devices requirements

This section provides a summary of the draft text for the test Type V (durability of pollution control devices) requirements. It is included to help the reader understand further how the SRC-LeCV cycles will be incorporated into the wider requirements. In principle, the specific implementation of requirements should be in line with existing durability procedures wherever possible. The following sections present a number of important considerations with respect to the implementation of the durability procedure.

The final SRC-LeCV cycles are presented in Appendix Q.

9.1 Distance accumulation methods

The following provides a summary of the durability testing with mileage accumulation procedure, firstly in overview and then for each specific option. Important considerations concerning the accumulation of durability distance are presented below. These include the characteristics of the track used, showing restrictions as well as flexibility. In addition, articles that would help a test rider perform the cycle are provided.

9.1.1 General

- The Standard Road Cycle for L-Category Vehicles (SRC-LeCV) is a kilometre accumulation cycle in order to age L-category vehicles and in particular their pollution control devices in a defined and repeatable way.
- The SRC-LeCV shall consist of 5 laps of a 6 km course.
- There are 4 versions of the SRC-LeCV (phase 3) cycle. The appropriate cycle should be chosen based on the classification system in Table 9-1. This classification has been derived from UN GTR No. 2 stage 3 (revised WMTC).
- The manufacturer may request to alternatively perform the next higher numbered cycle with the agreement of the approval authority if they feel it better represents the real-world use of that vehicle.
- No stopping is permitted mid cycle.
- The test vehicle(s) may follow the SRC-LeCV on the road, on a test track or on a chassis dynamometer.
- If performed on a track or road:
    - The test track or test road shall be selected at the discretion of the manufacturer.
    - The track or road selected should be shaped to not significantly hinder the proper execution of the test instructions.
    - The route used should form a loop to allow continuous execution.
    - Track lengths which are multiples, half or quarter of this length are permitted. The length of the lap may be changed to accommodate the length of the mileage accumulation track or road.
    - Four points should be marked or landmarks identified, on the track or road which equate to quarter intervals of the lap.

  - The distance accumulated shall be calculated from the number of cycles required to complete the test distance. This calculation shall take into account the length of the road or track and chosen lap length. Alternatively an electronic means of accurately measuring the actual distance travelled may be used. The vehicles odometer shall not be used.
- If performed on a chassis dynamometer:
  - In particular, the chassis dynamometer shall be equipped with systems, equivalent as used in the Type I emission laboratory test set-out in Annex I of Regulation (EU) No [xxx/2013], simulating the same inertia and resistance to progress. Emission analysis equipment is not required for mileage accumulation. The same inertia and flywheel settings and calibration procedures shall be used for the chassis dynamometer used to accumulate mileage with the test vehicle(s) as set-out in Annex I.
  - The test vehicle(s) may be moved to a different bench in order to conduct Type I emission verification tests.
  - This dynamometer shall enable the durability mileage accumulation cycle set-out in Appendix 1 or 2, as applicable, to be carried out.
  - A dynamometer should be configured such that when ¼ intervals of 6 km are passed this is indicated to the test rider or robot rider to specify when to proceed with the following set of actions.
  - A timer displaying seconds should also be made available for execution of the idling periods.
  - The distance travelled shall be calculated from the number of rotations of the roller and the roller circumference.
- With the agreement of the testing authority, the manufacturer is permitted to implement additional restrictions to gain compatibility with other regions test requirements, as long as they do not impede the scientific integrity of this test procedure. For instance, additional tests may be performed in addition to but not replacing those required herein.

9.1.2 Vehicle

Important considerations concerning the test vehicles are presented below. This section details the condition of the vehicle at the start and is in line with similar requirements of other Type V tests, followed by preparations required before testing and finally certain considerations that are required when performing the cycle.

- The test vehicle(s)' cooling system shall enable the vehicle to operate at temperatures similar to those experienced in normal road use conditions (oil, coolant, exhaust system etc.).
- If the durability test is completed on a test track or road, the test vehicle's reference mass shall be at least equal to that retained for Type I emission tests conducted on a chassis dynamometer.
- If approved by the technical service the Type V test procedure may be carried out using a test vehicle, which has a different body style, gear box (automatic or

manual) and size of the wheels or tyres, from those of the vehicle type for which the type approval is sought.

- The test vehicle(s) used for the durability testing and in particular the pollution control and peripheral devices that are relevant for the emission abatement system shall be representative for the vehicle type produced in series and placed on the market.

9.1.2.1 *Preparation*

- The pollution control devices on the test vehicle(s) shall be permanently marked before start of mileage accumulation and be listed together with the vehicle identification number, the software used and the calibration sets of the test vehicle(s). Upon request of the approval authority, the manufacturer shall make that list available.
- The test vehicle(s) shall be in good mechanical order at the start of mileage accumulation and it shall not have more than 100 km accumulated after it was first started at the end of the production line. The propulsion and the pollution control devices shall not have been used since its manufacture, with the exception of quality control tests and accumulation of the first 100 km.
- For all mileage accumulation, regardless of the selected durability test procedure by the manufacturer, all pollution control devices and systems, both including hardware and software, fitted on the test vehicle(s) shall be installed and operating for the entire mileage accumulation period.
- The durability test shall be conducted with a suitable commercially available fuel according to the guidance provided by the manufacturer to the consumer. If the test vehicle(s) is equipped with a two-stroke engine, lubricating oil shall be used in the proportion and of the grade according to the guidance provided by the manufacturer to the consumer.

9.1.3 Instruction definitions

- The definitions of the instructions used in the SRC-LeCV:
    - Idle instructions
        - If not already stopped the vehicle should decelerate to a stop. Take the vehicle out of gear. Release the throttle fully. Do not turn off the ignition.
        - Do not prepare the vehicle for the following action until the full required duration has passed.
    - Acceleration instructions
        - Accelerate to required vehicle speed using sub-action methodologies below. If the vehicle is unable to reach the required speed use WoT throttle (and if available other user selectable options) to attain the vehicle’s maximum vehicle speed.
        - Moderate: Normal (part-load) acceleration, up to approximately half throttle.

        - Hard: High acceleration (part-load), up to full throttle.
    - Deceleration instructions
        - Decelerate by amount required from either: the previous action OR the maximum vehicle speed attained in the previous action, whichever is lower.
        - If to perform the deceleration the vehicle would reach 0 km/h, the vehicle must be stopped before proceeding to the following action. No additional idling periods can be performed beyond what is required to prepare for moving off.
        - Moderate: Normal let-off of the throttle. Brakes, gears and clutch allowed as required. If possible, keep the vehicle in gear and throttle low-to-off.
        - Coast-through: Full let-off of the throttle, clutch disengaged and in-gear (i.e. no foot/hand control actuated), no brakes. If the target speed is 0 km/h (idle) and if the actual vehicle speed ≤ 5 km/h it is allowed to engage the clutch, to shift to neutral and to use the brakes in order to prevent engine stall and to entirely stop the vehicle. An upshift is not allowed during a coast-through deceleration. The rider may downshift to increase the braking effect of the engine. During gear changes, extra care shall be afforded to ensure that the gear change is performed promptly, with minimum coasting in neutral gear, clutch and partial clutch use, i.e. <2 s. The vehicle manufacturer may request to extend this time at the agreement of the approval authority if absolutely necessary.
        - Coast-down: A deceleration shall be initiated by de-clutching (i.e. separating the drive from the wheels) without the use of brakes until the target vehicle speed is reached.
        - Except where specified otherwise, the gear change procedure as laid down in Annex I of Regulation (EU) No [xxx/2012] shall be used. The vehicle manufacturer is permitted to adapt them at the agreement of the approval authority if absolutely necessary.
    - Cruise instructions
        - Accelerate or decelerate as required to meet required vehicle speed.
        - Throttle as required to attain and stay at required vehicle speed.
- An instruction should be performed in its entirety. Additional idling time, acceleration to above and deceleration to below the required vehicle speed is permitted in order to ensure that the requirement of an action was performed.
- Gear changes should be carried out according to the guidance laid down in paragraph 4.5.5. to Annex I of Regulation (EU) No [xxx/2013]. Alternatively, guidance provided by the manufacturer to the consumer may be used if approved by the type approval authority.

9.1.4 *Driving style*

- Whenever the test vehicle(s) cannot achieve or reach the desired vehicle speeds set out in the applicable SRC-LeCV accumulation test cycle, the vehicle should be operated at its maximum attainable speed instead.
- If the following action is 'cruise' then the vehicle is permitted to be accelerated to attain the required vehicle speed.
- If moderate acceleration is no longer able to provide a noticeable increase in speed to reach a desired speed, then hard acceleration may be used.
- Maintenance, adjustments and the use of the controls of the test vehicle(s) shall be those recommended by the manufacturer.

9.2 Type I tests

An important consideration concerning the emission test is presented below. These rules are in line with current Type V test. The following has been designed to help ease harmonisation between regions without a penalty to the manufacturer.

- The Type I emission verification tests prior, during and after finishing durability mileage accumulation shall be conducted as per the requirements of the applicable Type I test.
- If the Type I test requires additional testing based on the magnitude of divergence between limits and result, the limits shall be multiplied by the fixed factors set out in part B of Annex VII of Regulation (EU) No [xxx/2013].
- The manufacturer is permitted to perform additional tests up to the number of tests permitted by the Type I test.
- Should multiple tests be taken at each mileage accumulation test point, the arithmetic mean of the Type I emission test results shall be taken as a single point used in any calculations. All arithmetic mean Type I emissions test results shall be plotted per emission constituent THC, CO, NO_x and if applicable NMHC and PM against accumulation distance rounded to the nearest kilometre.
- All Type I emission verification test results shall be listed and made available to the technical service upon request. The Type I emission verification test results for all tests completed during durability mileage accumulation shall be added to the information folder.
- The distance accumulated in all valid emissions tests shall be added to the tally of distance accumulated. Distance accumulated when travelling to/from test track/storage cannot be added to the tally of distance accumulated.
- All tests taken between stopping and restarting the durability distance accumulation shall be considered a single test point, with the exception of two tests performed either side of periodic maintenance.

9.3 Method (a): full distance accumulation

- An overview of the procedure is shown in Figure 9-1.
- For method (a), a vehicle passes the test by completing the full applicable distance and demonstrating during and at the end of the procedure that the

pollutants or emission limits were not exceeded for the relevant Type I emission laboratory test cycle.

- Multiple Type I emission tests shall be conducted during the mileage accumulation phase with a frequency and amount of Type I test procedures at the choice of the manufacturer. The Type I emission test results shall provide sufficient statistical relevance as to identify the deterioration trend, which shall be representative for the vehicle type placed on the market.

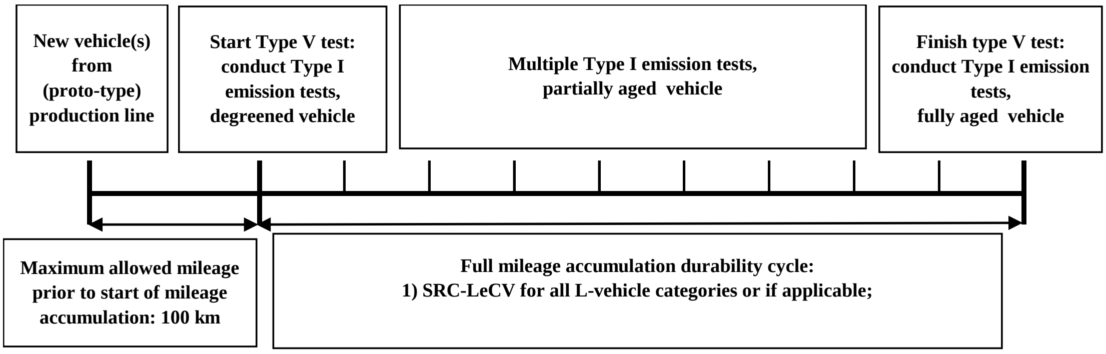


Figure 9-1: Test Type V, durability test procedure with full mileage accumulation

9.4 Method (b): partial distance accumulation

Important considerations concerning the partial distance durability accumulation are presented below. The legislation is designed to provide a good data set to accurately predict the future emissions of the vehicle without having to complete the full distance accumulation.

- Partial mileage accumulation shall mean the L-category vehicle completing a minimum of 50% of the test distance as specified by part A of Annex VII of Regulation (EU) No [xxx/2013] . This is also known as the accelerated durability test procedure of vehicles with partial mileage accumulation, refered to in paragraph 3(b) of Article 21.
- The intention is that at the choice of the manufacturer this accelerated durability test procedure may be conducted as an alternative to the durability test procedure with full mileage accumulation (see Section 9.3) laid down in order to provide evidence to the approval authority that the emission performance of a type approved L-category vehicle is durable and permissible.
- The manufacturer shall provide evidence that the emission limits in the applicable Type I emission laboratory test cycle, set out in Annex VI (A) to Regulation (EU) No [xxx/2013] of the tested aged vehicle(s) are not exceeded when starting mileage accumulation, during the mileage accumulation phase and after the partial or entire mileage accumulation has been finalised.

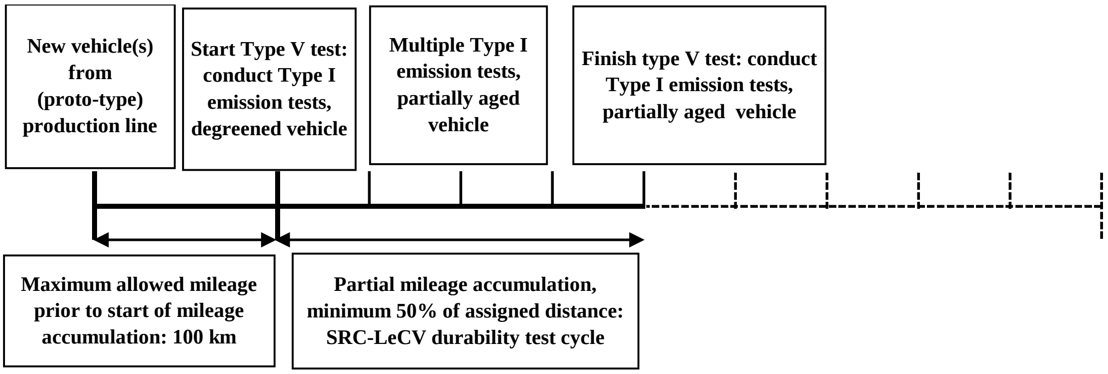


Figure 9-2: Test Type V, accelerated durability test procedure with partial mileage accumulation

- The SRC-LeCV shall be the only set of four durability mileage accumulation cycles to be used for partial mileage accumulation and is applicable to all L-category vehicles. One out of these four durability mileage accumulation cycles shall be conducted for mileage accumulation by the test vehicle(s) according to the technical details laid down in Annex xxx of Regulation (EU) No [xxx/2013].
- Stop criteria for partial mileage accumulation:
    - If a minimum of 50% of the applicable test distance laid down in part A of Annex VII of Regulation (EU) No [xxx/2013] has been accumulated; and
    - If all the Type I emission verification test results are below the emission limits laid down in Annex VI (A) to Regulation (EU) No [xxx/2013] at all times during the partial mileage accumulation phase; and
    - If the Type I emission verification test results extrapolated to full distances as specified by part A of Annex VII of Regulation (EU) No [xxx/2013] are below the emission limits laid down in Annex VI (A) to Regulation (EU) No [xxx/2013].

9.4.1 *Test points*

- Multiple Type I emission tests shall be conducted during mileage accumulation with a frequency and amount of Type I test procedures at the choice of the manufacturer. The Type I emission test results shall provide sufficient statistical relevance as to identify the deterioration trend, which shall be representative for the vehicle type placed on the market. Figure 9-2 outlines the process.
    - All vehicles shall undergo at least five Type I emission tests:
        - One on a de-greened vehicle, i.e. which has accumulated between 0 km and 100 km
        - One at half distance
        - Three at equal intervals between 0 km and half distance
        - Additionally, two tests shall be performed at either side of periodic maintenance (if applicable). It is permitted to align this with one of the five required tests so that only one additional test is needed.
        - Additional tests may be performed; such tests must be at equal intervals and approved by the approval authority prior to starting service accumulation.
    - Periodic maintenance conditions shall be carried out according to the guidance provided by the manufacturer to the consumer.
- Verfication of results

- All test results (or arithmetic mean of multiple tests at one test point) shall be used for the extrapolated DF calculation. At the request of the manufacturer excluding all tests taken before 20% of the durability mileage.
- The best fit linear line (trendline, y=ax+b) shall be fitted and drawn through all these data points based on the method of least squares. This best fit straight trendline shall be extrapolated over the full durability mileage as laid down in part A of Annex VII of Regulation (EU) No [xxx/2013]. At the request of the manufacturer the trendline may start as of 20% of the durability mileage laid down in part A of Annex VII of Regulation (EU) No [xxx/2013], in order to take into account possible run-in effects of the pollution control devices.
- The applicable emission limits as set out in Annex VI (A) to Regulation (EU) No [xxx/2012] shall be plotted in the graphs per emission constituent as set out in Paragraph 3.2.5.3.2. of Regulation (EU) No [xxx/2013] The plotted trend line referred to in Paragraph 3.2.5.3.2. shall not at any mileage data point exceed these applicable emission limits. The graph per emission constituent THC, CO, NO_x and if applicable NMHC and PM plotted against accumulation distance shall be attached to the information folder. The list with all the Type I emission test results used to establish the best fit straight trendline shall be made available to the technical service upon request.
- Figure 9-3 provides an example of the plotted Type I total hydrocarbon (THC) emission test results, the plotted Type I THC test limit and the best fit straight trend line of a Euro 4 motorcycle (L3e >130 km/h), all versus accumulated mileage. Please note that the first data point starts at 100 km and not at 0 km.

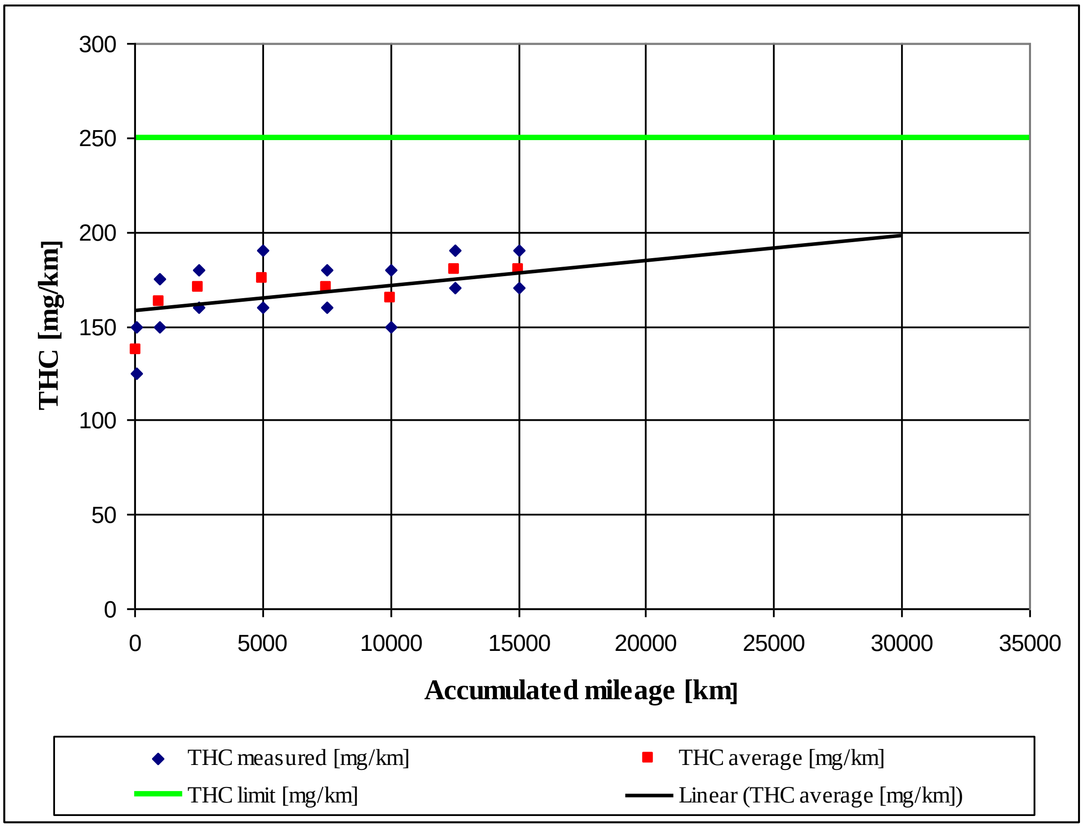


Figure 9-3: Theoretical example of the plotted Type I total hydrocarbon (THC) emission test results (tests up to 50% of full distance accumulated, results extrapolated to full distance)

- If the manufacturer cannot prove that the stop criteria set out in Paragraph 3.2.5 are met the mileage accumulation shall continue to the point where those stop criteria are met or mileage accumulation shall continue up to the fully accumulated mileage as set out in part A of Annex VII to Regulation (EU) No [xxx/2012].

9.4.2 *Golden parts*

- The pollutant control devices may be removed from the test vehicle(s) after the stop criteria are met and the Type V test procedure with partial mileage accumulation is completed. At the choice of the manufacturer, these 'golden parts' may be used for durability performance verification and approval demonstration on the same vehicle type later in the vehicle development cycle.
- Those 'golden parts' shall be permanently marked and the marking number, the associated Type I emission test results and the specifications shall be made available to the type approval authority upon request.
- In addition, the manufacturer shall mark and store new, non-aged emission relevant components with the same specifications as the ones from the 'golden parts' and make these available as a 'reference base' to the approval authority at the same time as a request is made for the 'golden parts' to be made available.
- The approval authority and technical service shall be permitted access at any point of time during or after the approval process, both to the 'golden parts' and 'new, non-aged' pollution control devices. The approval authority or technical service may request and witness a verification test carried out by the

manufacturer or may have the 'new, non-aged' and 'golden' pollution control devices tested by an independent test laboratory in a non-destructive way.

9.5 Method (c): mathematical durability procedure

A manufacturer may choose not to undertake any actual durability testing with mileage accumulation. In this situation Method (c) stipulates the following:

For each emission constituent, the product of the multiplication of the deterioration factor set out in part B of Annex VII and the environmental test result of a vehicle which has accumulated more than 100 km after it was first started at the end of the production line shall be lower than the environmental limit set out in part A of Annex VI. (EC, 2010)

This calculation shall be executed by multiplying the fixed factors set out in part B of Annex VII of Regulation (EU) No [xxx/2013] with the Type I emission test results of the de-greened test vehicle(s) (maximum accumulated mileage 100 km). Those calculated aged vehicle emission results shall not exceed the emission limits set out in Annex VI(A) to Regulation (EU) No [xxx/2013]. Those calculated emission results shall be added to the information folder.

9.6 Annexes

Figure 9-4 shows a highly simplified graphic of a possible test track configuration. Table 9-1 and Table 9-2 show the revised vehicle classification system and cycle instructions, as developed through the validation project and phase 3 of the test development.

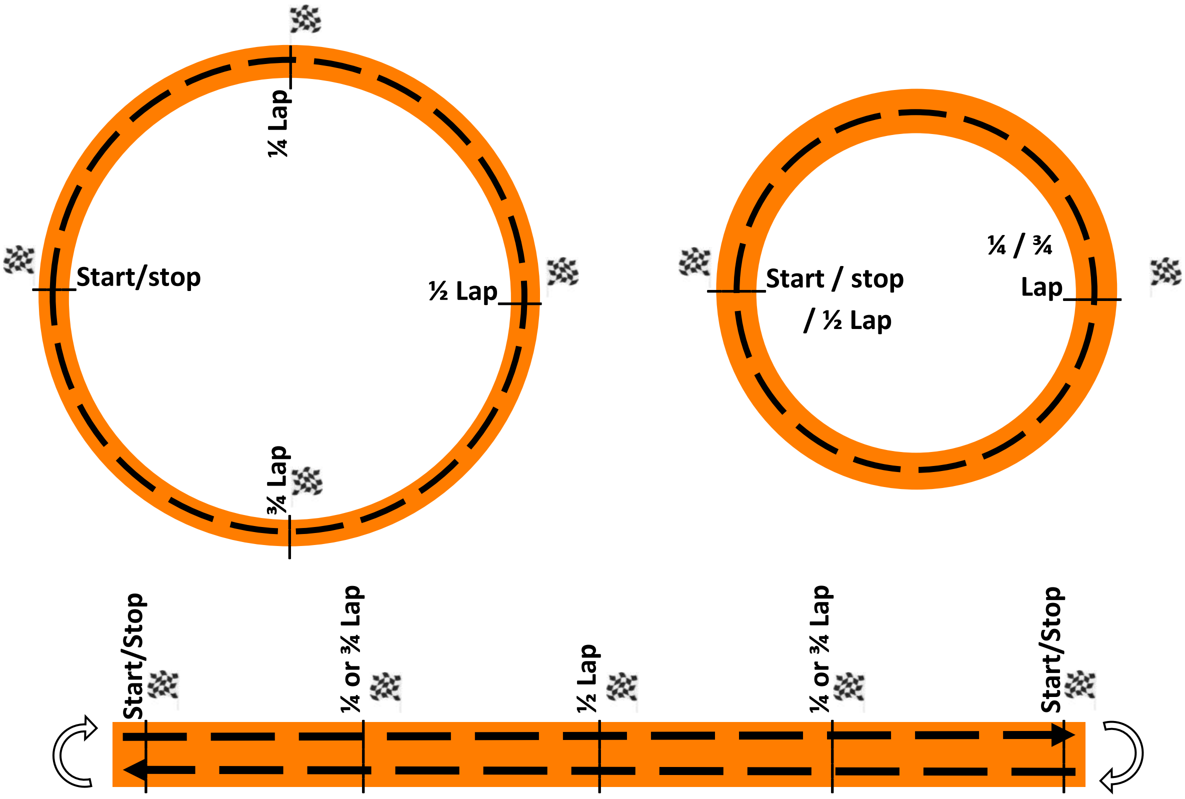


Figure 9-4: Test track configurations

Table 9-1: Vehicle classification system (derived from UN GTR No. 2 stage 3)

Cycle	WMTC Class	Vehicle maximum design speed	Vehicle engine capacity (PI)	Net power (alternative drive)
1	1	$v_{max} \leq 50$ km/h	$Vd \leq 50$ cm^3	≤ 6 kW
2		50 km/h $< v_{max} <$ 100 km/h	50 cm^3 $< Vd <$ 150 cm^3	< 14 kW
3	2	100 km/h $\leq v_{max} <$ 130 km/h	$Vd \geq 150$ cm^3	≥ 14 kW
4	3	130 km/h $\leq v_{max}$		

Where: Vd = engine displacement volume and v_{max} = maximum design speed (velocity)

Table 9-2: SRC-LeCV cycle instructions (Stage 3: 1 & 2. Stage 2: 3 & 4)

				Cycle:	1		2		3		4	
Lap	**Sub-lap**	**Action**	**Sub-action**	**Time**	**To/at**	**By**	**To/at**	**By**	**To/at**	**By**	**To/at**	**By**
1	1st 1/4			[s]	[km/h]							
		Stop & Idle		10								
		Accelerate	Hard		35		50		55		90	
		Cruise			35		50		55		90	
	2nd 1/4											
		Decelerate	Moderate			15		15		15		15
		Accelerate	Moderate		35		50		55		90	
		Cruise			35		50		55		90	
	3rd 1/4											
		Decelerate	Moderate			15		15		15		15
		Accelerate	Moderate		45		60		75		100	
		Cruise			45		60		75		100	
	4th 1/4											
		Decelerate	Moderate			20		10		15		20
		Accelerate	Moderate		45		60		75		100	
		Cruise			45		60		75		100	

				Cycle:	1		2		3		4	
Lap	**Sub-lap**	**Action**	**Sub- action**	**Time**	**To/at**	**By**	**To/at**	**By**	**To/at**	**By**	**To/at**	**By**
2	1st 1/2											
		Decelerate	Coast-through (Coast-thro')		0		0		0		0	
		Stop & Idle		10								
		Accelerate	Hard		50		100		100		130	
		Decelerate	Coast-down			10		20		10		15
		Optional acceleration	Hard		40		80		90		115	
		Cruise			40		80		90		115	
	2nd 1/2											
		Decelerate	Moderate			15		20		25		35
		Accelerate	Moderate		50		75		80		105	
		Cruise			50		75		80		105	
3	1st 1/2											
		Decelerate	Moderate			25		15		15		25
		Accelerate	Moderate		50		90		95		120	
		Cruise			50		90		95		120	
	2nd 1/2											
		Decelerate	Moderate			25		10		30		40
		Accelerate	Moderate		45		70		90		115	
		Cruise			45		70		90		115	

				Cycle:	1		2		3		4	
Lap	**Sub-lap**	**Action**	**Sub-action**	**Time**	**To/at**	**By**	**To/at**	**By**	**To/at**	**By**	**To/at**	**By**
4	1st 1/2											
		Decelerate	Moderate			20		20		25		35
		Accelerate	Moderate		45		70		90		115	
		Decelerate	Coast-down			20		15		15		15
		Optional acceleration	Moderate		35		55		75		100	
		Cruise			35		55		75		100	
	2nd 1/2											
		Decelerate	Moderate			10		10		10		20
		Accelerate	Moderate		45		65		80		105	
		Cruise			45		65		80		105	

				Cycle:	1		2		3		4	
Lap	**Sub-lap**	**Action**	**Sub-action**	**Time**	**To/at**	**By**	**To/at**	**By**	**To/at**	**By**	**To/at**	**By**
5	1st 1/4											
		Decelerate	Coast-thro’		0		0		0		0	
		Stop & Idle		45								
		Accelerate	Hard		30		55		70		90	
		Cruise			30		55		70		90	
	2nd 1/4											
		Decelerate	Moderate			15		15		20		25
		Accelerate	Moderate		30		55		70		90	
		Cruise			30		55		70		90	
	3rd 1/4											
		Decelerate	Moderate			20		25		20		25
		Accelerate	Moderate		20		45		65		80	
		Cruise			20		45		65		80	
	4th 1/4											
		Decelerate	Moderate			10		15		15		15
		Accelerate	Moderate		20		45		65		80	
		Cruise			20		45		65		80	
		Decelerate	Coast-thro’		0		0		0		0	

10 Conclusions and recommendations

The aim of this project was to define a mileage accumulation methodology that would appropriately test the durability of emissions relevant components and systems of L-category vehicles and to propose associated regulatory text capable of ensuring that the tailpipe emissions of regulated pollutants are below the required Euro stage limits at the end of the typical vehicle life. Furthermore, the objectives and technical challenges for were that the mileage accumulation methodology defined by the project should result in an emissions durability test that is:

- Challenging, aimed at controlling lifetime emissions from L-category vehicles, i.e. 'work' all the emission critical components in current vehicles;
- Practical, relatively easy to undertake and repeatable;
- Representative of real-world usage; and
- Efficient and not over-burdensome on manufacturers, especially with respect to SMEs.

An in-depth review of available international durability mileage accumulation cycles found that none were ideal for L-category vehicles in Europe. As a consequence, a new durability cycle (SRC-LeCV) was developed by this project which was designed to balance the aforementioned criteria.

To address the first objective, key degradation mechanisms were identified from a literature study and stakeholder consultation These degradation mechanisms were: thermal ageing of the pollution control devices (such as the catalytic converter and lambda sensor), poisoning of the pollution control devices, carbon deposits and mechanical wear, shocks and vibrations. Of these, thermal ageing of the pollution control devices was deemed important, with the temperature of those pollution control devices fitted in the exhaust being most closely related to engine load and thermal cycling, and to a lesser extent to engine or vehicle speed. Frequency of thermal cycling is linked to the pattern of the cycle, which in turn should be representative of the demands of real-world use. It was found that carbon deposits are predominately created at low engine loads and are no longer a major issue for current engines and fuels. However, they still play an important role in durability, both with older designs and with some newer fuelling techniques.

TRL compared existing US durability cycles for motorcycles (US EPA AMA) and those for cars and light goods vehicles (US EPA, EU and UN: SRC) and the world harmonised emissions laboratory test cycle for motorcycles (WMTC) in terms of the proportions of time (and distance) of the cycle spent at engine loads likely to lead to degradation of the emission critical parts. The WMTC was specifically developed to represent real-world use around the world, and therefore was used as a benchmark for both the analysis of current cycles and design of the proposed durability cycle(s). This found that the SRC shared a greater similarity with the varied real-world use represented in the WMTC emission cycle than the AMA, meaning that the SRC was a better basis for the design of a cycle representative with L-category vehicle use.

Testing carried out by the Commissions Joint Research Centre (JRC) according to the stage 3 (revised) WMTC, EDC / UN Regulation 47 and EDC / UN Regulation 40 emission test cycles showed that in these tests exhaust temperatures adjacent to the catalyst did not exceed 850°C. Previous studies have shown that modern catalysts remain durable after prolonged and realistic exposure to temperatures around 950°C (Pace L. J. F., 2011) (Pace L. R. A., 2008) (Twigg M., 2002) and current engine management systems are capable of protecting the catalyst and other exhaust components if the exhaust temperature rises temporarily above the design limit.

Using the key degradation mechanisms identified as important for the entire L-category fleet, a range of 4 cycles was developed. These "phase 1" cycles were reassessed against the objectives and this found that the burden to vehicle manufacturers was still significant and therefore was given greater priority over the inclusion of low engine load sections used for carbon deposit creation. A "phase 2" cycle was then developed which removed two slower speed sections from the test, changing them from 7 lap to 5 lap cycles so that they could be completed in a shorter period of time and would be less burdensome for manufacturers, especially SMEs where additional cost might reasonably be expected to have a proportionately greater effect. A comparison of estimated test cost between the SRC-LeCV (5 and 7 lap) and US AMA test cycle found that the SRC-LeCV was more cost-effective (for the 5 lap) or generally equivalent (for the 7 lap).

These "phase 2" cycles were published, including a categorisation system to match vehicles against the appropriate cycle that it should perform. Stakeholders were then able to provide feedback on a range of issues with the new cycles. This process highlighted that the categorisation system was not able to appropriately class the vehicles and some special fuelling regimes were not sufficiently addressed (such as mixture enrichment to protect the catalyst and DFCO).

A validation of the proposed "phase 2" cycles was carried out to ensure that vehicles across the L-category range could follow the relevant cycle and to check that the cycle invoked the intended ageing mechanisms. The result of this validation was that cycles 1 and 2 required further adjustment, the categorisation system was replaced with one aligned with that of the UN GTR No. 2 (WMTC), and changes were made to the instructions to both simplify the execution of the test and better ensure that the technical objectives of the test were carried out. This resulted in "phase 3" cycles which were revalidated to demonstrate their feasibility. This revalidation proved that cycles 1 and 2 were technically feasible to carry out, included features that induced relevant ageing mechanisms, and were appropriate for implementation.

The main conclusions of the study can be summarised as follows:

- The US EPA AMA motorcycle durability cycle developed in the 1970s does not reflect the current ageing mechanisms of the emissions system as well as the SRC durability cycle for cars.
- The SRC durability cycle for cars does not fully cater for the characteristics and performance of the entire L-category fleet. Therefore, a modified version of the SRC for passenger cars has been developed for L-category vehicles: the SRC-LeCV.
- The SRC-LeCV contains relevant degradation mechanisms for both modern pollution control devices fitted on L-category vehicles and less complex systems still in use, including: thermal ageing (highest priority), poisoning, mechanical wear of the engine (assumed worse at higher engine speed and load), carbon deposits (from bad combustion at low load engine operation etc.) and thermal shock from deceleration fuel cut-off (DFCO).

- The SRC-LeCV follows a journey which represents an averaged representation of real-world use, so that the proportions of degradation mechanisms contained are not accelerated, but balanced.
- The SRC-LeCV durability cycle has been demonstrated to be more cost-effective than the US durability standards for cars and motorcycles, and has been validated with respect to real-world applicability by correlation with the WMTC emission data.
- A balance was drawn between the various objectives of the programme, with special emphasis placed on a test cycle which induces relevant and realistic ageing and which can be carried out most efficiently.
- Options for the application of the durability cycle comprise comparison of emissions with limit values specified by COM 542(2010):
    - a) Direct measurement of emissions after the appropriate full durability distance specified by COM 542(2010)
    - b) Extrapolation of emission measurements taken after 50% of appropriate durability distance specified by COM 542(2010)
    - c) Initial emission measurements (Type I test) multiplied by fixed DFs specified by COM 542(2010)
- Four SRC-LeCV durability cycles were developed to cover all of the varying capabilities and designs of L-category vehicles.
- A supplementary test programme was carried out in which the SRC-LeCV was applied to a wide range of L-category vehicles as a validation exercise, investigating technical feasibility and providing confirmation of the theoretical analysis and conclusions contained within this report.
- The result of this validation was that while cycles 3 and 4 were shown to be technically feasible and appropriate for use, cycles 1 and 2 required further adjustment and the categorisation system needed further adjustment. The required changes were made and reported. Final revisions of these cycles and categorisation system were revalidated to demonstrate their feasibility.
- The results of this revalidation of changes made to cycles 1 and 2 have shown that they are now technically feasible and appropriate for use.
- Estimates for the time duration required to run the full durability distances were made. These show that the speed capabilities of the vehicle and average total vehicle milage set in EC, 2010 are the primary factors in the time taken to complete the final cycles.

11 Further work

11.1 Continued improvement

From the analysis of older durability cycles used in other regions (EPA, 2006) it was identified that they were outdated and did not represent both current driving trends and the technologies now in use. Therefore, a new test cycle and procedure was devised to cover these concerns. However it can be seen from this outcome that a test cycle cannot be held static and at appropriate intervals or when a step change in vehicle use or technology occurs, the testing procedures used should be assessed and revised as necessary.

It may be prudent to assign a maximum period for the application of the SRC-LeCV, after which the cycle will be assessed to ascertain whether it is still able to suitably test L-category vehicles and either develop a new cycle or extend its use depending on the outcome. The US EPA AMA cycle has been in use for over 30 years, yet it can be seen that it has been becoming increasingly outdated over the past 10 years with the increasing use of direct injection, newer fuels and changes to emission legislation. In addition, it can be seen that electric, hybrid and other alternative drives are expected to become much more prevalent over the coming decades. Therefore, a rolling period before reassessment of 10-15 years could be used.

11.2 Alternative cycle development programme

A possible further step would be to design a cycle based directly on measured real-world use (rather than estimated real-world use) for each L-category type in a way that can be repeated in the manner required to accumulate the large distances required for durability testing. There is an argument that, because of the large range of vehicle types (and therefore real-world uses) of L-category vehicles, durability cycles tailored specifically to measured real-world use would be more accurate than the cycles presented in this study. However, the time and resources required to generate more accurate accumulation cycles are considered vastly disproportionate to the likely benefits over and above the cycles proposed by this study. Implementing cycles developed by this project, which have been designed to represent real-world use, incorporating the important ageing mechanisms and which have been adjusted for applicability and cost-effectiveness, are considered a scientifically appropriate method in which to assure emissions from L-category vehicles over their lifetime.

Further testing could include testing a range of L-category vehicles using the durability cycles developed in this project. However, if implemented in type approval requirements, test data could be used to directly monitor practicality and test cost issues.

11.3 Appropriate proportions of coast-through and coast-down decelerations

In the development of the cycle, certain essential ageing mechanisms, such as the effect of DFCO, may become more prevalent in the future or might be more frequently activated in normal use. However, the sample size for them in the testing programme was considered to be small. As mentioned in Section 7.11.1.1, the activation criteria used for DFCO may vary between vehicles, and this mechanism may become more prevalent in the future as increasing demands are placed on emissions and fuel economy. This fuel consumption and emission reducing technique is activated when the vehicle is experiencing medium to higher vehicle speeds, higher engine speeds, low engine load and closed throttle. It has been proposed that the probability of DFCO activation during the SRC-LeCV test cycle could be increased by implementing a representative amount of coast-through decelerations or at least have both coast-through and coast-down decelerations represented to replicate real-world use as much as possible.

From the model of the SRC-LeCV in Figure 7-44 (Section 7.11.1.1) it can be seen that the majority of the DFCO events occurred in the three long decelerations from high vehicle speeds to a stop, and therefore should be special instructions for these three decelerations.

If this is the case, then the following additional article could be added to the legislation:

"During coast-through decelerations to 0 km/h (idle), the gear shall only be changed once the vehicle has reached the lowest engine speed it can perform at that given load and vehicle speed. Below that engine speed, a de-clutch and braking is allowed to prevent an engine stall. During gear changes, extra care shall be afforded to ensure that the gear change is performed promptly, with minimum coasting in neutral gear, clutch and partial clutch use."

12 List of Figures

13 List of Tables

14 References

ACEM. (2004). *MAIDS Final Report.*

ACEM. (2012). Workshop Type-approval and market surveillance of two- or three wheel vehicles and quadricycles. *MCWG*, (pp. 29-52). Brussels.

Eastwood, P. (2000). *Critical Topics in Exhaust Gas Aftertreatment.* Baldock, Herts, England: Research Studies Press Ltd.

EPA. (2006). *Emission Durability Procedures and Component Durability Procedures for New Light-Duty Vehicles, Light-Duty Trucks and Heavy-Duty Vehicles; Final Rule and Proposed Rule. Vol. 71, No. 10. Tuesday, January 17, 2006. Rules and Regulations.* Federal Register.

Favre C, B. D. (2009). *An Emissions performance evaluation of state-of-the-art motorcycles over EURO 3 and WMTC drive cycles. SAE 2009-01-1841.*

Jurgen, R. K. (2004). *Electronic Engine Control Technologies: 2nd Edition (PT-110).* Warrendale, PA, USA: Society of Automotive Engineers, Inc.

Lassi, U. (2003). *Deactivation Correlations of Pd/Rh Three-way Catalysts Designed for Euro IV Emission Limits. Effect of Ageing Atmosphere, Temperature and Time.* Department of Process and Environmental Engineering. Oulu: University of Oulu.

Nathanson, A., McCarthy, M., Cuerden, R., Lawton, B., & Knight I., M. P. (2012). *Tampering prevention in L-category vehicle approval legislation.* Crowthorne: TRL.

Pace L., J. F. (2011). *Accelerated Durability Test for Metallic Substrates Tailored for Motorcycle Application.* Warrendale, PA, USA: Society of Automotive Engineers, Inc.

Pace L., P. M. (2010). *Changing the Substrate Technology to met future Emission Limits.* Warrendale, PA, USA: SAE.

Pace L., R. A. (2008). *Metallic substrates with structured foils and advanced coating technology: a cost effective solution to meet future emission levels.* Beijing: 2008 International Motorcycle Emission Control Technology Seminar.

Proposal for European Parliament and Council Regulation (EU) No .../2010 of the European Parliament and of the Council on the approval and market surveillance of two- or three-wheel vehicles and quadricycles [COM(2010) 542 final] (2010).

R Cuerden, A. N. (2012). *Durability of pollution control measures for L-category vehicles.* Bracknell: TRL.

SAE. (1994). *New Technologies for Low Emission Vehicle Testing (SP-1014).* Warrendale, PA, USA: Society of Automotive Engineers, Inc.

SAE. (1991). *Worldwide Emission Control Advancements (SP-863).* Warrendale, PA, USA: Society of Automotive Engineers, Inc.

Stone, R. (1992). *Introduction to Internal Combustion Engines: Second edition.* London: The Macmillan Press Ltd.

Twigg M., C. N. (2002). *High Temperature Durable Three-way Catalysts to meet European Stage IV Emission Requirements. SAE 2002-01-0351.*

15 Acknowledgments

The work described in this report was carried out in the Safety Division of the Transport Research Laboratory and JRC. The authors are grateful to Iain Knight, Mike McCarthy and Matthias Seidl who carried out the technical review and auditing of this report and for the technical input and testing carried out by JRC-ISPRA.

16 Glossary of terms

Term	Description
AMA	US (United States of America) EPA Approved Mileage Accumulation, a durability driving cycle
ATV	All-terrain-vehicle, a quad bike
Carb	Abbreviation of carburettor, an apparatus for mixing air and fuel in PI engines
CARB	California air resources board
CI	Compression ignition, used in Diesel engines, where the pressure and temperature caused by compression start the combustion process
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
Co-decision	Legislation adopted by the European Parliament and Council
Comitology	A method of forming legislation through the use of multiple committees
CVT	Continuously Variable Transmission, a gearbox with an infinitely variable characteristic
DDV	Durability Data Vehicle
DF	Deterioration factor, a value used to multiply the results of an emission test to predict future results if parts were ageing. There are two versions of DFs: • Fixed or assigned deterioration factor: Fixed values assigned by legislating authority; these are used to set a safety factor against emission limits used on ‘de-greened’ vehicles (i.e. new vehicles which have performed less than 100 km of the durability accumulation cycle). ○ For the new legislation, Regulation (EU) No [xxx/2013], this is set out in Article 21 (3c). • Extrapolated deterioration factor: This method generates a slope by extrapolating the results from multiple tests taken with the vehicle performing a portion of the full durability distance accumulation. This is used to predict the likely increase in emissions over the entire distance tailored for that specific vehicle under test. ○ For the new legislation, Regulation (EU) No [xxx/2013], this is set-out in Article 21 (3b). As the two versions of DFs perform different functions, they can both be used at different points in the same legislation.
DFCO	Deceleration fuel cut-off, a fuelling regime that cuts off fuel while the engine is running under certain conditions to save fuel and reduce pollution

Term	Description
EC	European Commission, the EU's executive body
ECU	Electronic control unit
EDC	A european driving cycle for L-category vehicles, following the same trace as the UN R40 cycle. This was the predecessor of the WMTC. The EDC consists of 6 cycles and the EUDC whereas the NEDC for passenger cars only contains 12 cycles.
EDV	EDV
EMS	Engine Management System
EPA	US (United States of America) Environmental Protection Agency
EU	European Union
EUC	Extra Urban (Driving) Cycle, an additional high vehicle speed section for the EDC / UN Regulation 40 Type I emission test cycle (see Directive 97/24/EC as amended, Chapter 5, Annex II, Appendix 1, sub-appendix 1a, page 312).
EUDC	Extra Urban Driving Cycle, as above when referring to NEDC emission cycle used for passenger cars. The change in the terminology is perhaps intended to prevent confusion with each other.
FTP	US (United States of America) Federal Test Procedure
HC	Hydrocarbon, such as vaporised petrol or diesel
JRC	European Commission Joint Research Centre
L#e	Vehicle categorisation system: L = light, # = sub-category, e = Europe (if “e” is not included in this expression, e.g. L1e vs L1, the L-category vehicle is being categorised according to UN ECE Consolidated Resolution on the Construction of Vehicles R.E.3.) See Appendix A for a full list.
Lambda sensor	A sensor that determines the relative proportion of oxygen in a fluid.
Matlab	A numerical computing environment.
Mini-car	A four wheeled L-category vehicle with the appearance of and used as a small conventional car. These are now termed “quadri-mobile” for the purposes of classification.
MCWG	Motorcycle Working Group, a European Commission group of experts
NEDC	New European Driving Cycle, an emission driving cycle for passenger cars.
NMHC	Non-methane hydrocarbon
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

Term	Description
Phase 1, 2 & 3	The term phase has been used to differentiate the different stages in the process of designing and validating the SRC-LeCV cycles.
PI	Positive ignition, i.e. spark ignition used in petrol engines where a positive addition of energy is used to start the combustion process
PM	Particulate matter, in extreme cases this is visible as soot or an off colour haze from exhaust gases
PN	Particulate number
R40	UN Regulation No 40, includes a test procedure and cycle for heavy L-category vehicles. The same test cycle is used by many global regions under different guises using modified testing procedures. For this project, all testing with this cycle used the EDC-R40 procedure as laid out in Directive 97/24/EC Chapter 5 Annex II. It may be used by manufacturers to demonstrate emission performance during type approval for a Euro 3 motorcycle (L3e), Euro 2 tricycle (L5e) or heavy quadricycle (L7e). However, the UN test procedure is not accepted as the EU has not acceded to UN Regulation No 40. See Appendix D.3 for a full explanation of the test cycle.
R47	UN Regulation No 47, includes a test procedure and cycle for low performance L-category vehicles (i.e. mopeds and light quadricycles). The same test cycle is used by many global regions under different guises using modified testing procedures. For this project, all testing with this cycle used the ECE-R47 procedure as laid out in Directive 97/24/EC Chapter 5 Annex I. It may be used by manufacturers to demonstrate emission performance during type approval for a Euro 2 moped (L1e), light tricycle (L2e) or light quadricycle (L6e). However, the UN test procedure is not accepted as the EU has not acceded to UN Regulation No 47. See Appendix D.1 for a full explanation of the test cycle.
Regulation (EU) No [xxx/2012]	This is a reference to the EC regulation where the durability test will be incorporated. This regulation was in draft form and unpublished at the time of publishing this report. "Regulation on the environmental and propulsion performance requirements for the approval and market surveillance of two- or three-wheel vehicles and quadricycles (REPPR)
SbS	Side-by-side, a quadricycle where the driver and passengers can sit next to each other as with a car
SMEs	Small and medium enterprises
SRC	US (United States of America) EPA Standard Road Cycle, a durability driving cycle

Term	Description
SRC-LeCV	Standard Road Cycle for L-Category Vehicles. The durability driving cycle developed by this project.
Stage 1, 2 & 3	When referring to the WMTC, the cycle described in UN GTR No. 2, used to differentiate the different stages of published changes. Note: WMTC stage 3 is also called the "revised WMTC"
THC	Total hydrocarbon
Type # test	Emissions tests performed during type approval are numbered thus: Test Type I, tailpipe emissions test after cold start Test Type II, tailpipe emissions test at (increased) idle / free acceleration test Test Type III, emission test of crankcase gases Test Type IV, evaporative emissions test Test Type V, durability testing of pollution control devices Test Type VI, , tailpipe emissions test after cold start in cold conditions Test Type VII, measurement of CO2 emissions, fuel consumption, electric energy consumption and electric range determination Test Type VIII, on-board diagnostics test (environmental part only of OBD)
UN	United Nations, a forum for the world's nations to discuss issues
UNECE	United Nations Economic Commission for Europe, a body of the UN tasked with, among other things, harmonising international vehicle legislation
Vd	Volume displacement, the volume swept by all the pistons inside the cylinders of an internal combustion engine in a single movement from top dead centre (TDC) to bottom dead centre (BDC).
VELA	The JRC Vehicle Emission Laboratory
Washcoat	The coating of the catalytic converter monolith that holds the catalyst in place
WHO	World Health Organisation, an agency of the UN, concerned with international public health
WoT	Wide open Throttle, i.e. full throttle, the maximum throttle control position. This is not necessarily the highest fuel flow.

Term	Description
WMTC	World harmonised motorcycle test cycle, an emissions laboratory test cycle. Set out in UN GTR No 2. There have been three versions (see Stage 1, 2 & 3 above). It is a proposal by the EC to type approve low performance category vehicles such as L1e, L2e and L6e also with an adapted WMTC rather than with the ECE R47 cycle. The revised WMTC for the higher performance vehicles like L3e is equal to WMTC stage 3. The WMTC stage 1 is the type approval test cycle for e.g. Euro 3 motorcycles L3e. WMTC stage 2 contains some minor changes vs stage 1 like e.g. a change in the gear shift prescriptions. See Appendix D.2 for a full explanation of the test cycle. Latest version as published on UNECE website: http://www.unece.org/trans/main/wp29/wp29wgs/wp29gen/wp29glob_registry.html

Appendix A L-category vehicle definitions

Table 16-1: L-category vehicle classification and definitions

Category	Sub category	Classification criteria
L1e Light two-wheel powered vehicle	L1Ae powered cycle	Engine aids pedalling of vehicle Engine Vd ≤ 50 cm^3 V_{max} ≤ 25 km/h No aux. propulsion above V_{max} 250 W< $P_{max.cont}$ ≤ 1 kW
	L1Be two-wheel moped	Engine Vd ≤ 50 cm^3 V_{max} ≤ 45 km/h $P_{max.cont}$ ≤ 4 kW
L2e Three-wheeled moped	-	Engine Vd ≤ 50 cm^3 V_{max} ≤ 45 km/h $P_{max.cont}$ ≤ 4 kW
L3e Two-wheel motorcycle	A1 Two-wheel motorcycle low performance	Engine Vd ≤ 50 cm^3 V_{max} > 45 km/h 4 kW < $P_{max.cont}$ ≤ 11 kW power/weight ≤ 0.1 kW/kg
	A2 Two-wheel motorcycle medium performance	Engine Vd > 50 cm^3 V_{max} > 45 km/h 11 kW < $P_{max.cont}$ ≤ 35 kW power/weight ≤ 0.2 kW/kg
	A3 Two-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 V_{max} > 45 km/h $P_{max.cont}$ > 4 kW

Category	Sub category	Classification criteria
	L5Be Commercial tricycles	Engine Vd > 50 cm^3 V_{max} > 45 km/h $P_{max.cont}$ > 4 kW Open and enclosed driver and passenger (2 people including driver) Carriage of goods (bed area > 30% of vehicle length times width)
L6e Light quadricycle	L6Ae Light on-road quad	Engine Vd ≤ 50 cm^3 V_{max} ≤ 45 km/h $P_{max.cont}$ ≤ 4 kW Mass ≤ 425 kg
	L6Be Light quadri-mobiles	Engine Vd ≤ 50 cm^3 V_{max} ≤ 45 km/h $P_{max.cont}$ ≤ 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	V_{max} > 45 km/h $P_{max.cont}$ ≤ 15 kW Mass ≤ 450 kg for passengers, 600 kg for transport of goods 2 people max (Includes passenger)
	L7Be Heavy all terrain quads	45 < V_{max} ≤ 90 km/h (all terrain quads) or $P_{max.cont}$ ≤ 15 kW (all terrain buggies) Ground clearance ≥180 mm; Wheelbase to ground clearance ratio ≤ 6
	L7Ce Heavy quadri-mobiles	45 km/h < V_{max} ≤ 90 km/h $P_{max.cont}$ ≤ 15 kW Mass ≤ 450 kg for passengers Mass ≤ 600 kg for goods

Appendix B Maximum legal road speeds

B.1 Speed limits in Europe

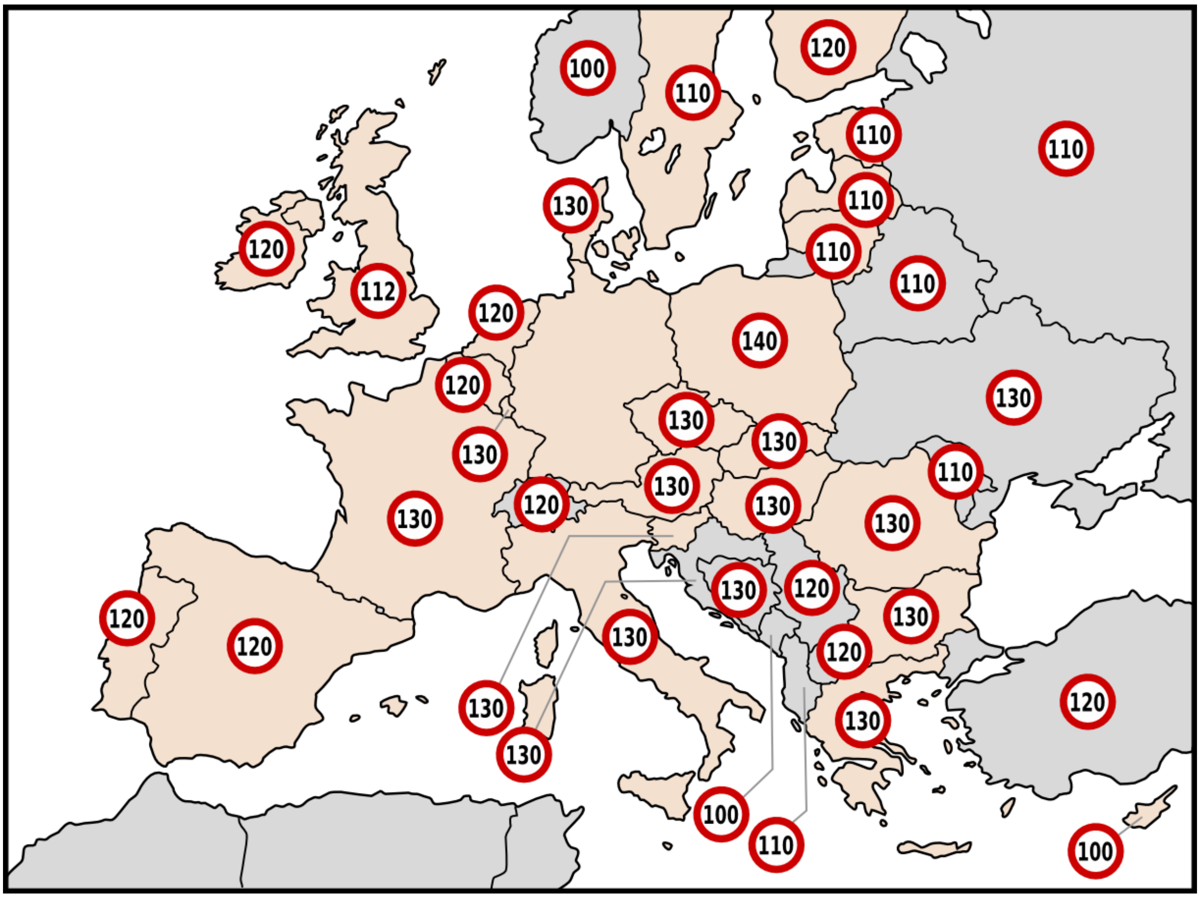


Figure 16-1: Speed limits within Europe[17,18]

---

[17] Author: Bußgeldkatalog Verkehr, Date: 08/07/2009, Data source - URL: <http://www.bussgeldkatalog-verkehr.de/ausland/verkehrsregeln-im-ausland-135.html>

[18] Author: KaterBegemot, Date: 07/06/2010, Image source - URL: <http://upload.wikimedia.org/wikipedia/commons/9/90/Freeway_speed_limits_europe.png>

B.2 Speed limits in the USA

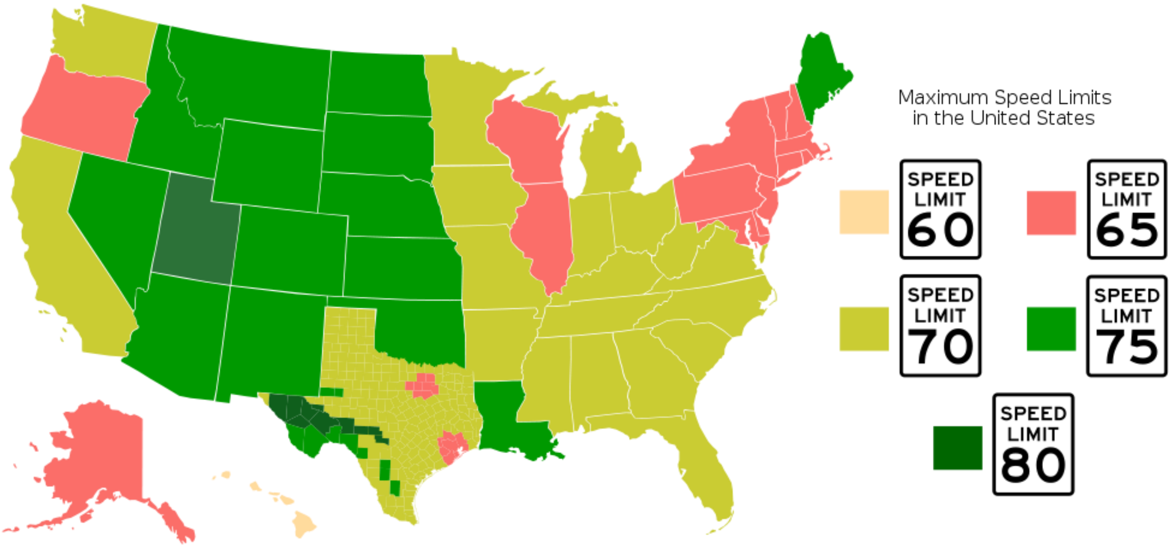


Figure 16-2: Speed limits in the USA[19]

mph	km/h
60	96.6
65	104.6
70	112.7
75	120.7
80	128.7

Table 16-2: Conversion of speed limits in the USA to metric

---

[19] Author: Shadowlink1014, Date 28/04/2007, URL: <http://upload.wikimedia.org/wikipedia/commons/thumb/b/b4/US_speed_limits.svg/1000px-US_speed_limits.svg.png>

Appendix C Air/fuel ratio effect of performance, emissions and durability (Tampering prevention in L-category vehicle approval legislation, 2012)

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 and other gasses) 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 kg of air to 1 kg of fuel. 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).

$$\lambda = \frac{A:F}{A:F_{Stoich}} = \frac{The\ air/fuel\ ratio}{The\ stochimetric\ air/fuel\ ratio}$$

Figure 16-3: Definition of lambda

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

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

Additionally air contains nitrogen which, in high temperature and oxygen rich environments, will react with oxygen to produce oxides of nitrogen (NO_x).

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 16-4 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 NO_x 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 combustion (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 holds the catalyst in place). However, there is a specific type of fuelling strategy called "ultra-lean burn" with air/fuel ratios >~20, where the NO_x reduces again, but this requires very closely controlled fuelling.

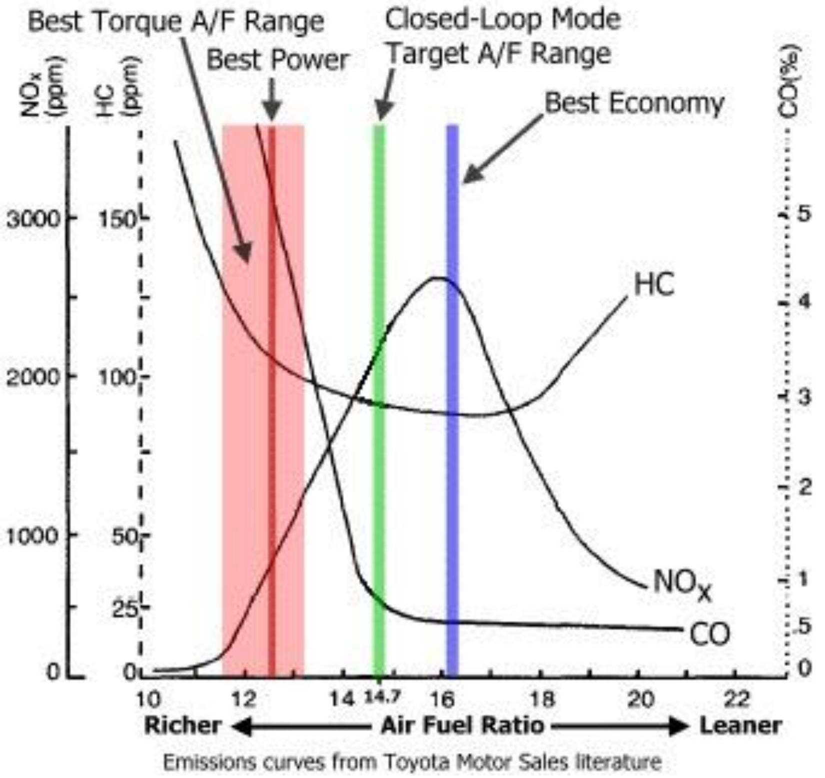


Figure 16-4: Air/fuel ratio consequence on emissions, power and efficiency[20]

Three way catalytic converters aim to reduce emissions of CO, THC and NO_x. To complete the combustion of the THC and CO extra oxygen is needed, therefore a lean mixture is preferred. This however leads to increasing NO_x as indicated in Figure 16-4. To separate NO_x back into nitrogen and oxygen a deficit of oxygen is required, therefore a rich mixture 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 fuel bias slightly rich (max -2% or air/fuel ratio: 14.5) and toggling to stoichiometry (air/fuel ratio: 14.7).

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

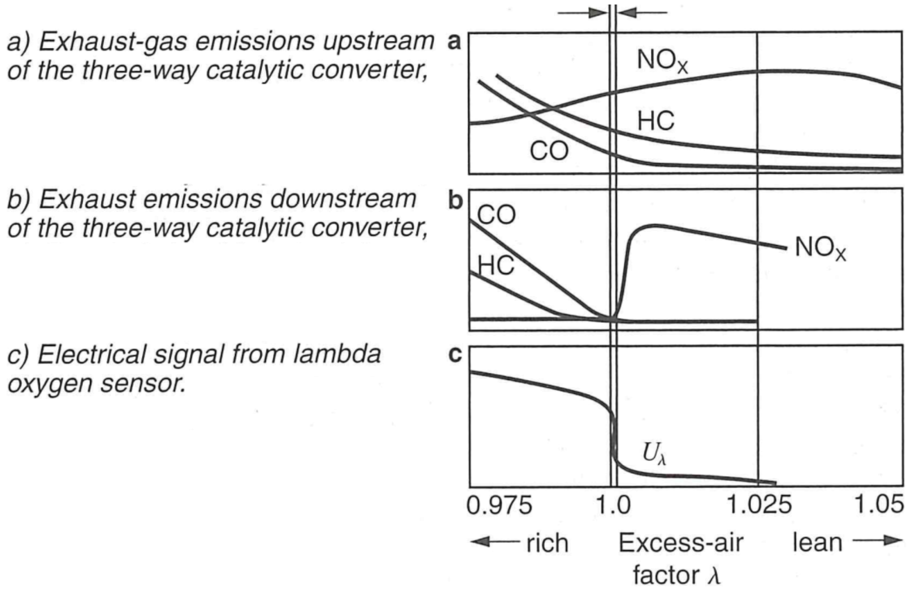
Mopeds are frequently equipped with a simple mechanical secondary air injection system, which means that the base mixture in the combustion chamber can be tuned rich to

---

[20] 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 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 a 2-3 year development phase prior to introducing a new vehicle type on the market and can easily be damaged when optimising only one of these parameters. Increasing power and torque will often result in increases of CO_2 emissions, fuel consumption and pollutant emissions. Minimising fuel consumption may lead to reduced vehicle performance and/or increased pollutant emissions.


a) Exhaust-gas emissions upstream of the three-way catalytic converter,

b) Exhaust emissions downstream of the three-way catalytic converter,

c) Electrical signal from lambda oxygen sensor.

Figure 16-5: Change in emissions using a three way catalyst[21]

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 16-6). Again Figure 16-6 shows that stoichiometric 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).

---

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

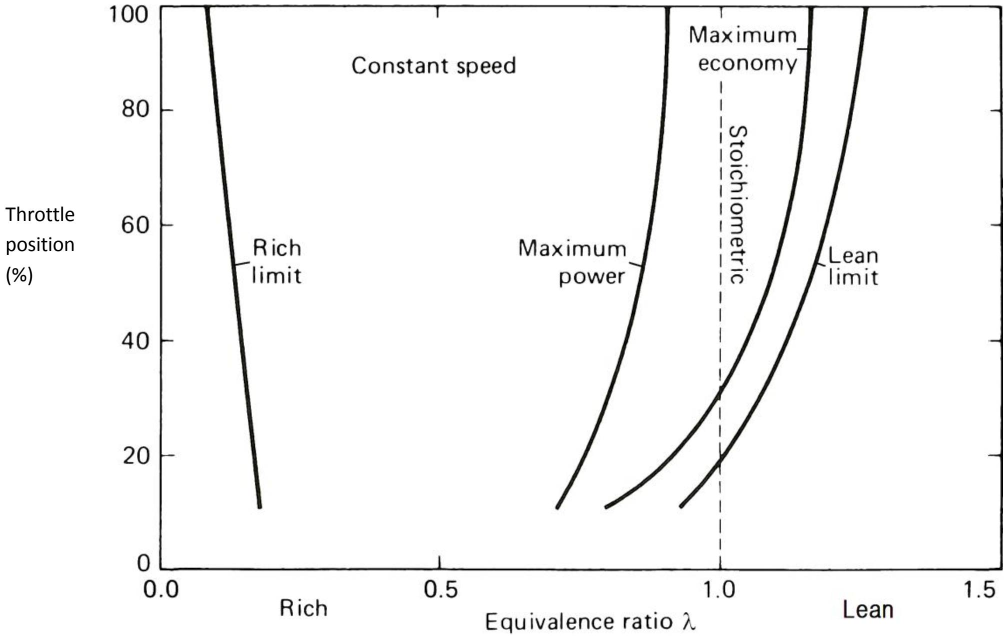


Figure 16-6: Change in peak power and efficiency with throttle position[22]

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

Deviating from the optimum air/fuel ratio for the catalyst will result in damage, which can be permanent: too rich and it could physically clog the catalyst or become poisoned, too lean and it will 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; 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, NO_x 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 mixture) leading to smooth driveability, but also to increased fuel consumption (CO_2 emissions) and toxic emissions (HC and CO)
- Reduce fuel consumption (lean mixture) possibly leading to bad combustion (misfire, knocking combustion, bad driveability), decreased engine and catalyst durability and increased toxic emissions (NO_x)

---

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

Appendix D Emission driving cycles

D.1 European driving Cycle R47 / UN R47 emissions driving cycle

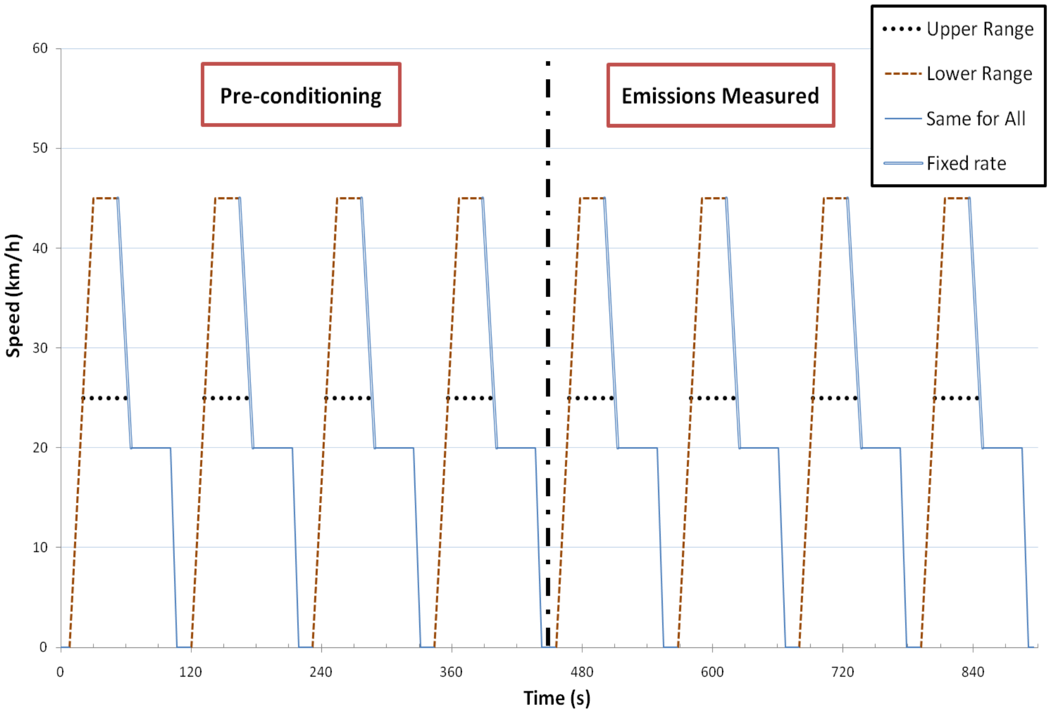


Figure 16-7: Graphical plot of EDC / UN R47 driving cycle

Table 16-3: General characteristics of the EDC / UN R47 driving cycle

	Example Low speed moped	Example High speed moped
Average vehicle speed during test	est. 18 km/h	est. 24 km/h
Effective running time	896 s total driving time, 112 s per part	
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 vehicle speed (±5 km/h or 10%)	25 km/h	45 km/h
Maximum acceleration	Unknown, example based on 0.56 m/s^2	
Maximum deceleration	-0.93 m/s^2	

The vehicle is cooled to room temperature for 6 hours, then placed on an inertia dynamometer, the vehicle is started and the cycle performed. The first 4 parts are ignored to allow the vehicle to get up to temperature, in the second set of 4 parts a proportion of the gasses are stored in a bag, and these gasses are then measured to find the average emissions over the cycle, and compared with the legislated emission limits.

D.2 WMTC emissions driving cycle (Stage 1 & 2, normal & reduced speed, cycles 1, 2 & 3)

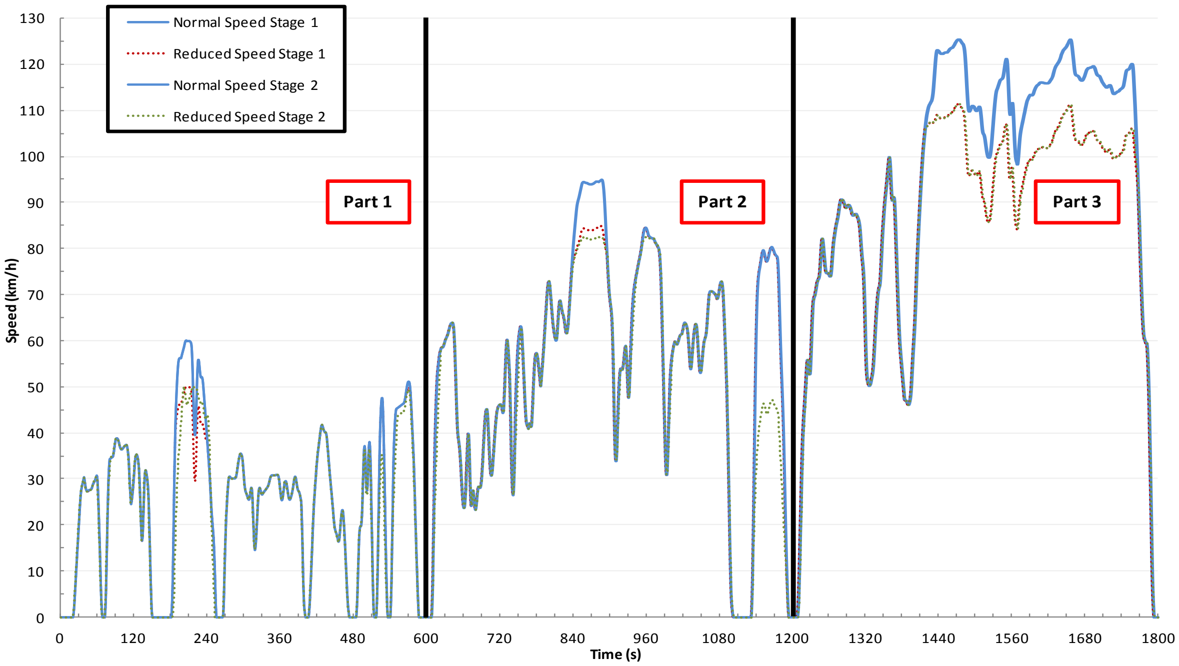


Figure 16-8: Graphical plot of WMTC driving cycle, normal vehicle speed trace

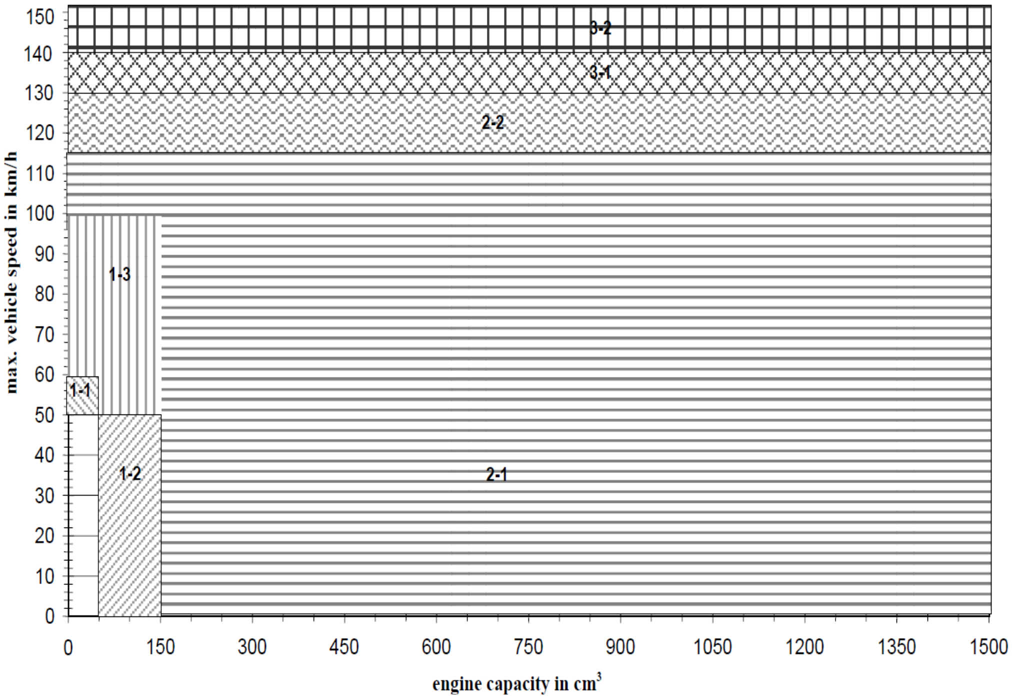


Figure 16-9: Class identification for the UNECE GTR No 2 (WMTC) driving cycle

Table 16-4: Cycle parts to be run depending on class, 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:	
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 16-5: Cycle parts to be run depending on class, UNECE GTR No 2 (WMTC) driving cycle, stage 2 and 3

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.

Additionally in stage 2 and 3 there is a modified gear shift pattern in comparison to stage 1.

Table 16-6: UN GTR No 2 vehicle categorisation (WMTC stage 3/revised)

Class		Engine Capacity	Vehicle speed	Cycle design
1	n/a	$50\ \text{cm}^3 < Vd < 150\ \text{cm}^3$	$v_{max} < 50$ km/h	Part 1 reduced speed, followed by Part 1 reduced speed.
		$Vd < 150\ \text{cm}^3$	$50\ \text{km/h} \leq v_{max} < 100$ km/h	
2	2-1	$Vd < 150\ \text{cm}^3$	$100\ \text{km/h} \leq v_{max} < 115$ km/h	Part 1 reduced speed, followed by Part 2 reduced speed.
		$Vd \geq 150\ \text{cm}^3$	$v_{max} < 115$ km/h	
	2-2		$115\ \text{km/h} \leq v_{max} < 130$ km/h	Part 1, followed by Part 2.
3	3-1		$130 \leq v_{max} < 140$ km/h	Part 1, followed by Part 2, followed by Part 3 reduced speed.
	3-2		$v_{max} \geq 140$ km/h	Part 1, followed by Part 2, followed by Part 3.

Where: Vd = Volume displacement and v_{max} = Maximum vehicle speed

Table 16-7: General characteristics of UNECE GTR No 2 (WMTC) driving cycle

	Part 1 and 2 (subclass 2-2)	**Part 1, 2 and 3 (subclass 3-2)**
Average vehicle 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 vehicle 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 16-9) and this is then used to select which parts of the cycle are used (see Table 16-5).

The vehicle is cooled to room temperature for 6 hours, and then placed on an inertia dynamometer where 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.

D.3 European driving cycle R40 / UN Regulation No 40, based on UNECE R40 emissions driving cycle

The vehicle is cooled to room temperature for 6 hours, then placed on an inertia dynamometer, the vehicle is started and the cycle performed. A proportion of the gasses from the tailpipe exhaust 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. For tricycles and quadricycles the first 2 parts are ignored to allow the vehicle to warm up to operating temperature, but for motorcycles they are not.

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.

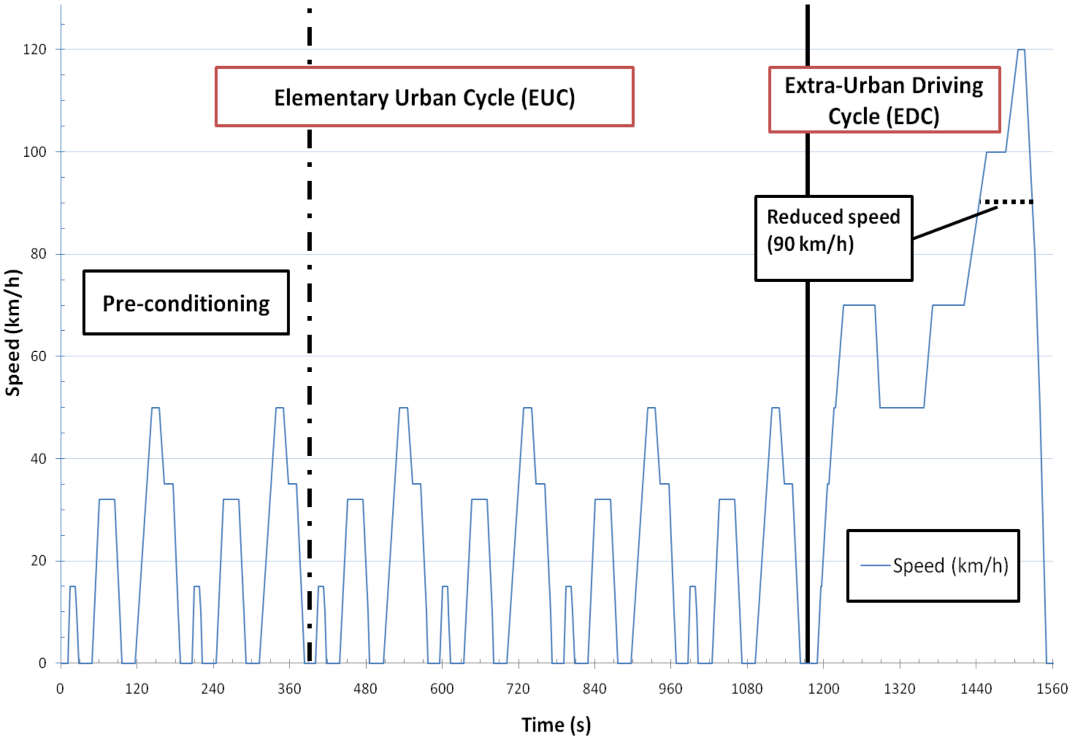


Figure 16-10: Graphical plot of UN R40 / EDC R40 driving cycle

Table 16-8: General characteristics of the UN R40 / EDC R40 driving cycle

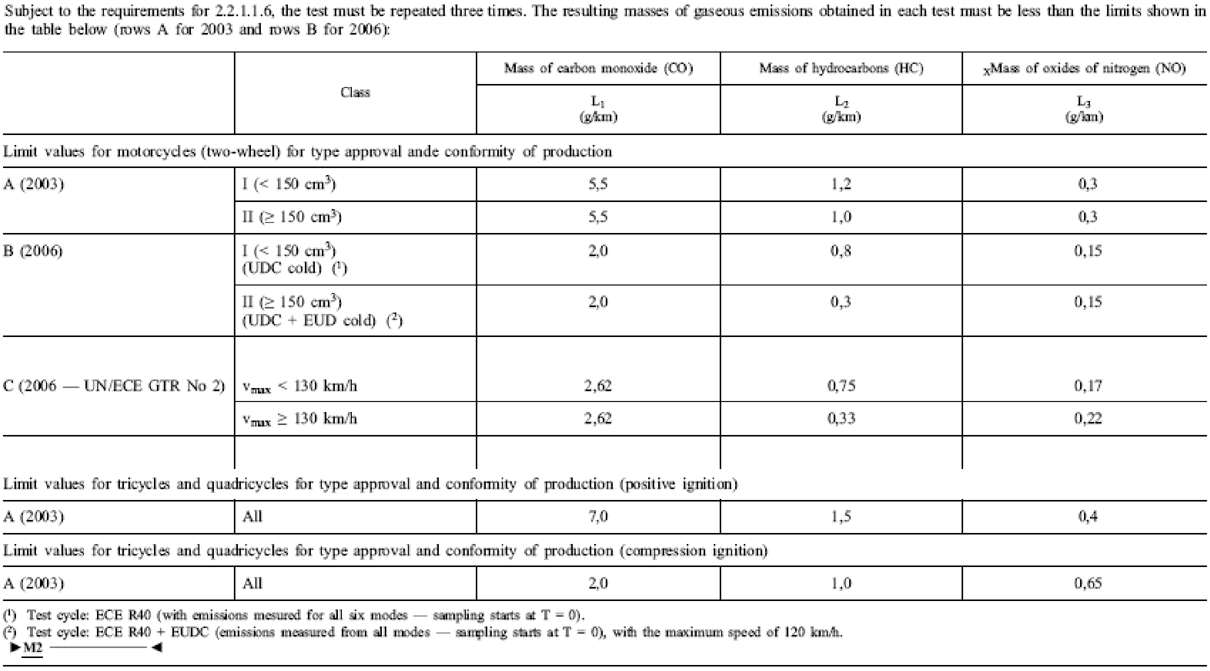
	EUC	EUC + EDC	EUC + EDC reduced vehicle speed
Average vehicle speed during test	13.9 km/h	19.7 km/h	19.1 km/h
Effective running time (±0.5 s)	1,170 s (19.5‟)	1,570 s (26.2‟)	1,570 s (26.2‟)
Distance covered (±2%)	5,964 m	12,947 m	12,554 m
Maximum vehicle speed (±1 km/h)	50 km/h	120 km/h	90 km/h
Maximum 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}

Appendix E Tailpipe emission after cold start - limits

Table 16-9: Euro 2 emission limits for mopeds (Directive 97/24/EC & Directive 2006/72/EC)

	CO (g/km) L1	HC + NO_x (g/km) L2
2 wheeled mopeds	1	1.2
3 wheeled mopeds and light quadricycles	3.5	1.2

Table 16-10: Directive 97/24/EC & Directive 2006/72/EC Euro 2 (Euro 3 for L3e motorcycles as of 2006)



Subject to the requirements for 2.2.1.1.6, the test must be repeated three times. The resulting masses of gaseous emissions obtained in each test must be less than the limits shown in the table below (rows A for 2003 and rows B for 2006):

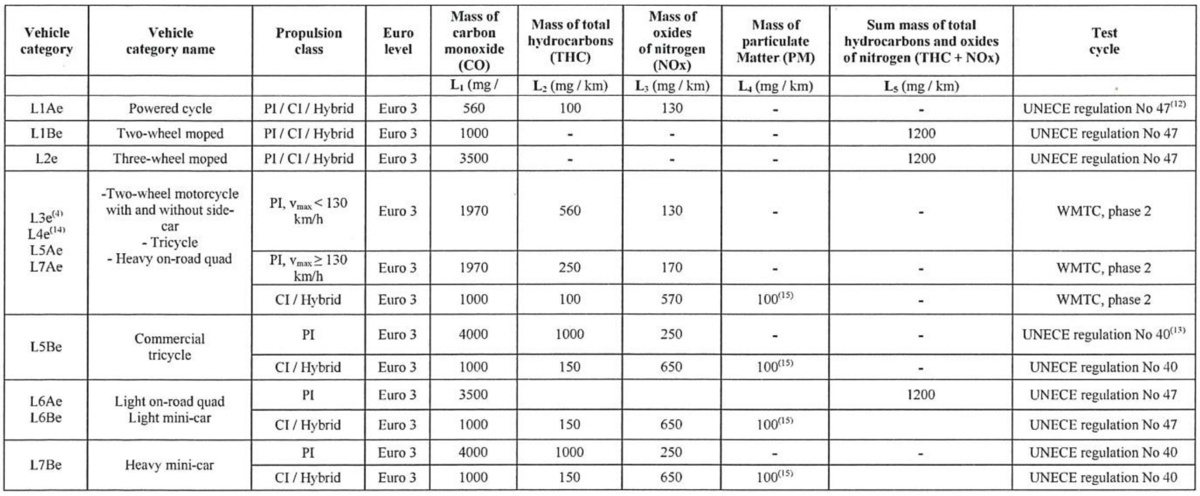
	Class	Mass of carbon monoxide (CO)	Mass of hydrocarbons (HC)	$_X$Mass of oxides of nitrogen (NO)
		L_1 (g/km)	L_2 (g/km)	L_3 (g/km)
Limit values for motorcycles (two-wheel) for type approval ande conformity of production				
A (2003)	I (< 150 cm^3)	5,5	1,2	0,3
	II (≥ 150 cm^3)	5,5	1,0	0,3
B (2006)	I (< 150 cm^3) (UDC cold) (1)	2,0	0,8	0,15
	II (≥ 150 cm^3) (UDC + EUD cold) (2)	2,0	0,3	0,15
C (2006 — UN/ECE GTR No 2)	v_{max} < 130 km/h	2,62	0,75	0,17
	v_{max} ≥ 130 km/h	2,62	0,33	0,22
Limit values for tricycles and quadricycles for type approval and conformity of production (positive ignition)				
A (2003)	All	7,0	1,5	0,4
Limit values for tricycles and quadricycles for type approval and conformity of production (compression ignition)				
A (2003)	All	2,0	1,0	0,65

(1) Test cycle: ECE R40 (with emissions mesured for all six modes — sampling starts at T = 0).

(2) Test cycle: ECE R40 + EUDC (emissions measured from all modes — sampling starts at T = 0), with the maximum speed of 120 km/h.

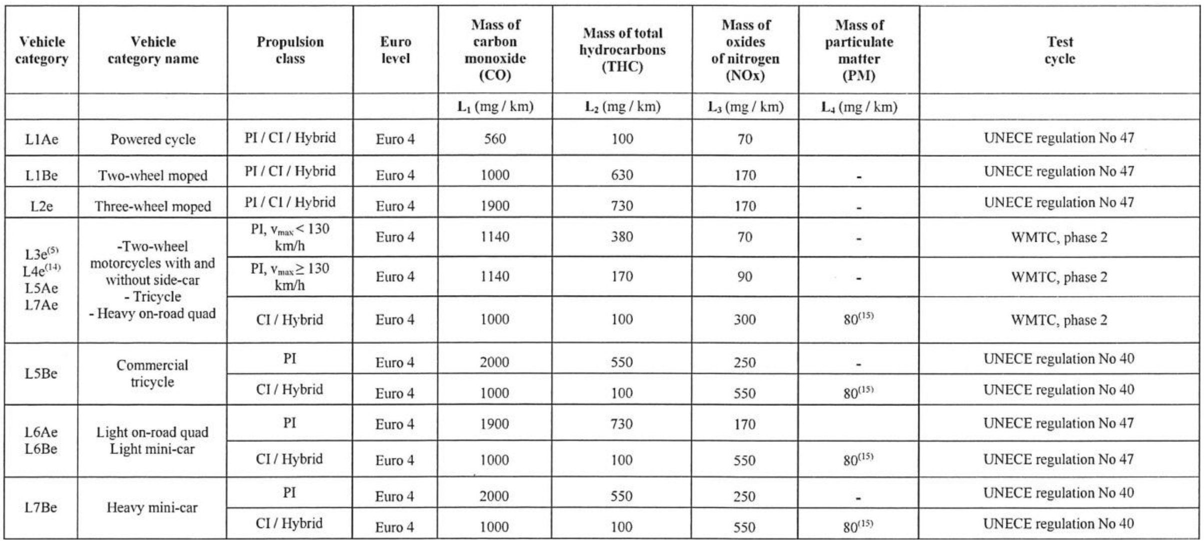
►M2 ———————— ◄

Table 16-11: COM (2010) 542 Final; Annex VI, (A1) Euro 3 (Euro 4 for L3e motorcycles)



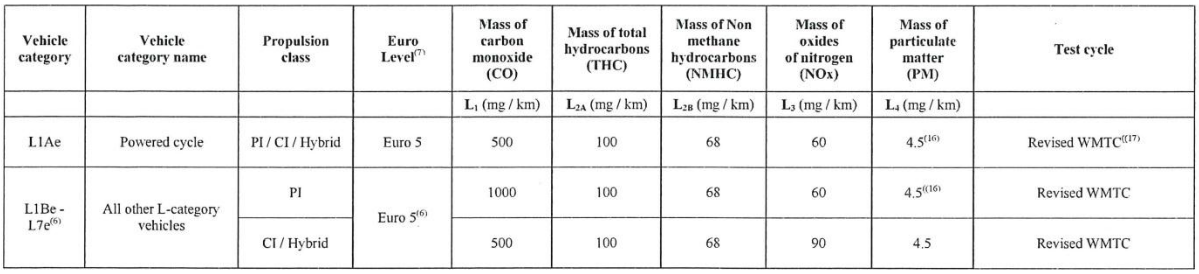
Vehicle category	Vehicle category name	Propulsion class	Euro level	Mass of carbon monoxide (CO)	Mass of total hydrocarbons (THC)	Mass of oxides of nitrogen (NOx)	Mass of particulate Matter (PM)	Sum mass of total hydrocarbons and oxides of nitrogen (THC + NOx)	Test cycle
				L_1 (mg /	L_2 (mg / km)	L_3 (mg / km)	L_4 (mg / km)	L_5 (mg / km)	
L1Ae	Powered cycle	PI / CI / Hybrid	Euro 3	560	100	130	-	-	UNECE regulation No 47(12)
L1Be	Two-wheel moped	PI / CI / Hybrid	Euro 3	1000	-	-	-	1200	UNECE regulation No 47
L2e	Three-wheel moped	PI / CI / Hybrid	Euro 3	3500	-	-	-	1200	UNECE regulation No 47
L3e(4) L4e(14) L5Ae L7Ae	-Two-wheel motorcycle with and without side-car - Tricycle - Heavy on-road quad	PI, $v_{max} < 130$ km/h	Euro 3	1970	560	130	-	-	WMTC, phase 2
		PI, $v_{max} \geq 130$ km/h	Euro 3	1970	250	170	-	-	WMTC, phase 2
		CI / Hybrid	Euro 3	1000	100	570	100(15)	-	WMTC, phase 2
L5Be	Commercial tricycle	PI	Euro 3	4000	1000	250	-	-	UNECE regulation No 40(13)
		CI / Hybrid	Euro 3	1000	150	650	100(15)	-	UNECE regulation No 40
L6Ae L6Be	Light on-road quad Light mini-car	PI	Euro 3	3500				1200	UNECE regulation No 47
		CI / Hybrid	Euro 3	1000	150	650	100(15)		UNECE regulation No 47
L7Be	Heavy mini-car	PI	Euro 3	4000	1000	250	-	-	UNECE regulation No 40
		CI / Hybrid	Euro 3	1000	150	650	100(15)		UNECE regulation No 40

Table 16-12: COM (2010) 542 Final; Annex VI, (A2) Euro 4 (Euro 5 for L3e motorcycles)



Vehicle category	Vehicle category name	Propulsion class	Euro level	Mass of carbon monoxide (CO)	Mass of total hydrocarbons (THC)	Mass of oxides of nitrogen (NOx)	Mass of particulate matter (PM)	Test cycle
				L_1 (mg / km)	L_2 (mg / km)	L_3 (mg / km)	L_4 (mg / km)	
L1Ae	Powered cycle	PI / CI / Hybrid	Euro 4	560	100	70		UNECE regulation No 47
L1Be	Two-wheel moped	PI / CI / Hybrid	Euro 4	1000	630	170	-	UNECE regulation No 47
L2e	Three-wheel moped	PI / CI / Hybrid	Euro 4	1900	730	170	-	UNECE regulation No 47
L3e(5) L4e(14) L5Ae L7Ae	-Two-wheel motorcycles with and without side-car - Tricycle - Heavy on-road quad	PI, $v_{max} < 130$ km/h	Euro 4	1140	380	70	-	WMTC, phase 2
		PI, $v_{max} \geq 130$ km/h	Euro 4	1140	170	90	-	WMTC, phase 2
		CI / Hybrid	Euro 4	1000	100	300	80(15)	WMTC, phase 2
L5Be	Commercial tricycle	PI	Euro 4	2000	550	250	-	UNECE regulation No 40
		CI / Hybrid	Euro 4	1000	100	550	80(15)	UNECE regulation No 40
L6Ae L6Be	Light on-road quad Light mini-car	PI	Euro 4	1900	730	170		UNECE regulation No 47
		CI / Hybrid	Euro 4	1000	100	550	80(15)	UNECE regulation No 47
L7Be	Heavy mini-car	PI	Euro 4	2000	550	250	-	UNECE regulation No 40
		CI / Hybrid	Euro 4	1000	100	550	80(15)	UNECE regulation No 40

Table 16-13: COM (2010) 542 Final; Annex VI, (A3) Euro 5 (Euro 6 for L3e motorcycles)



Vehicle category	Vehicle category name	Propulsion class	Euro Level(7)	Mass of carbon monoxide (CO)	Mass of total hydrocarbons (THC)	Mass of Non methane hydrocarbons (NMHC)	Mass of oxides of nitrogen (NOx)	Mass of particulate matter (PM)	Test cycle
				L_1 (mg / km)	L_{2A} (mg / km)	L_{2B} (mg / km)	L_3 (mg / km)	L_4 (mg / km)	
L1Ae	Powered cycle	PI / CI / Hybrid	Euro 5	500	100	68	60	4.5(16)	Revised WMTC((17)
L1Be - L7e(6)	All other L-category vehicles	PI	Euro 5(6)	1000	100	68	60	4.5((16)	Revised WMTC
		CI / Hybrid		500	100	68	90	4.5	Revised WMTC

Appendix F Stakeholder consultation

F.1 Internet questionnaire

Links to an internet questionnaire regarding durability were sent to 406 stakeholders including manufacturers, consumer groups, technical groups and government agencies etc. Three questionnaire responses were received. The questions asked and the responses are shown in Table 16-14.

Table 16-14: Internet questionnaire responses

1-Which L-category vehicle components effect emissions?
Basically, all fuel and ignition system components have an influence on engine out emissions, as do certain engine components such as camshafts, combustion chambers and valves. However, when it comes to durability, the components that affect emissions performance to the greatest extent are those subjected to thermal cycling (i.e. catalysts in the exhaust system).
- catalytic converter - EGR - Secondary Air Injection - Gearbox - Silencer"
The complete engine with carburetor or fuel injection, ignition system and the emission control system (e.g. air injection and catalyst).
2-Can you provide objective data which shows how these components effect the emissions produced with accumulated mileage?
The effect of typical deterioration in relation to increasing mileage can be seen in US EP's certification data - downloadable at http://www.epa.gov/otaq/crttst.htm Attached data 20110617 US data is a selection of this data (Filter: only EFI and 3-way cat / invaluable or questionable data deleted) which was used for the calculation of proposed DF's.
The rights of the data that we provide belong to the customer. As a consequence, we need the permission.
It is hard to give objective data as the engines and emission system vary broadly over the different classes of motorbikes and mopeds. A low-tech moped engine is totally different from a high-tech, high power motorbike with fuel injection and close-loop controlled catalyst. Catalyst efficiency is strongly linked to air-fuel ratio (AFR) control and deterioration of any component that affect AFR control will have an effect on emissions. This is particularly important in bikes where AFR is controlled through mechanical components such as carburettors or secondary air valves. Replacement catalysts should also be subject to durability requirements."
3-Can you provide data on how specific emissions change with distance travelled with typical use and typical levels of maintenance?
See answer to question 2
No
Same a question 2, but generally open-loop carburetors tend to a richer tuning over life time, resulting in higher CO emissions. Catalyst deterioration on motorcycles and mopeds may be higher than with cars. Catalyst deactivation can lead to increased emissions of HC, CO and NO_x. It is normally based on high temperature sintering processes and on poisoning by engine oil. Temperature sintering: Uncontrolled spikes of fuel or oil as the fuel and lubrication systems age may cause a higher rate of deterioration for some systems and may also be

influenced to some degree by the way the bike is driven over its lifetime. A truly representative emission deterioration method is very difficult to achieve but ageing all air, fuel, combustion and catalyst components together for the full useful life is likely to be much more representative of the combined effect of component wear than linear extrapolation.

Oil poisoning: while engine oils for cars have been modified for the use of catalysts, this is not so easy for motorbikes since the engine oil is in many cases used for the gearbox lubrication and even the clutch is in most cases operating in engine oil. This does not allow the significant reduction of extreme pressure additives as in engine oil for cars and the friction modifiers used in engine oils for cars cannot be used. In addition we have learned from our moped test program, that the specific oil consumption e.g. of moped engines is significantly higher than for car engines.

4-Can you demonstrate, using objective data, how each specific emission type varies with accumulated distance? Is such data available for a range of L-category vehicles?

See answer to question 2

No

This has to be discussed for individual engines and emission concepts. However, linear extrapolation to 100% after 50% of the mileage accumulated is not realistic; the ageing curve flattens. As previously said, total system durability needs to be assessed to ensure the combined effect of deterioration of emission critical components is assessed. In general, catalyst efficiency tends to deteriorate at a lower rate as mileage is accumulated if AFR and oil consumption remains steady. If AFR and/or engine emissions deteriorates in use throughout the lifetime of the bike this could lead to a significant deteriorating in emissions at the tailpipe at extended mileages. To follow the current practice for passenger cars in Europe and in the USA, the alternative DF should be a multiplicative factor.

5-Can you provide objective information on the implications for cost and vehicle production development timescales of methods 3a and 3b?

- Method 3a (full distance mileage accumulation) would result in a doubling of the cost and testing burden compared to todays durability compliance demonstration method (i.e. mileage accumulation according to standardized US EPA 11 lap mode up to half of useful distance with extrapolation to full distance).
- Method 3b (use of aged components + fixed DF) is not part of any current regional or national regulation so there is no experience. Moreover, the combined use of aged components and fixed DF is illogical and should be replaced by use of either aged components that are demonstrated by the manufacturer to the satisfaction of the type approval authority as being equivalent to the standard mileage accumulation test or application of fixed DFs.

No

6-How and when in the development cycle is the durability of the system currently measured? Can you describe what this entails? Can you describe what this entails?

The durability performance requirement is confirmed at early stage of development. It is impossible to start development without fixing development requirement (limit, durability condition etc). As with any vehicle development subject (e.g. brake performance) physical testing is conducted as part of the vehicle development process.

There's no durability measurements required.

This depends on the motorbike manufacturer; normally it is one of the last steps in the development, after finalizing the basic engine performance tests. The old AMA test, which has been proposed (and used by AECC in our motorcycle test program), is most likely inappropriate for the bigger bikes (>250 cc) as it is not a realistic cycle for those motorbikes. Minimum requirement would be something like the Standard Road Cycle (SRC) for cars described in the Commission Regulation 692/2008, Annex VII, Appendix 3.

7-Do you foresee any issues with using emission-relevant components which have been subject to accumulated mileages in the development phase being tested for emission

durability?
The use of components that have been used during the development process is not an established method for emission durability testing. Typical development processes include operating conditions that are not representative for normal street use so components may not be suitable for emission durability compliance demonstration.
Especially two-stroke engines effect the catalytic converter.
By its nature, the development phase of a bike has unplanned events making it hard to be sure a component has seen a realistic duty cycle for assessing its deterioration in normal use. As the bike emission deterioration will be a complex, combined effect, as outlined above, selecting individually aged components to determine the total system deterioration may not be realistic. It may however be the best compromise if the cost of full system deterioration is considered prohibitive, provided an appropriate level of control is possible to ensure appropriate components were used. The mileage accumulation test should be performed with engine and emission control. As shown in the AECC moped test program, small engines are really cheap and the carburetor is very simple. Oil consumption can be quite high. As a consequence, deterioration is not only coming from the catalyst but also from the engine itself.
8-How would you propose to demonstrate to a type approval authority correlation between results obtained from full and partial mileage accumulations in a cost-effective way?
The proposals made by ACEM to TRL and the Commission deal with this issue. Catalyst performance is well documented by various learned authorities as having an initial deterioration followed by a slower but predictable decline. The proposals made by ACEM to TRL and the Commission fully consider this in proposing a test to 50% distance with extrapolation to the final distance to calculate the results, also aiming for harmonization with the method required in US.
The basis have to be the type approval driving cycle.
Deterioration due to thermal events may be realistically modelled using hydrothermal ageing. For example a hydrothermal ageing procedure can be developed to mimic real life ageing of the catalyst. This does not account for exotherms caused by poorly controlled fuelling transients or poisoning by oil components and will not lead to an understanding of real world emissions from a particular engine/catalyst duty cycle, full system durability is the only way to provide an indication of total system performance in use.
9-What effect does the fuel and lubrication oil used and the ambient conditions (temperature and pressure) have on durability testing procedures and the test results?
Durability test should be used with the aspect specified fuel and recommended oil by manufacturer. There are however well documented issue with sulphur poisoning derived from fuel and oil and also with lead poisoning (for fuel see also attached file “Pb poisoning”). No significant influence expected due to differences in ambient conditions (ambient temperature difference will always be small compared to temperature to which critical components are exposed in the exhaust system and in the engine).
The calculation of the exhaust emissions are effected by the ambient pressure and the used fuel. The oil temperature effects the cold start in the driving cycle.
Based on experience with cars, ambient conditions have a minor effect on durability tests. Even fuel effects are not that important, regular fuel should be ok for the durability test, but certification fuel should be used for emission tests. The effect of lubrication oil has been discussed in question 3.
L1Ae Powered cycle - Average lifetime distances (km)
L1Ae Powered cycle - Average lifetime (years)

L1Ae Powered cycle - Comments

Reply to Q10 sent separately by email to L-category@trl.co.uk

L1Be, L2e, L6Ae - Average lifetime distances

L1Be, L2e, L6Ae - Average lifetime (years)

L1Be, L2e, L6Ae - Comments

L3e, L4e, L5e, L6Be, L7Be - Average lifetime distances

L3e, L4e, L5e, L6Be, L7Be - Average lifetime (years)

L3e, L4e, L5e, L6Be, L7Be - Comments

L3e, L4e, L7Ae - Average lifetime distances

L3e, L4e, L7Ae - Average lifetime (years)

L3e, L4e, L7Ae - Comments

11 - a: increased engine out emissions and the main reasons (e.g. increased blow-by, changing characteristics of engine sensors and actuators, insufficient compensation, valve overlap changes, leaking / worn intake/exhaust valves etc.)

This question relates to emission performance deterioration due to mechanical engine degradation/wear which can be expected to be small compared to deterioration of the thermal/chemical degradation of components in the exhaust system. (See also answer to question 1)

Motorcycles are often repaired or adjusted by the owner. Silencers without catalyst are used. EGR systems are deactivated and so on.

Old fuel or old oil maybe effect the emissions due to long periods, where the motorcycle is not used.

11 - b: thermal ageing of emission relevant components for each propulsion type.

See answer to question 1 and 2

Thermal ageing only effects the catalytic converter.

11 - c: the mechanisms which lead to poisoning of emission relevant components and to what extent these are \"self-healing\".

This question is understood to relate to contamination/poisoning caused by fuel or oil components. There are numerous published papers on this subject which TRL can refer to.

Carburetor equipped motorcycles have a lot of possibilities to increase the emissions by aged rubber, fuel that was left over winter time changes the jets and needles and so on.

11 - d: the decreased adsorption efficiency of evaporative emission control system and the influence on evaporative and/or exhaust emission performance.

When it comes to durability, the components that affect emissions performance to the greatest extent are those subjected to thermal cycling (i.e. catalysts in the exhaust system). Manufacturers use an active purge control on most vehicle types that maintains adequate flow rates through the canister and therefore the risk of decreased absorption efficiency is substantially reduced.

Evaporative systems are not required in Europe in the moment.

12-Please provide any other comments or information that you feel is important.

Please refer to comment, evidence and most importantly the ACEM proposal already provided in two meetings with TRL at Triumph and Honda UK.

Durability testing is new in Europe. The mileage of motorcycles per year are often around 1000 to 2000 km. The problem can be seen in the time, where the motorcycle is not used and parts maybe are effected. Modern motorcycles with injection valves don\'t have this effect.

As the AECC motorcycle and moped test programs have shown, durability and in-use compliance tests are necessary to reduce emissions. More information is available at www.aecc.eu/en/Publications/Publications.html.

Appendix G Emission test data

The following are the cumulative plots of the real-time gaseous emissions data for vehicle 10. This plot is useful when comparing gasses.

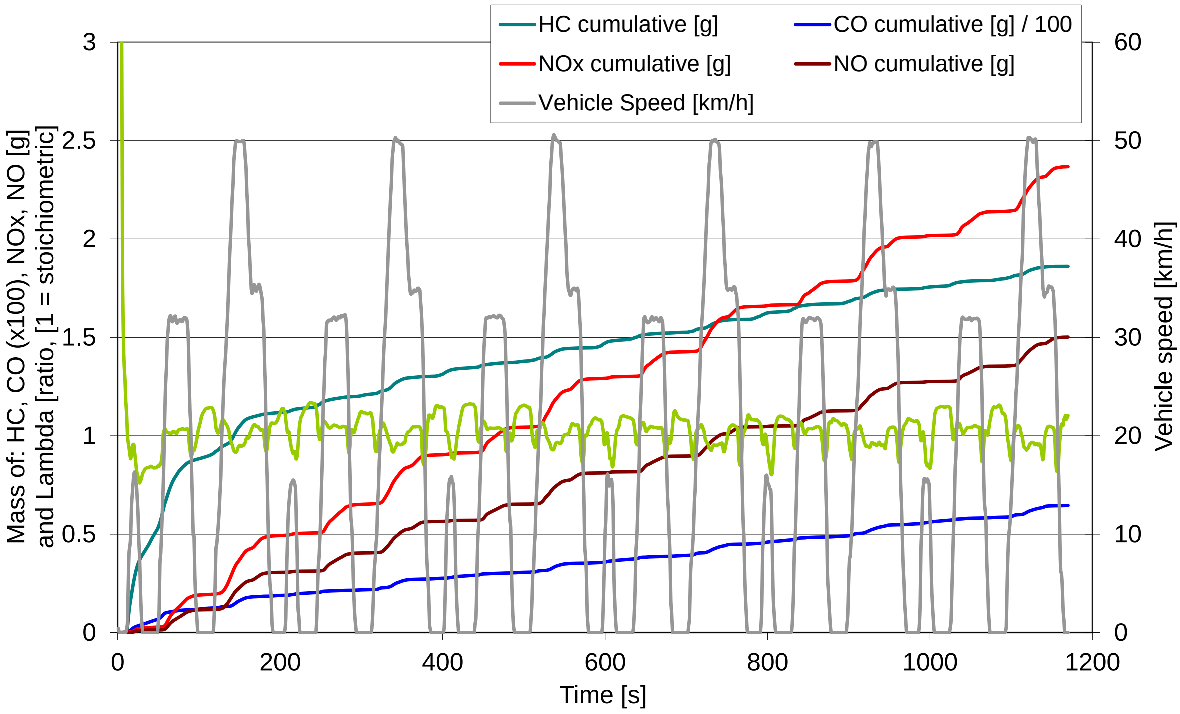


Figure 16-11: Vehicle 10: L7Ae, emissions, R40 cycle, cumulative plot

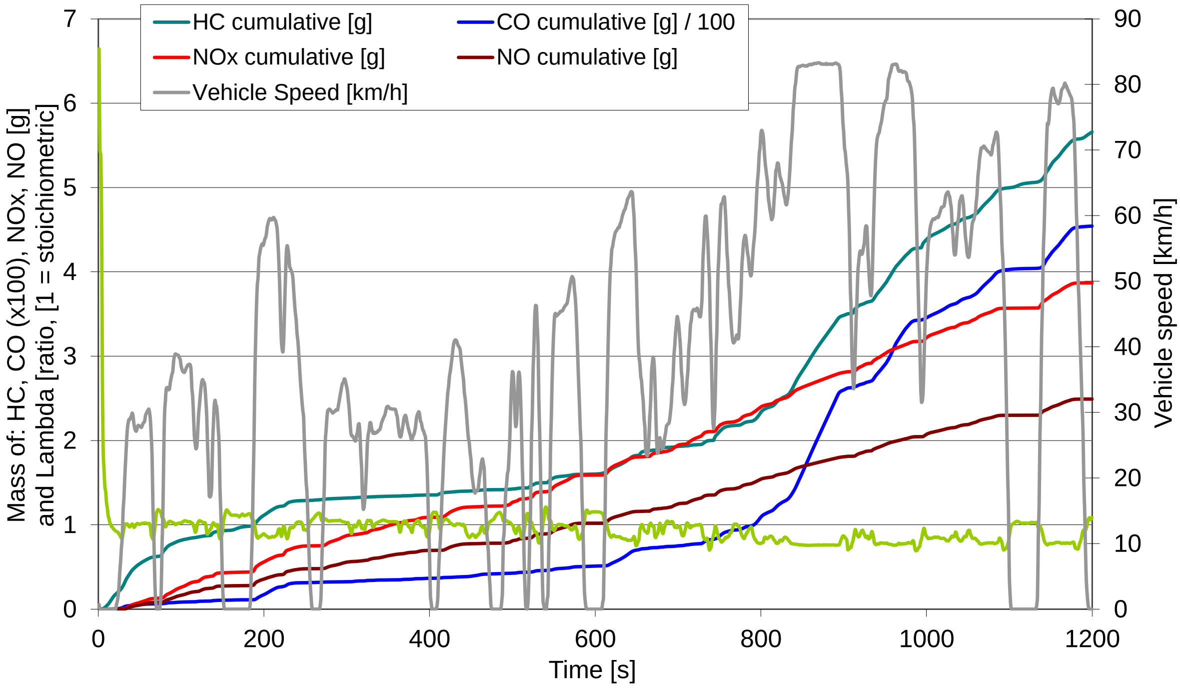


Figure 16-12: Vehicle 10: L7Ae, emissions, WMTC cycle, cumulative plot

The following are the real-time instantaneous gaseous emissions data for vehicle 10. This style of plot is useful when looking for anomalies. Therefore, this style was found to be more useful for this study.

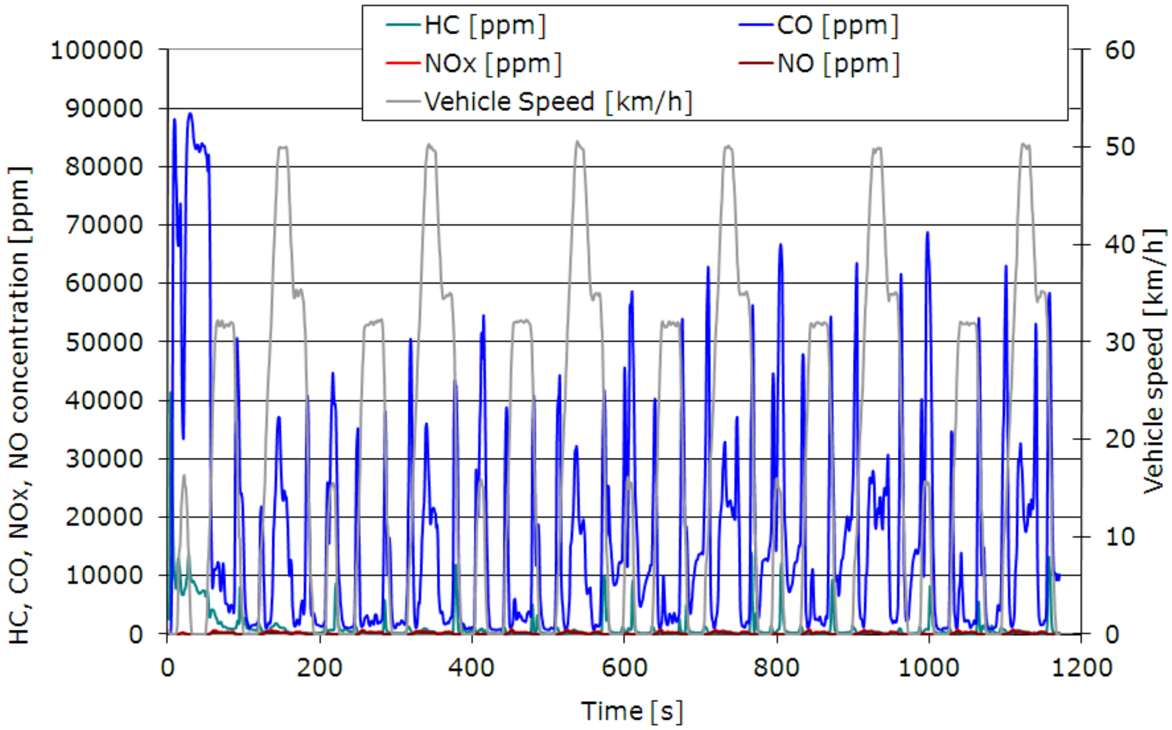


Figure 16-13: Vehicle 10: L7Ae, emissions, R40 cycle

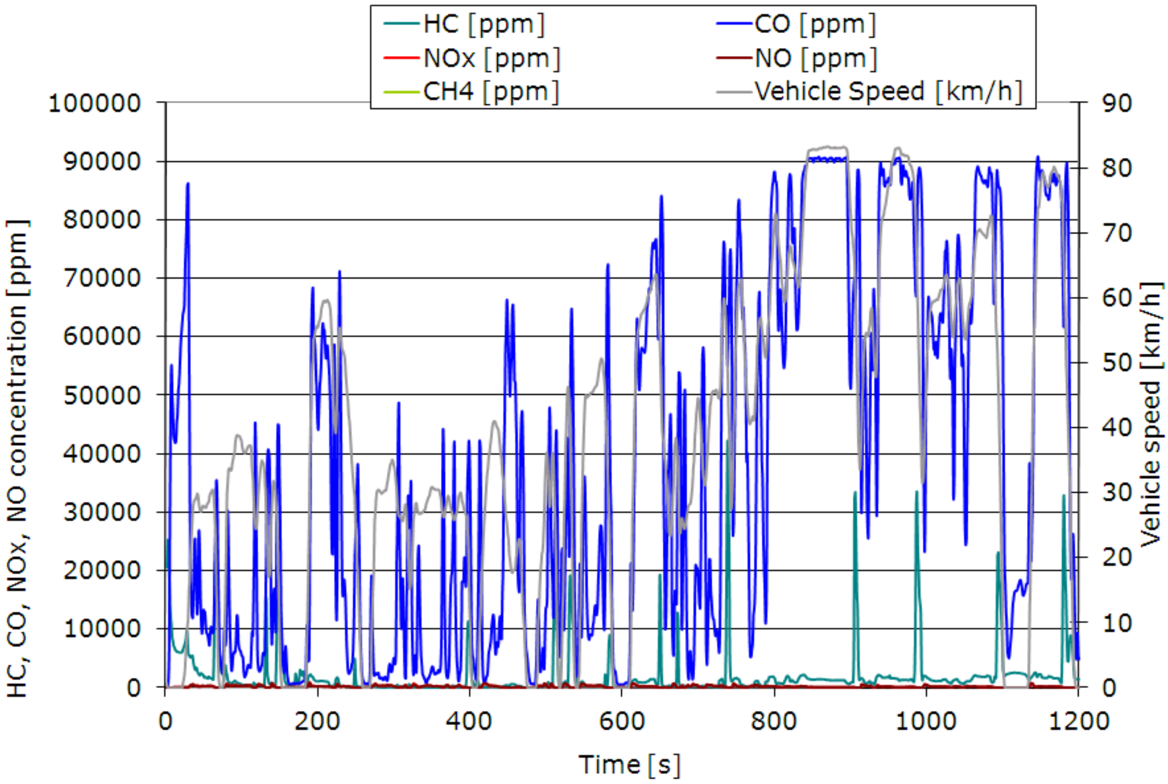


Figure 16-14: Vehicle 10: L7Ae, emissions, WMTC cycle

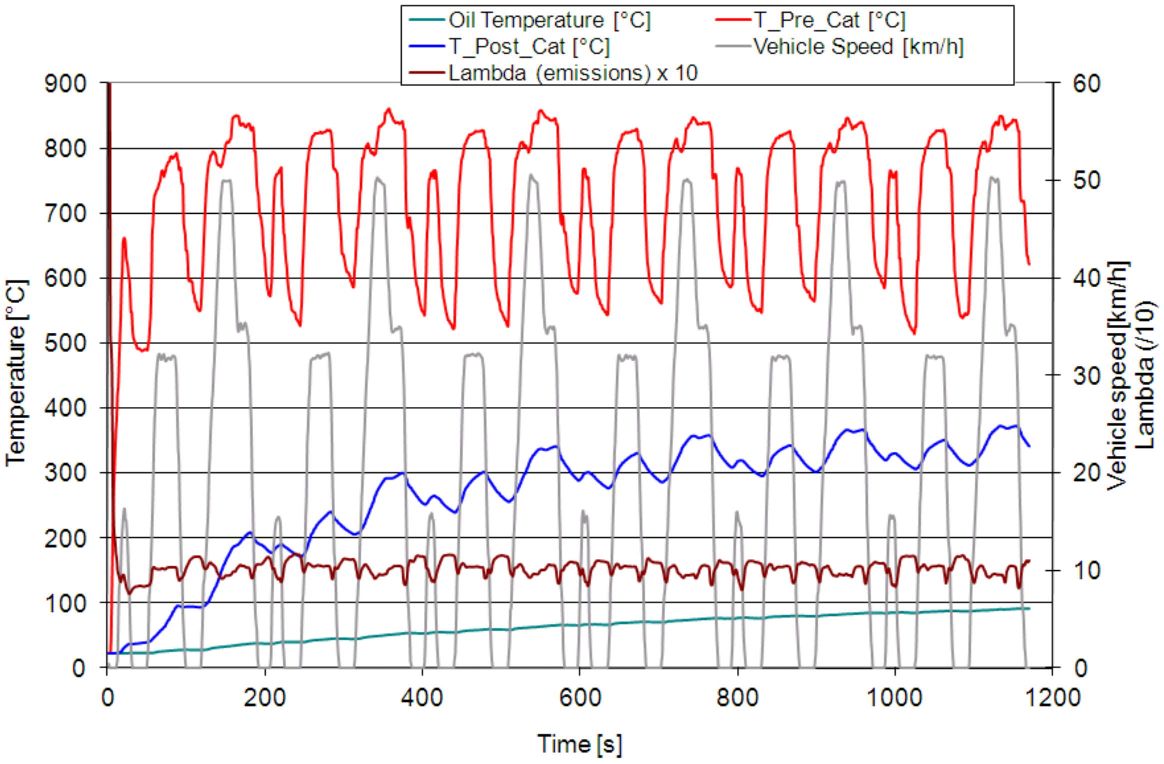


Figure 16-15: Vehicle 10: L7Ae, temperatures, R40 cycle

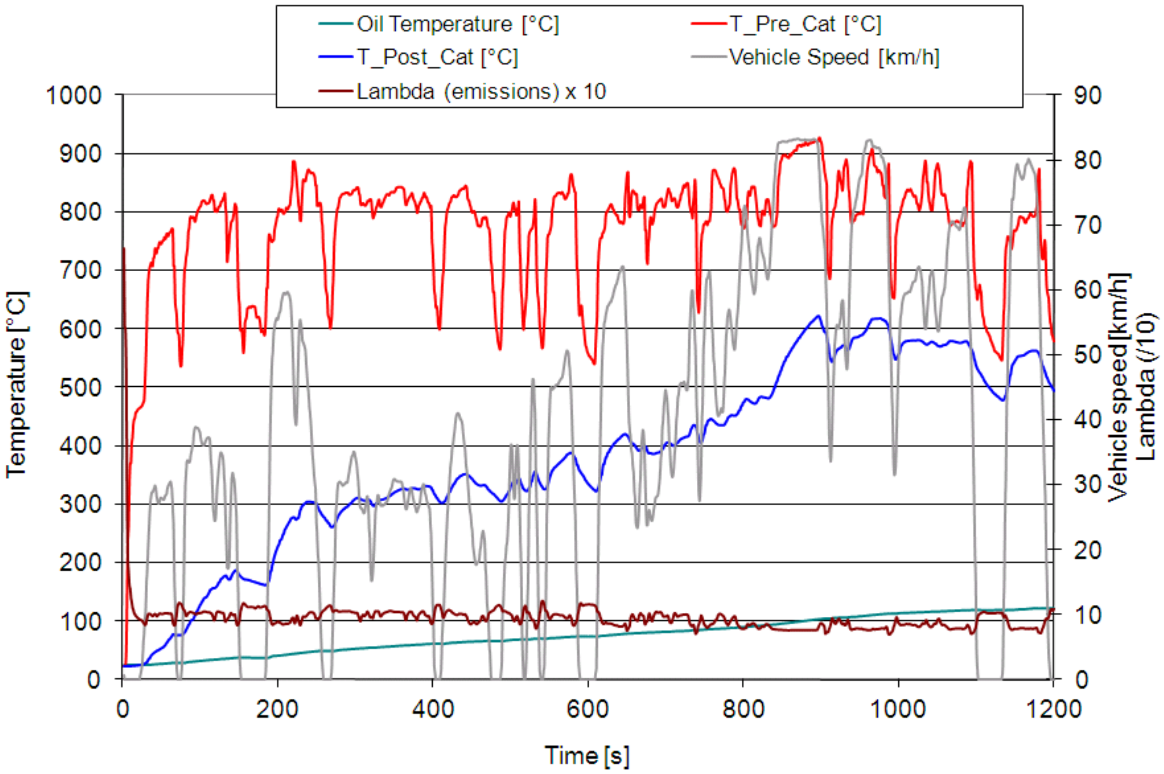


Figure 16-16: Vehicle 10: L7Ae, temperatures, WMTC cycle

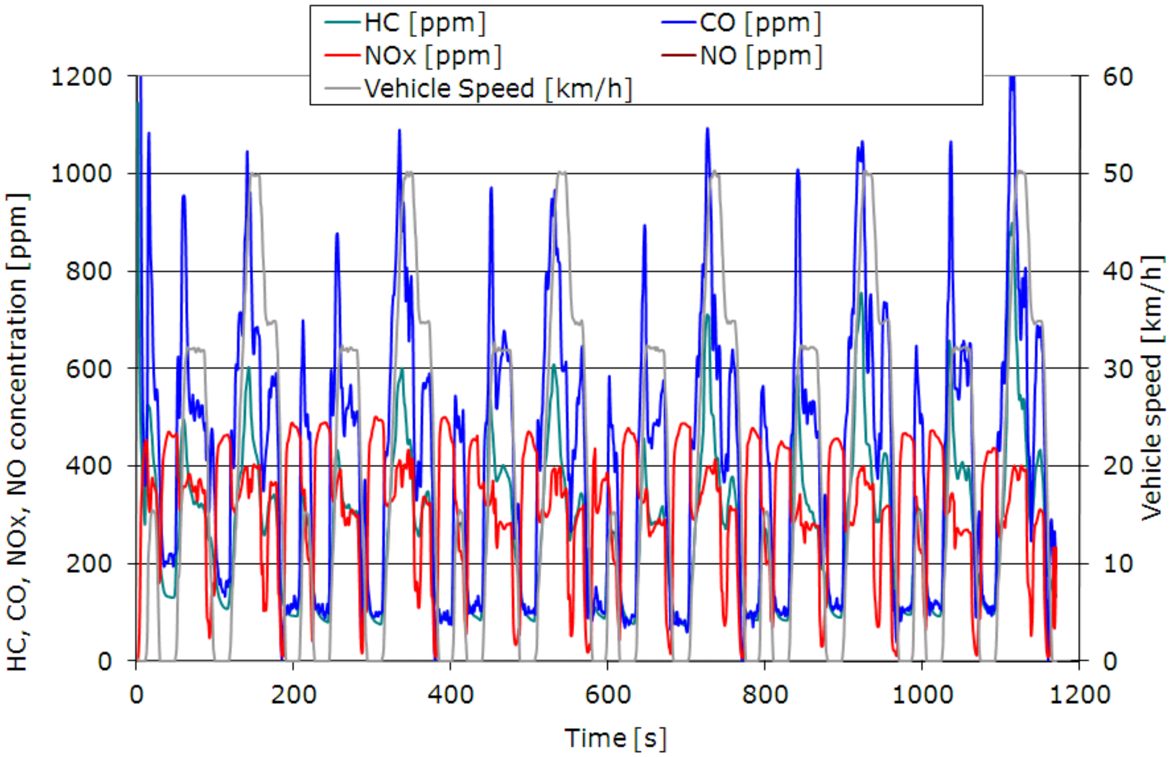


Figure 16-17: Vehicle 12: L7Be, emissions, R40 cycle

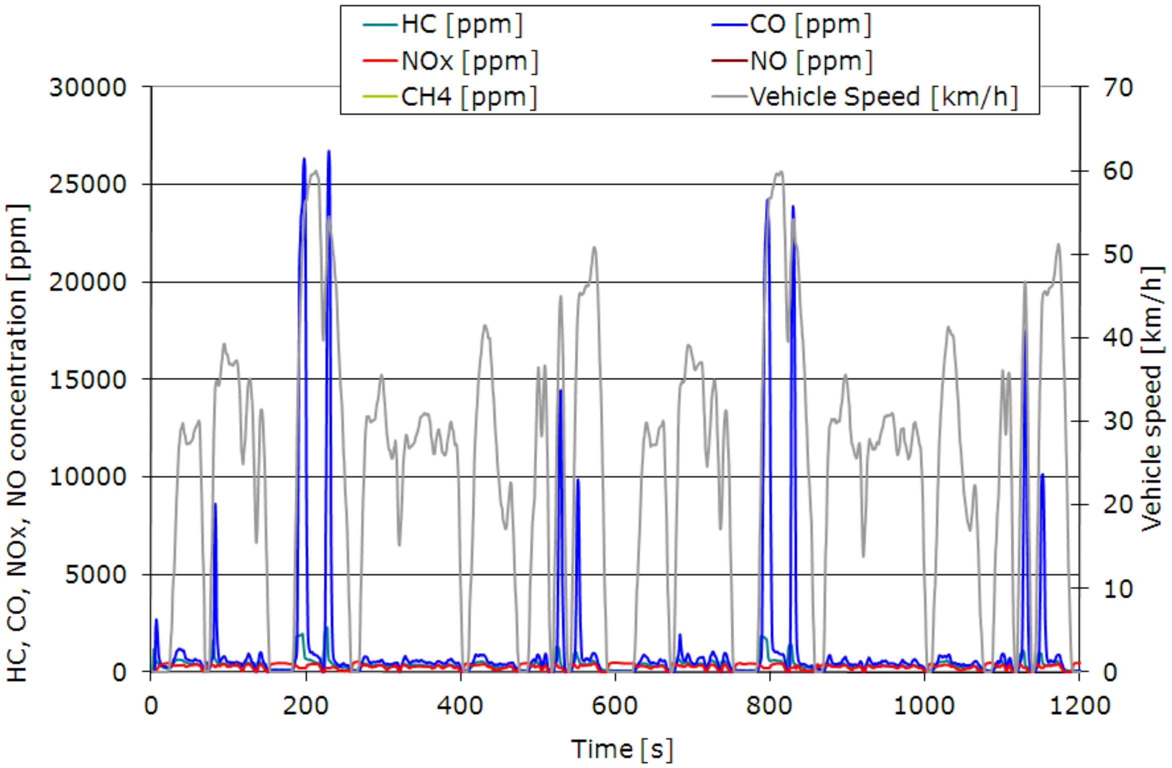


Figure 16-18: Vehicle 12: L7Be, emissions, WMTC cycle

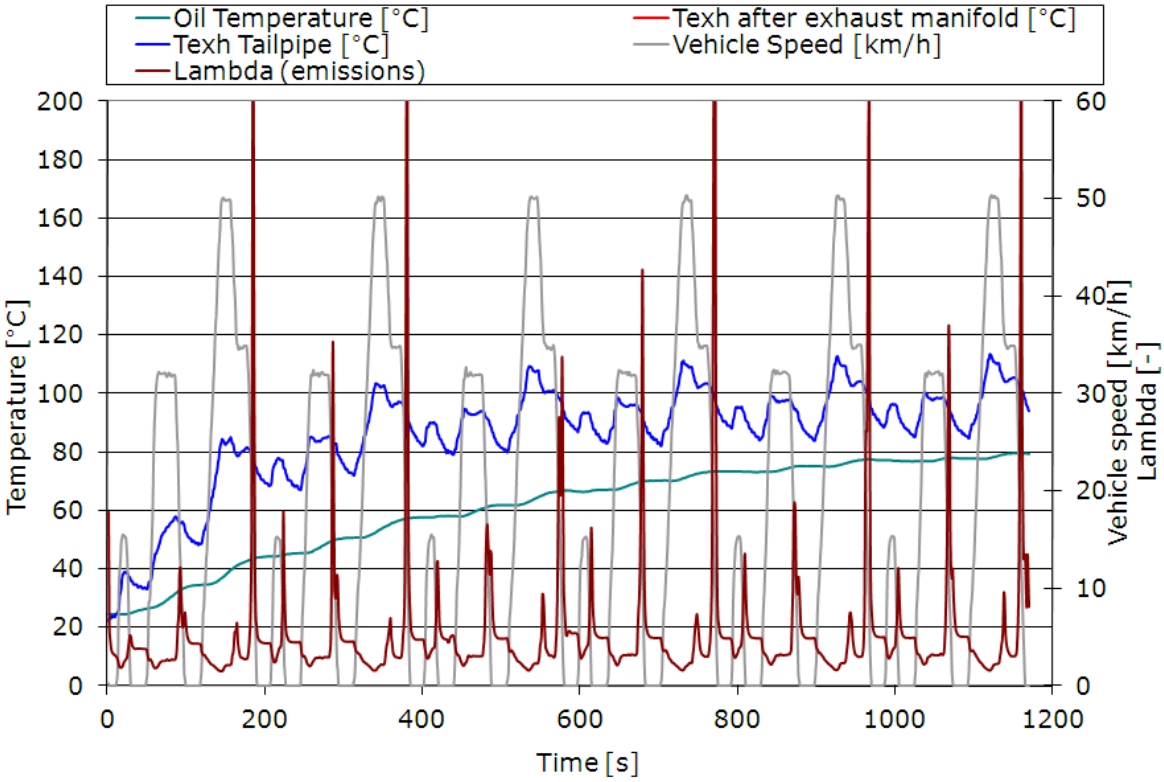


Figure 16-19: Vehicle 12: L7Be, temperatures, R40 cycle

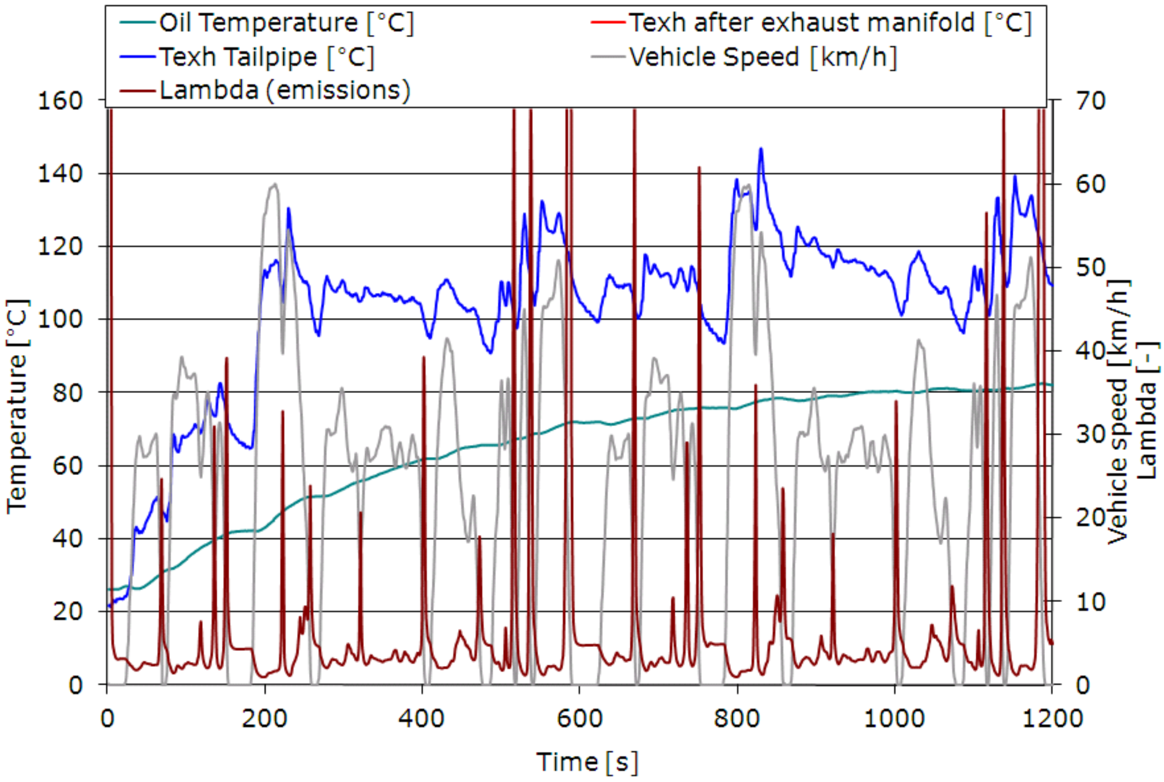


Figure 16-20: Vehicle 12: L7Be, temperatures, WMTC cycle

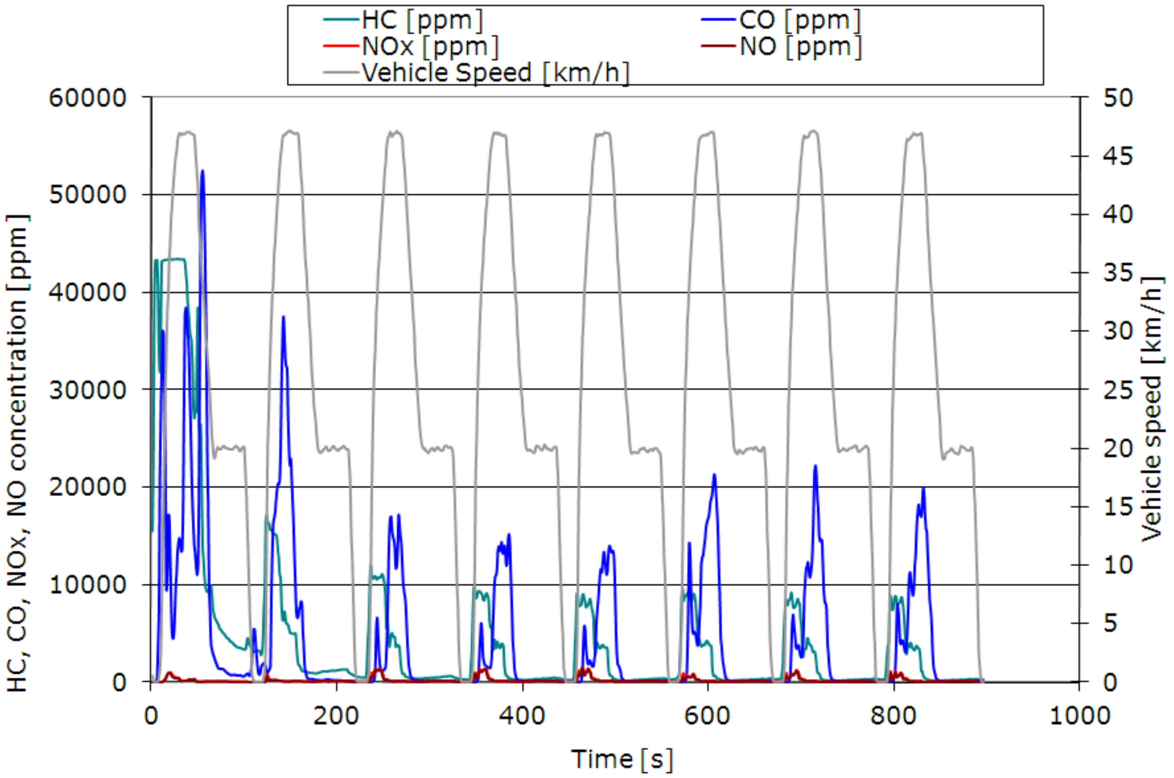


Figure 16-21: Vehicle 9: L6Ae, emissions, R40 cycle

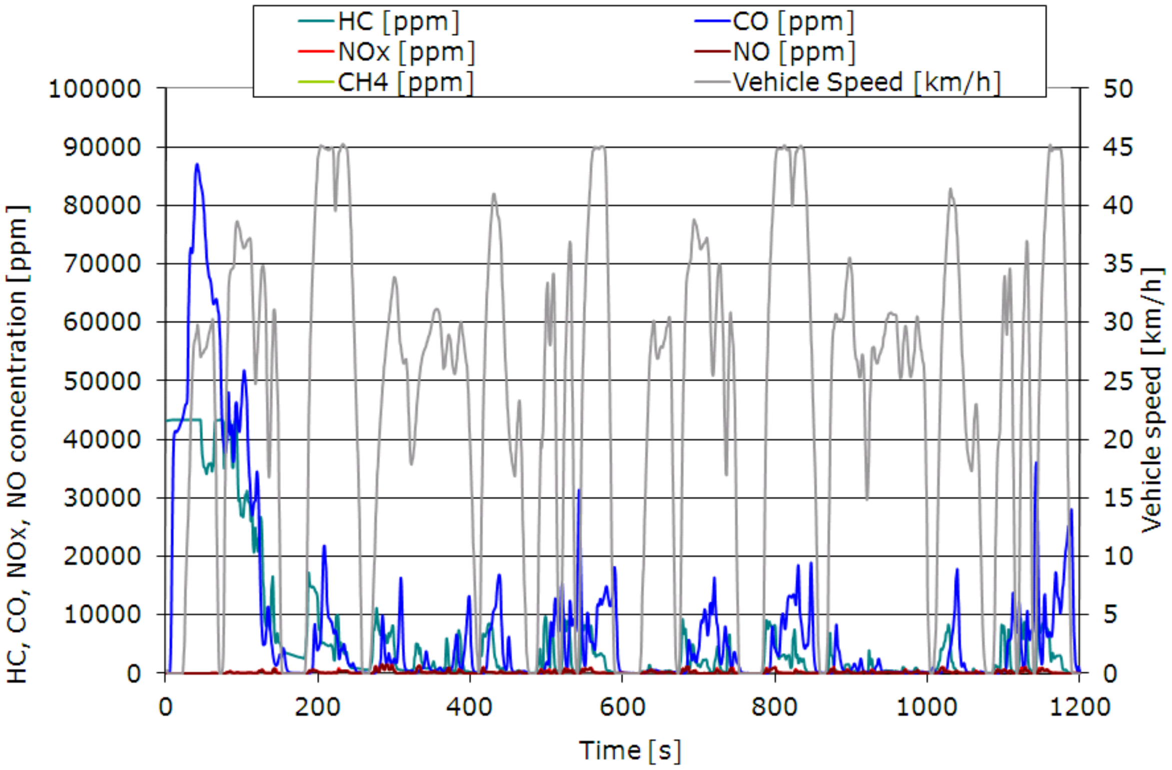


Figure 16-22: Vehicle 9: L6Ae, emissions, WMTC cycle

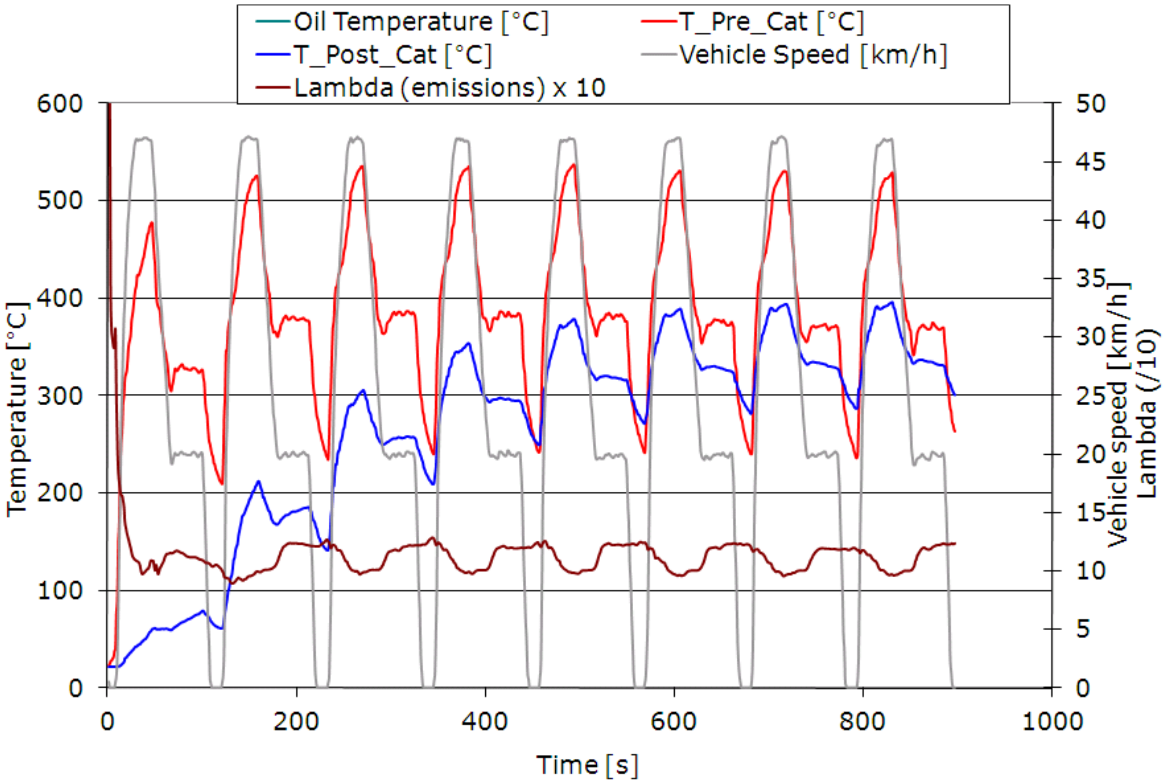


Figure 16-23: Vehicle 9: L6Ae, temperatures, R40 cycle

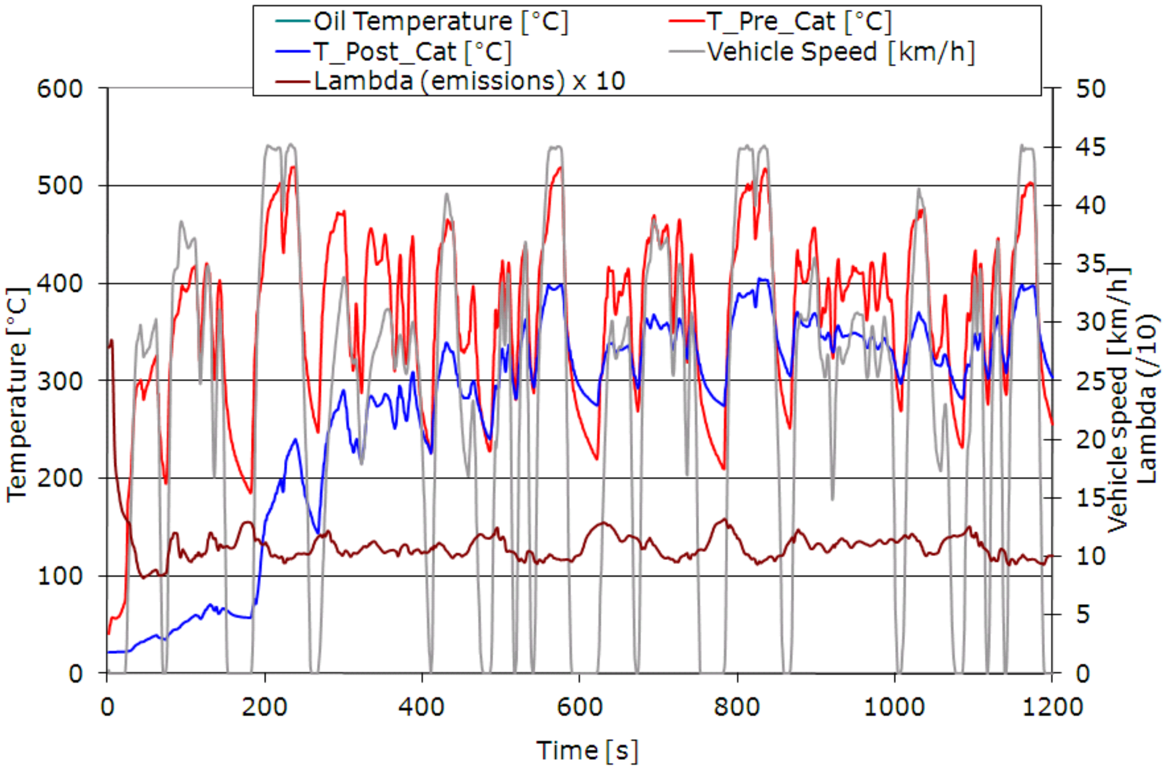


Figure 16-24: Vehicle 9: L6Ae, temperatures, WMTC cycle

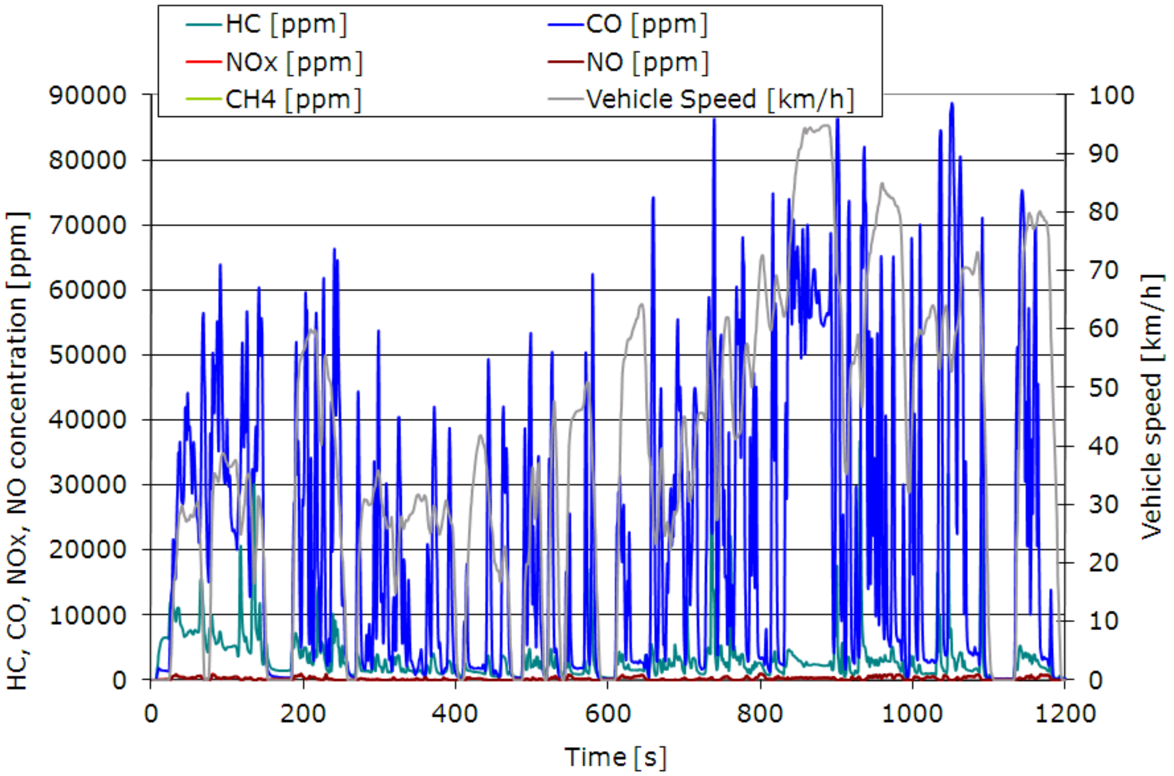


Figure 16-25: Vehicle 5: L3e-A1, emissions, WMTC cycle stage 1

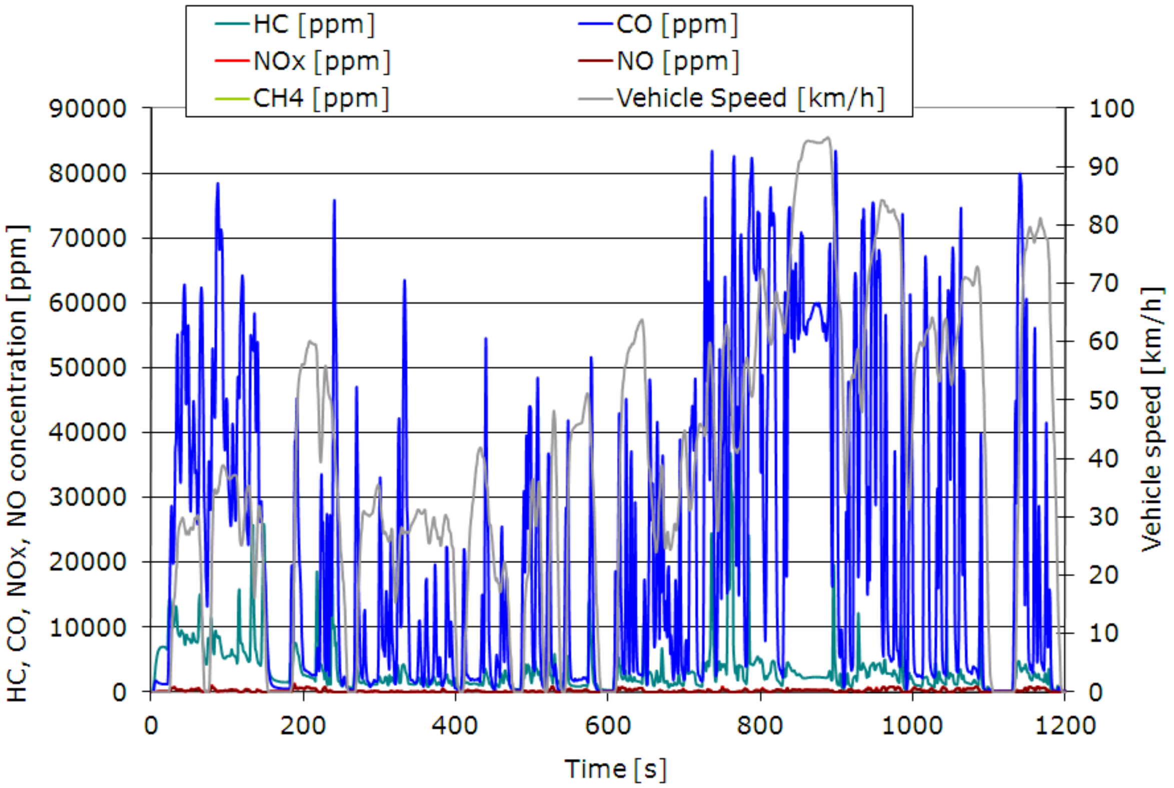


Figure 16-26: Vehicle 5: L3e-A1, emissions, WMTC cycle stage 2

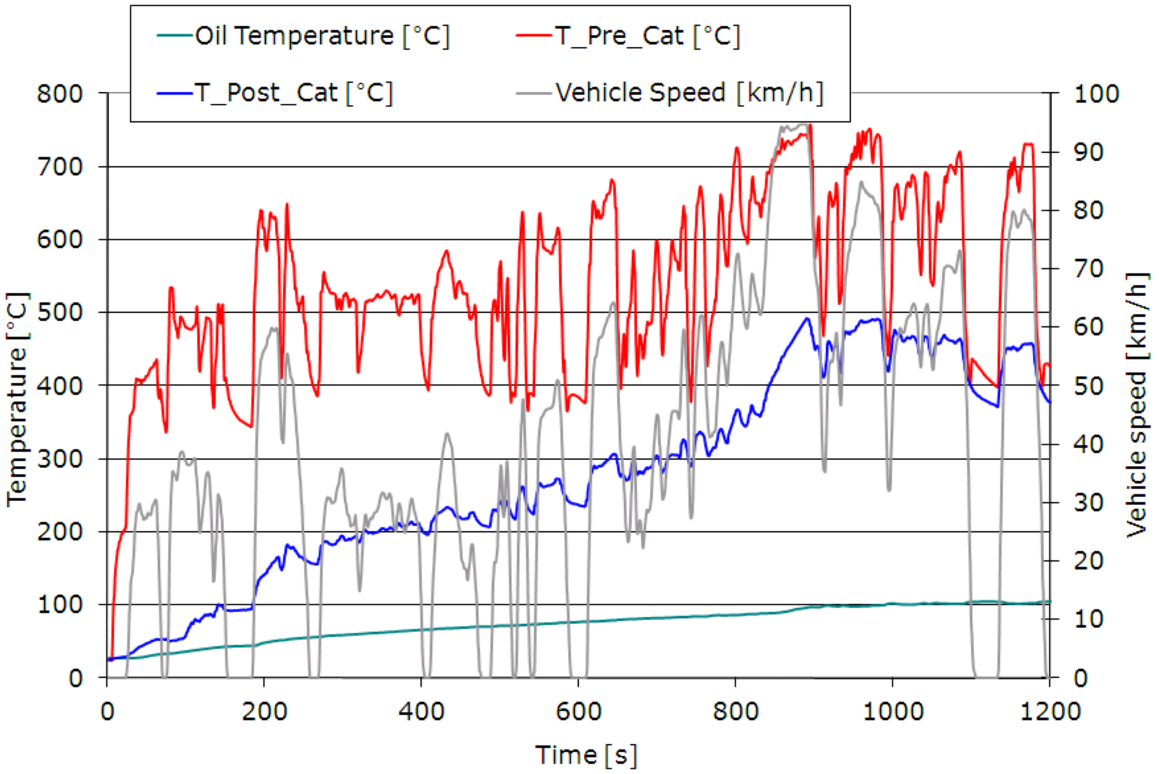


Figure 16-27: Vehicle 5: L3e-A1, emissions WMTC cycle stage 1

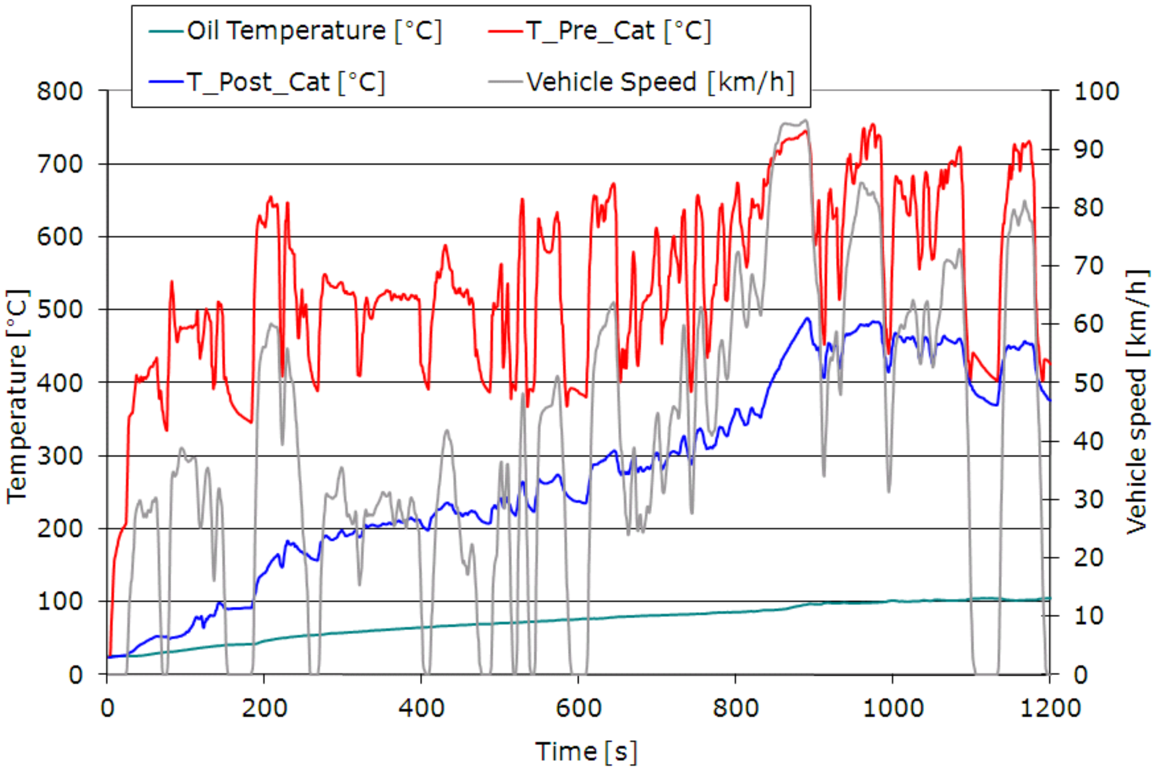


Figure 16-28: Vehicle 5: L3e-A1, temperatures, WMTC cycle stage 2

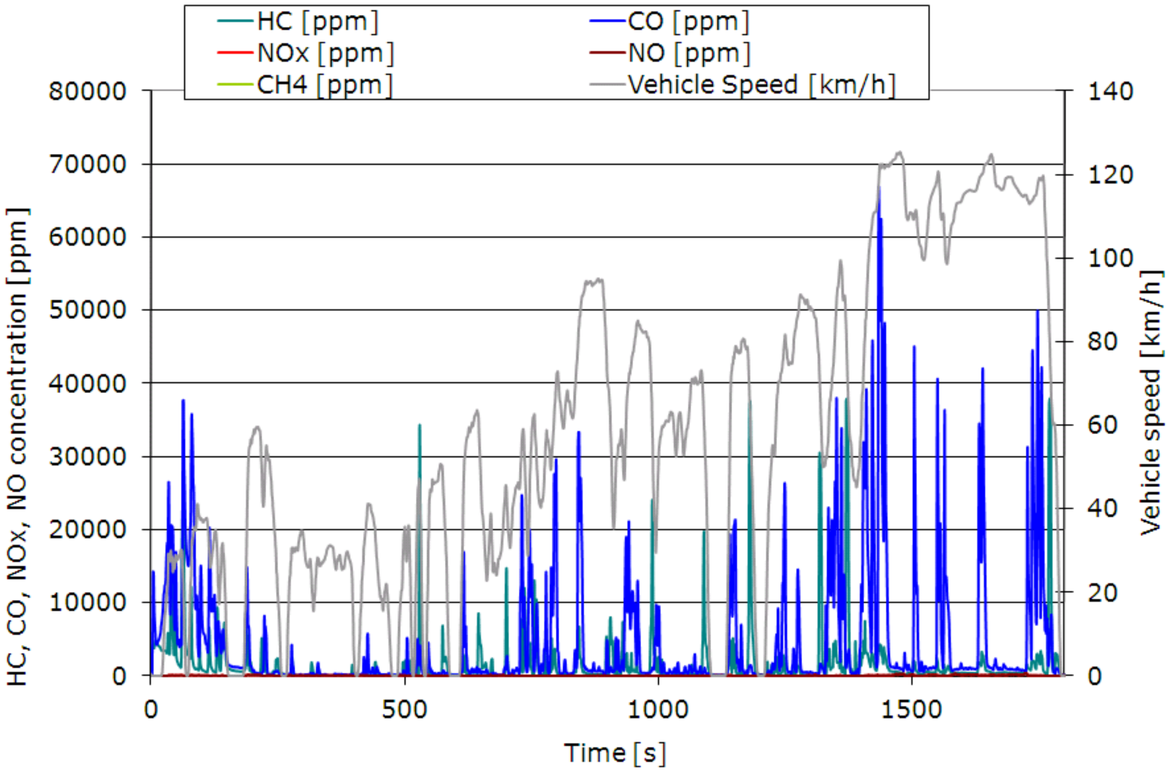


Figure 16-29: Vehicle 6: L3e-A3, emissions, WMTC cycle stage 1

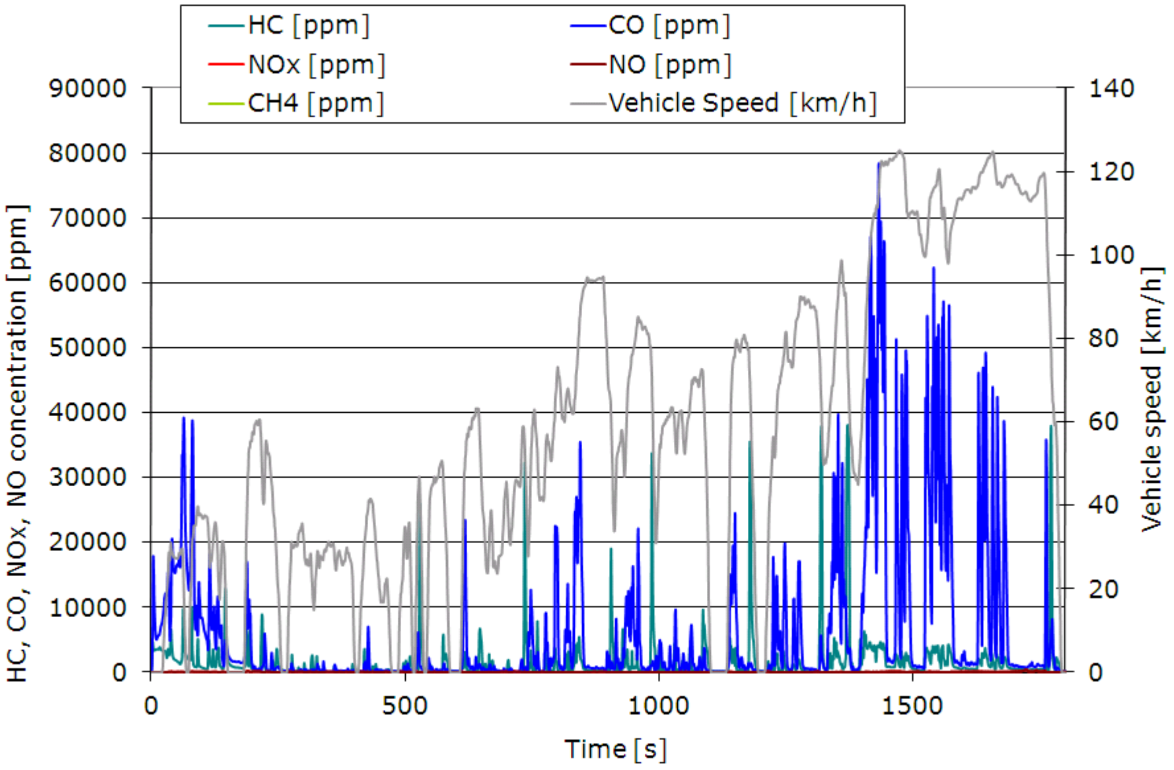


Figure 16-30: Vehicle 6: L3e-A3, emissions, WMTC cycle stage 2

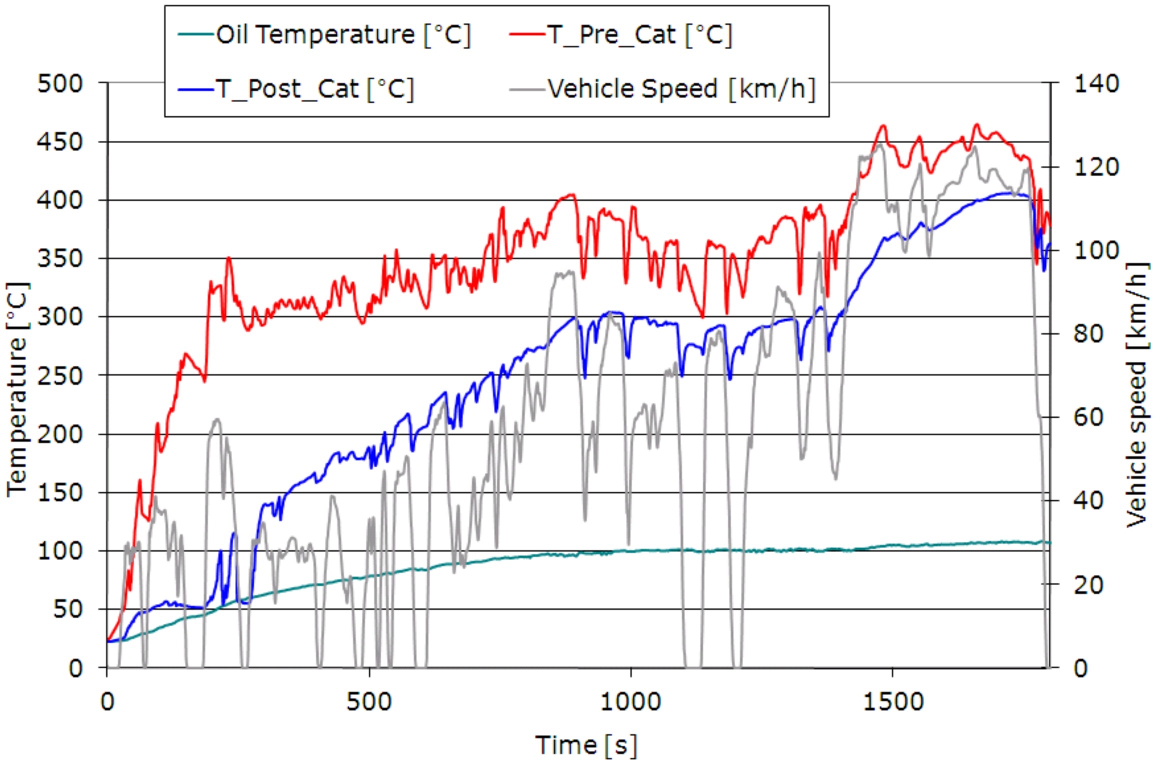


Figure 16-31: Vehicle 6: L3e-A3, temperatures, WMTC cycle stage 1

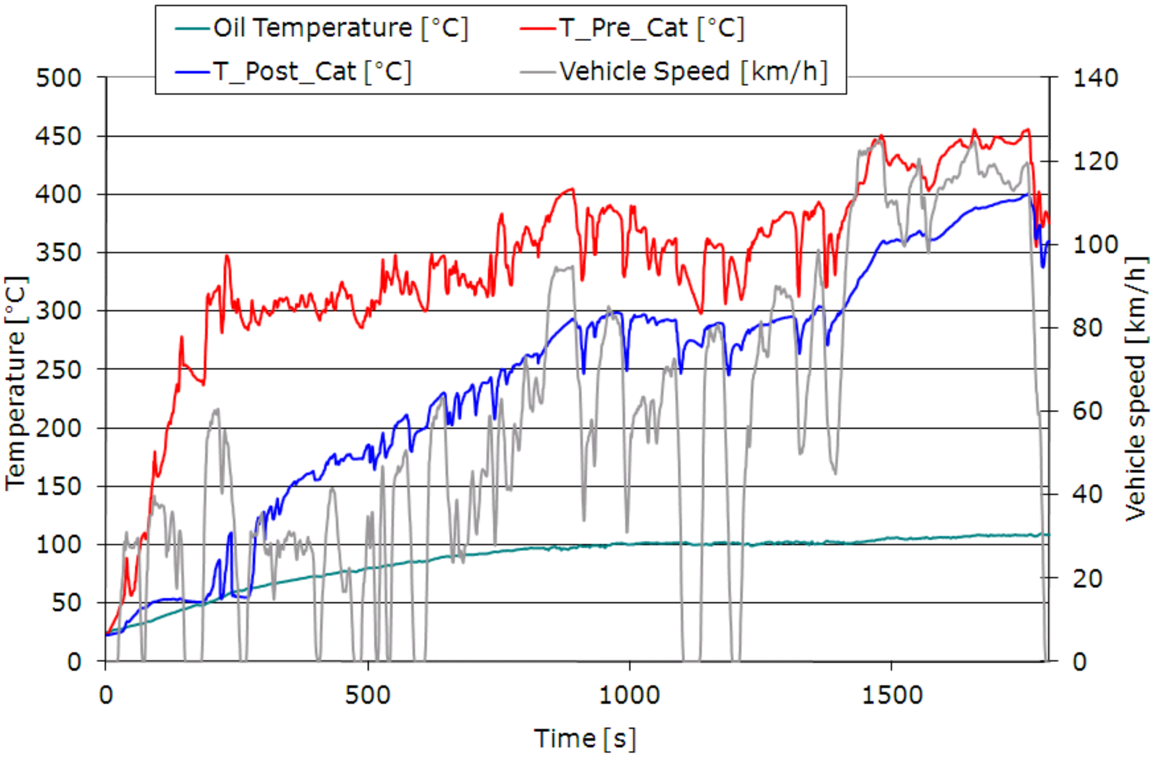


Figure 16-32: Vehicle 6: L3e-A3, temperatures, WMTC cycle stage 2

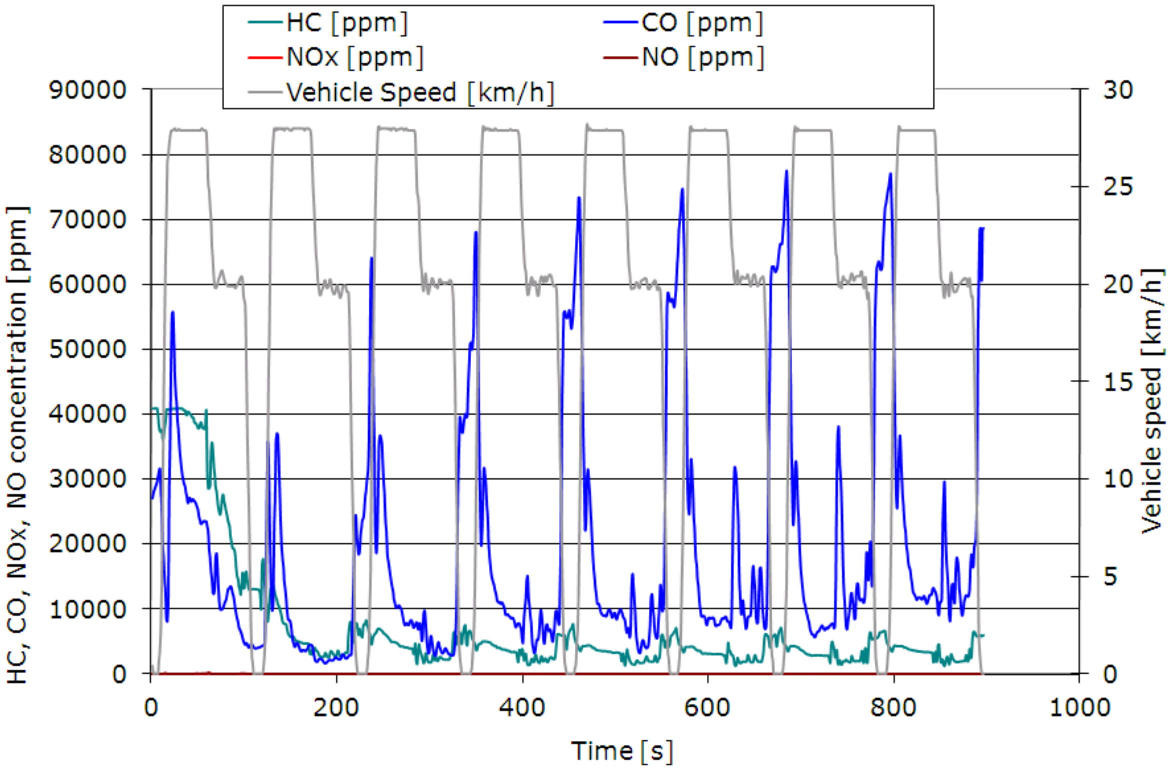


Figure 16-33: Vehicle 4: L1Be, emissions, R47 cycle

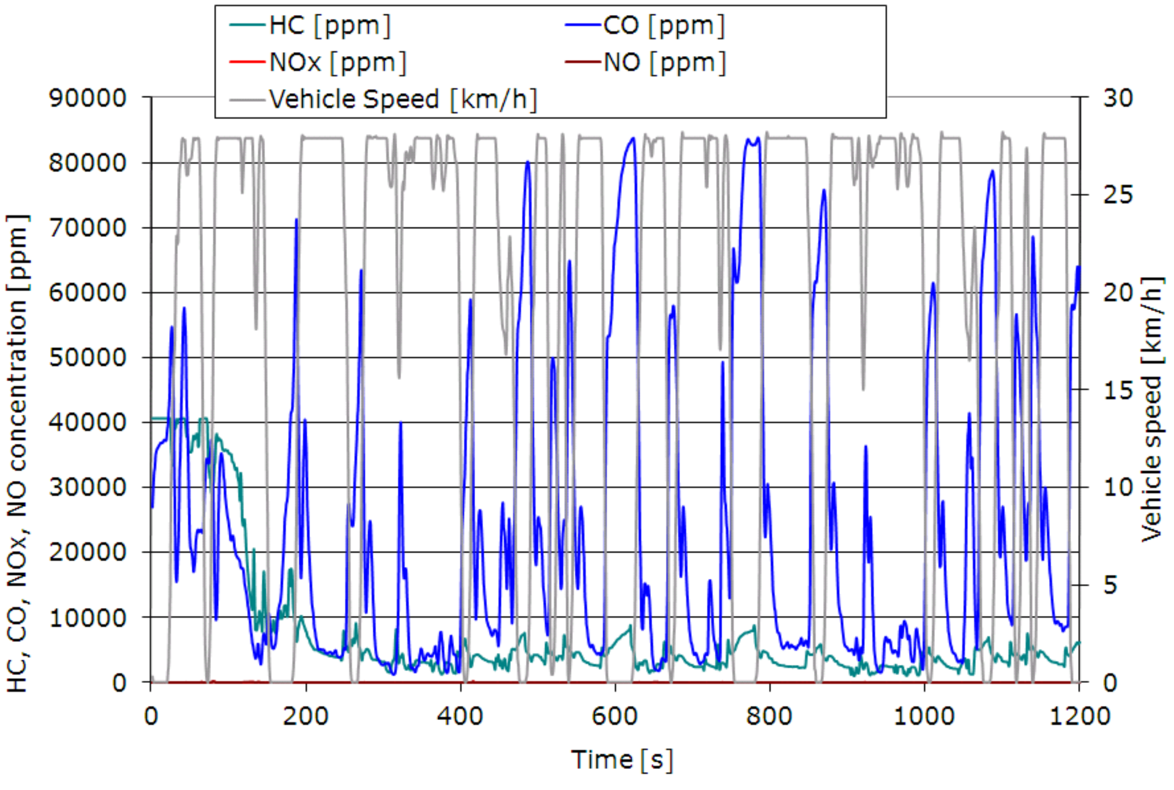


Figure 16-34: Vehicle 4: L1Be, emissions, WMTC cycle

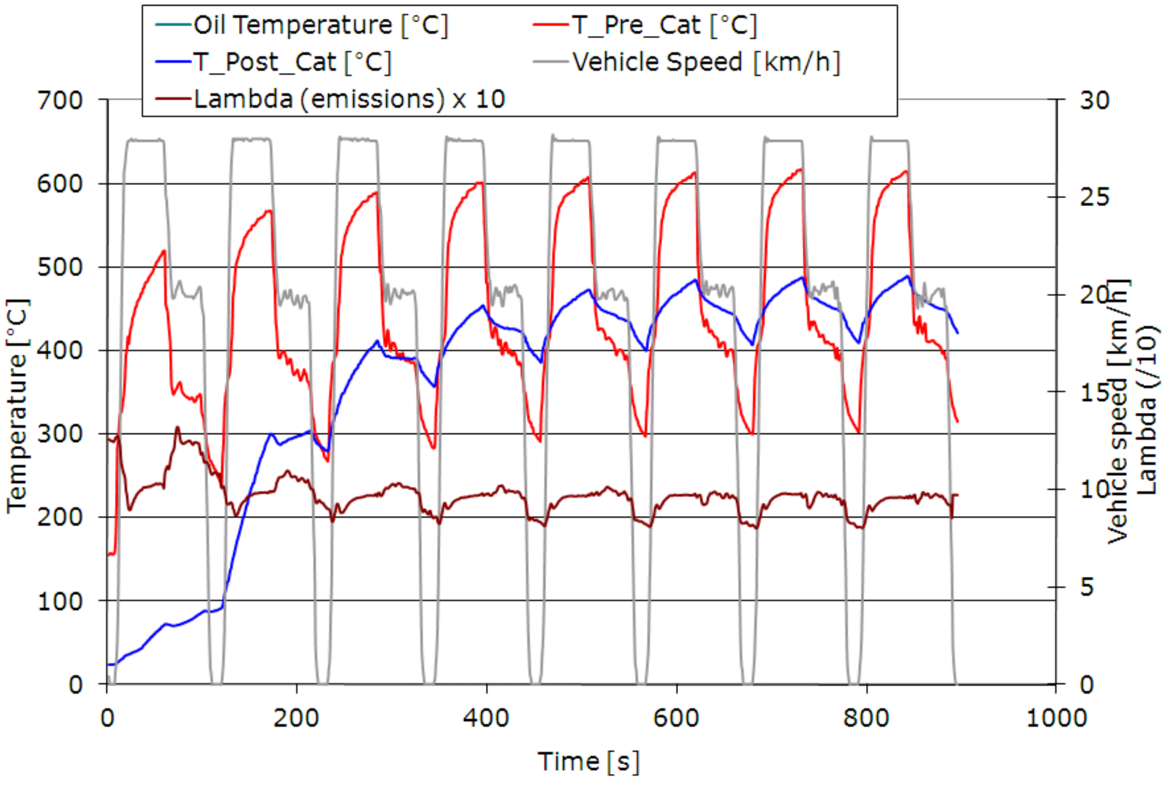


Figure 16-35: Vehicle 4: L1Be, temperatures, R47 cycle

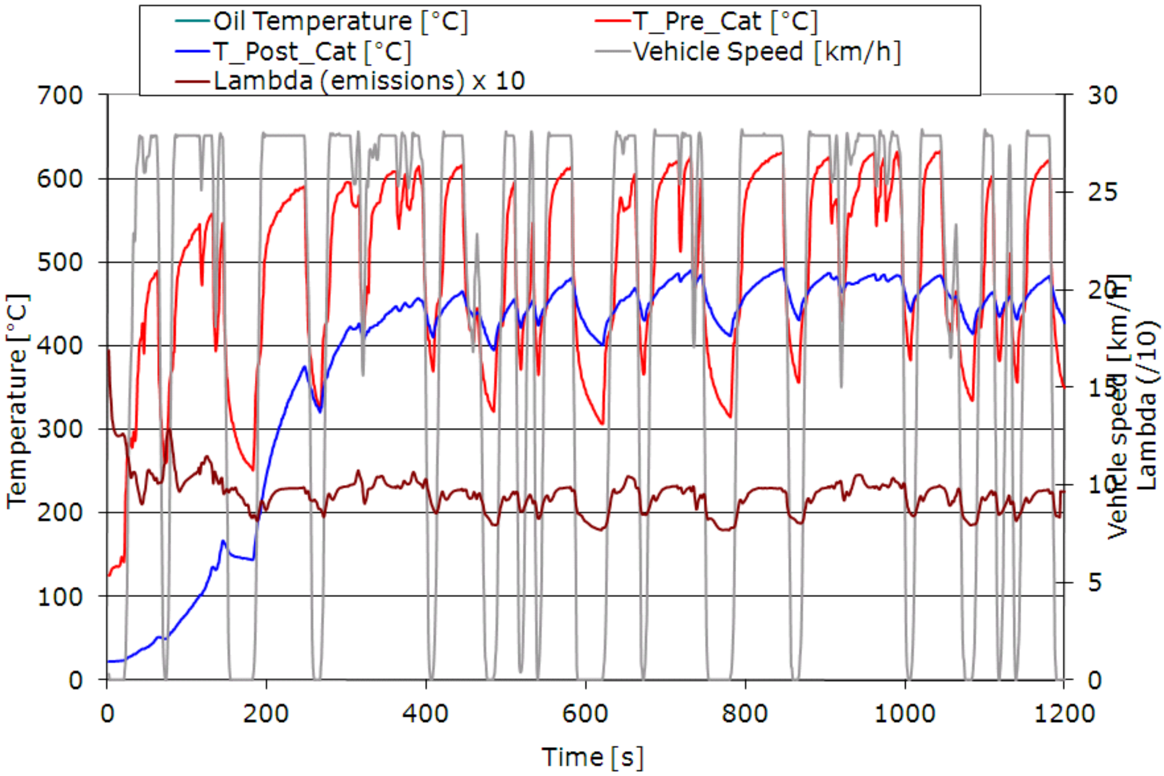


Figure 16-36: Vehicle 4: L1Be, temperatures, WMTC cycle

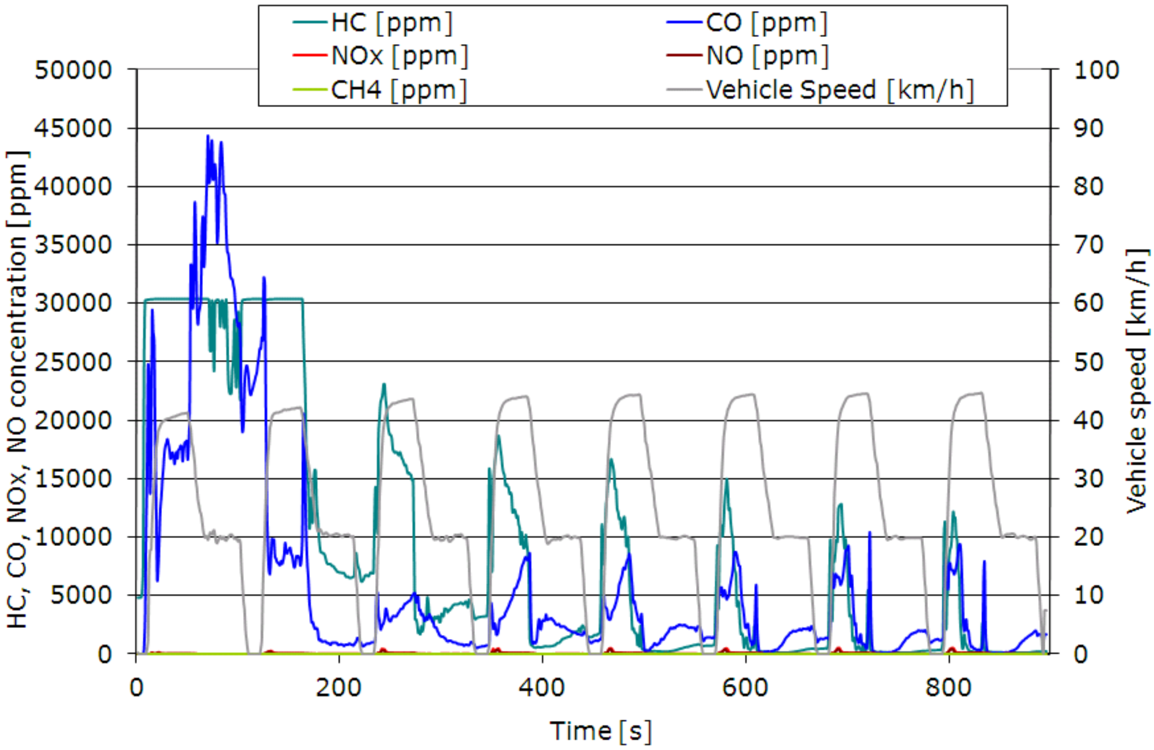


Figure 16-37: Vehicle 2: L1Be, emissions, R47 cycle

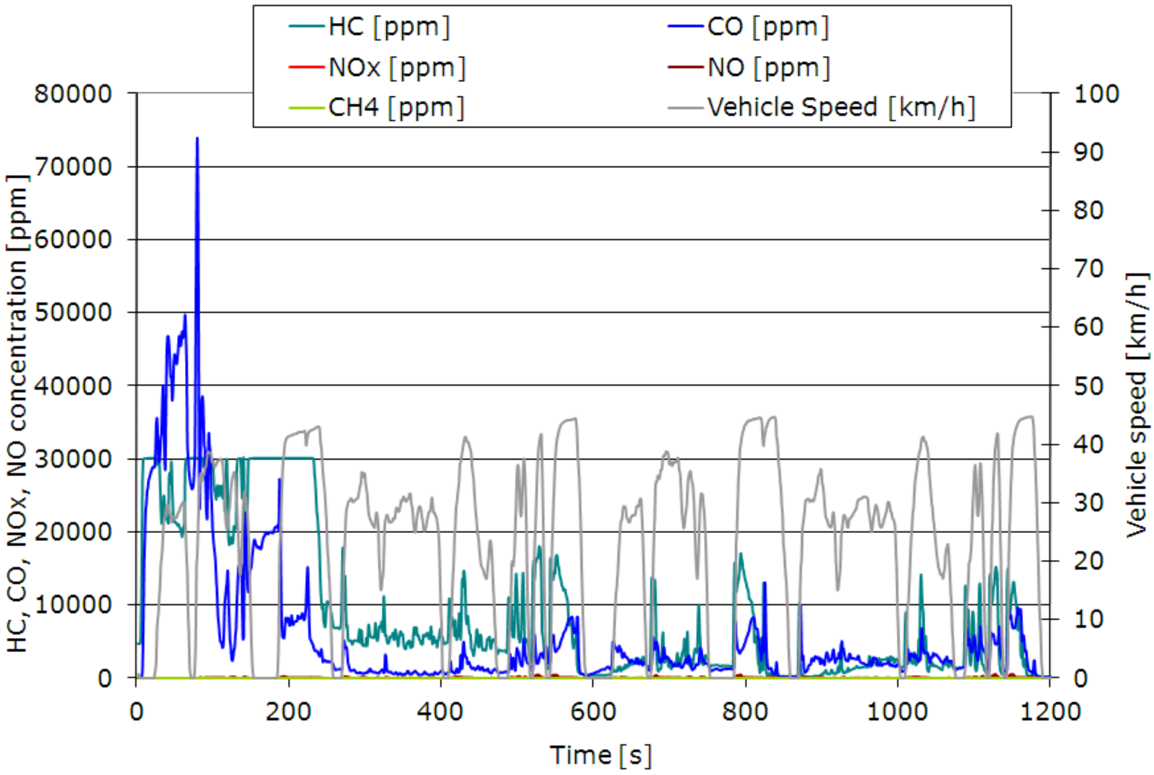


Figure 16-38: Vehicle 2: L1Be, emissions, WMTC cycle

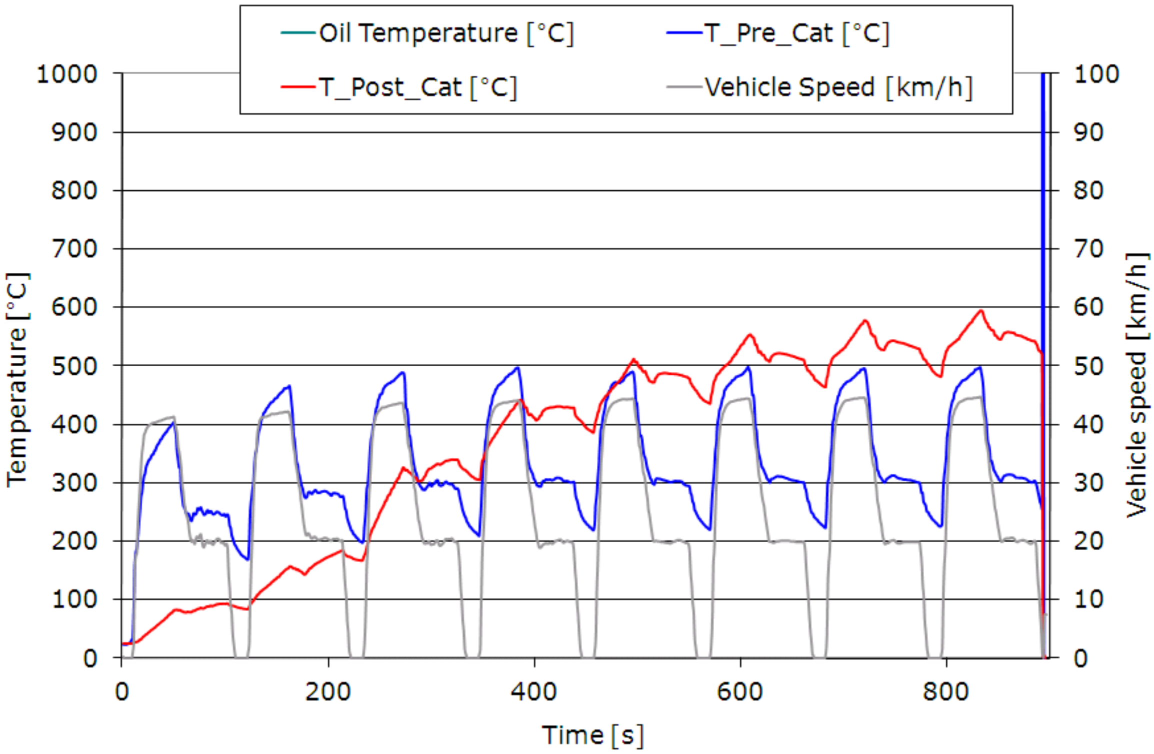


Figure 16-39: Vehicle 2: L1Be, temperatures, R47 cycle

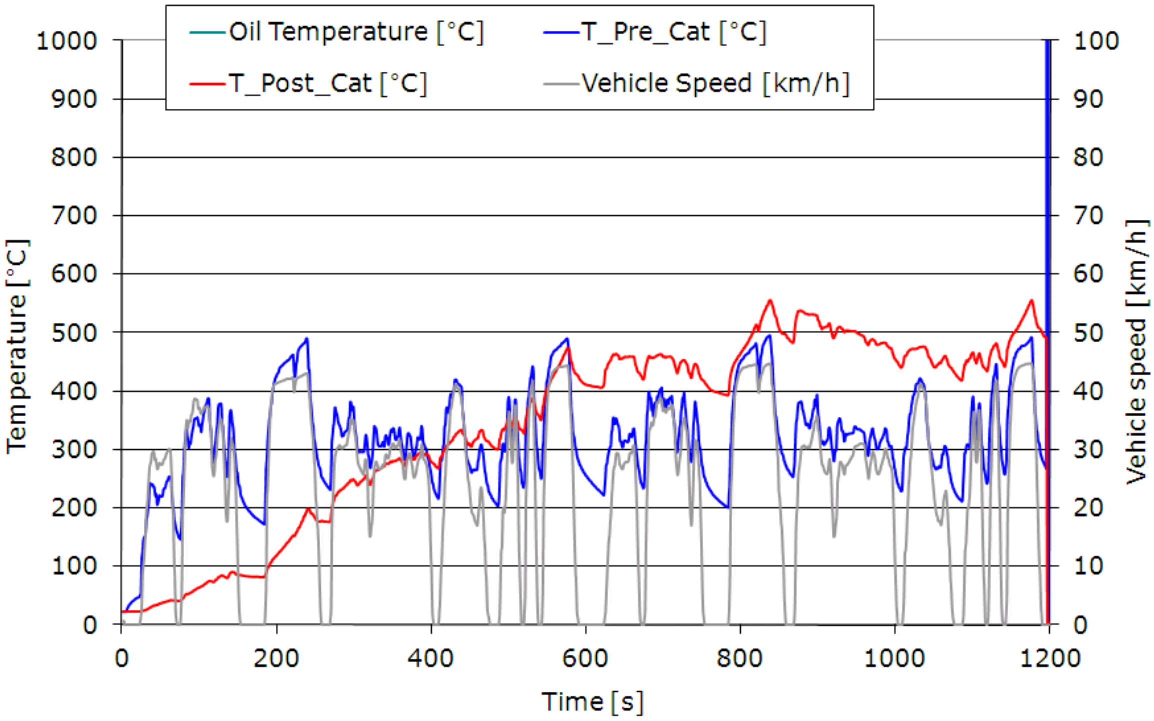


Figure 16-40: Vehicle 2: L1Be, temperatures, WMTC cycle

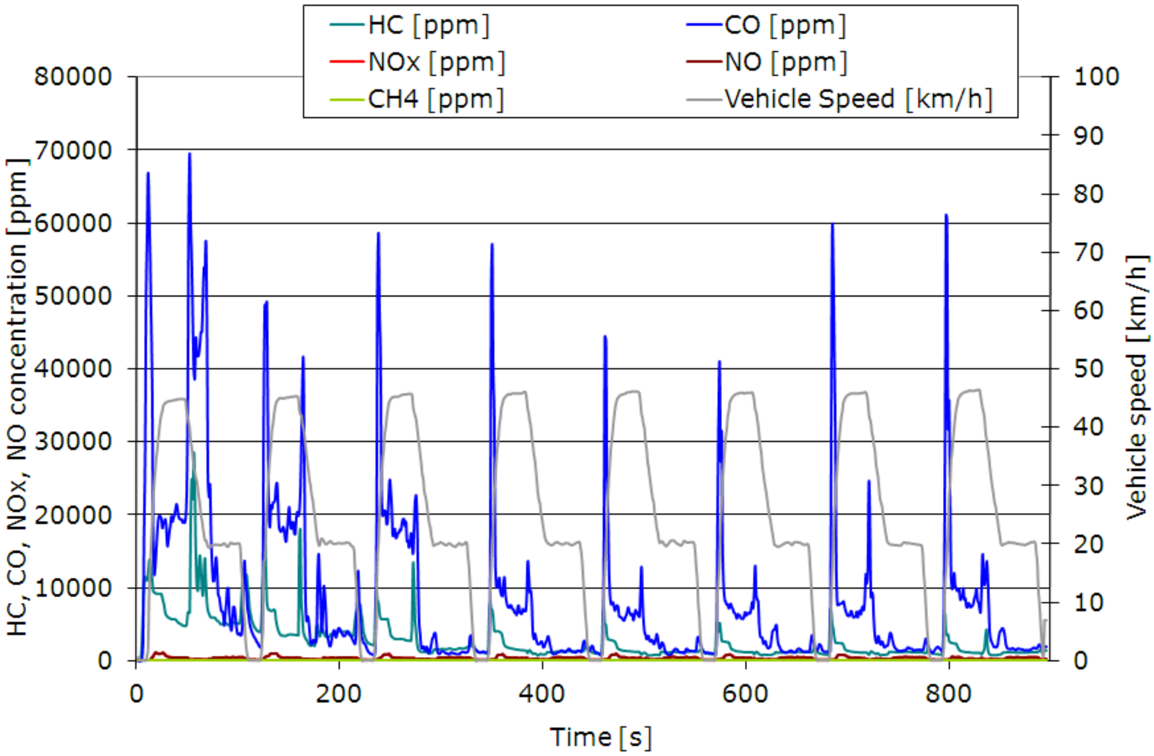


Figure 16-41: Vehicle 3: L1Be, emissions, R47 cycle

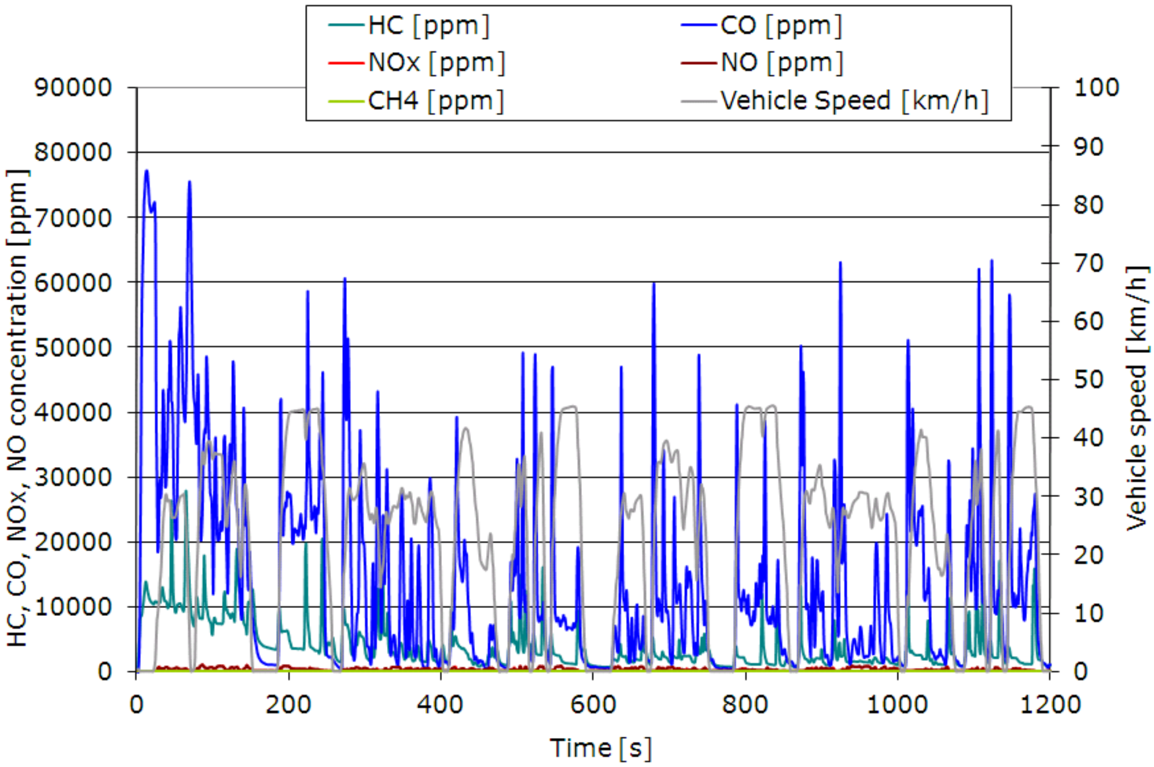


Figure 16-42: Vehicle 3: L1Be, emissions, WMTC cycle

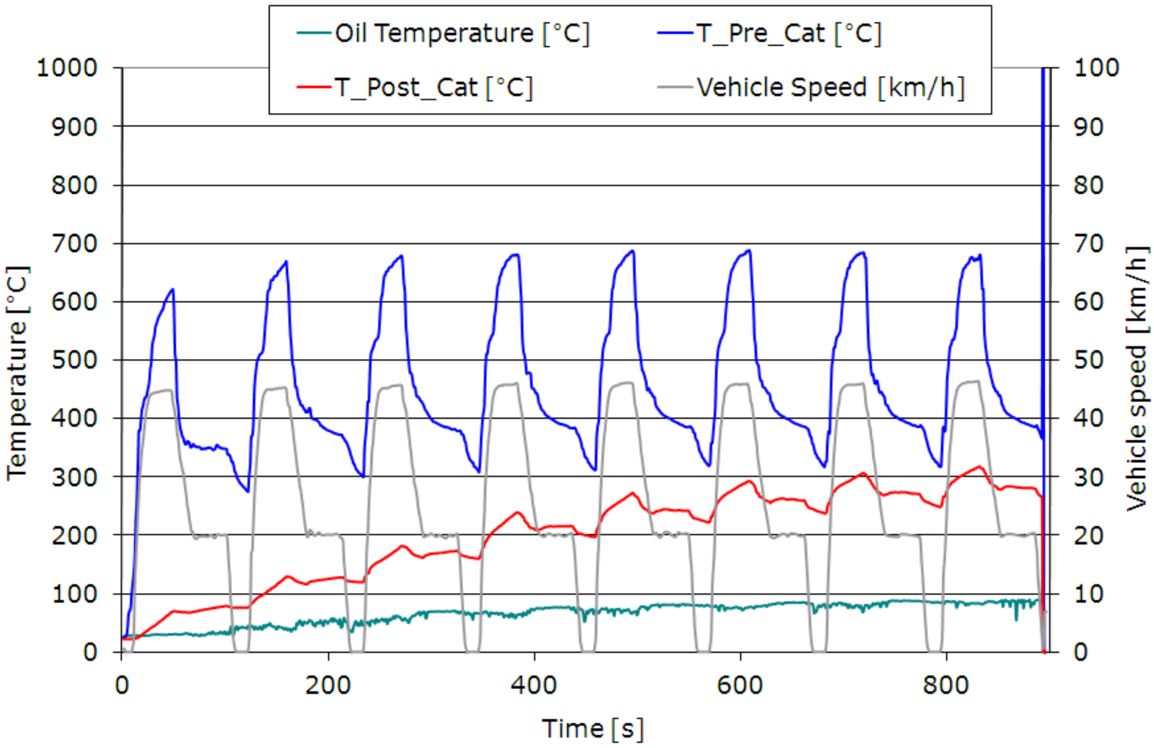


Figure 16-43: Vehicle 3: L1Be, temperatures, R47 cycle

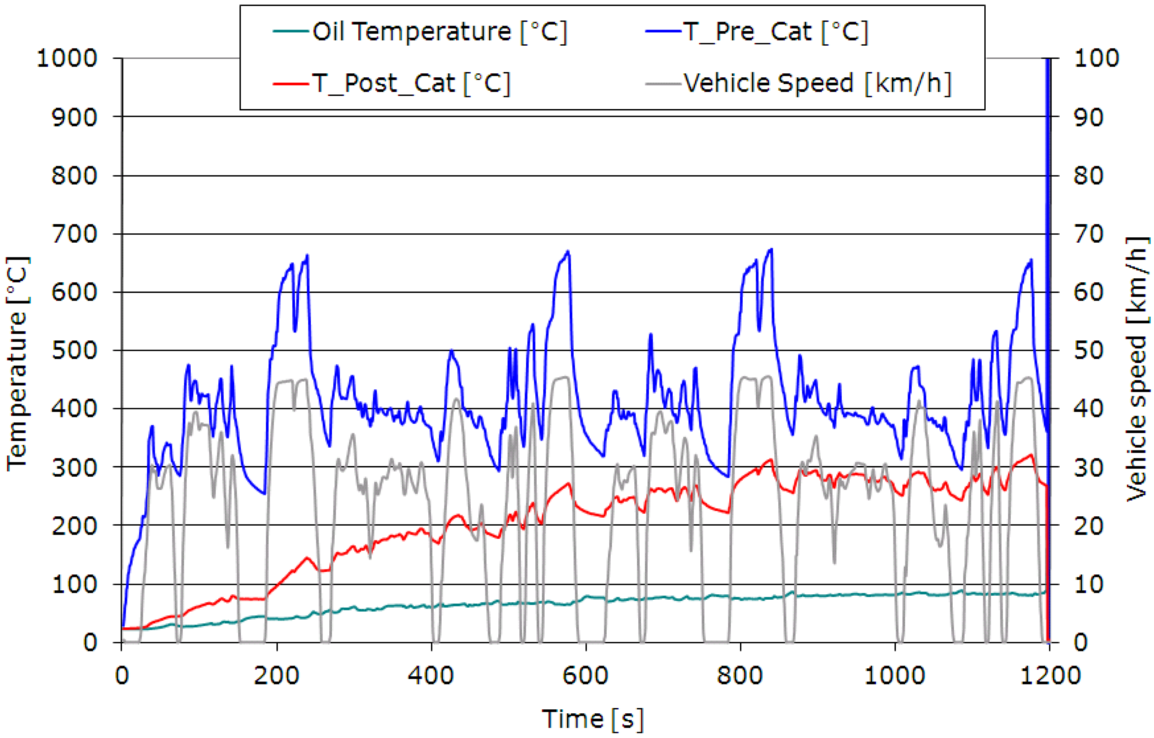


Figure 16-44: Vehicle 3: L1Be, temperatures, R47 cycle

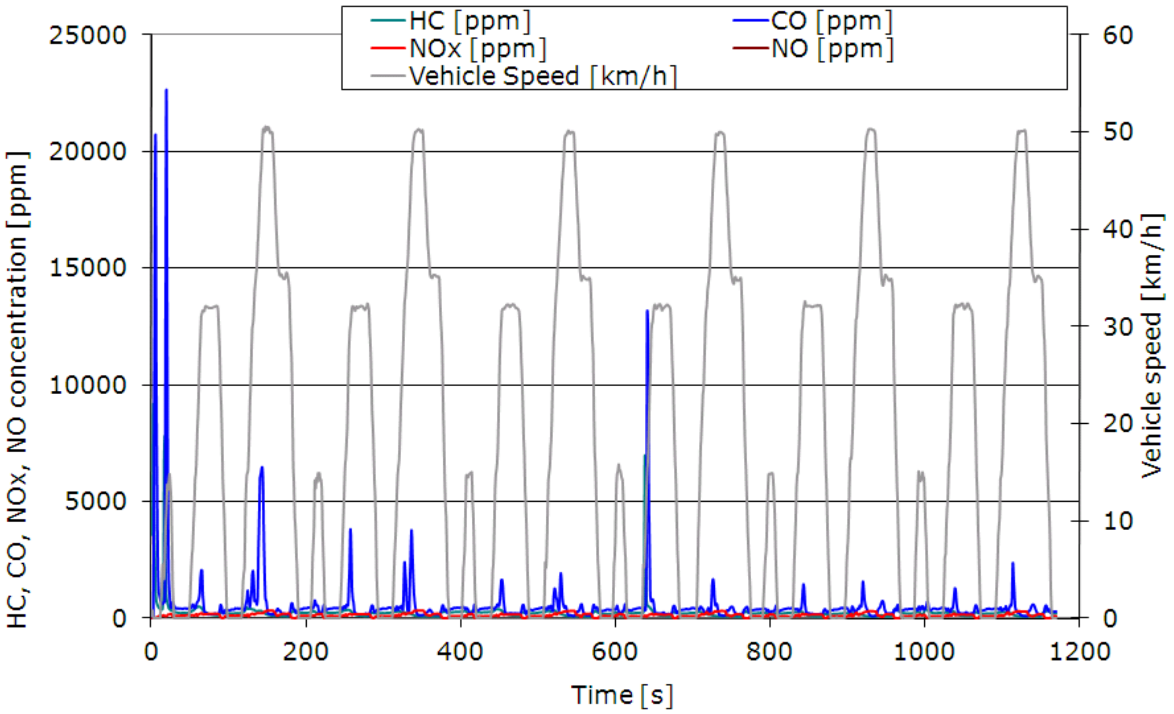


Figure 16-45: Vehicle 8: L5Ae, emissions, R40 cycle

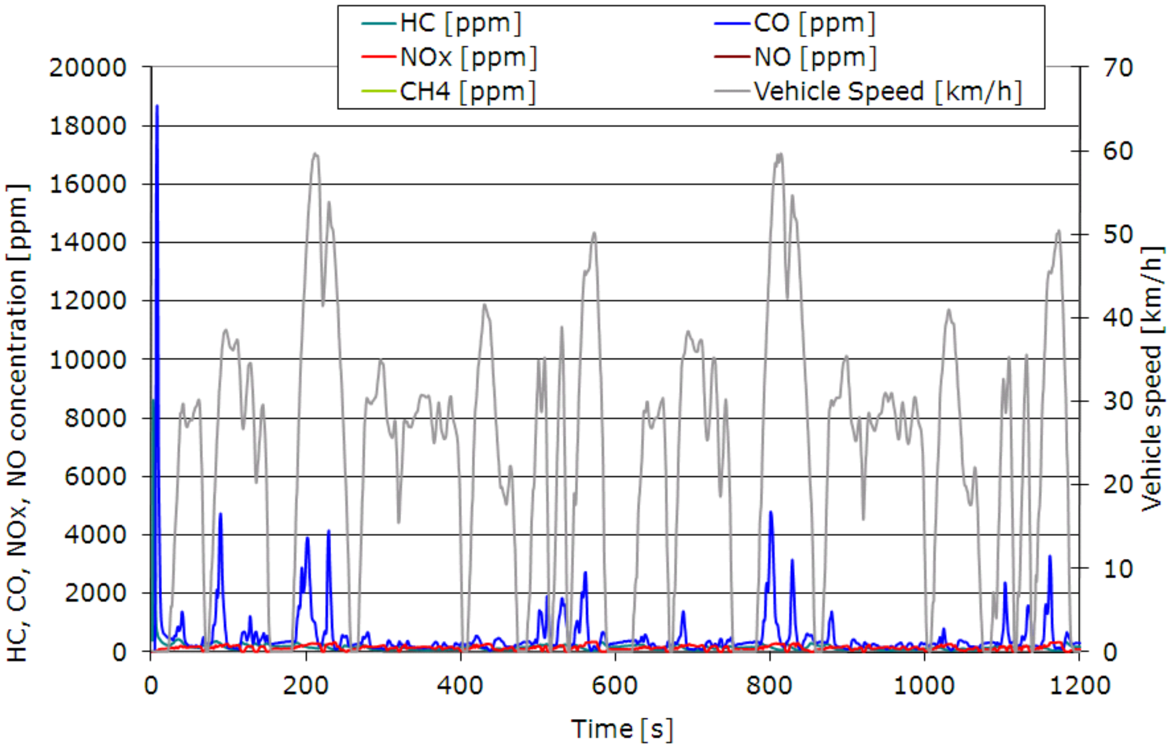


Figure 16-46: Vehicle 8: L5Ae, emissions, WMTC cycle

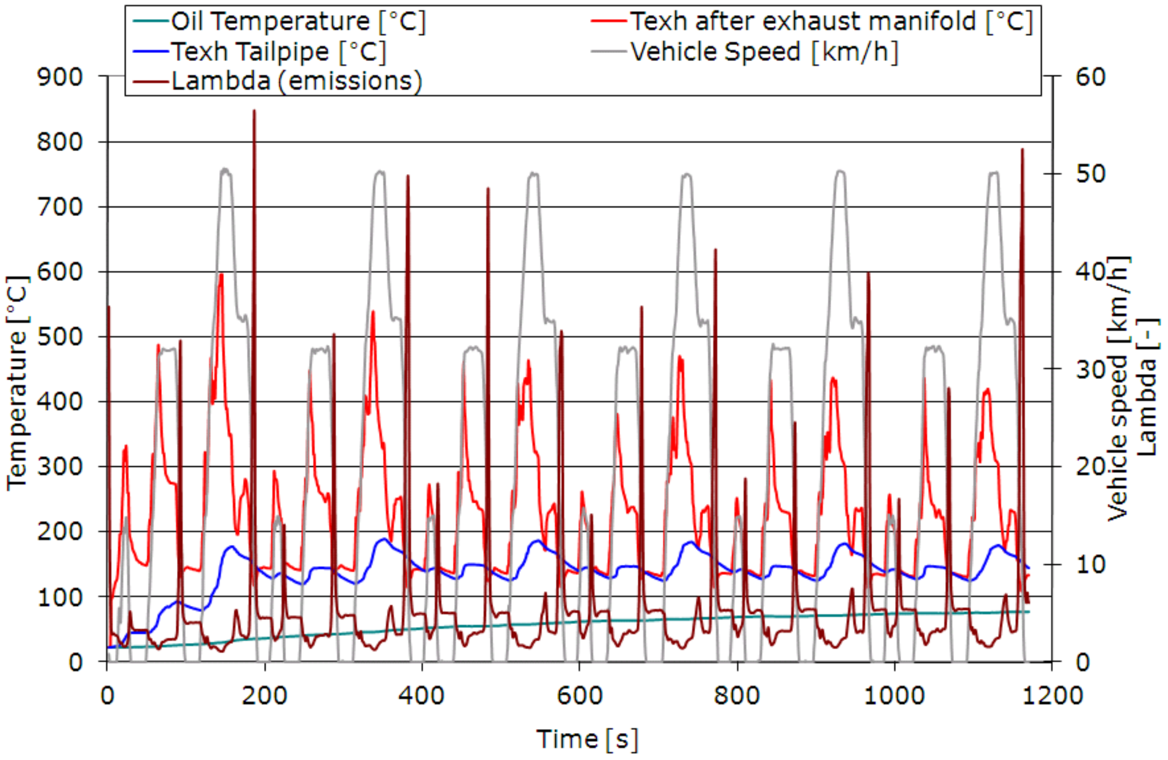


Figure 16-47: Vehicle 8: L5Ae, temperatures, R40 cycle

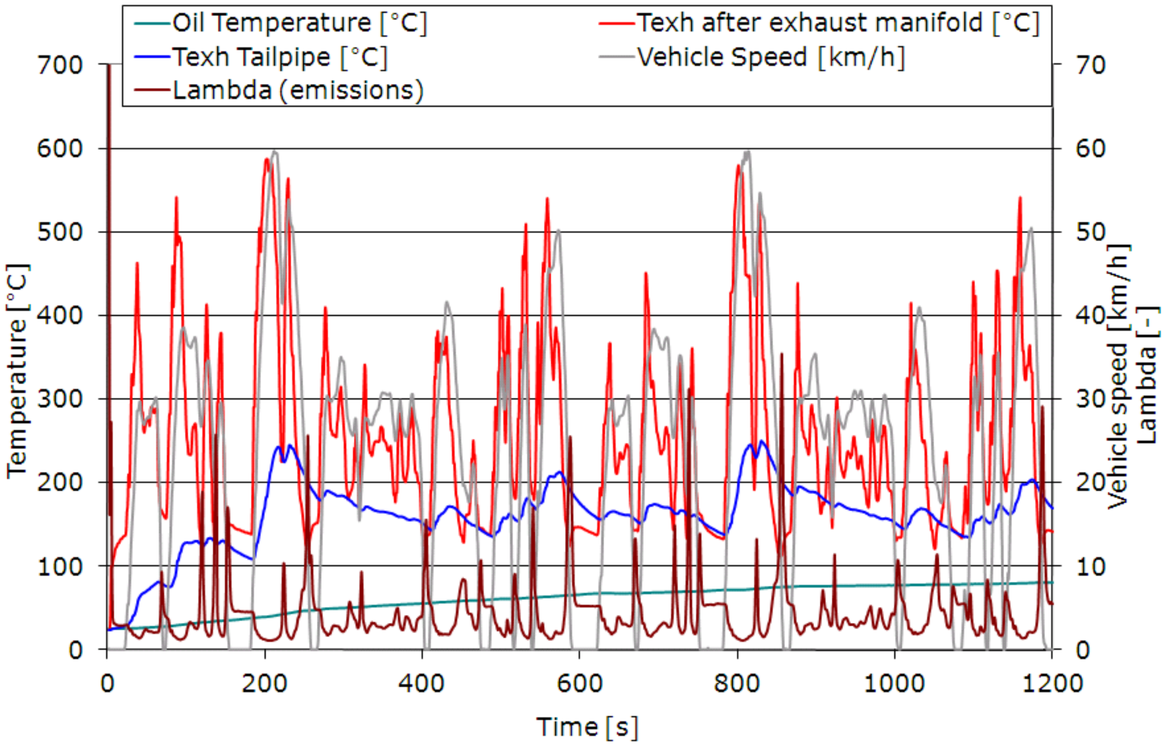


Figure 16-48: Vehicle 8: L5Ae, temperatures, WMTC cycle

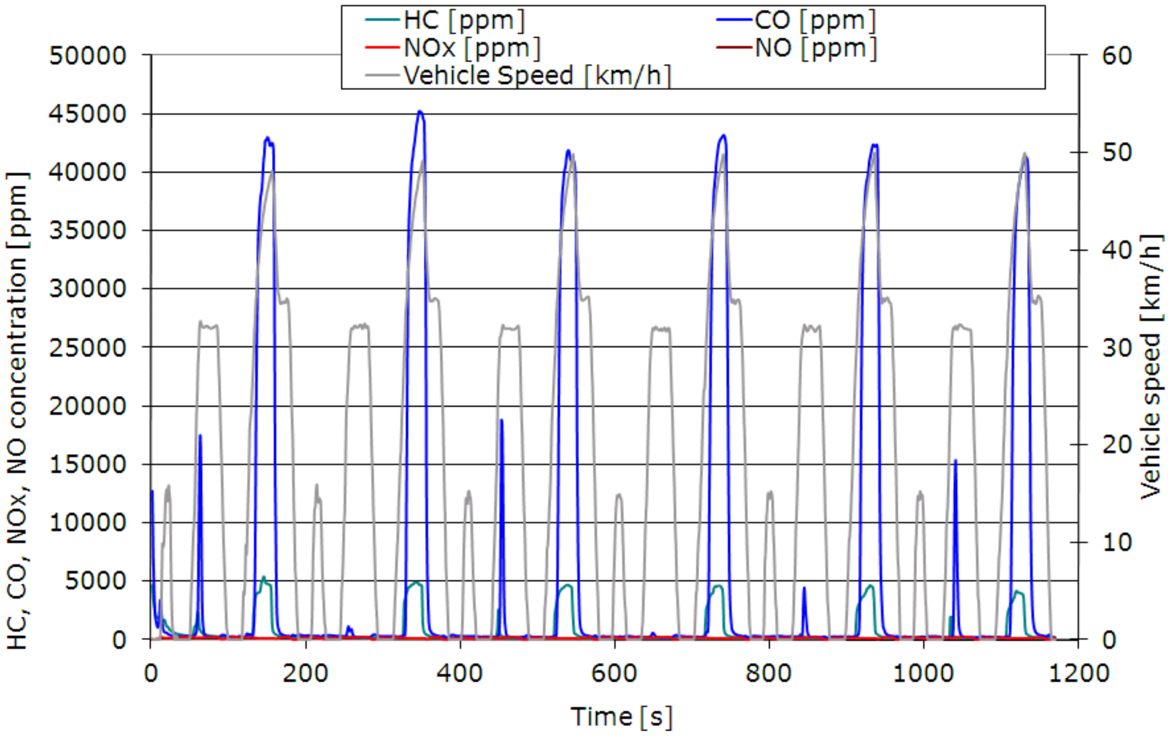


Figure 16-49: Vehicle 11: L7Ae, emissions, R40 cycle

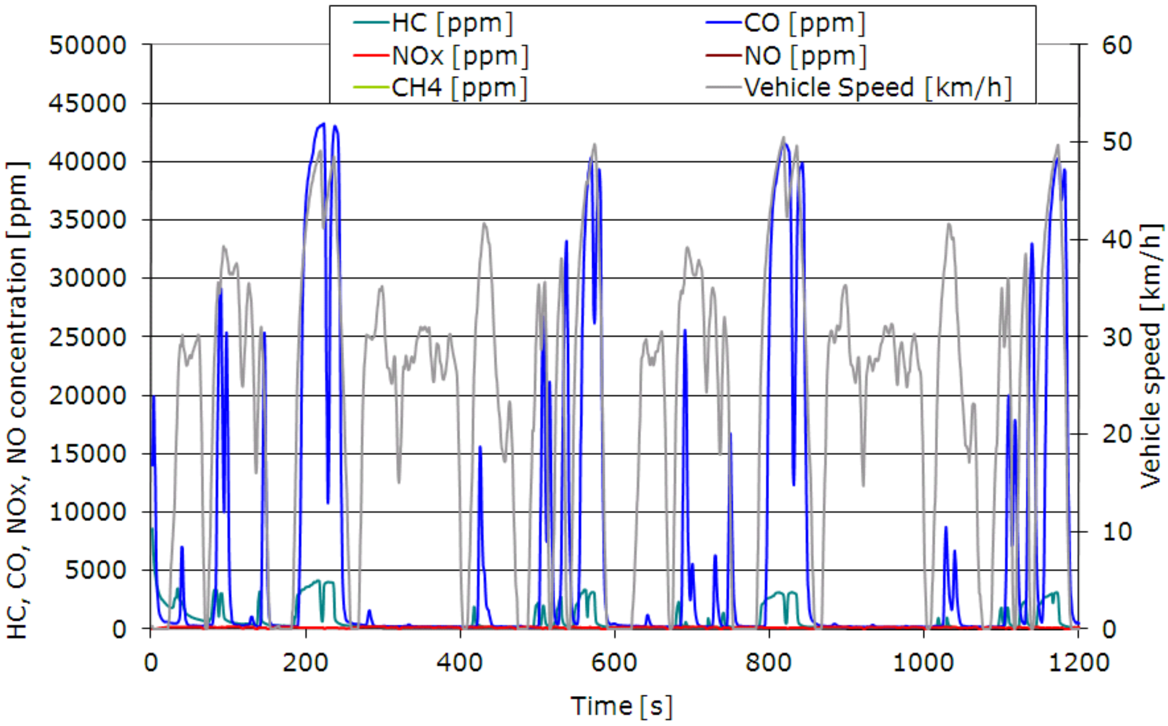


Figure 16-50: Vehicle 11: L7Ae, emissions, WMTC cycle

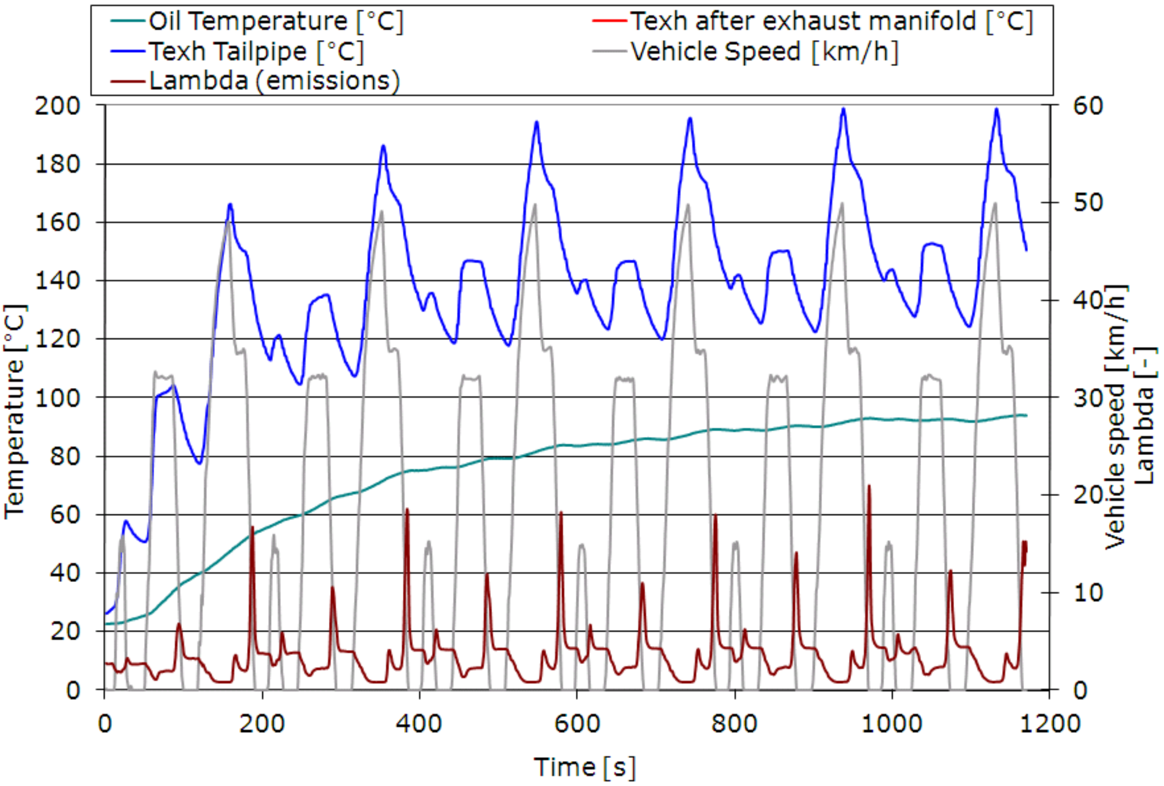


Figure 16-51: Vehicle 11: L7Ae, temperatures, R40 cycle

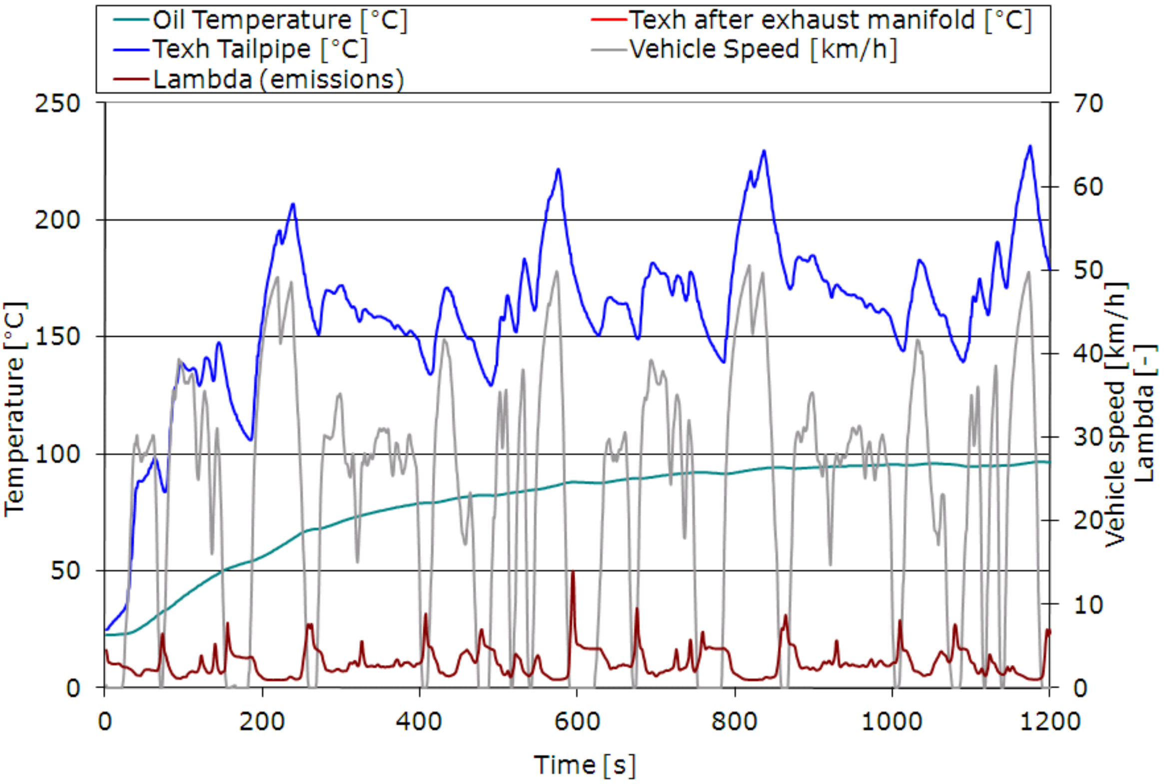


Figure 16-52: Vehicle 11: L7Ae, temperatures, WMTC cycle

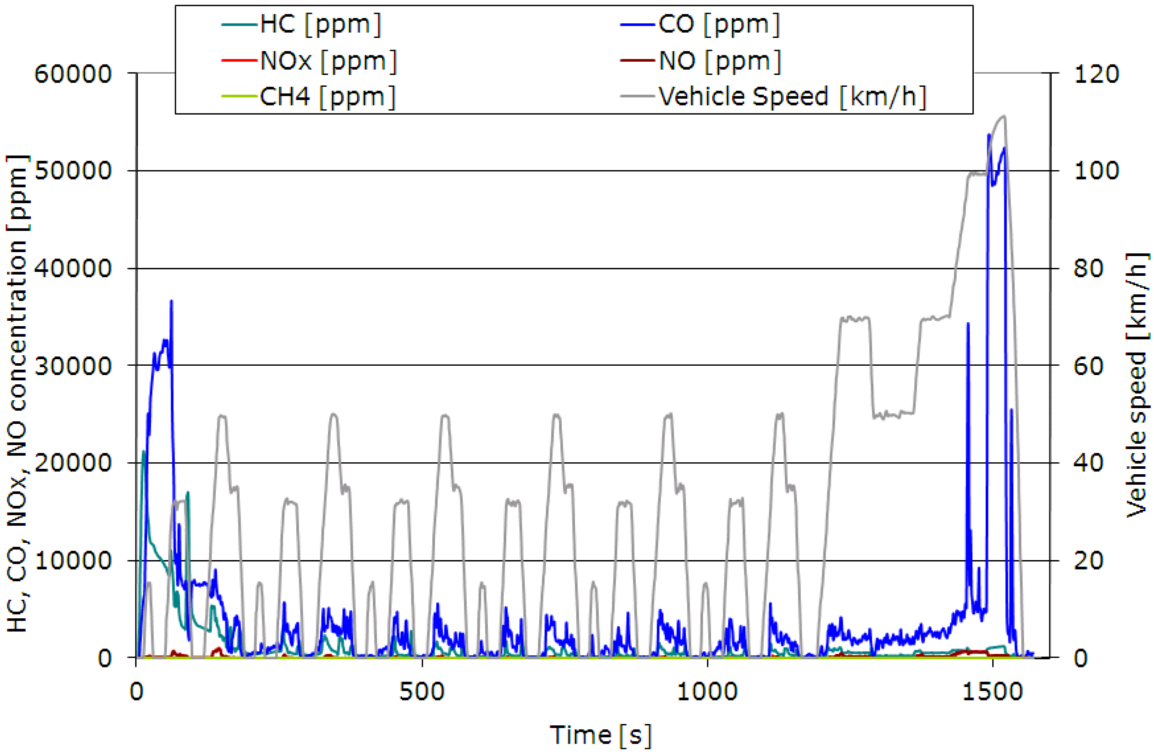


Figure 16-53: Vehicle 7, 100% charged battery: L5Ae, emissions, R40 cycle

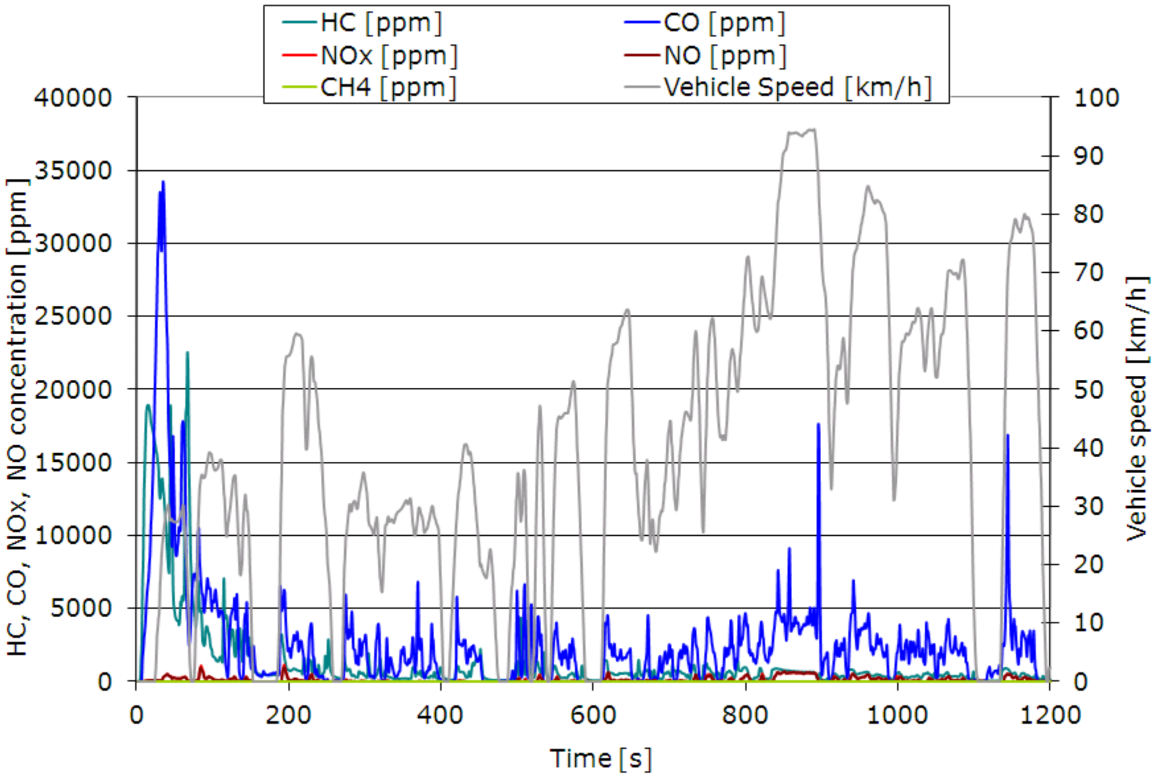


Figure 16-54: Vehicle 7, 100% charged battery: L5Ae, emissions, WMTC cycle

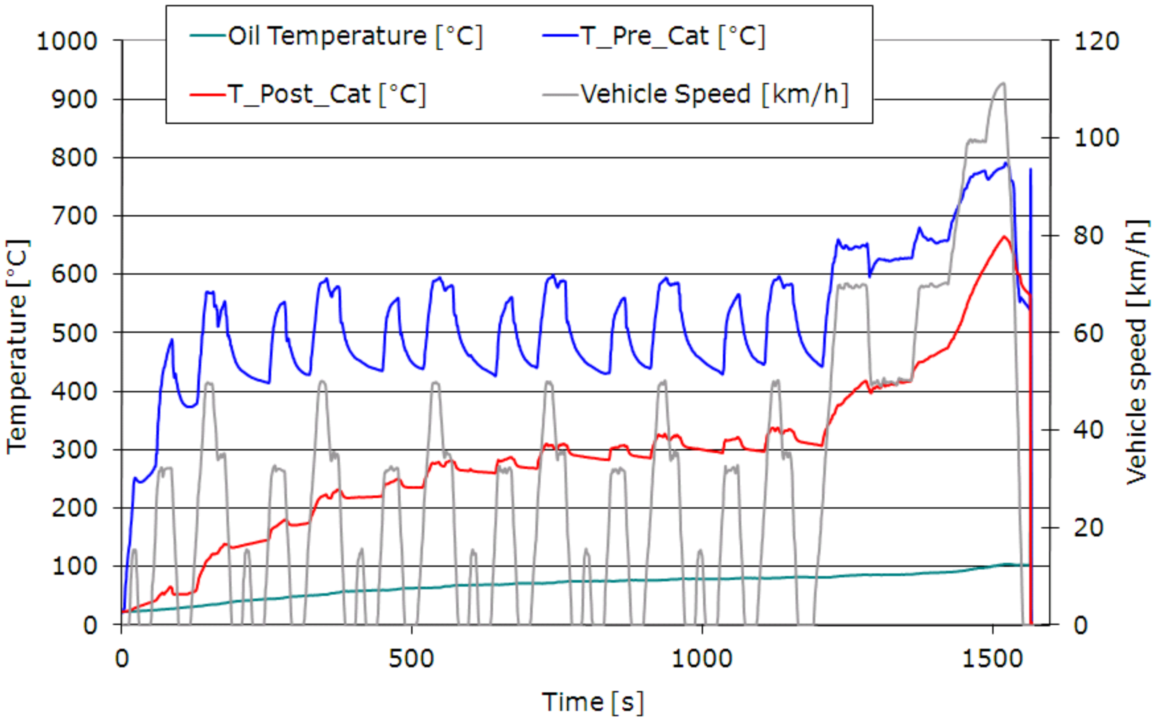


Figure 16-55: Vehicle 7, 100% charged battery: L5Ae, temperatures, R40 cycle

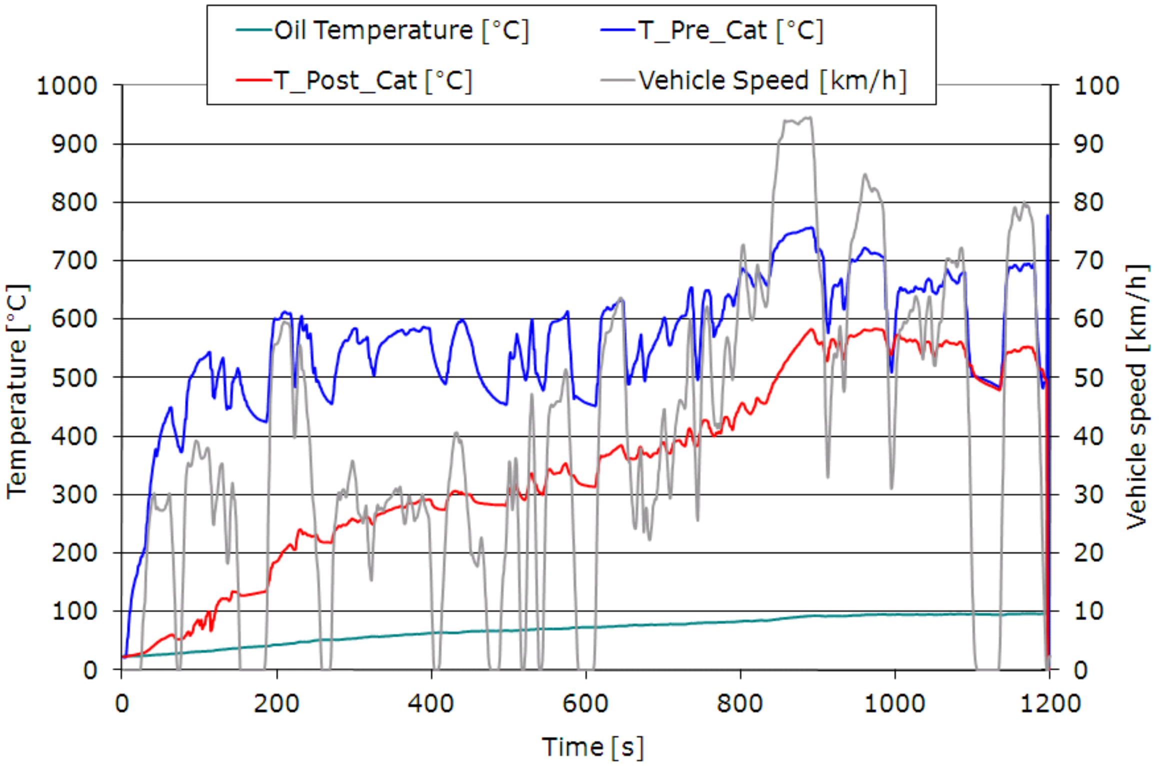


Figure 16-56: Vehicle 7, 100% charged battery: L5Ae, temperatures, WMTC cycle

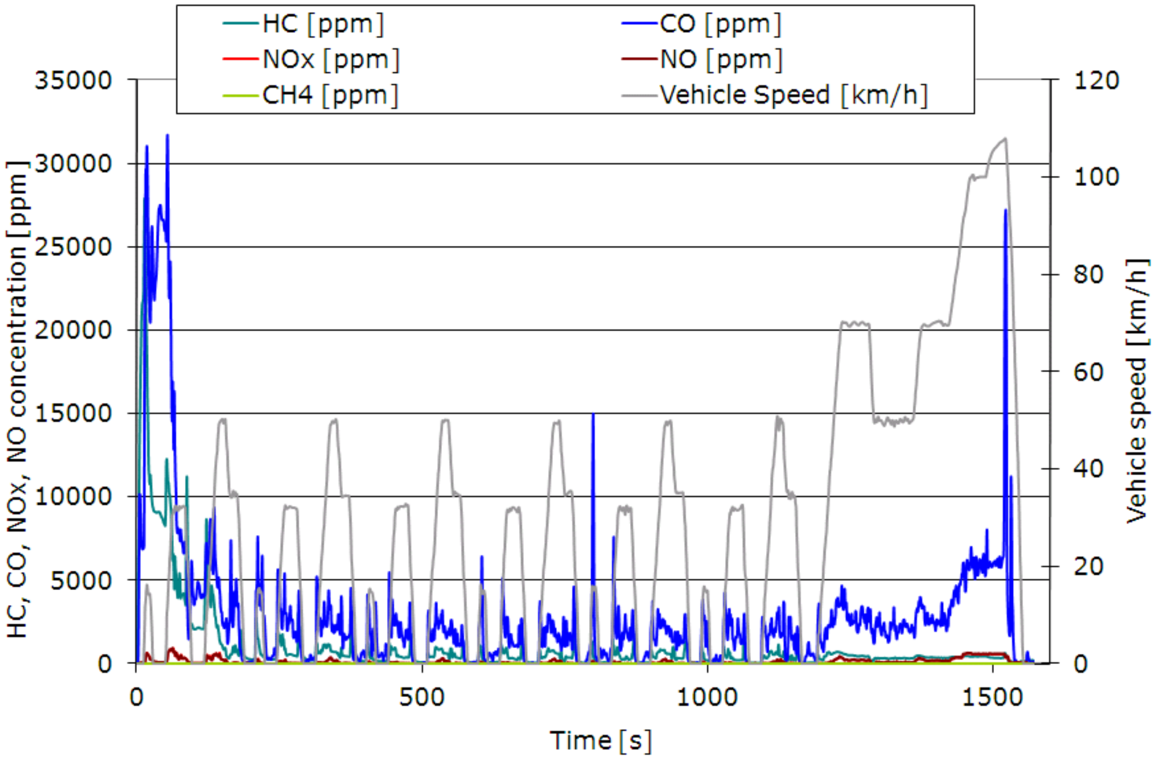


Figure 16-57 Vehicle 7, 25% charged battery: L5Ae, emissions, R40 cycle

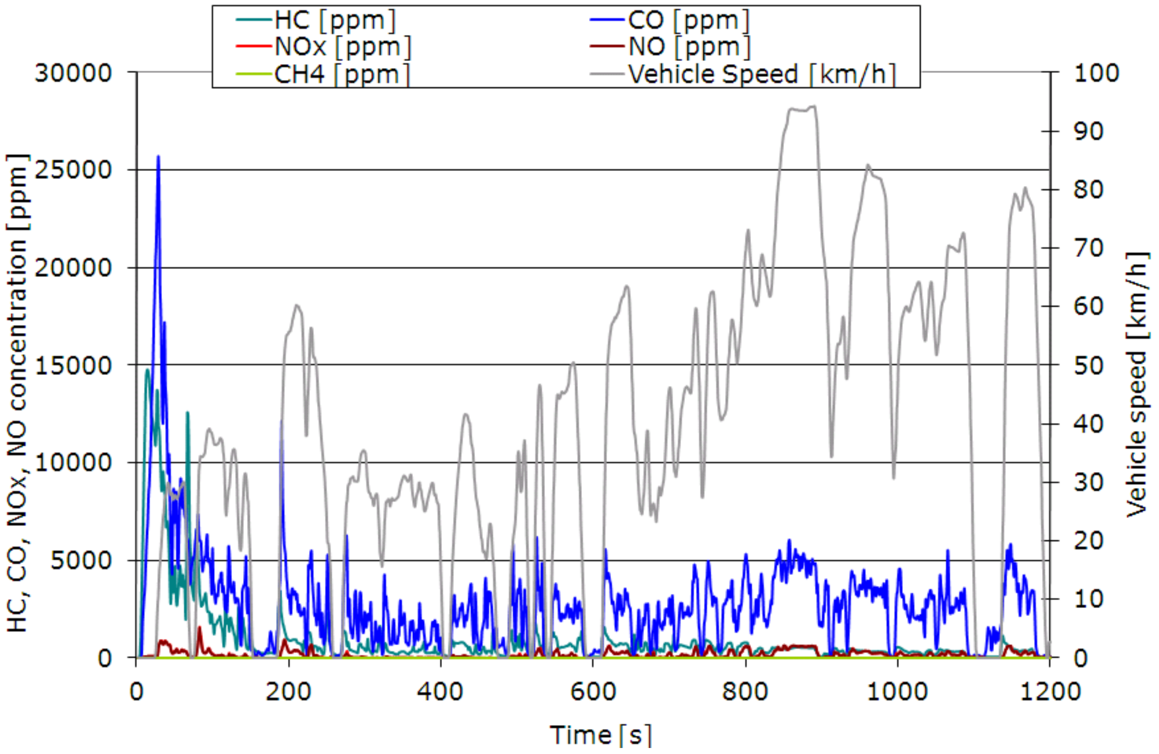


Figure 16-58: Vehicle 7, 25% charged battery: L5Ae, emissions, WMTC cycle

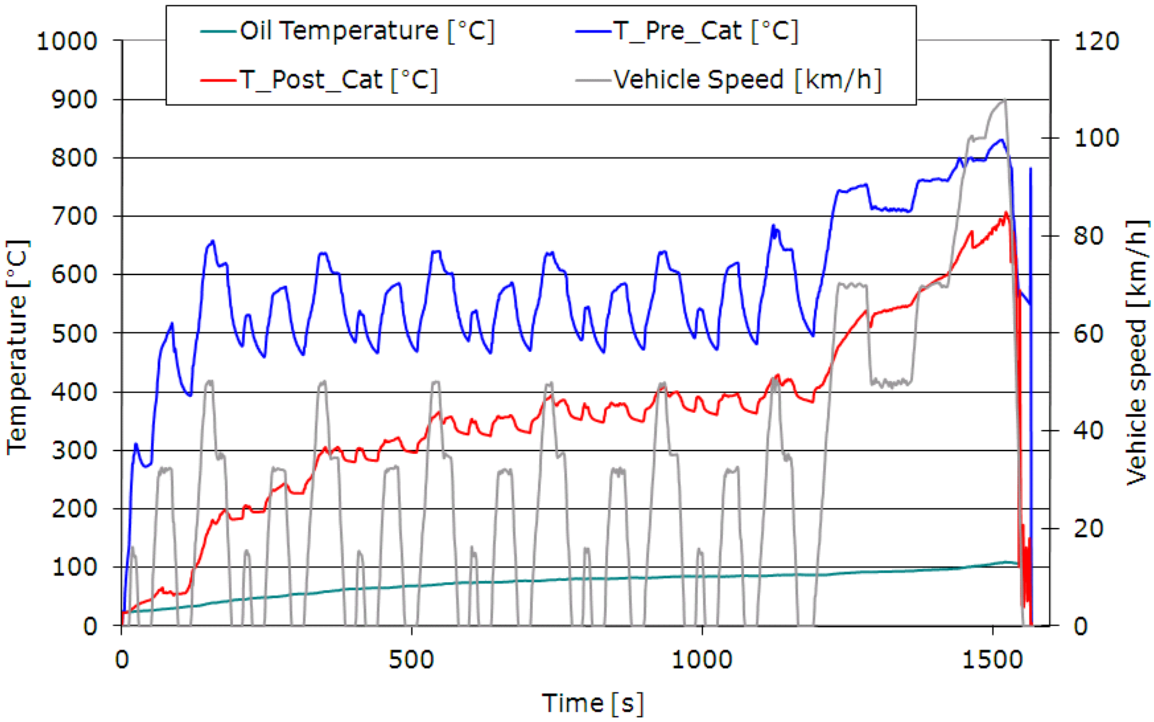


Figure 16-59: Vehicle 7, 25% charged battery: L5Ae, temperatures, R40 cycle

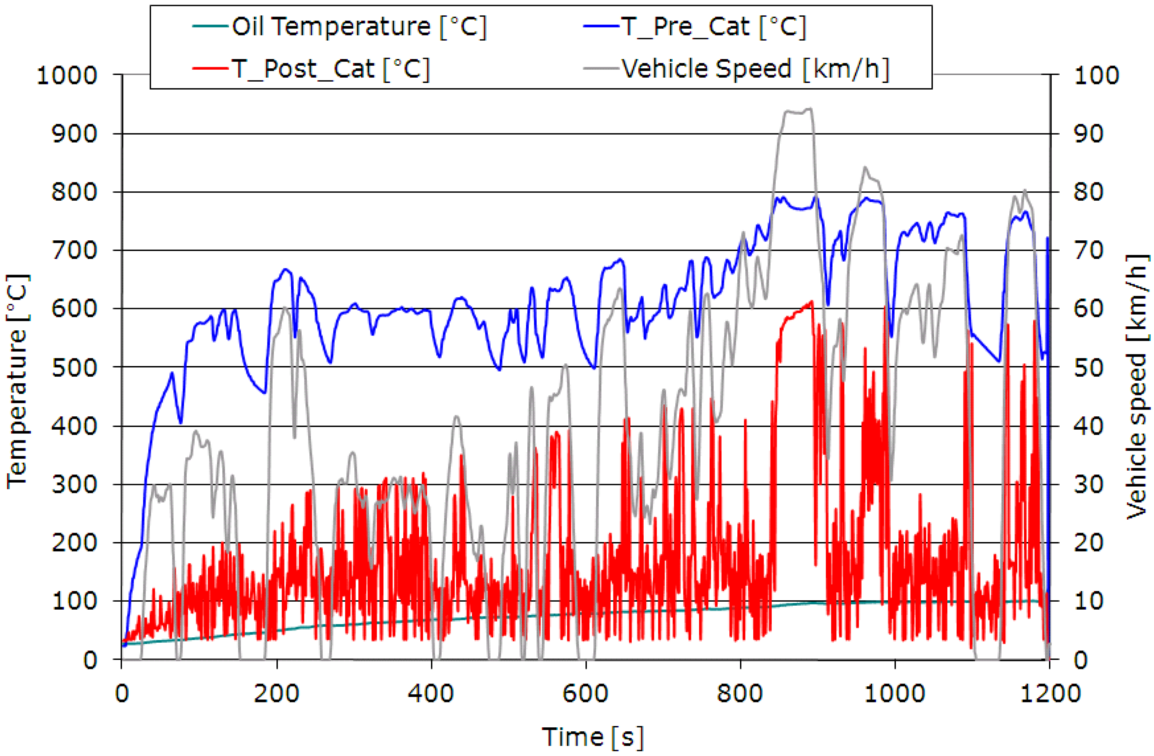


Figure 16-60: Vehicle 7, 25% charged battery: L5Ae, temperatures, WMTC cycle

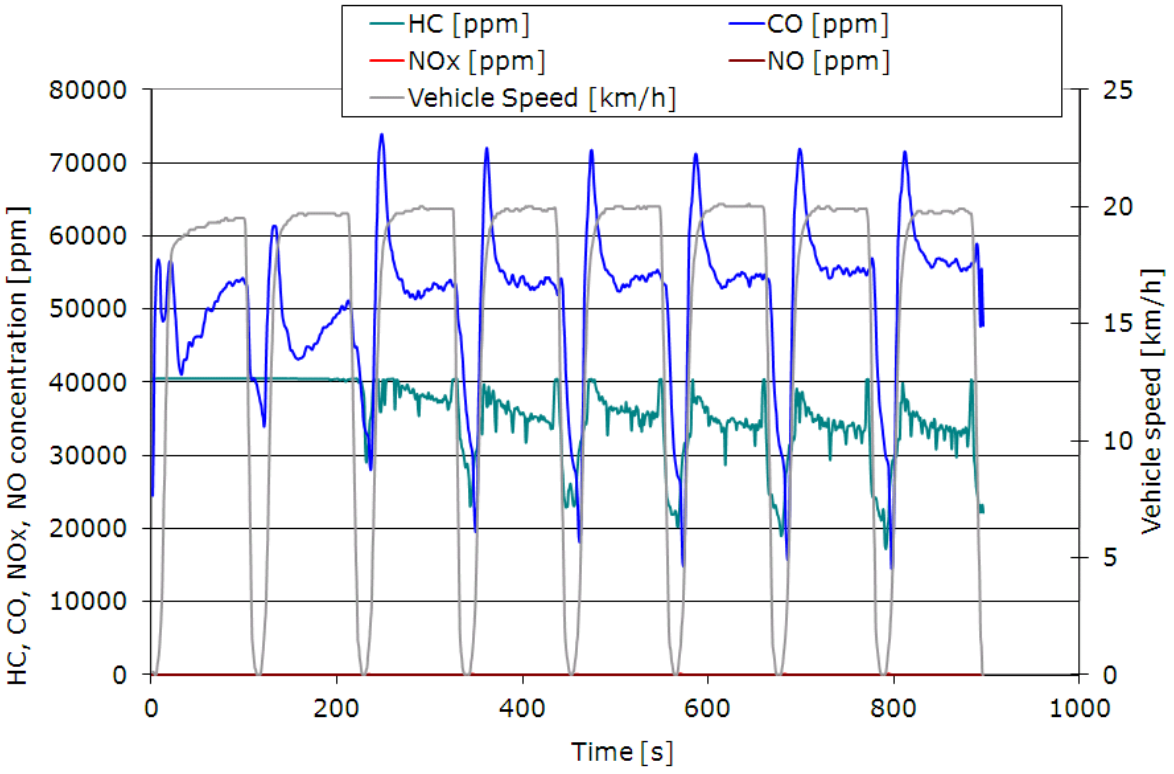


Figure 16-61: Vehicle 1: L1Ae, emissions, R47 cycle

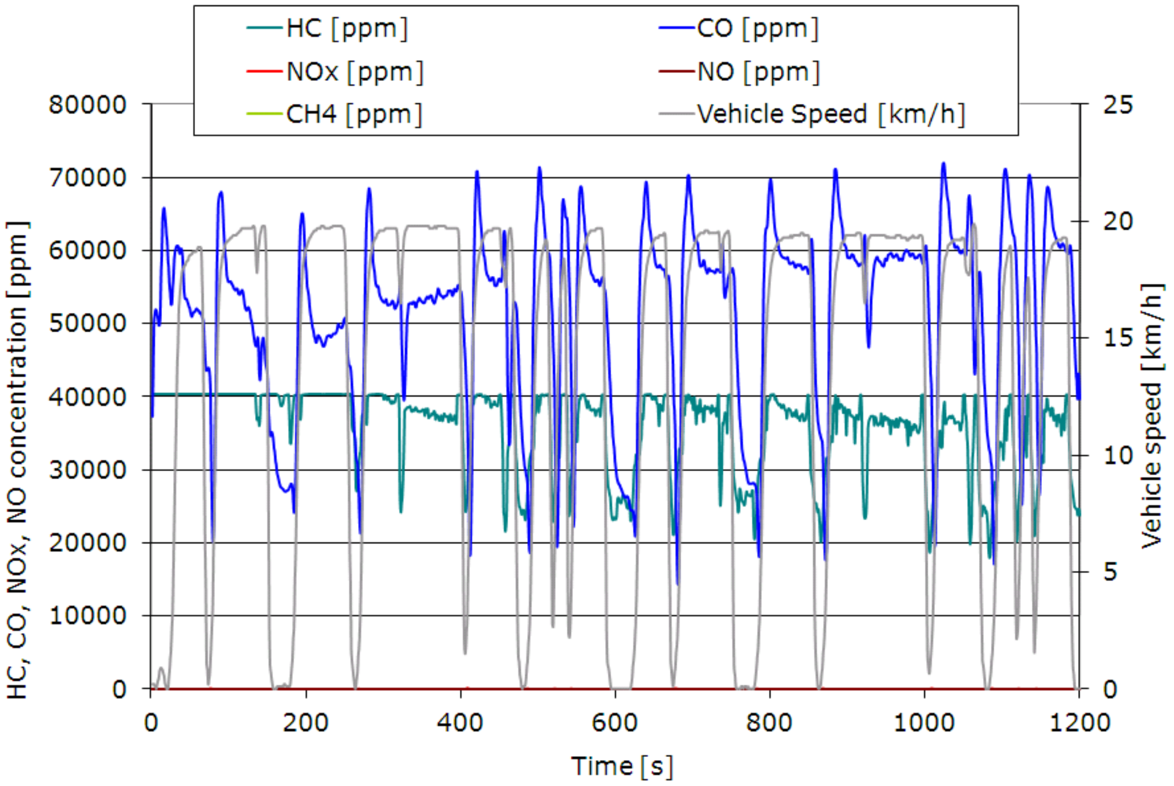


Figure 16-62: Vehicle 1: L1Ae, emissions, WMTC cycle

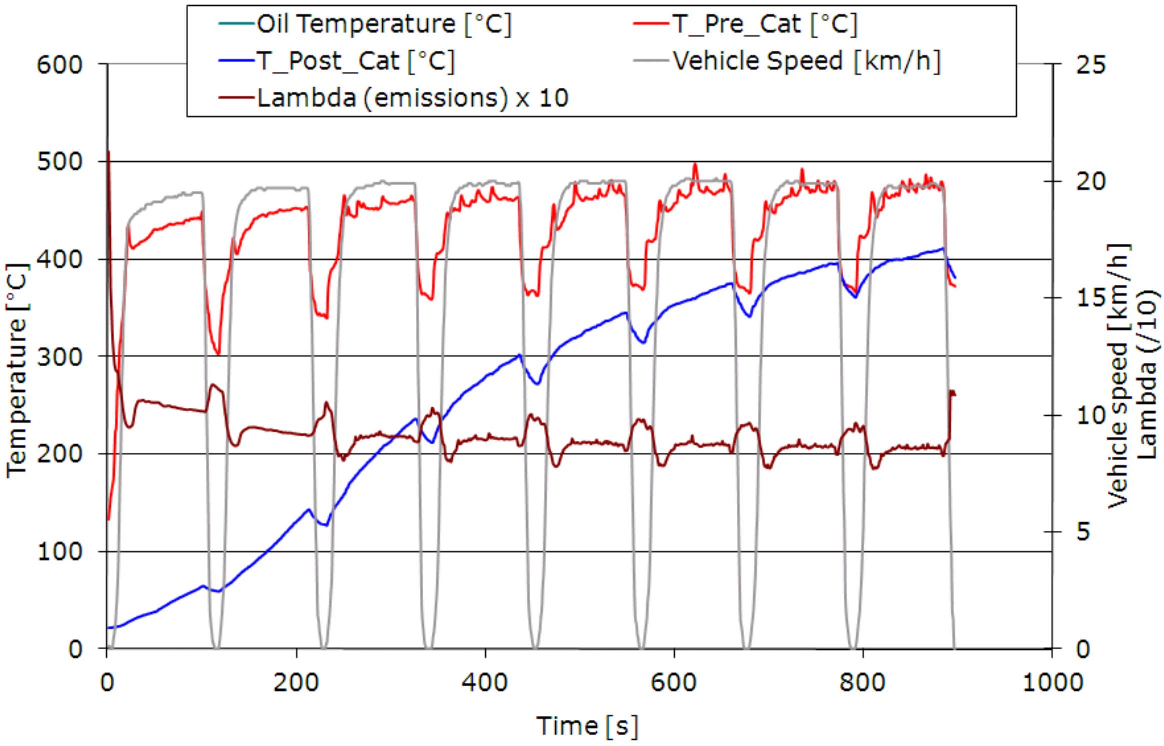


Figure 16-63: Vehicle 1: L1Ae, temperatures, R47 cycle

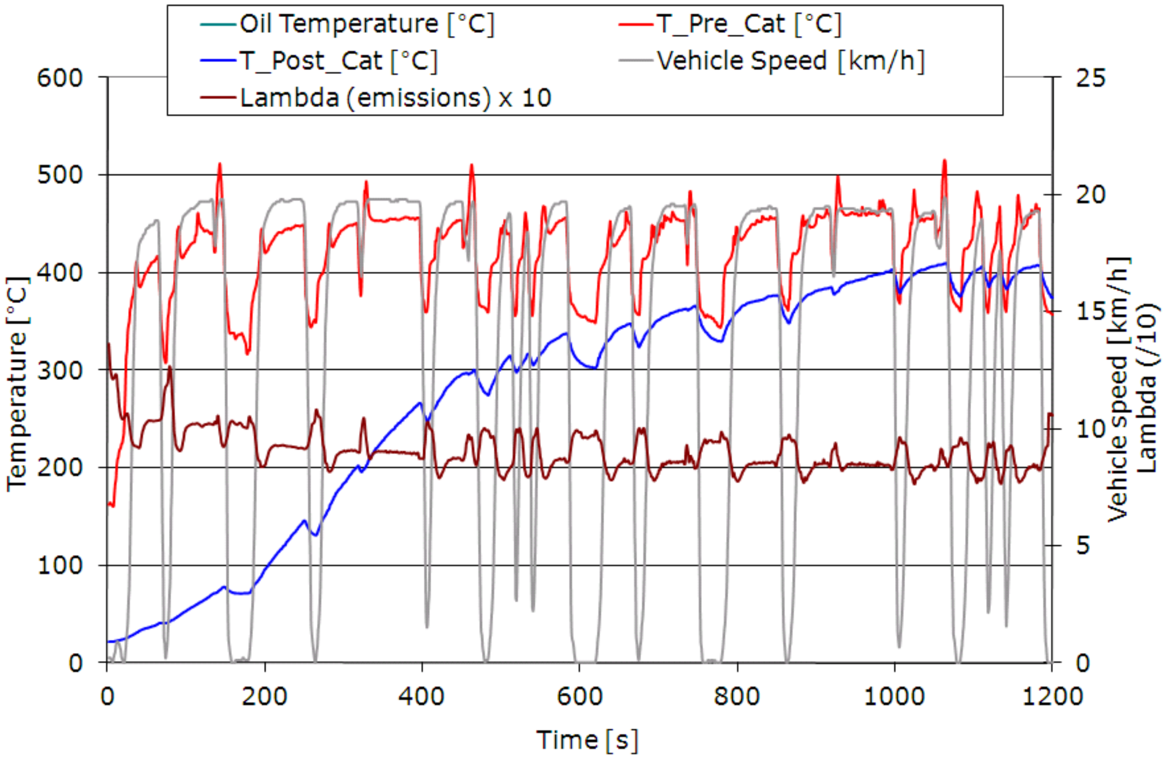


Figure 16-64: Vehicle 1: L1Ae, emissions, WMTC cycle

Appendix H Power and speed against time plots

The measurement of power was used to discover the vehicle speed at which various levels of power could be experienced by the vehicle. This was then used in the assessment of high, medium and low load on the vehicle which is a main factor in designing and consequently assessing a durability test cycle.

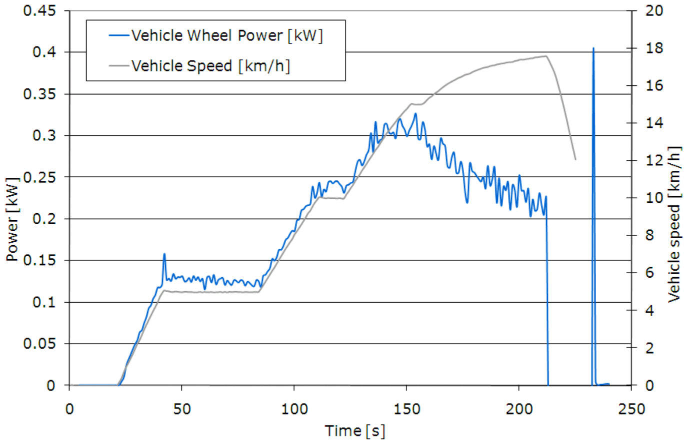


Figure 16-65: Vehicle 1: L1Ae, power and vehicle speed against time

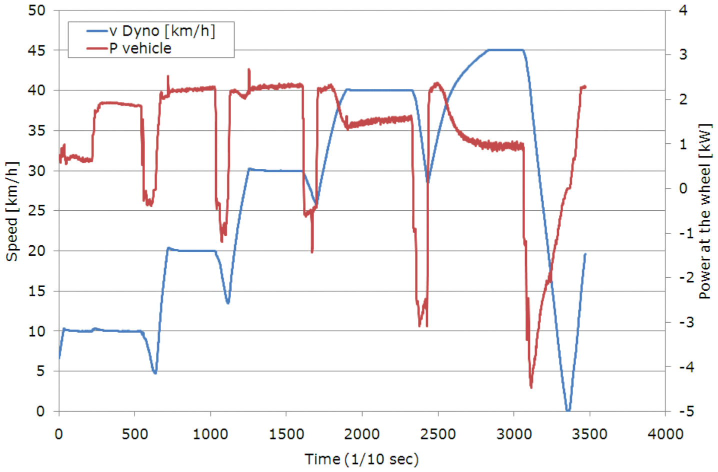


Figure 16-66: Vehicle 2: L1Be, power and vehicle speed against time

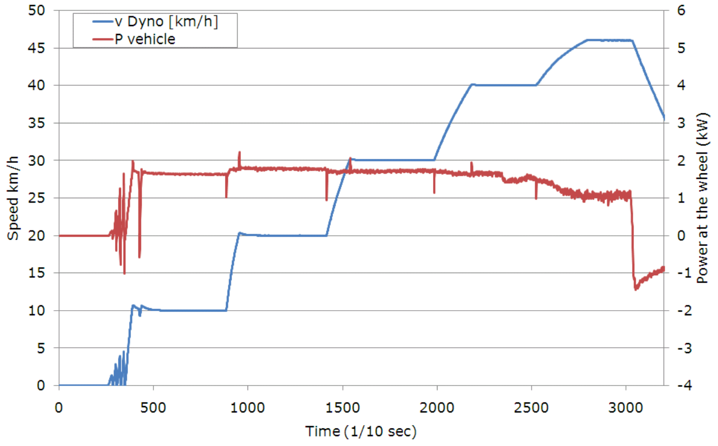


Figure 16-67: Vehicle 3: L1Be, power and vehicle speed against time

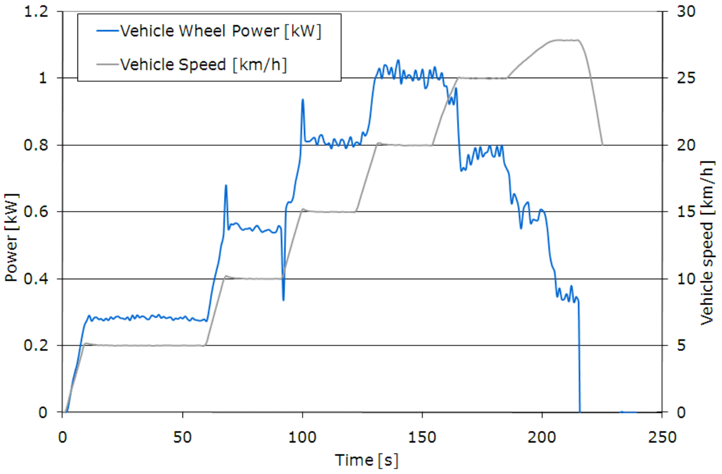


Figure 16-68: Vehicle 4: L1Be, power and vehicle speed against time

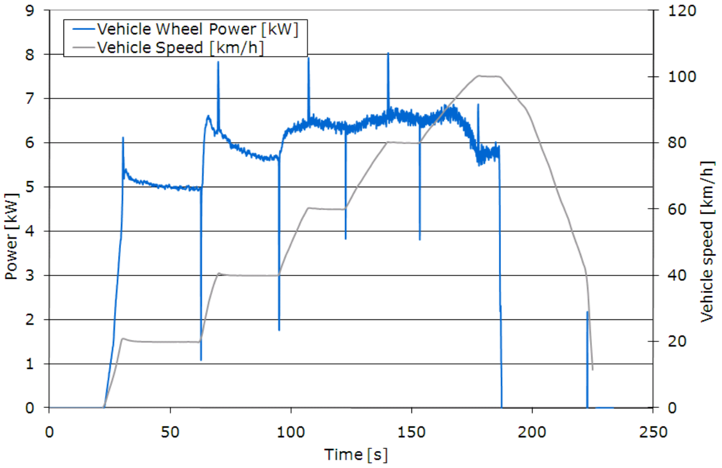


Figure 16-69: Vehicle 5: L3e-A1, power and vehicle speed against time

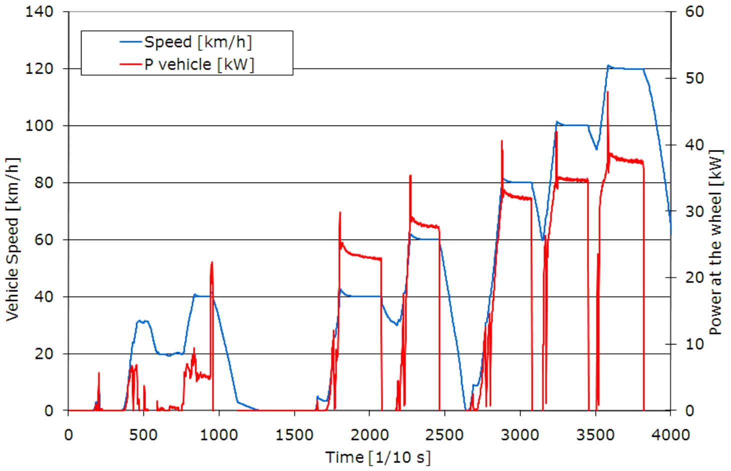


Figure 16-70: Vehicle 6: L3e-A3, power and vehicle speed against time

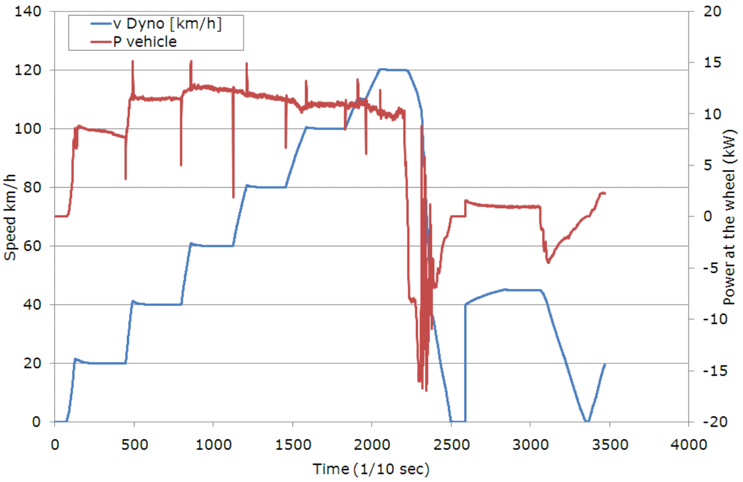


Figure 16-71: Vehicle 7: L5Ae, power and vehicle speed against time

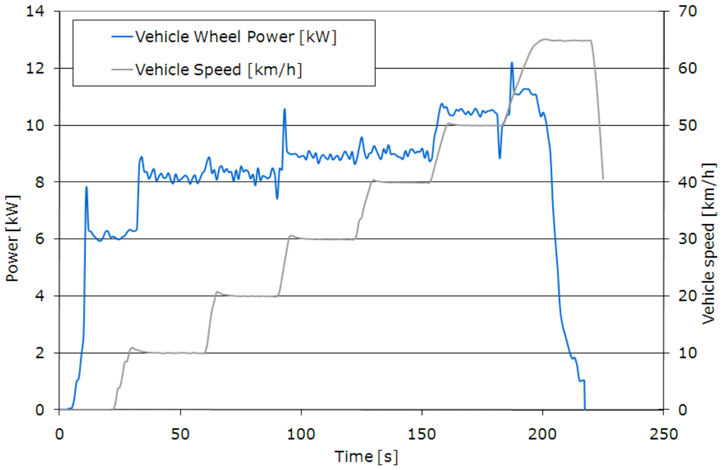


Figure 16-72: Vehicle 8: L5Ae, power and vehicle speed against time

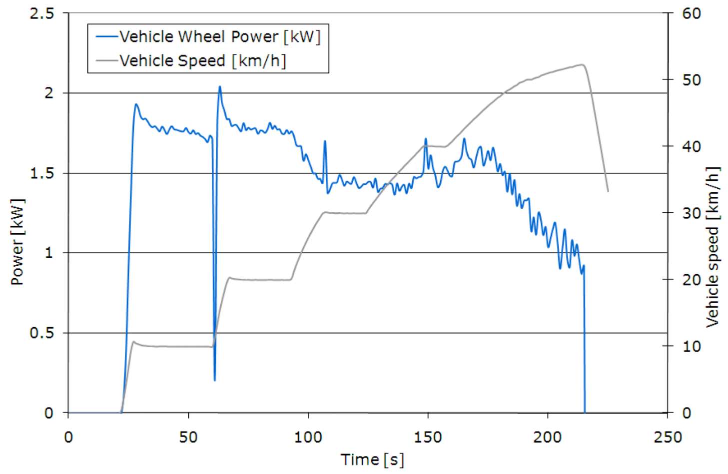


Figure 16-73: Vehicle 9: L6Ae, power and vehicle speed against time

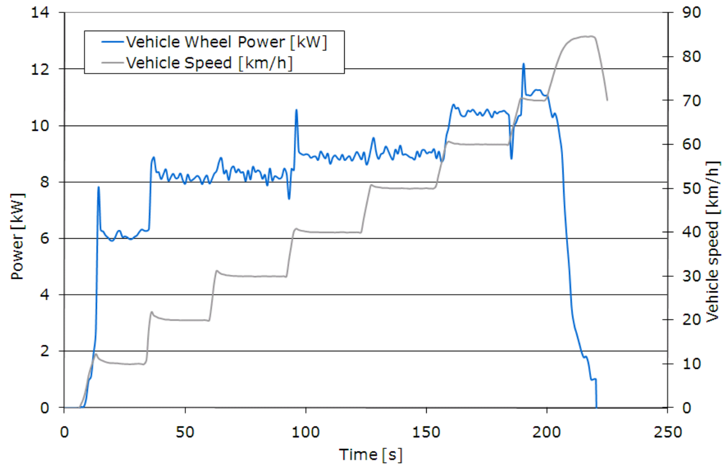


Figure 16-74: Vehicle 10: L7Ae, power and vehicle speed against time

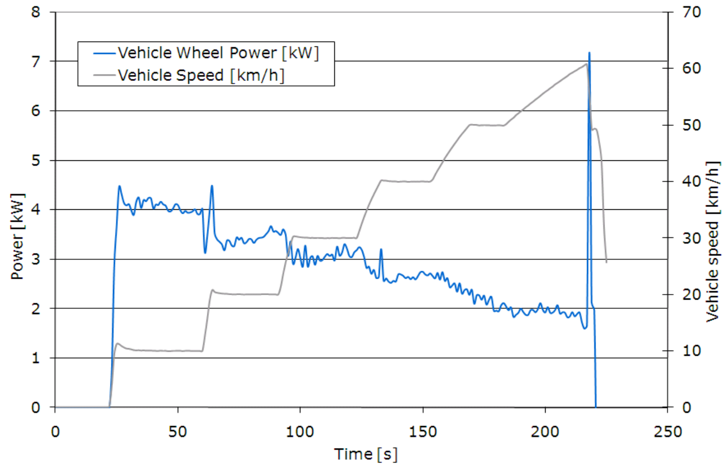


Figure 16-75: Vehicle 11: L7Ae, power and vehicle speed against time

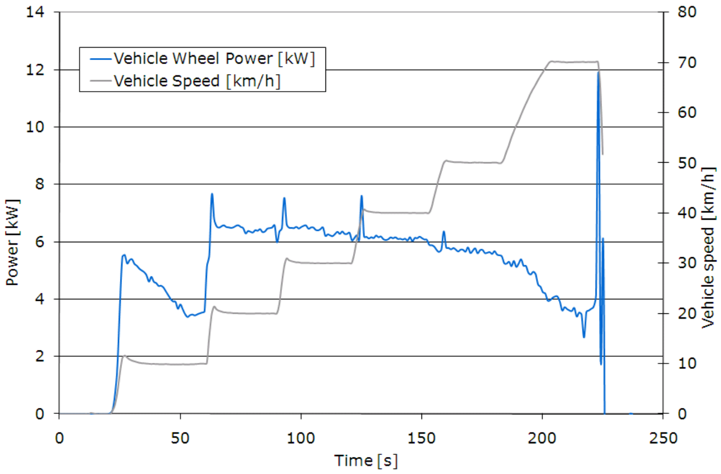


Figure 16-76: Vehicle 11: L7Be, power and vehicle speed against time

Appendix I Duration and cost tables (phase 2)

I.1 US EPA AMA

I.1.1 *Track methods, 40 hour week*

Method A - full distance only					
Vehicle Category	Category name	Calendar time required for test (weeks)		Estimated cost of test (€)	
		Min	Max	Min	Max
L1Ae	Powered cycle	10.8	12.8	€ 42,851	€ 50,575
L3e-AxT (x=1,2,3)	Two wheel trial motorcycle	5.4	6.2	€ 19,950	€ 23,094
L1Be	Two wheel moped (<25 km/h)	20.0	24.0	€ 81,469	€ 97,416
	Two wheel moped (<45 km/h)	10.8	13.0	€ 43,301	€ 51,615
L2e	Three wheel moped	10.8	13.0	€ 43,301	€ 51,615
L3e-AxE (x=1,2,3)	Two wheel Enduro motorcycle	9.0	10.8	€ 35,668	€ 42,454
L6Ae	Light on-road quad	10.8	13.0	€ 43,301	€ 51,615
L3e	Two wheel motorcycle (Vmax<130km/h)	14.8	24.4	€ 60,815	€ 100,036
L4e	Two wheel motorcycle with sidecar (Vmax<130km/h)	14.8	24.4	€ 60,815	€ 100,036
L5e	Tricycle	14.8	24.4	€ 60,815	€ 100,036
L6Be	Light quadri-mobile	18.2	29.8	€ 74,556	€ 122,937
L7Be	All Terrain Vehicles	18.2	29.8	€ 74,556	€ 122,937
L7Ce	Heavy quadri-mobile	18.2	29.8	€ 74,556	€ 122,937
L3e	Two wheel motorcycle (Vmax>=130km/h)	24.0	39.4	€ 99,036	€ 163,905
L4e	Two wheel motorcycle with side-car (Vmax>=130km/h)	24.0	39.4	€ 99,036	€ 163,905
L7Ae	Heavy on-road quad	24.0	39.4	€ 99,036	€ 163,905

Method B - half distance only					
Vehicle Category	Category name	Calendar time required for test (weeks)		Estimated cost of test (€)	
		Min	Max	Min	Max
L1Ae	Powered cycle	6.4	7.2	€ 23,542	€ 27,404
L3e-AxT (x=1,2,3)	Two wheel trial motorcycle	3.6	4.0	€ 12,092	€ 13,664
L1Be	Two wheel moped (<25 km/h)	10.8	12.8	€ 42,851	€ 50,575
	Two wheel moped (<45 km/h)	6.4	7.2	€ 23,767	€ 27,674
L2e	Three wheel moped	6.4	7.2	€ 23,767	€ 27,674
L3e-AxE (x=1,2,3)	Two wheel Enduro motorcycle	5.4	6.2	€ 19,950	€ 23,094
L6Ae	Light on-road quad	6.4	7.2	€ 23,767	€ 27,674
L3e	Two wheel motorcycle (Vmax<130km/h)	9.0	13.0	€ 35,668	€ 51,885
L4e	Two wheel motorcycle with sidecar (Vmax<130km/h)	9.0	13.0	€ 35,668	€ 51,885
L5e	Tricycle	9.0	13.0	€ 35,668	€ 51,885
L6Be	Light quadri-mobile	10.8	15.6	€ 43,301	€ 63,335
L7Be	All Terrain Vehicles	18.2	29.8	€ 74,556	€ 122,937
L7Ce	Heavy quadri-mobile	18.2	29.8	€ 74,556	€ 122,937
L3e	Two wheel motorcycle	12.8	20.4	€ 51,385	€ 83,819
L4e	Two wheel motorcycle with side-car (Vmax>=130km/h)	12.8	20.4	€ 51,385	€ 83,819
L7Ae	Heavy on-road quad	12.8	20.4	€ 51,385	€ 83,819

I.1.2 *Track 16 hours per day, 7 days per week*

Method A - full distance only					
Vehicle Category	Category name	Calendar time required for		Estimated cost of test (€)	
		Min	Max	Min	Max
L1Ae	Powered cycle	4.0	4.6	€ 42,328	€ 50,052
L3e-AxT (x=1,2,3)	Two wheel trial motorcycle	2.0	2.3	€ 19,428	€ 22,571
L1Be	Two wheel moped (<25 km/h)	7.1	8.6	€ 80,946	€ 96,893
	Two wheel moped (<45 km/h)	4.0	4.6	€ 42,778	€ 51,092
L2e	Three wheel moped	4.0	4.6	€ 42,778	€ 51,092
L3e-AxE (x=1,2,3)	Two wheel Enduro motorcycle	3.3	3.9	€ 35,145	€ 41,932
L6Ae	Light on-road quad	4.0	4.6	€ 42,778	€ 51,092
L3e	Two wheel motorcycle (Vmax<130km/h)	5.4	8.8	€ 60,292	€ 99,513
L4e	Two wheel motorcycle with sidecar (Vmax<130km/h)	5.4	8.8	€ 60,292	€ 99,513
L5e	Tricycle	5.4	8.8	€ 60,292	€ 99,513
L6Be	Light quadri-mobile	6.6	10.6	€ 74,033	€ 122,414
L7Be	All Terrain Vehicles	6.6	10.6	€ 74,033	€ 122,414
L7Ce	Heavy quadri-mobile	6.6	10.6	€ 74,033	€ 122,414
L3e	Two wheel motorcycle (Vmax>=130km/h)	8.6	14.1	€ 98,513	€ 163,382
L4e	Two wheel motorcycle with side-car (Vmax>=130km/h)	8.6	14.1	€ 98,513	€ 163,382
L7Ae	Heavy on-road quad	8.6	14.1	€ 98,513	€ 163,382
Method B - half distance only					
Vehicle Category	Category name	Calendar time required for		Estimated cost of test (€)	
		Min	Max	Min	Max
L1Ae	Powered cycle	2.3	2.6	€ 23,019	€ 26,881
L3e-AxT (x=1,2,3)	Two wheel trial motorcycle	1.3	1.4	€ 11,569	€ 13,141
L1Be	Two wheel moped (<25 km/h)	4.0	4.6	€ 42,328	€ 50,052
	Two wheel moped (<45 km/h)	2.3	2.6	€ 23,244	€ 27,151
L2e	Three wheel moped	2.3	2.6	€ 23,244	€ 27,151
L3e-AxE (x=1,2,3)	Two wheel Enduro motorcycle	2.0	2.3	€ 19,428	€ 22,571
L6Ae	Light on-road quad	2.3	2.6	€ 23,244	€ 27,151
L3e	Two wheel motorcycle (Vmax<130km/h)	3.3	4.6	€ 35,145	€ 51,362
L4e	Two wheel motorcycle with sidecar (Vmax<130km/h)	3.3	4.6	€ 35,145	€ 51,362
L5e	Tricycle	3.3	4.6	€ 35,145	€ 51,362
L6Be	Light quadri-mobile	4.0	5.6	€ 42,778	€ 62,812
L7Be	All Terrain Vehicles	6.6	10.6	€ 74,033	€ 122,414
L7Ce	Heavy quadri-mobile	6.6	10.6	€ 74,033	€ 122,414
L3e	Two wheel motorcycle (Vmax>=130km/h)	4.6	7.3	€ 50,862	€ 83,296
L4e	Two wheel motorcycle with side-car (Vmax>=130km/h)	4.6	7.3	€ 50,862	€ 83,296
L7Ae	Heavy on-road quad	4.6	7.3	€ 50,862	€ 83,296

I.1.3 *Dynamometer, robot rider 16 hours per day 7 days per week*

Method A - full distance only					
Vehicle Category	Category name	Calendar time required for		Estimated cost of test (€)	
		Min	Max	Min	Max
L1Ae	Powered cycle	2.8	3.3	€ 16,063	€ 18,534
L3e-AxT (x=1,2,3)	Two wheel trial motorcycle	1.5	1.7	€ 9,007	€ 10,066
L1Be	Two wheel moped (<25 km/h)	5.1	6.1	€ 28,416	€ 33,858
	Two wheel moped (<45 km/h)	3.3	3.9	€ 18,723	€ 22,225
L2e	Three wheel moped	3.3	3.9	€ 18,723	€ 22,225
L3e-AxE (x=1,2,3)	Two wheel Enduro motorcycle	2.4	2.9	€ 14,304	€ 16,923
L6Ae	Light on-road quad	3.3	3.9	€ 18,723	€ 22,225
L3e	Two wheel motorcycle (Vmax<130km/h)	3.9	6.5	€ 22,779	€ 37,632
L4e	Two wheel motorcycle with sidecar (Vmax<130km/h)	3.9	6.5	€ 22,779	€ 37,632
L5e	Tricycle	3.9	6.5	€ 22,779	€ 37,632
L6Be	Light quadri-mobile	5.4	8.9	€ 30,733	€ 50,248
L7Be	All Terrain Vehicles	5.4	8.9	€ 30,733	€ 50,248
L7Ce	Heavy quadri-mobile	5.4	8.9	€ 30,733	€ 50,248
L3e	Two wheel motorcycle (Vmax>=130km/h)	6.2	10.2	€ 35,991	€ 59,178
L4e	Two wheel motorcycle with side-car (Vmax>=130km/h)	6.2	10.2	€ 35,991	€ 59,178
L7Ae	Heavy on-road quad	6.2	10.2	€ 35,991	€ 59,178
Method B - half distance only					
Vehicle Category	Category name	Calendar time required for		Estimated cost of test (€)	
		Min	Max	Min	Max
L1Ae	Powered cycle	1.7	1.9	€ 9,887	€ 11,122
L3e-AxT (x=1,2,3)	Two wheel trial motorcycle	1.0	1.1	€ 6,359	€ 6,888
L1Be	Two wheel moped (<25 km/h)	2.8	3.3	€ 16,063	€ 18,534
	Two wheel moped (<45 km/h)	1.9	2.2	€ 11,217	€ 12,718
L2e	Three wheel moped	1.9	2.2	€ 11,217	€ 12,718
L3e-AxE (x=1,2,3)	Two wheel Enduro motorcycle	1.5	1.7	€ 9,007	€ 10,066
L6Ae	Light on-road quad	1.9	2.2	€ 11,217	€ 12,718
L3e	Two wheel motorcycle (Vmax<130km/h)	2.4	3.5	€ 14,304	€ 20,421
L4e	Two wheel motorcycle with sidecar (Vmax<130km/h)	2.4	3.5	€ 14,304	€ 20,421
L5e	Tricycle	2.4	3.5	€ 14,304	€ 20,421
L6Be	Light quadri-mobile	3.3	4.7	€ 18,723	€ 26,729
L7Be	All Terrain Vehicles	5.4	8.9	€ 30,733	€ 50,248
L7Ce	Heavy quadri-mobile	5.4	8.9	€ 30,733	€ 50,248
L3e	Two wheel motorcycle (Vmax>=130km/h)	3.4	5.3	€ 19,601	€ 31,194
L4e	Two wheel motorcycle with side-car (Vmax>=130km/h)	3.4	5.3	€ 19,601	€ 31,194
L7Ae	Heavy on-road quad	3.4	5.3	€ 19,601	€ 31,194

I.1.4 *Dynamometer, robot rider, 24 hours per day, 7 days per week*

Method A - full distance only					
Vehicle Category	Category name	Calendar time required for		Estimated cost of test (€)	
		Min	Max	Min	Max
L1Ae	Powered cycle	2.1	2.4	€ 11,224	€ 12,901
L3e-AxT (x=1,	Two wheel trial motorcy	1.2	1.3	€ 6,520	€ 7,256
L1Be	Two wheel moped (<25 km/h)	3.6	4.3	€ 19,610	€ 23,464
	Two wheel moped (<45 km/h)	2.4	2.8	€ 13,147	€ 15,709
L2e	Three wheel moped	2.4	2.8	€ 13,147	€ 15,709
L3e-AxE (x=1,	Two wheel Enduro moto	1.8	2.1	€ 10,201	€ 12,174
L6Ae	Light on-road quad	2.4	2.8	€ 13,147	€ 15,709
L3e	Two wheel motorcycle	2.8	4.5	€ 16,091	€ 26,853
L4e	Two wheel motorcycle	2.8	4.5	€ 16,091	€ 26,853
L5e	Tricycle	2.8	4.5	€ 16,091	€ 26,853
L6Be	Light quadri-mobile	3.8	6.1	€ 21,394	€ 35,264
L7Be	All Terrain Vehicles	3.8	6.1	€ 21,394	€ 35,264
L7Ce	Heavy quadri-mobile	3.8	6.1	€ 21,394	€ 35,264
L3e	Two wheel motorcycle	4.3	7.0	€ 25,426	€ 42,150
L4e	Two wheel motorcycle	4.3	7.0	€ 25,426	€ 42,150
L7Ae	Heavy on-road quad	4.3	7.0	€ 25,426	€ 42,150

Method B - half distance only					
Vehicle Category	Category name	Calendar time required for		Estimated cost of test (€)	
		Min	Max	Min	Max
L1Ae	Powered cycle	1.3	1.5	€ 7,032	€ 7,870
L3e-AxT (x=1,	Two wheel trial motorcy	0.9	0.9	€ 4,679	€ 5,048
L1Be	Two wheel moped (<25 km/h)	2.1	2.4	€ 11,224	€ 12,901
	Two wheel moped (<45 km/h)	1.5	1.7	€ 7,993	€ 9,024
L2e	Three wheel moped	1.5	1.7	€ 7,993	€ 9,024
L3e-AxE (x=1,	Two wheel Enduro moto	1.2	1.3	€ 6,520	€ 7,256
L6Ae	Light on-road quad	1.5	1.7	€ 7,993	€ 9,024
L3e	Two wheel motorcycle	1.8	2.5	€ 10,201	€ 14,596
L4e	Two wheel motorcycle	1.8	2.5	€ 10,201	€ 14,596
L5e	Tricycle	1.8	2.5	€ 10,201	€ 14,596
L6Be	Light quadri-mobile	2.4	3.3	€ 13,147	€ 18,801
L7Be	All Terrain Vehicles	3.8	6.1	€ 21,394	€ 35,264
L7Ce	Heavy quadri-mobile	3.8	6.1	€ 21,394	€ 35,264
L3e	Two wheel motorcycle	2.4	3.8	€ 13,882	€ 22,245
L4e	Two wheel motorcycle	2.4	3.8	€ 13,882	€ 22,245
L7Ae	Heavy on-road quad	2.4	3.8	€ 13,882	€ 22,245

I.2 SRC-LeCV 7 lap

I.2.1 *Track methods, 40 hour week*

Method A - full distance only					
Vehicle Category	Category name	Calendar time required for test (weeks)		Estimated cost of test (€)	
		Min	Max	Min	Max
L1Ae	Powered cycle	11.2	13.2	€ 48,852	€ 56,939
L3e-AxT (x=1,2,3)	Two wheel trial motorcycle	4.6	5.2	€ 20,862	€ 23,351
L1Be	Two wheel moped (<25 km/h)	20.8	25.0	€ 89,287	€ 105,961
	Two wheel moped (<45 km/h)	13.2	15.8	€ 57,299	€ 67,575
L2e	Three wheel moped	13.2	15.8	€ 57,299	€ 67,575
L3e-AxE (x=1,2,3)	Two wheel Enduro motorcycle	7.4	8.8	€ 33,307	€ 38,786
L6Ae	Light on-road quad	13.2	15.8	€ 57,299	€ 67,575
L3e	Two wheel motorcycle (Vmax<130km/h)	12.0	23.2	€ 53,220	€ 101,099
L4e	Two wheel motorcycle with sidecar (Vmax<130km/h)	12.0	23.2	€ 53,220	€ 101,099
L5e	Tricycle	12.0	23.2	€ 53,220	€ 101,099
L6Be	Light quadri-mobile	22.4	36.8	€ 96,404	€ 156,563
L7Be	All Terrain Vehicles	22.4	36.8	€ 96,404	€ 156,563
L7Ce	Heavy quadri-mobile	22.4	36.8	€ 96,404	€ 156,563
L3e	Two wheel motorcycle (Vmax>=130km/h)	14.2	23.2	€ 63,026	€ 101,099
L4e	Two wheel motorcycle with side-car (Vmax>=130km/h)	14.2	23.2	€ 63,026	€ 101,099
L7Ae	Heavy on-road quad	19.2	31.4	€ 83,590	€ 135,372

Method B - half distance only					
Vehicle Category	Category name	Calendar time required for test (weeks)		Estimated cost of test (€)	
		Min	Max	Min	Max
L1Ae	Powered cycle	6.4	7.4	€ 28,634	€ 32,677
L3e-AxT (x=1,2,3)	Two wheel trial motorcycle	3.2	3.4	€ 14,639	€ 15,884
L1Be	Two wheel moped (<25 km/h)	11.2	13.2	€ 48,852	€ 56,939
	Two wheel moped (<45 km/h)	7.4	8.6	€ 32,857	€ 37,746
L2e	Three wheel moped	7.4	8.6	€ 32,857	€ 37,746
L3e-AxE (x=1,2,3)	Two wheel Enduro motorcycle	4.6	5.2	€ 20,862	€ 23,351
L6Ae	Light on-road quad	7.4	8.6	€ 32,857	€ 37,746
L3e	Two wheel motorcycle (Vmax<130km/h)	6.8	10.6	€ 30,818	€ 46,253
L4e	Two wheel motorcycle with sidecar (Vmax<130km/h)	6.8	10.6	€ 30,818	€ 46,253
L5e	Tricycle	6.8	10.6	€ 30,818	€ 46,253
L6Be	Light quadri-mobile	12.0	19.2	€ 52,410	€ 82,240
L7Be	All Terrain Vehicles	12.0	5.2	€ 52,410	€ 82,240
L7Ce	Heavy quadri-mobile	12.0	5.2	€ 52,410	€ 82,240
L3e	Two wheel motorcycle	7.8	12.4	€ 35,471	€ 54,508
L4e	Two wheel motorcycle with side-car (Vmax>=130km/h)	7.8	12.4	€ 35,471	€ 54,508
L7Ae	Heavy on-road quad	10.4	16.4	€ 45,753	€ 71,644

I.2.2 *Track 16 hours per day, 7 days per week*

Method A - full distance only					
Vehicle Category	Category name	Calendar time required for		Estimated cost of test (€)	
		Min	Max	Min	Max
L1Ae	Powered cycle	4.0	4.7	€ 44,146	€ 52,233
L3e-AxT (x=1,2,3)	Two wheel trial motorcycle	1.7	1.9	€ 16,156	€ 18,645
L1Be	Two wheel moped (<25 km/h)	7.4	8.9	€ 84,581	€ 101,255
	Two wheel moped (<45 km/h)	4.7	5.6	€ 52,593	€ 62,869
L2e	Three wheel moped	4.7	5.6	€ 52,593	€ 62,869
L3e-AxE (x=1,2,3)	Two wheel Enduro motorcycle	2.7	3.2	€ 28,602	€ 34,080
L6Ae	Light on-road quad	4.7	5.6	€ 52,593	€ 62,869
L3e	Two wheel motorcycle	4.3	8.4	€ 48,514	€ 96,393
L4e	Two wheel motorcycle with sidecar (Vmax<130km/h)	4.3	8.4	€ 48,514	€ 96,393
L5e	Tricycle	4.3	8.4	€ 48,514	€ 96,393
L6Be	Light quadri-mobile	8.0	13.2	€ 91,699	€ 151,857
L7Be	All Terrain Vehicles	8.0	13.2	€ 91,699	€ 151,857
L7Ce	Heavy quadri-mobile	8.0	13.2	€ 91,699	€ 151,857
L3e	Two wheel motorcycle	5.1	8.4	€ 58,320	€ 96,393
L4e	Two wheel motorcycle with side-car (Vmax>=130km/h)	5.1	8.4	€ 58,320	€ 96,393
L7Ae	Heavy on-road quad	6.9	11.2	€ 78,884	€ 130,666
Method B - half distance only					
Vehicle Category	Category name	Calendar time required for		Estimated cost of test (€)	
		Min	Max	Min	Max
L1Ae	Powered cycle	2.3	2.7	€ 23,928	€ 27,972
L3e-AxT (x=1,2,3)	Two wheel trial motorcycle	1.1	1.3	€ 9,933	€ 11,178
L1Be	Two wheel moped (<25 km/h)	4.0	4.7	€ 44,146	€ 52,233
	Two wheel moped (<45 km/h)	2.7	3.1	€ 28,152	€ 33,040
L2e	Three wheel moped	2.7	3.1	€ 28,152	€ 33,040
L3e-AxE (x=1,2,3)	Two wheel Enduro motorcycle	1.7	1.9	€ 16,156	€ 18,645
L6Ae	Light on-road quad	2.7	3.1	€ 28,152	€ 33,040
L3e	Two wheel motorcycle	2.4	3.8	€ 26,112	€ 41,547
L4e	Two wheel motorcycle with sidecar (Vmax<130km/h)	2.4	3.8	€ 26,112	€ 41,547
L5e	Tricycle	2.4	3.8	€ 26,112	€ 41,547
L6Be	Light quadri-mobile	4.3	6.9	€ 47,704	€ 77,534
L7Be	All Terrain Vehicles	4.3	1.9	€ 47,704	€ 77,534
L7Ce	Heavy quadri-mobile	4.3	1.9	€ 47,704	€ 77,534
L3e	Two wheel motorcycle	2.9	4.4	€ 30,765	€ 49,802
L4e	Two wheel motorcycle with side-car (Vmax>=130km/h)	2.9	4.4	€ 30,765	€ 49,802
L7Ae	Heavy on-road quad	3.7	5.9	€ 41,047	€ 66,938

I.2.3 *Dynamometer, robot rider 16 hours per day, 7 days per week*

Method A - full distance only					
Vehicle Category	Category name	Calendar time required for test (weeks)		Estimated cost of test (€)	
		Min	Max	Min	Max
L1Ae	Powered cycle	3.0	3.5	€ 16,761	€ 19,371
L3e-AxT (x=1,2,3)	Two wheel trial motorcycle	1.4	1.6	€ 8,585	€ 9,559
L1Be	Two wheel moped (<25 km/h)	5.4	6.4	€ 29,811	€ 35,531
	Two wheel moped (<45 km/h)	3.7	4.4	€ 21,187	€ 25,182
L2e	Three wheel moped	3.7	4.4	€ 21,187	€ 25,182
L3e-AxE (x=1,2,3)	Two wheel Enduro motorcycle	2.3	2.7	€ 13,459	€ 15,908
L6Ae	Light on-road quad	3.7	4.4	€ 21,187	€ 25,182
L3e	Two wheel motorcycle	3.6	6.8	€ 21,257	€ 41,511
L4e	Two wheel motorcycle with sidecar (Vmax<130km/h)	3.6	6.8	€ 21,257	€ 41,511
L5e	Tricycle	3.6	6.8	€ 21,257	€ 41,511
L6Be	Light quadri-mobile	6.3	10.3	€ 35,168	€ 57,640
L7Be	All Terrain Vehicles	6.3	10.3	€ 35,168	€ 57,640
L7Ce	Heavy quadri-mobile	6.3	10.3	€ 35,168	€ 57,640
L3e	Two wheel motorcycle	4.2	6.8	€ 25,391	€ 41,511
L4e	Two wheel motorcycle with side-car (Vmax>=130km/h)	4.2	6.8	€ 25,391	€ 41,511
L7Ae	Heavy on-road quad	5.7	9.4	€ 33,455	€ 54,952
Method B - half distance only					
Vehicle Category	Category name	Calendar time required for		Estimated cost of test (€)	
		Min	Max	Min	Max
L1Ae	Powered cycle	1.8	2.0	€ 10,236	€ 11,541
L3e-AxT (x=1,2,3)	Two wheel trial motorcycle	1.0	1.1	€ 6,147	€ 6,635
L1Be	Two wheel moped (<25 km/h)	3.0	3.5	€ 16,761	€ 19,371
	Two wheel moped (<45 km/h)	2.2	2.5	€ 12,449	€ 14,196
L2e	Three wheel moped	2.2	2.5	€ 12,449	€ 14,196
L3e-AxE (x=1,2,3)	Two wheel Enduro motorcycle	1.4	1.6	€ 8,585	€ 9,559
L6Ae	Light on-road quad	2.2	2.5	€ 12,449	€ 14,196
L3e	Two wheel motorcycle (Vmax<130km/h)	2.1	3.2	€ 12,484	€ 18,833
L4e	Two wheel motorcycle with sidecar (Vmax<130km/h)	2.1	3.2	€ 12,484	€ 18,833
L5e	Tricycle	2.1	3.2	€ 12,484	€ 18,833
L6Be	Light quadri-mobile	3.4	5.4	€ 19,439	€ 30,425
L7Be	All Terrain Vehicles	3.4	1.6	€ 19,439	€ 30,425
L7Ce	Heavy quadri-mobile	3.4	1.6	€ 19,439	€ 30,425
L3e	Two wheel motorcycle	2.3	3.7	€ 14,301	€ 22,361
L4e	Two wheel motorcycle with side-car (Vmax>=130km/h)	2.3	3.7	€ 14,301	€ 22,361
L7Ae	Heavy on-road quad	3.1	4.9	€ 18,333	€ 29,081

I.2.4 *Dynamometer, robot rider, 24 hours per day, 7 days per week*

Method A - full distance only					
Vehicle Category	Category name	Calendar time required for		Estimated cost of test (€)	
		Min	Max	Min	Max
L1Ae	Powered cycle	2.2	2.5	€ 11,689	€ 13,459
L3e-AxT (x=1,2,3)	Two wheel trial motorcycle	1.1	1.2	€ 6,238	€ 6,918
L1Be	Two wheel moped (<25 km/h)	3.8	4.5	€ 20,539	€ 24,580
	Two wheel moped (<45 km/h)	2.7	3.2	€ 14,790	€ 17,680
L2e	Three wheel moped	2.7	3.2	€ 14,790	€ 17,680
L3e-AxE (x=1,2,3)	Two wheel Enduro motorcycle	1.7	2.0	€ 9,638	€ 11,498
L6Ae	Light on-road quad	2.7	3.2	€ 14,790	€ 17,680
L3e	Two wheel motorcycle	2.6	4.7	€ 15,077	€ 30,373
L4e	Two wheel motorcycle with sidecar (Vmax<130km/h)	2.6	4.7	€ 15,077	€ 30,373
L5e	Tricycle	2.6	4.7	€ 15,077	€ 30,373
L6Be	Light quadri-mobile	4.4	7.1	€ 24,351	€ 40,192
L7Be	All Terrain Vehicles	4.4	7.1	€ 24,351	€ 40,192
L7Ce	Heavy quadri-mobile	4.4	7.1	€ 24,351	€ 40,192
L3e	Two wheel motorcycle	3.0	4.7	€ 18,359	€ 30,373
L4e	Two wheel motorcycle with side-car (Vmax>=130km/h)	3.0	4.7	€ 18,359	€ 30,373
L7Ae	Heavy on-road quad	4.0	6.5	€ 23,735	€ 39,333

Method B - half distance only					
Vehicle Category	Category name	Calendar time required for		Estimated cost of test (€)	
		Min	Max	Min	Max
L1Ae	Powered cycle	1.4	1.5	€ 7,264	€ 8,149
L3e-AxT (x=1,2,3)	Two wheel trial motorcycle	0.9	0.9	€ 4,539	€ 4,879
L1Be	Two wheel moped (<25 km/h)	2.2	2.5	€ 11,689	€ 13,459
	Two wheel moped (<45 km/h)	1.6	1.8	€ 8,814	€ 10,010
L2e	Three wheel moped	1.6	1.8	€ 8,814	€ 10,010
L3e-AxE (x=1,2,3)	Two wheel Enduro motorcycle	1.1	1.2	€ 6,238	€ 6,918
L6Ae	Light on-road quad	1.6	1.8	€ 8,814	€ 10,010
L3e	Two wheel motorcycle	1.6	2.3	€ 8,958	€ 13,537
L4e	Two wheel motorcycle with sidecar (Vmax<130km/h)	1.6	2.3	€ 8,958	€ 13,537
L5e	Tricycle	1.6	2.3	€ 8,958	€ 13,537
L6Be	Light quadri-mobile	2.5	3.8	€ 13,595	€ 21,265
L7Be	All Terrain Vehicles	2.5	1.2	€ 13,595	€ 21,265
L7Ce	Heavy quadri-mobile	2.5	1.2	€ 13,595	€ 21,265
L3e	Two wheel motorcycle	1.7	2.6	€ 10,349	€ 16,356
L4e	Two wheel motorcycle with side-car (Vmax>=130km/h)	1.7	2.6	€ 10,349	€ 16,356
L7Ae	Heavy on-road quad	2.3	3.5	€ 13,037	€ 20,836

I.3 SRC-LeCV 5 lap

I.3.1 *Track methods, 40 hour week*

Method A - full distance only					
Vehicle Category	Category name	Calendar time required for test (weeks)		Estimated cost of test (€)	
		Min	Max	Min	Max
L1Ae	Powered cycle	9.8	11.4	€ 42,454	€ 49,261
L3e-AxT (x=1,2,3)	Two wheel trial motorcycle	4.0	4.4	€ 18,196	€ 20,152
L1Be	Two wheel moped (<25 km/h)	17.8	21.2	€ 76,491	€ 90,606
	Two wheel moped (<45 km/h)	10.6	12.6	€ 46,636	€ 54,780
L2e	Three wheel moped	10.6	12.6	€ 46,636	€ 54,780
L3e-AxE (x=1,2,3)	Two wheel Enduro motorcycle	6.2	7.2	€ 27,976	€ 32,388
L6Ae	Light on-road quad	10.6	12.6	€ 46,636	€ 54,780
L3e	Two wheel motorcycle (Vmax<130km/h)	9.8	19.4	€ 43,624	€ 85,390
L4e	Two wheel motorcycle with sidecar (Vmax<130km/h)	9.8	19.4	€ 43,624	€ 85,390
L5e	Tricycle	9.8	19.4	€ 43,624	€ 85,390
L6Be	Light quadri-mobile	17.8	29.2	€ 77,211	€ 124,575
L7Be	All Terrain Vehicles	17.8	29.2	€ 77,211	€ 124,575
L7Ce	Heavy quadri-mobile	17.8	29.2	€ 77,211	€ 124,575
L3e	Two wheel motorcycle (Vmax>=130km/h)	12.0	19.4	€ 53,601	€ 85,390
L4e	Two wheel motorcycle with side-car (Vmax>=130km/h)	12.0	19.4	€ 53,601	€ 85,390
L7Ae	Heavy on-road quad	15.4	25.2	€ 67,595	€ 108,715
Method B - half distance only					
Vehicle Category	Category name	Calendar time required for test (weeks)		Estimated cost of test (€)	
		Min	Max	Min	Max
L1Ae	Powered cycle	5.8	11.4	€ 25,435	€ 49,261
L3e-AxT (x=1,2,3)	Two wheel trial motorcycle	4.0	4.4	€ 18,196	€ 20,152
L1Be	Two wheel moped (<25 km/h)	17.8	21.2	€ 76,491	€ 90,606
	Two wheel moped (<45 km/h)	10.6	12.6	€ 46,636	€ 54,780
L2e	Three wheel moped	10.6	12.6	€ 46,636	€ 54,780
L3e-AxE (x=1,2,3)	Two wheel Enduro motorcycle	6.2	7.2	€ 27,976	€ 32,388
L6Ae	Light on-road quad	10.6	12.6	€ 46,636	€ 54,780
L3e	Two wheel motorcycle (Vmax<130km/h)	9.8	15.8	€ 43,624	€ 68,595
L4e	Two wheel motorcycle with sidecar (Vmax<130km/h)	9.8	15.8	€ 43,624	€ 68,595
L5e	Tricycle	9.8	15.8	€ 43,624	€ 68,595
L6Be	Light quadri-mobile	17.8	29.2	€ 77,211	€ 124,575
L7Be	All Terrain Vehicles	17.8	4.4	€ 77,211	€ 124,575
L7Ce	Heavy quadri-mobile	17.8	4.4	€ 77,211	€ 124,575
L3e	Two wheel motorcycle	12.0	19.4	€ 53,601	€ 85,390
L4e	Two wheel motorcycle with side-car (Vmax>=130km/h)	12.0	19.4	€ 53,601	€ 85,390
L7Ae	Heavy on-road quad	15.4	25.2	€ 67,595	€ 108,715

I.3.2 *Track 16 hours per day, 7 days per week*

Method A - full distance only					
Vehicle Category	Category name	Calendar time required for		Estimated cost of test (€)	
		Min	Max	Min	Max
L1Ae	Powered cycle	3.6	4.1	€ 37,748	€ 44,555
L3e-AxT (x=1,2,3)	Two wheel trial motorcycle	1.4	1.6	€ 13,490	€ 15,446
L1Be	Two wheel moped (<25 km/h)	6.4	7.6	€ 71,785	€ 85,900
	Two wheel moped (<45 km/h)	3.9	4.5	€ 41,930	€ 50,074
L2e	Three wheel moped	3.9	4.5	€ 41,930	€ 50,074
L3e-AxE (x=1,2,3)	Two wheel Enduro motorcycle	2.3	2.6	€ 23,270	€ 27,682
L6Ae	Light on-road quad	3.9	4.5	€ 41,930	€ 50,074
L3e	Two wheel motorcycle	3.6	6.9	€ 38,918	€ 80,684
L4e	Two wheel motorcycle with sidecar (Vmax<130km/h)	3.6	6.9	€ 38,918	€ 80,684
L5e	Tricycle	3.6	6.9	€ 38,918	€ 80,684
L6Be	Light quadri-mobile	6.4	10.5	€ 72,505	€ 119,869
L7Be	All Terrain Vehicles	6.4	10.5	€ 72,505	€ 119,869
L7Ce	Heavy quadri-mobile	6.4	10.5	€ 72,505	€ 119,869
L3e	Two wheel motorcycle	4.4	6.9	€ 48,895	€ 80,684
L4e	Two wheel motorcycle with side-car (Vmax>=130km/h)	4.4	6.9	€ 48,895	€ 80,684
L7Ae	Heavy on-road quad	5.5	9.1	€ 62,890	€ 104,009
Method B - half distance only					
Vehicle Category	Category name	Calendar time required for		Estimated cost of test (€)	
		Min	Max	Min	Max
L1Ae	Powered cycle	2.1	2.4	€ 20,729	€ 24,133
L3e-AxT (x=1,2,3)	Two wheel trial motorcycle	1.0	1.1	€ 8,600	€ 9,578
L1Be	Two wheel moped (<25 km/h)	3.6	4.1	€ 37,748	€ 44,555
	Two wheel moped (<45 km/h)	2.3	2.6	€ 22,820	€ 26,642
L2e	Three wheel moped	2.3	2.6	€ 22,820	€ 26,642
L3e-AxE (x=1,2,3)	Two wheel Enduro motorcycle	1.4	1.6	€ 13,490	€ 15,446
L6Ae	Light on-road quad	2.3	2.6	€ 22,820	€ 26,642
L3e	Two wheel motorcycle	2.1	3.1	€ 21,314	€ 33,550
L4e	Two wheel motorcycle with sidecar (Vmax<130km/h)	2.1	3.1	€ 21,314	€ 33,550
L5e	Tricycle	2.1	3.1	€ 21,314	€ 33,550
L6Be	Light quadri-mobile	3.6	5.5	€ 38,108	€ 61,540
L7Be	All Terrain Vehicles	3.6	1.6	€ 38,108	€ 61,540
L7Ce	Heavy quadri-mobile	3.6	1.6	€ 38,108	€ 61,540
L3e	Two wheel motorcycle	2.4	3.9	€ 26,053	€ 41,947
L4e	Two wheel motorcycle with side-car (Vmax>=130km/h)	2.4	3.9	€ 26,053	€ 41,947
L7Ae	Heavy on-road quad	3.0	4.9	€ 33,050	€ 53,610

I.3.3 *Dynamometer, robot rider 16 hours per day, 7 days per week*

Method A - full distance only					
Vehicle Category	Category name	Calendar time required for test (weeks)		Estimated cost of test (€)	
		Min	Max	Min	Max
L1Ae	Powered cycle	2.8	3.3	€ 15,842	€ 18,269
L3e-AxT (x=1,2,3)	Two wheel trial motorcycle	1.2	1.3	€ 7,492	€ 8,249
L1Be	Two wheel moped (<25 km/h)	5.0	6.0	€ 27,974	€ 33,327
	Two wheel moped (<45 km/h)	3.2	3.8	€ 18,409	€ 21,849
L2e	Three wheel moped	3.2	3.8	€ 18,409	€ 21,849
L3e-AxE (x=1,2,3)	Two wheel Enduro motorcycle	1.8	2.2	€ 11,275	€ 13,287
L6Ae	Light on-road quad	3.2	3.8	€ 18,409	€ 21,849
L3e	Two wheel motorcycle	2.9	5.9	€ 17,326	€ 36,583
L4e	Two wheel motorcycle with sidecar (Vmax<130km/h)	2.9	5.9	€ 17,326	€ 36,583
L5e	Tricycle	2.9	5.9	€ 17,326	€ 36,583
L6Be	Light quadri-mobile	5.3	8.7	€ 30,168	€ 49,307
L7Be	All Terrain Vehicles	5.3	8.7	€ 30,168	€ 49,307
L7Ce	Heavy quadri-mobile	5.3	8.7	€ 30,168	€ 49,307
L3e	Two wheel motorcycle	3.6	5.9	€ 22,434	€ 36,583
L4e	Two wheel motorcycle with side-car (Vmax>=130km/h)	3.6	5.9	€ 22,434	€ 36,583
L7Ae	Heavy on-road quad	4.5	7.3	€ 26,903	€ 44,031

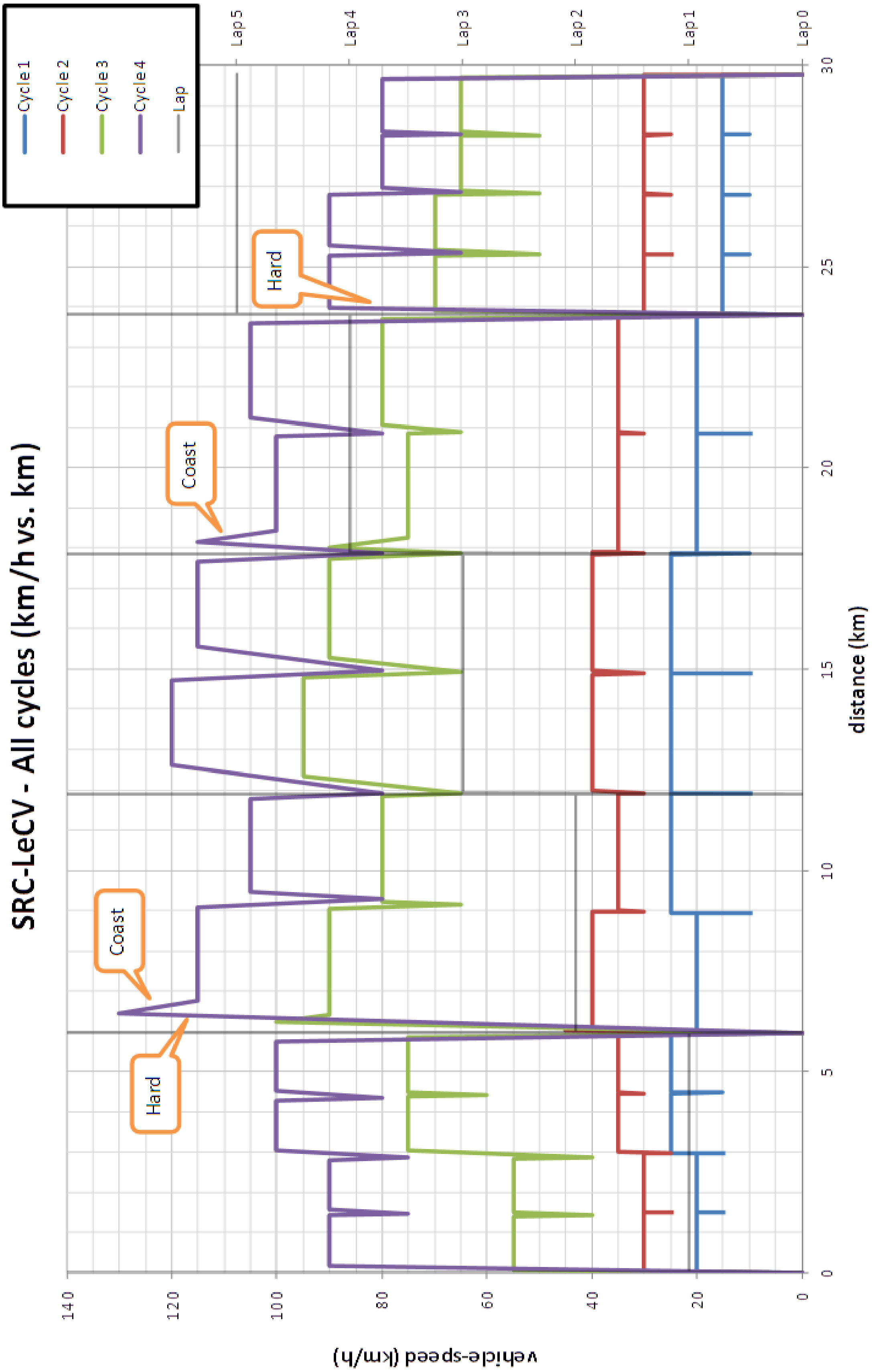
Method B - half distance only					
Vehicle Category	Category name	Calendar time required for		Estimated cost of test (€)	
		Min	Max	Min	Max
L1Ae	Powered cycle	1.7	1.9	€ 9,776	€ 10,990
L3e-AxT (x=1,2,3)	Two wheel trial motorcycle	0.9	1.0	€ 5,601	€ 5,980
L1Be	Two wheel moped (<25 km/h)	2.8	3.3	€ 15,842	€ 18,269
	Two wheel moped (<45 km/h)	1.9	2.2	€ 11,060	€ 12,530
L2e	Three wheel moped	1.9	2.2	€ 11,060	€ 12,530
L3e-AxE (x=1,2,3)	Two wheel Enduro motorcycle	1.2	1.3	€ 7,492	€ 8,249
L6Ae	Light on-road quad	1.9	2.2	€ 11,060	€ 12,530
L3e	Two wheel motorcycle (Vmax<130km/h)	1.7	2.6	€ 10,518	€ 15,557
L4e	Two wheel motorcycle with sidecar (Vmax<130km/h)	1.7	2.6	€ 10,518	€ 15,557
L5e	Tricycle	1.7	2.6	€ 10,518	€ 15,557
L6Be	Light quadri-mobile	2.9	4.6	€ 16,939	€ 26,259
L7Be	All Terrain Vehicles	2.9	1.3	€ 16,939	€ 26,259
L7Ce	Heavy quadri-mobile	2.9	1.3	€ 16,939	€ 26,259
L3e	Two wheel motorcycle	2.1	3.2	€ 12,822	€ 19,897
L4e	Two wheel motorcycle with side-car (Vmax>=130km/h)	2.1	3.2	€ 12,822	€ 19,897
L7Ae	Heavy on-road quad	2.5	3.9	€ 15,057	€ 23,621

I.3.4 *Dynamometer, robot rider, 24 hours per day, 7 days per week*

Method A - full distance only					
Vehicle Category	Category name	Calendar time required for		Estimated cost of test (€)	
		Min	Max	Min	Max
L1Ae	Powered cycle	2.1	2.4	€ 11,077	€ 12,724
L3e-AxT (x=1,2,3)	Two wheel trial motorcycle	1.0	1.1	€ 5,510	€ 6,045
L1Be	Two wheel moped (<25 km/h)	3.6	4.2	€ 19,315	€ 23,110
	Two wheel moped (<45 km/h)	2.3	2.7	€ 12,938	€ 15,458
L2e	Three wheel moped	2.3	2.7	€ 12,938	€ 15,458
L3e-AxE (x=1,2,3)	Two wheel Enduro motorcycle	1.4	1.6	€ 8,182	€ 9,750
L6Ae	Light on-road quad	2.3	2.7	€ 12,938	€ 15,458
L3e	Two wheel motorcycle	2.1	4.1	€ 12,456	€ 27,087
L4e	Two wheel motorcycle with sidecar (Vmax<130km/h)	2.1	4.1	€ 12,456	€ 27,087
L5e	Tricycle	2.1	4.1	€ 12,456	€ 27,087
L6Be	Light quadri-mobile	3.7	6.0	€ 21,017	€ 34,636
L7Be	All Terrain Vehicles	3.7	6.0	€ 21,017	€ 34,636
L7Ce	Heavy quadri-mobile	3.7	6.0	€ 21,017	€ 34,636
L3e	Two wheel motorcycle	2.6	4.1	€ 16,388	€ 27,087
L4e	Two wheel motorcycle with side-car (Vmax>=130km/h)	2.6	4.1	€ 16,388	€ 27,087
L7Ae	Heavy on-road quad	3.2	5.1	€ 19,367	€ 32,053

Method B - half distance only					
Vehicle Category	Category name	Calendar time required for		Estimated cost of test (€)	
		Min	Max	Min	Max
L1Ae	Powered cycle	1.3	1.5	€ 6,958	€ 7,782
L3e-AxT (x=1,2,3)	Two wheel trial motorcycle	0.8	0.8	€ 4,175	€ 4,442
L1Be	Two wheel moped (<25 km/h)	2.1	2.4	€ 11,077	€ 12,724
	Two wheel moped (<45 km/h)	1.5	1.6	€ 7,889	€ 8,898
L2e	Three wheel moped	1.5	1.6	€ 7,889	€ 8,898
L3e-AxE (x=1,2,3)	Two wheel Enduro motorcycle	1.0	1.1	€ 5,510	€ 6,045
L6Ae	Light on-road quad	1.5	1.6	€ 7,889	€ 8,898
L3e	Two wheel motorcycle	1.3	1.9	€ 7,647	€ 11,353
L4e	Two wheel motorcycle with sidecar (Vmax<130km/h)	1.3	1.9	€ 7,647	€ 11,353
L5e	Tricycle	1.3	1.9	€ 7,647	€ 11,353
L6Be	Light quadri-mobile	2.2	3.3	€ 11,928	€ 18,488
L7Be	All Terrain Vehicles	2.2	1.1	€ 11,928	€ 18,488
L7Ce	Heavy quadri-mobile	2.2	1.1	€ 11,928	€ 18,488
L3e	Two wheel motorcycle	1.6	2.3	€ 9,363	€ 14,713
L4e	Two wheel motorcycle with side-car (Vmax>=130km/h)	1.6	2.3	€ 9,363	€ 14,713
L7Ae	Heavy on-road quad	1.8	2.8	€ 10,853	€ 17,196

Appendix J SRC-LeCV durability cycle (phase 2)



Appendix K Temperature traces for uninterrupted repeat of durability cycles (validation phase 2)

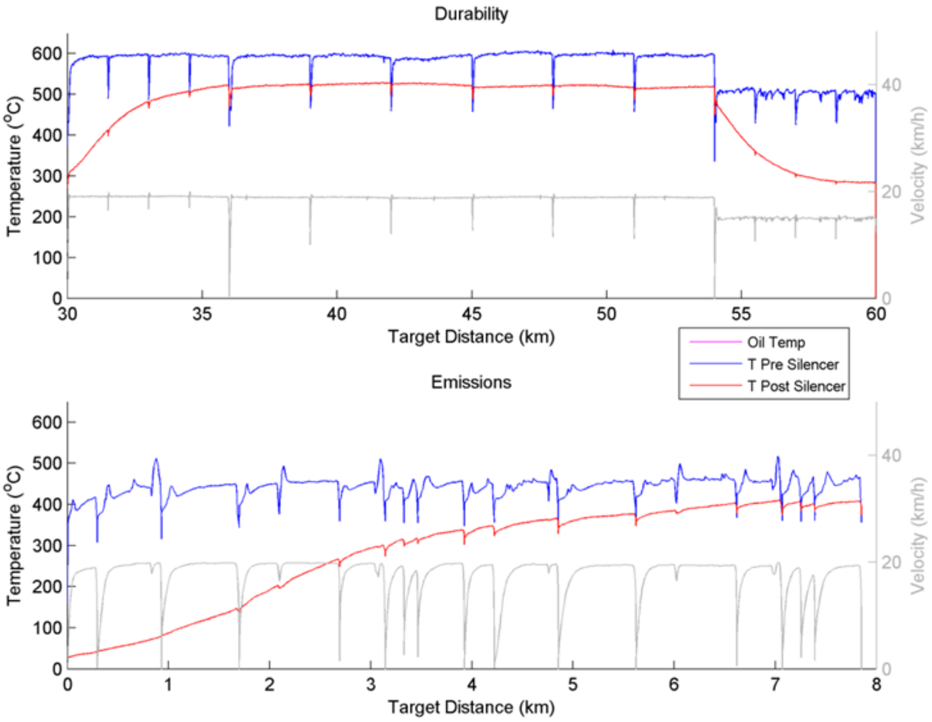


Figure 16-77: Vehicle 1, temperature trace, second durability cycle

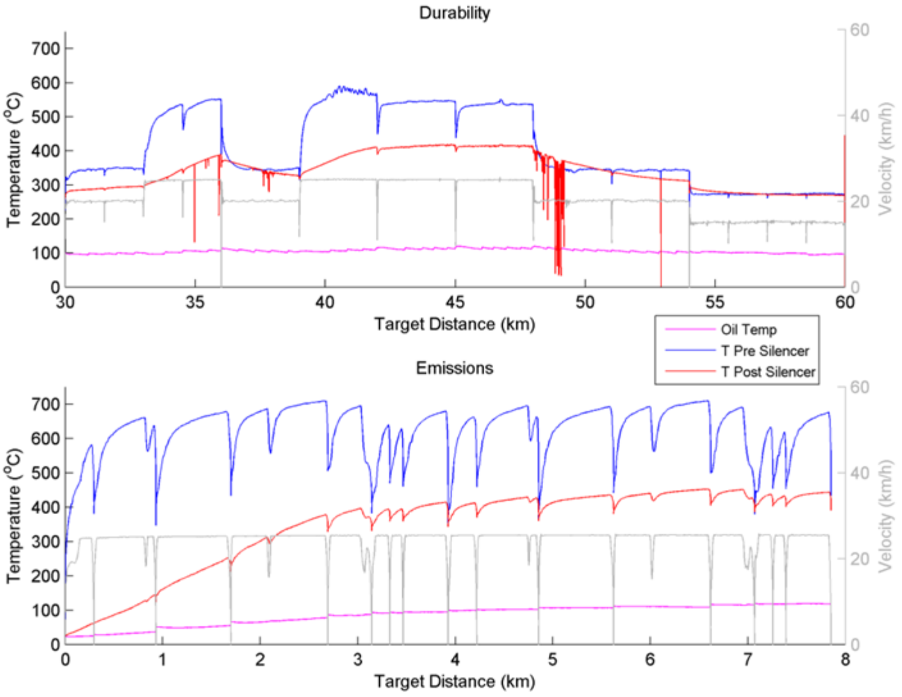


Figure 16-78: Vehicle 2, temperature trace, second durability cycle

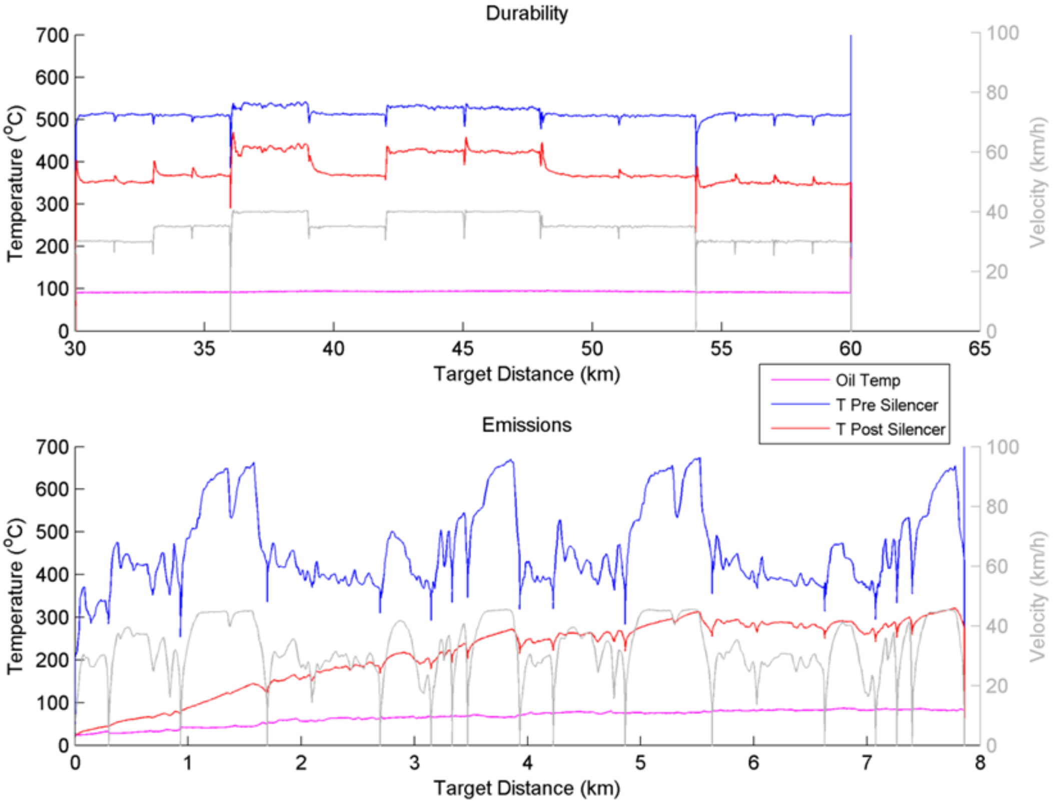


Figure 16-79: Vehicle 3, temperature trace, second durability cycle

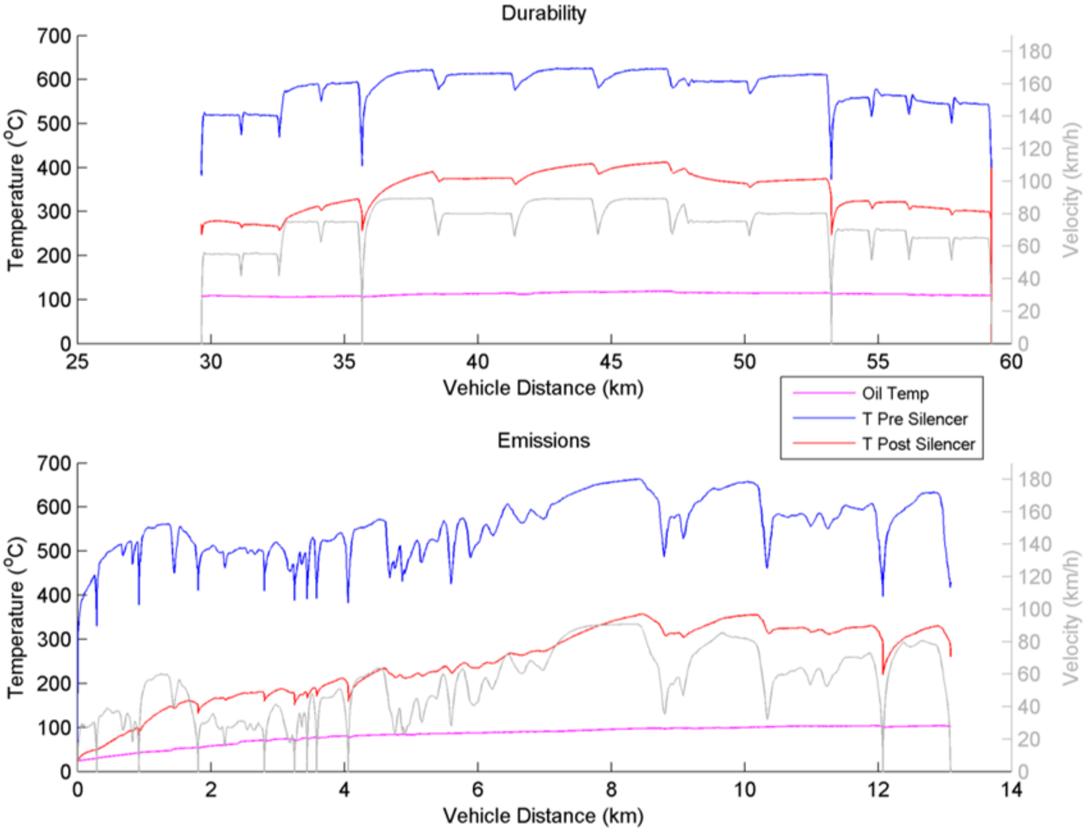


Figure 16-80: Vehicle 4, temperature trace, second durability cycle

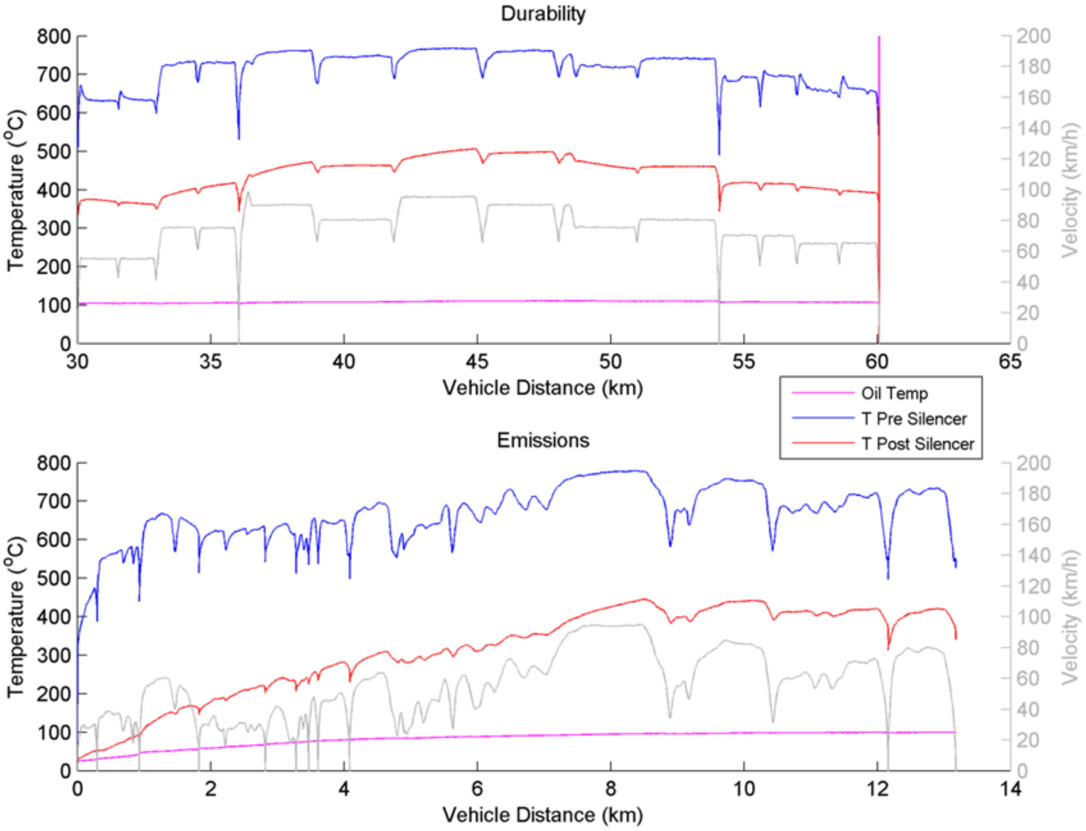


Figure 16-81: Vehicle 5, temperature trace, second durability cycle

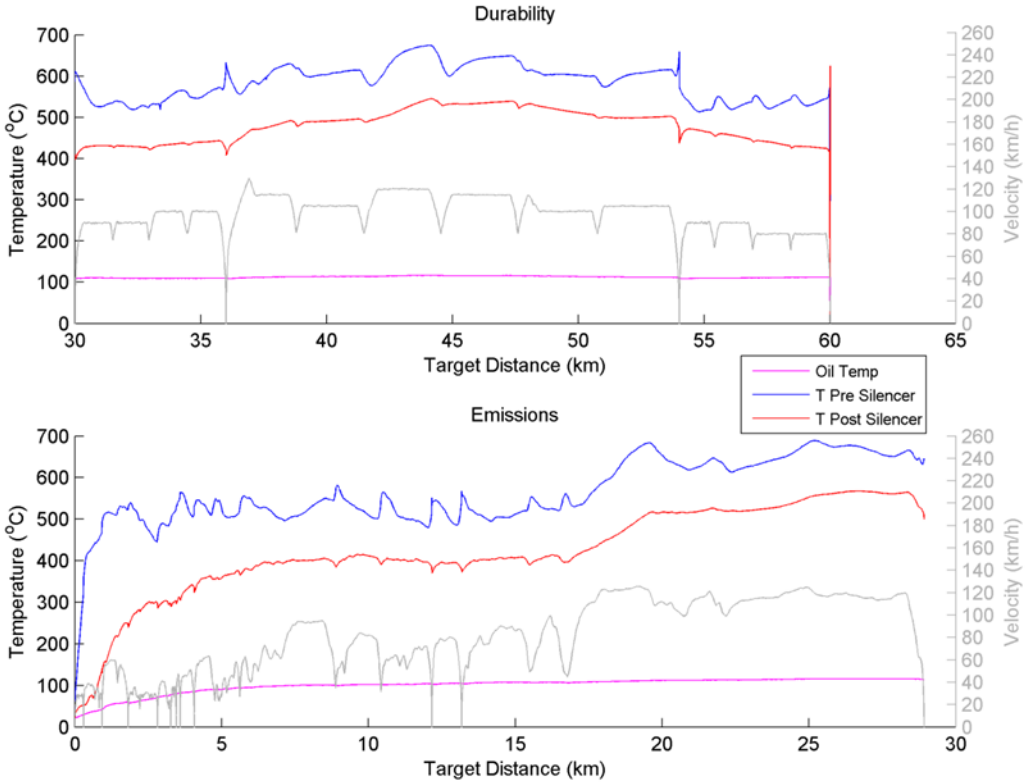


Figure 16-82: Vehicle 6, temperature trace, second durability cycle

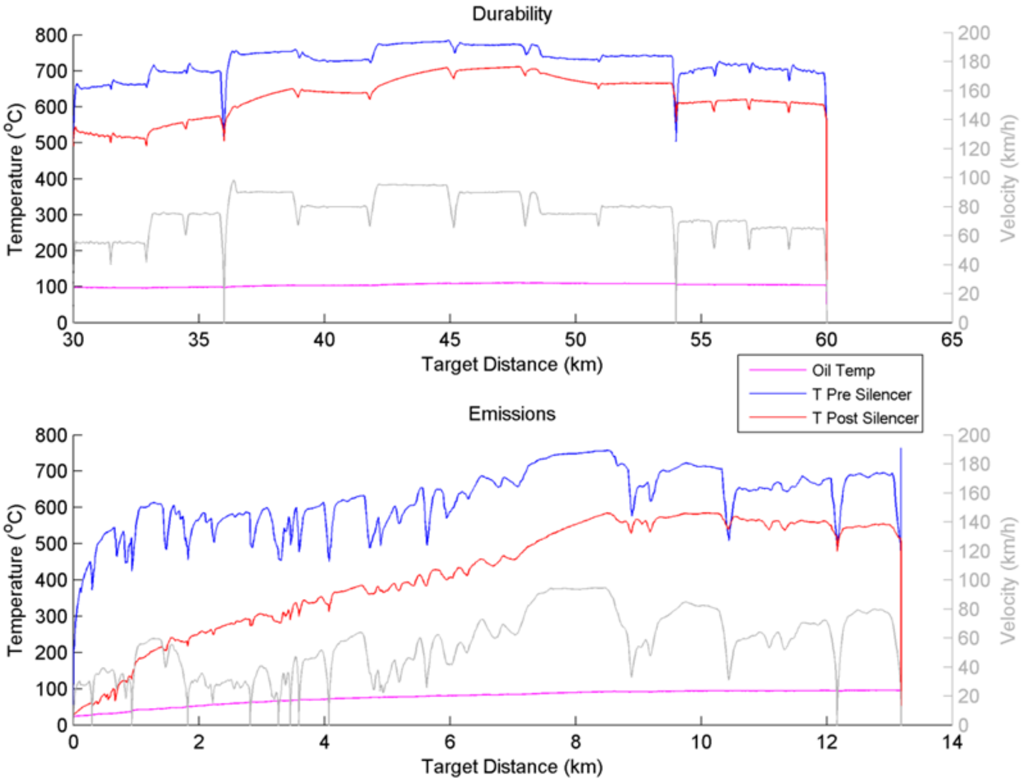


Figure 16-83: Vehicle 7, temperature trace, second durability cycle

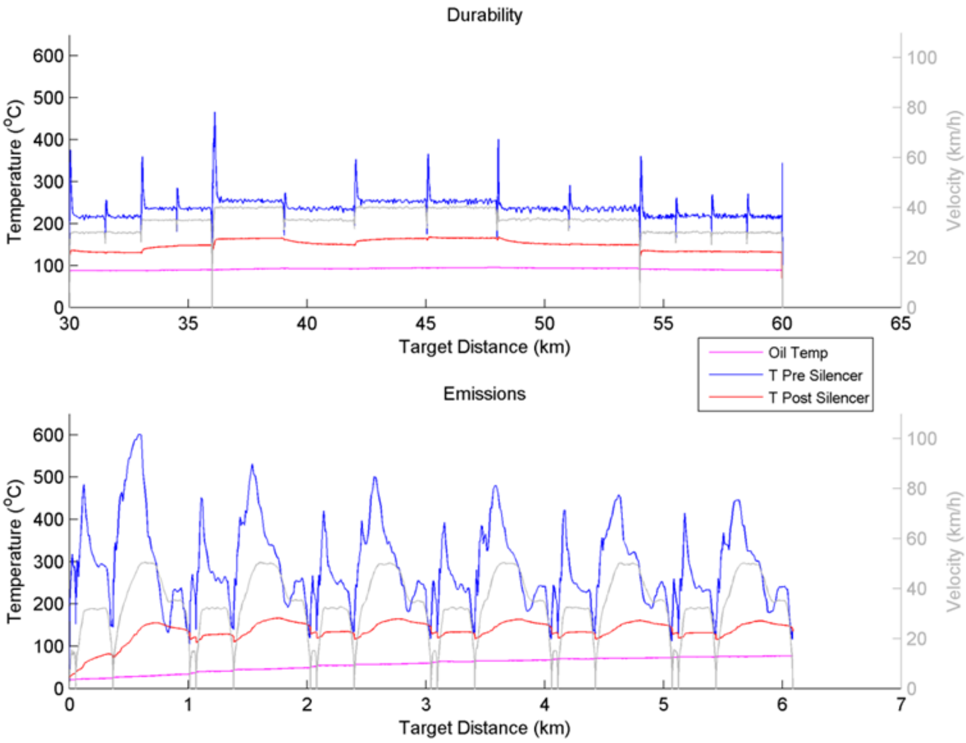


Figure 16-84: Vehicle 8, temperature trace, second durability cycle

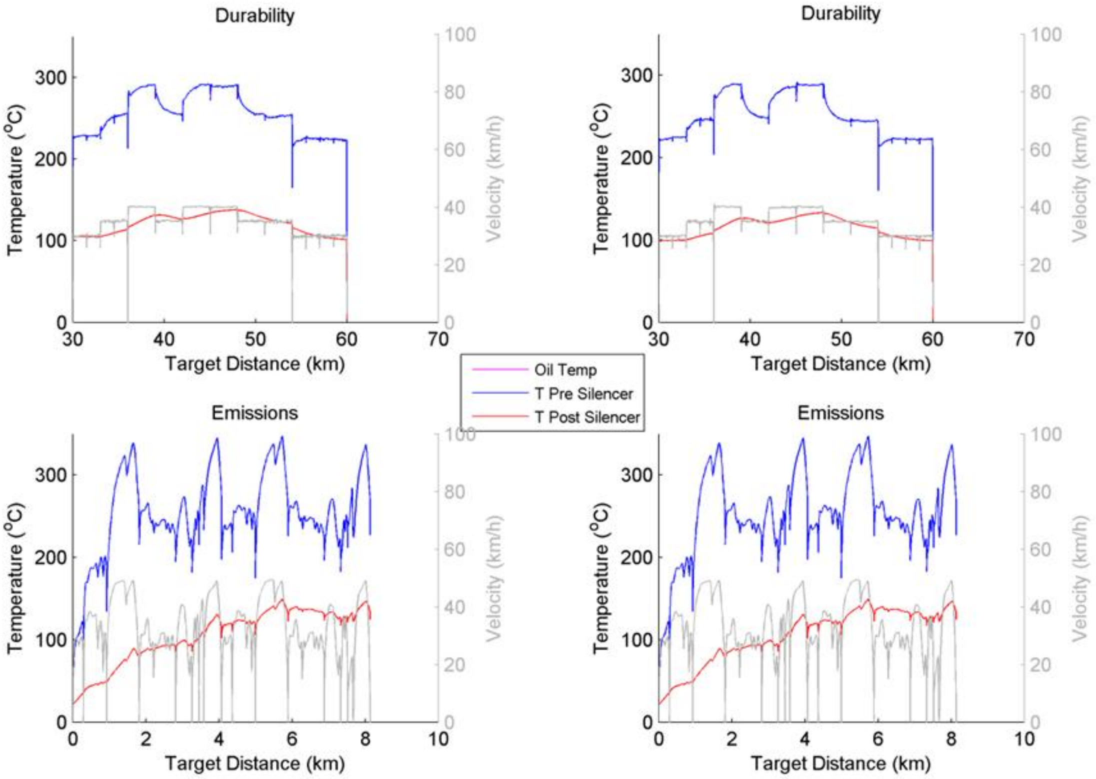


Figure 16-85: Vehicle 9, temperature trace, second durability cycle

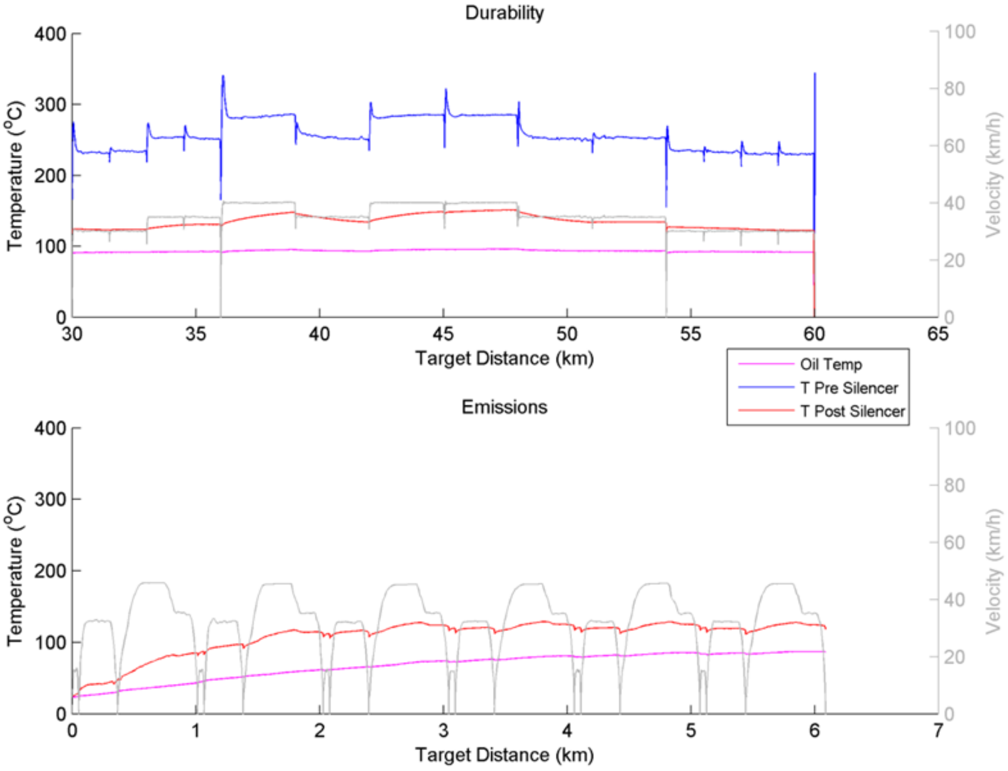


Figure 16-86: Vehicle 10, temperature trace, second durability cycle

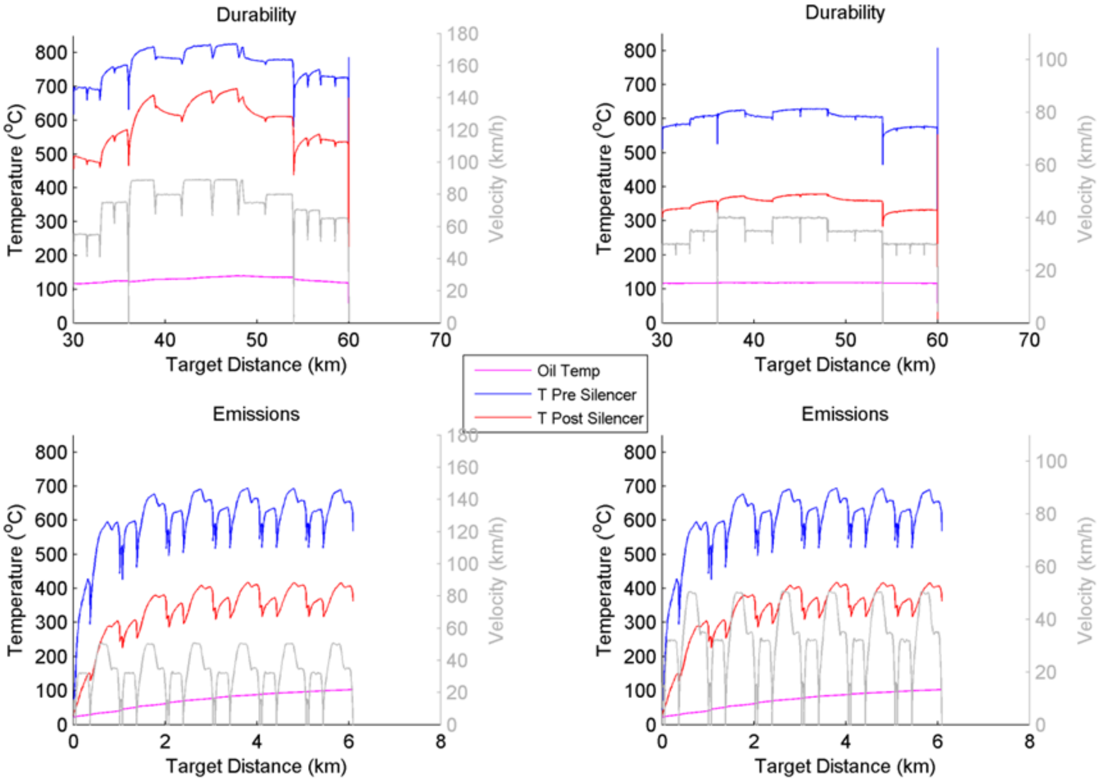


Figure 16-87: Vehicle 11, temperature trace, second durability cycle

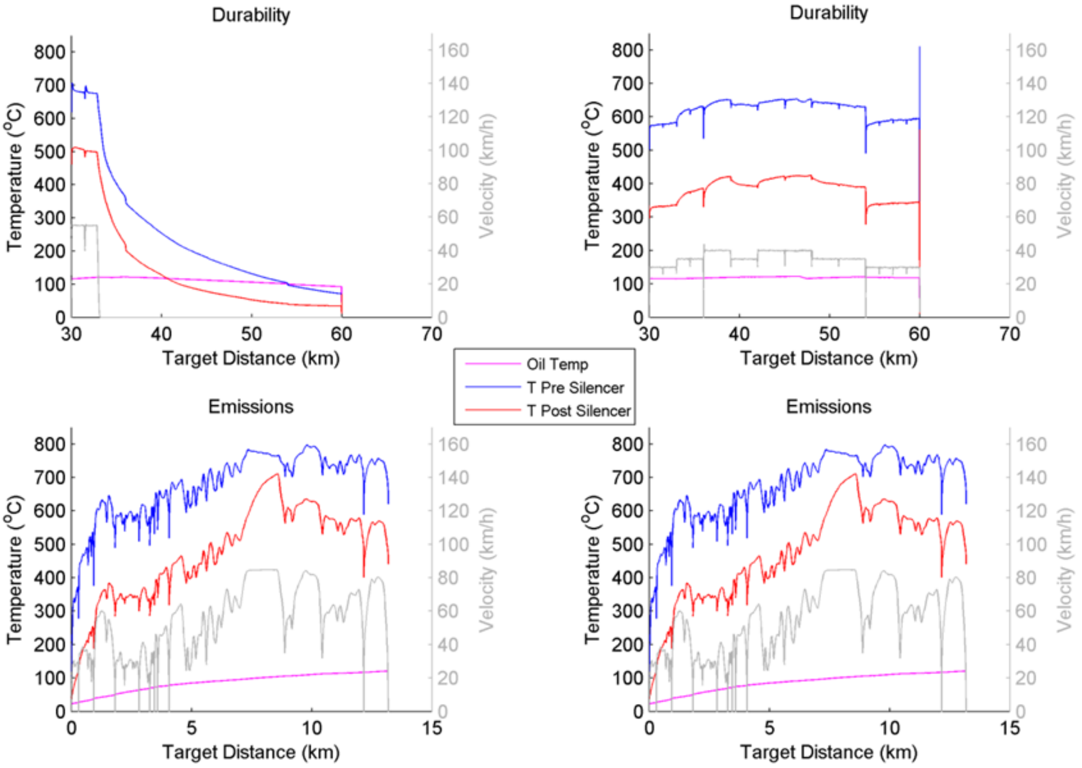


Figure 16-88: Vehicle 12, temperature trace, second durability cycle

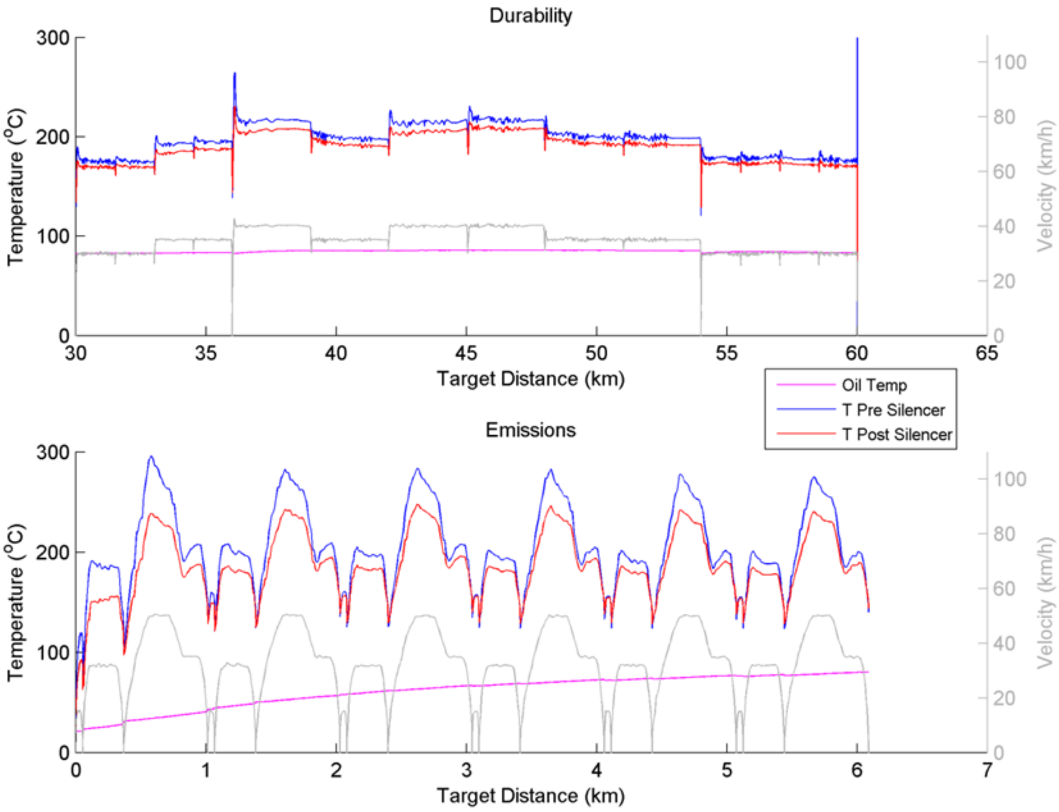


Figure 16-89: Vehicle 13, temperature trace, second durability cycle

Appendix L Temperature traces for uninterrupted repeat of durability cycles (validation phase 3)

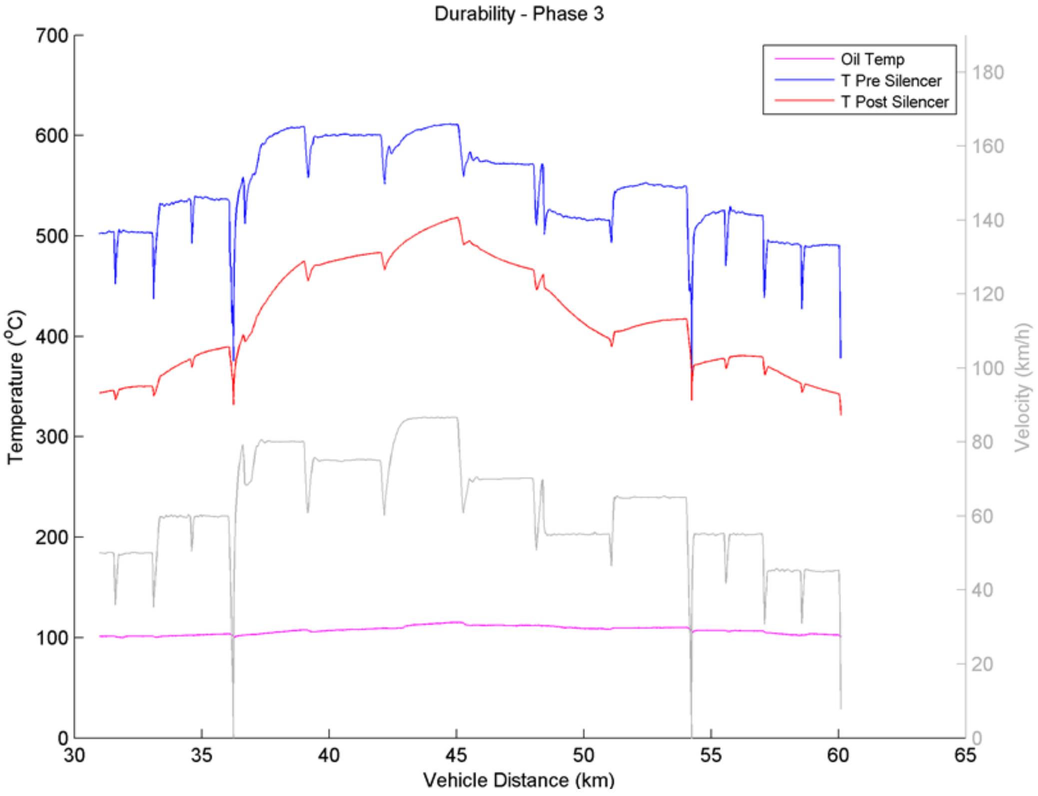


Figure 16.90: Vehicle 2, temperature trace, second durability cycle, phase 3

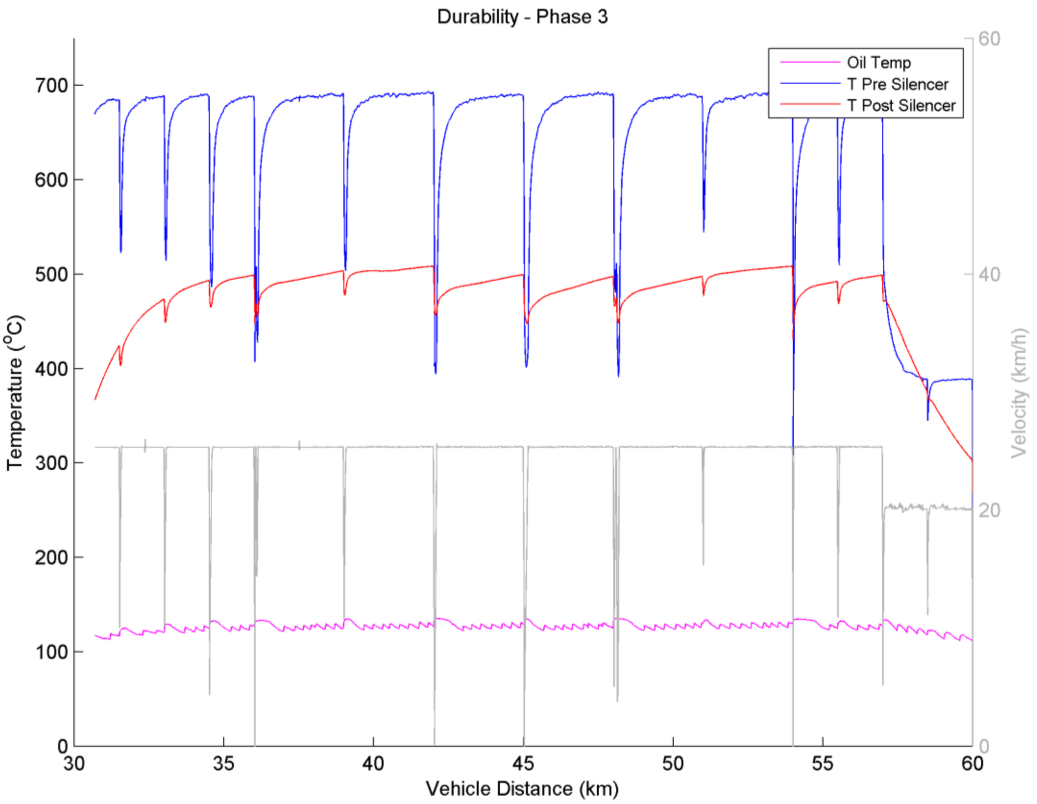


Figure 16.91: Vehicle 3, temperature trace, second durability cycle, phase 3

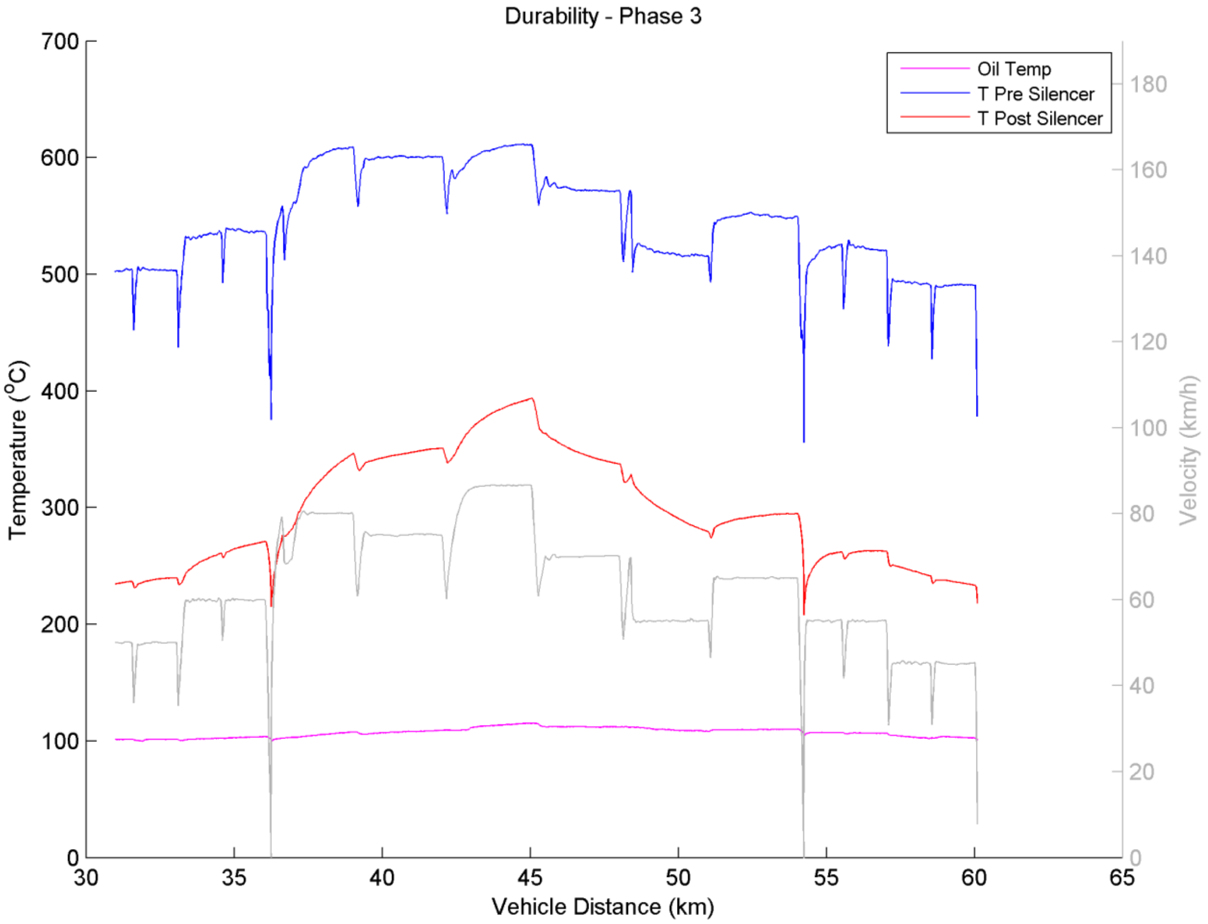


Figure 16.92: Vehicle 4, temperature trace, second durability cycle, phase 3

Appendix M Statistics (validation phase 2)

Averages of the following data for each cycle (of the vehicles classed as able to perform the given cycle)

Table 16-15: Average values

	Cycle 1	Cycle 2	Cycle 3	Cycle 4
Average speed (km/h)	18.9	34.1	71.3	93.1
Max speed (km/h)	23.0	42.0	92.2	129.9
Time per cycle (minutes)	90	54	26	20
Distance per cycle (km)	28.5	30.0	30.0	30.0

Appendix N Stakeholder testing (phase 2)

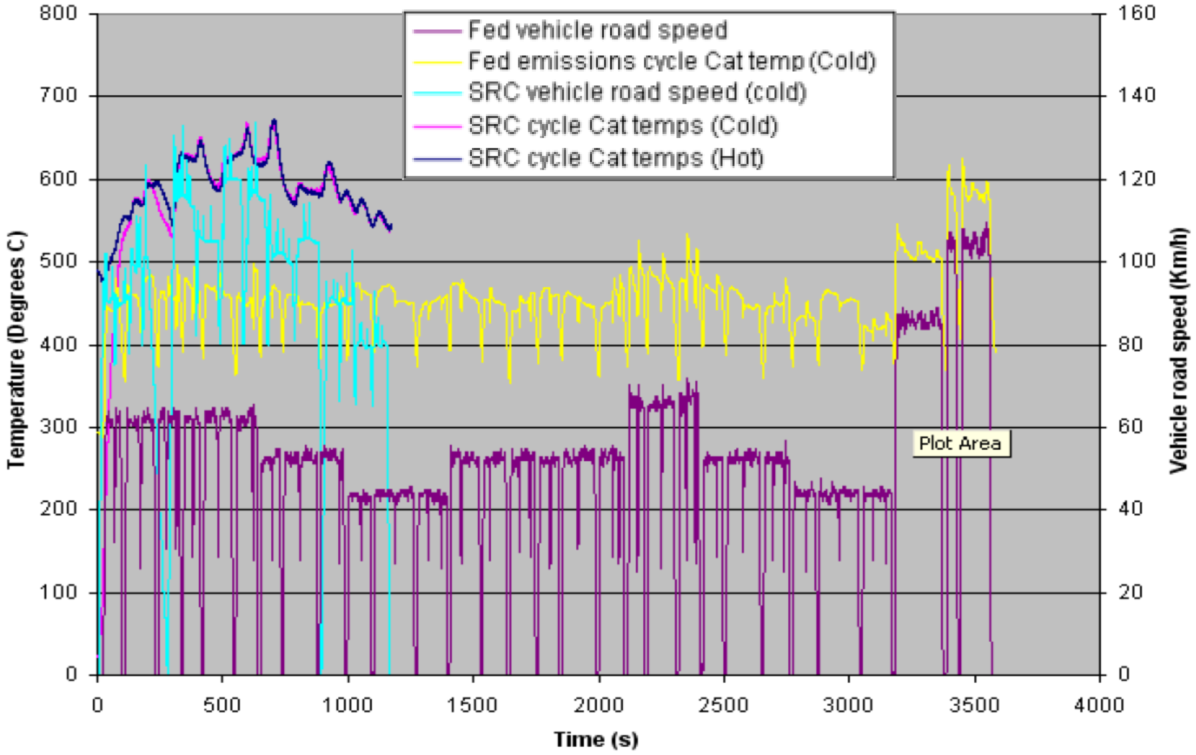


Figure 16-93: Comparison between SRC durability cycle and 11-lap EPA Federal durability cycle catalyst temperatures[23]

---

[23] ACEM, 2012. Page 46 and 48

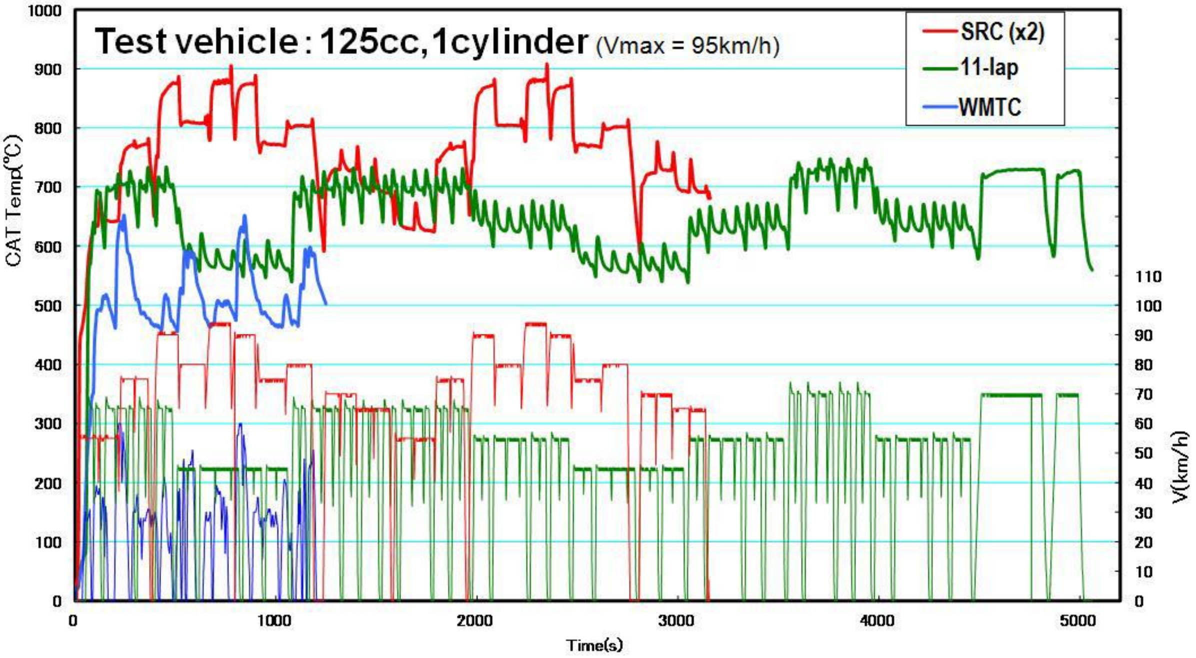


Figure 16-94: Comparison between SRC durability cycle, 11-lap EPA AMA durability cycle and WMTC emissions cycle (Class 1-3) catalyst temperatures[23]

Appendix O Assessment of SRC-LeCV use by JRC (validation phase 2)

O.1 Introduction

The European Commission adopted on 4th October 2010 a proposal for a regulation of the European Council and Parliament on approval and market surveillance of two- or three-wheel vehicles and quadricycles[24]. Those two- or three-wheel vehicles and quadricycles are grouped under the family name "L-category vehicles" with the "L" standing for "light".

The scope of the study includes an experimental programme in which the feasibility of the designed test Type V durability test cycle for L-category vehicles was assessed.

The overall objective of the study was to validate the designed test Type V durability test. This validation only contained the measurement of a number of defined engine and ambient parameters during limited mileage accumulation and it targeted to validate if the designed durability test cycles (Standard Road Cycle – SRC for L-category vehicles) are feasible in terms of driveability and how fast effectively such a durability test can possibly be executed by a manufacturer.

This document describes the transformation of the distance-based SRC to a time-based one in order to run the laboratory tests. The second part presents the track tests conducted by JRC on two motorcycles using the distance-based SRC.

O.2 Standard Road Cycles

A limited experimental programme was run to determine the distribution of engine speed, vehicle speed, lambda signal, engine-out temperature (exhaust manifold as close as possible to exhaust valve) and catalyst temperature (if applicable) over test time. The vehicles ran the vehicle speed profile (no emission measurements were executed) as designed in the proceeding durability project proposed by both TRL and JRC in 2011. The test vehicles were conditioned and soaked to ambient temperature before start of the test. The tests conducted in JRC Vehicle Emission Laboratory (VELA). Each test consisted of one SRC driven with cold engine and subsequently one additional SRC with a warm engine (maximum of approximately 60 km per vehicle). The vehicles were tested according to the distance-based vehicle speed profile described in Table 16-16.

---

[24] http://ec.europa.eu/enterprise/sectors/automotive/documents/proposals/index_en.htm

Table 16-16: Standard Road Cycle (SRC)

Step	Lap	Action	Sub-action	Distance	Time (s)	To Final Speed (km/h)			
						Group 1 ≤ 25 km/h	Group 2 ≤45 km/h	Group 3 ≲ 130 km/h	Group 4 >130 km/h
0	0	If not running start engine (if applicable)				0	0	0	0
1	1	Idle			10	0	0	0	0
2	1	Accelerate	Hard			20	30	55	90
3	1	Cruise		1/4 lap		20	30	55	90
4	1	Decelerate	Moderate			15	25	40	75
5	1	Accelerate	Moderate			20	30	55	90
6	1	Cruise		1/4 lap		20	30	55	90
7	1	Decelerate	Moderate			15	25	40	75
8	1	Accelerate	Moderate			25	35	75	100
9	1	Cruise		1/4 lap		25	35	75	100
10	1	Decelerate	Moderate			15	30	60	80
11	1	Accelerate	Moderate			25	35	75	100
12	1	Cruise		1/4 lap		25	35	75	100
13	1	Decelerate	Moderate			0	0	0	0
14	2	Idle			10	0	0	0	0
15	2	Accelerate	Hard			25	45	100	130
16	2	Decelerate	Coast-down			20	40	90	115
17	2	Cruise		1/2 lap		20	40	90	115
18	2	Decelerate	Moderate			10	30	65	80
19	2	Accelerate	Moderate			25	35	80	105
20	2	Cruise		1/2 lap		25	35	80	105

21	2	Decelerate	Moderate			10	30	65	80
22	3	Accelerate	Moderate			25	40	95	120
23	3	Cruise		1/2 lap		25	40	95	120
24	3	Decelerate	Moderate			10	30	65	80
25	3	Accelerate	Moderate			25	40	90	115
26	3	Cruise		1/2 lap		25	40	90	115
27	3	Decelerate	Moderate			10	30	65	80
28	4	Accelerate	Moderate			25	40	90	115
29	4	Decelerate	Coast-down			20	35	75	100
30	4	Cruise		1/2 lap		20	35	75	100
31	4	Decelerate	Moderate			10	30	65	80
32	4	Accelerate	Moderate			20	35	80	105
33	4	Cruise		1/2 lap		20	35	80	105
34	4	Decelerate	Moderate			0	0	0	0
35	5	Idle			45	0	0	0	0
36	5	Accelerate	Hard			15	30	70	90
37	5	Cruise		1/4 lap		15	30	70	90
38	5	Decelerate	Moderate			10	25	50	65
39	5	Accelerate	Moderate			15	30	70	90
40	5	Cruise		1/4 lap		15	30	70	90
41	5	Decelerate	Moderate			10	25	50	65
42	5	Accelerate	Moderate			15	30	65	80
43	5	Cruise		1/4 lap		15	30	65	80
44	5	Decelerate	Moderate			10	25	50	65
45	5	Accelerate	Moderate			15	30	65	80
46	5	Cruise		1/4 lap		15	30	65	80
47	5	Decelerate	Moderate			0	0	0	0

	n	Repeat from lap 1 to end of lap 5 until necessary				#	#	#	#

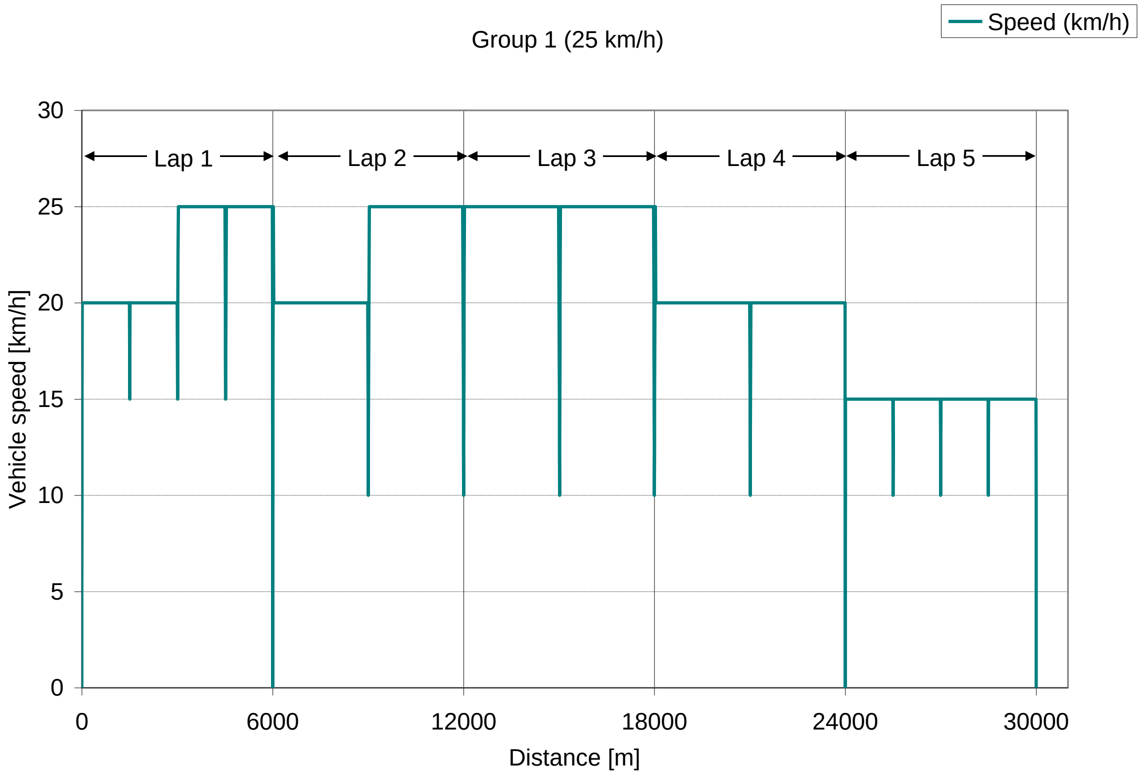
Each cycle consists of 5 laps. Each lap covers a driving distance of 6 km, in total the SRC covers 30 km.

Table 16-17 describes the definitions of the acceleration/deceleration events.

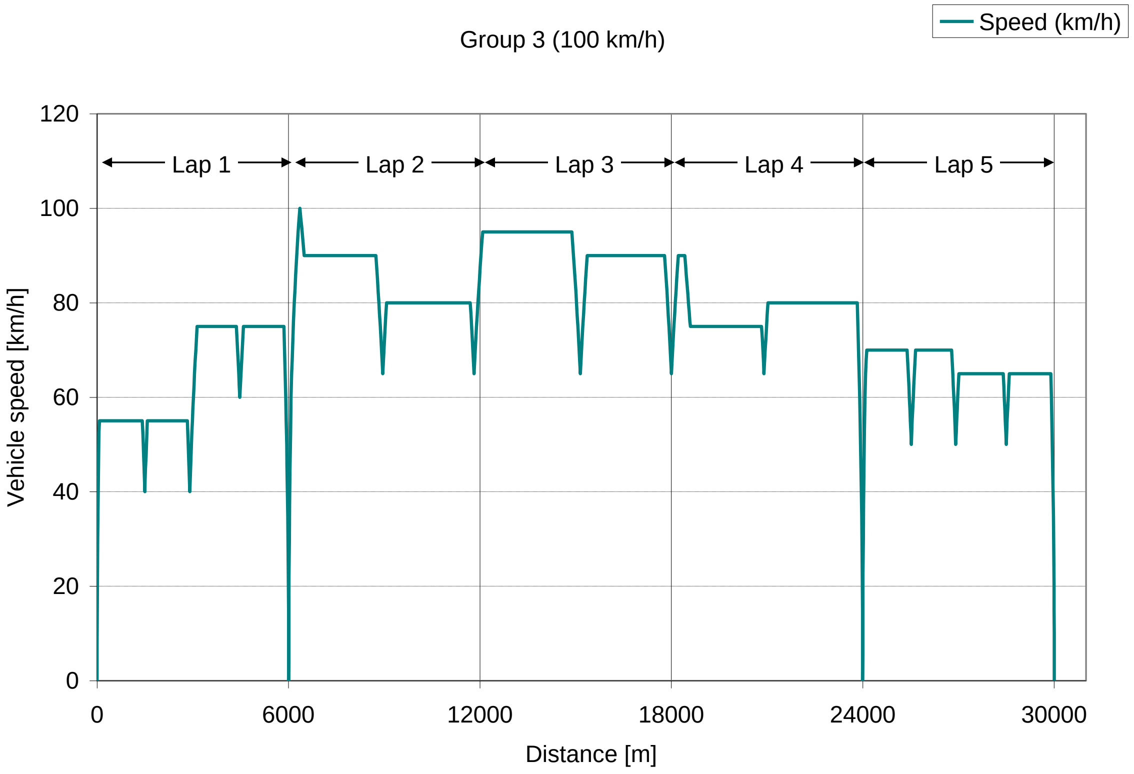
Table 16-17: Acceleration and deceleration sub-action definitions

Action	Sub-action	Definition
Acceleration	Moderate Hard	- (at the vehicles optimum engine speed) - (above the vehicles optimum engine speed i.e. full throttle)
Deceleration	Moderate Coast-down	- from ½ to fully off the throttle, brakes allowed as required - fully off the throttle, clutch engaged, no brakes

Figure 16-95 shows the speed profile plotted versus the covered distance for all the 4 SRC groups. In order to run the tests on VELA laboratory, the distance-based speed profile was transformed to a time-based one, since it was not technically feasible to run tests on the specific test cell using distance-based cycle. For each SRC group the duration of each sub-lap (½ lap, ¼ lap) was calculated according to the speed profile, until the desired distance was covered. For example, in order to cover the first ¼ lap (1.5 km) of the SRC group 1 with steady speed of 20 km/h, 0.075 h or 270 s are required. At this time period, the duration of the acceleration event must be added, since the vehicle speed is 0 km/h at the beginning of the cycle.


Speed (km/h)
Group 1 (25 km/h)
Lap 1
Lap 2
Lap 3
Lap 4
Lap 5
Vehicle speed [km/h]
30
25
20
15
10
5
0
0
6000
12000
18000
24000
30000
Distance [m]


Speed (km/h)
Group 2 (45 km/h)
Lap 1
Lap 2
Lap 3
Lap 4
Lap 5
Vehicle speed [km/h]
50
45
40
35
30
25
20
15
10
5
0
0
6000
12000
18000
24000
30000
Distance [m]



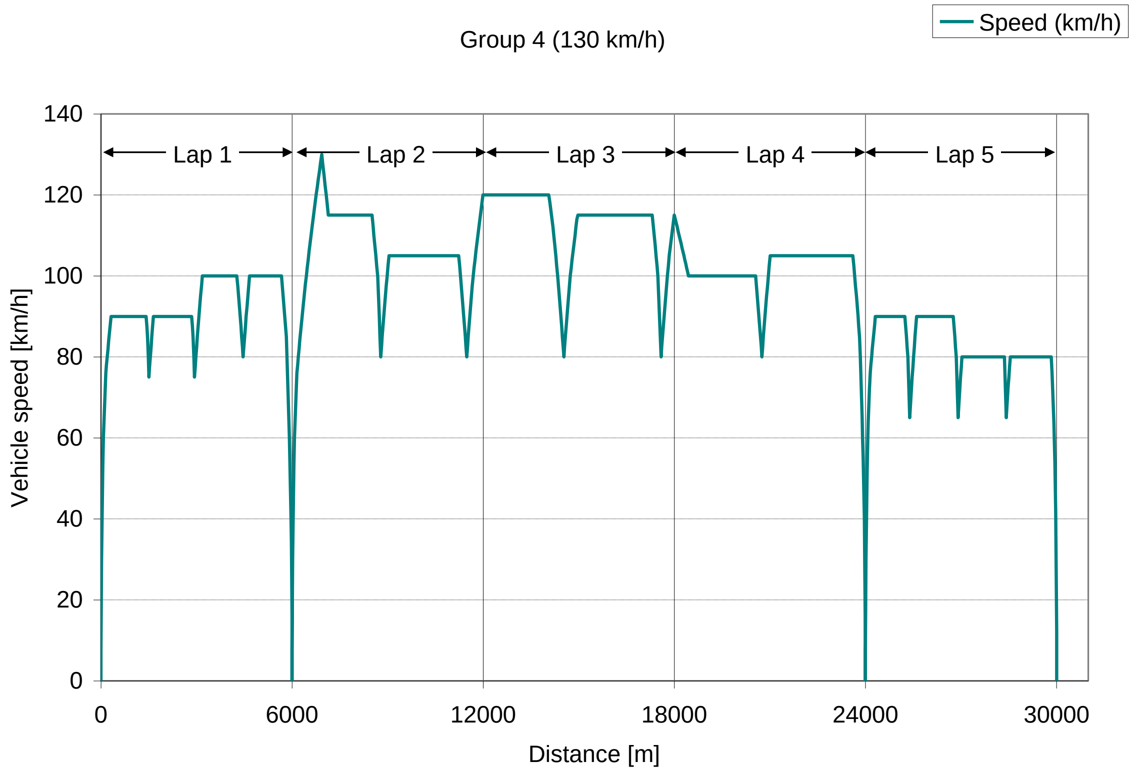


Figure 16-95: SRC speed profiles for the 4 groups (distance-based)

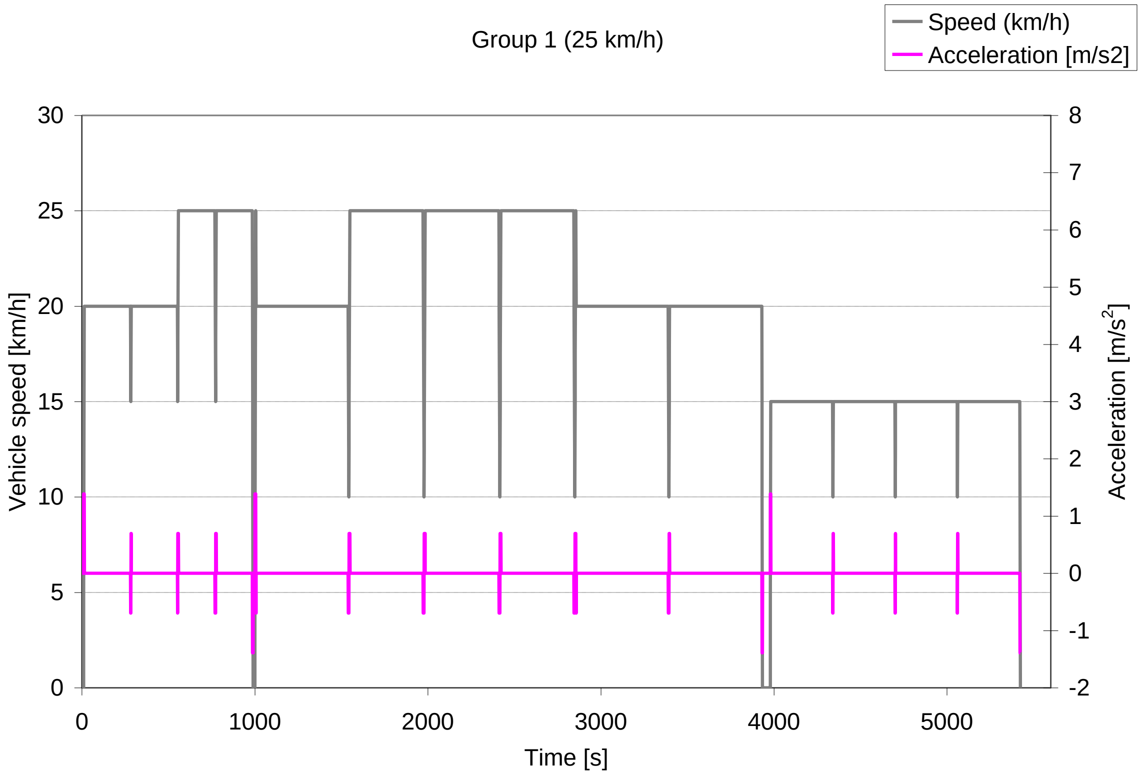
The next step was to estimate the acceleration and deceleration events of each SRC group. In general, the hard/moderate acceleration depends on the vehicle (engine performance, transmission ratios etc.) and on the initial speed. A hard acceleration from zero speed to e.g. 60 km/h would be higher than a hard acceleration from 90 km/h to

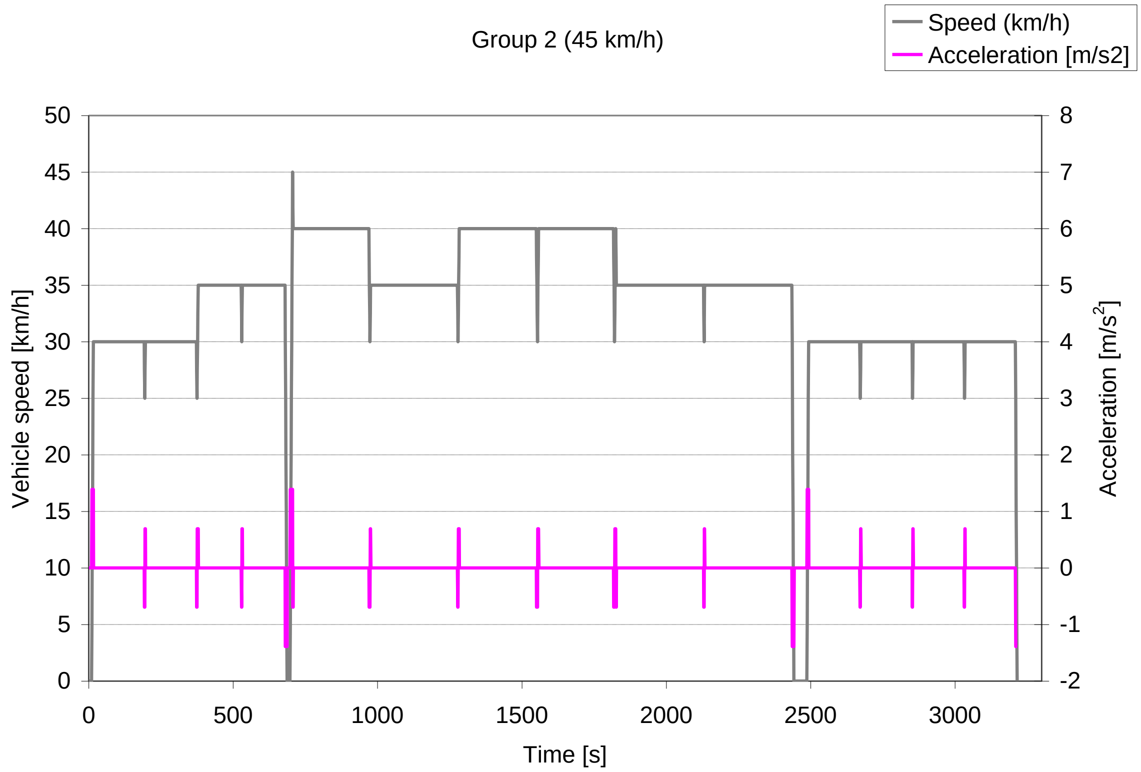
130 km/h, since the main force that acts on the vehicle (aerodynamic drag) increases parabolic with the speed. This is also valid during deceleration: A moderate deceleration from 90 km/h to 50 km/h would be lower than one from 40 km/h to 0 km/h. One single time-based speed profile for each SRC group was derived, irrespective of the tested vehicle. The acceleration/deceleration events that were used are presented in the following Table 16-18.

Table 16-18: Acceleration/deceleration events used for each SRC group

Action	**Sub-action**	**Group 1 ≤ 25 km/h**	**Group 2 ≤45 km/h**	**Group 3 ≤130 km/h**	**Group 4 >130 km/h**
Acceleration [m/s^2]	Moderate	0.694	0.694	0.694	0.694
	Hard	1.38	1.38	2.08 (0-60 km/h) 1.11 (60-80 km/h) 0.83 (80-100 km/h)	2.08 (0-60 km/h) 1.11 (60-80 km/h) 0.55 (80-130 km/h)
Deceleration [m/s^2]	Moderate	-0.694 -1.38 (to 0 km/h)	-0.694 -1.38 (to 0 km/h)	-0.694 -1.38 (to 0 km/h)	-0.694 (90-85 km/h) -1.38 (85-40 km/h) -1.66 (40-0 km/h)
	Coast-down	-0.694	-0.694	-0.55	-0.694 (130-115 km/h) -0.277 (115-100 km/h)

Figure 16-96 shows the time-based speed profiles of the four SRC groups. The acceleration is also included in the charts (secondary axis). It is here worthwhile to mention that short deceleration-acceleration events (e.g. from 20 km/h to 15 km/h and back to 20 km/h, encountered at SRC group 1) were not easily-followed by the vehicle while testing. In such low speeds it is not easy to keep a steady deceleration/acceleration rate, since the time required to reach the desired speed is very short. As the vehicle speed increases, the speed profile was easier achievable, from the driveability point of view.


Group 1 (25 km/h)
Speed (km/h)
Acceleration [m/s2]
Vehicle speed [km/h]
Acceleration [m/s^2]
Time [s]
0
5
10
15
20
25
30
-2
-1
0
1
2
3
4
5
6
7
8
0
1000
2000
3000
4000
5000


Group 2 (45 km/h)
Speed (km/h)
Acceleration [m/s2]
Vehicle speed [km/h]
Acceleration [m/s^2]
Time [s]
0
5
10
15
20
25
30
35
40
45
50
-2
-1
0
1
2
3
4
5
6
7
8
0
500
1000
1500
2000
2500
3000

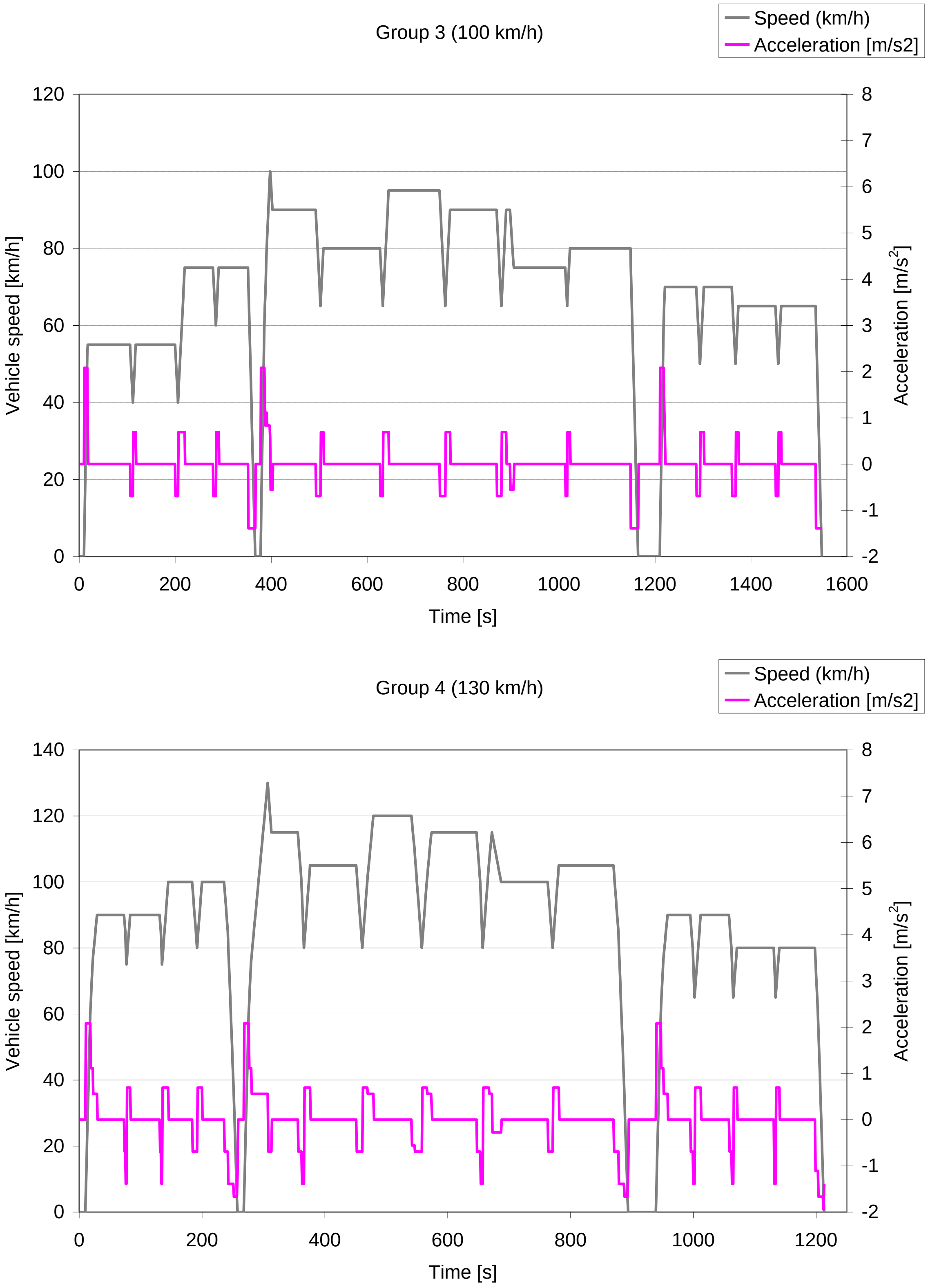


Figure 16-96: SRC speed profiles for the 4 groups (time-based)

During the experimental campaign at VELA and for a limited number of the tests (4 out of 13), the vehicles did not manage to follow the theoretical time-based speed profile, as the maximum speed of the vehicle was lower than the maximum speed of the SRC. This resulted in decreased distance covered during each SRC. A distance-based speed profile would have been required in the laboratory tests, in order to avoid such phenomena.

O.3 Track SRC tests

In this section the methodology of the SRC tests conducted in the track (for a limited number of vehicles) is presented and analysed. In this case the vehicles' engines were already warmed up, consequently, only one SRC was run for each vehicle (approximately 30 km per vehicle).

Table 16-19 presents the main technical features of the tested vehicles in the track. Two vehicles have been tested: A two-wheel moped (vehicle 3) tested over the SRC group 2 (max. speed: 45 km/h), and a two-wheel medium performance motorcycle (vehicle 5) over the SRC group 3 (max. speed: 100 km/h).

Table 16-19: Vehicles' technical specifications

Vehicle	Engine technology	Category	Engine capacity [cm^3]	Rated Power [kW]	Emission standard
3	4-stroke	L1Be (two-wheel moped)	49.9	2.6	Euro 2
5	4-stroke	L3e-A2 (two-wheel medium performance motorcycle)	278	16.4	Euro 3

The vehicles before the test were equipped with instrumentation to monitor and record some operational characteristics:

- ECU recorder: "Rapid EVO Bike" for
    - Engine speed [rpm]
    - Lambda signal
    - Injection time [ms] (only for vehicle 5)
- Temperature recorder: Type K thermocouples were installed on the vehicles for
    - T_engine_out (as close as possible to the engine)
    - T_pre_cat (upstream the catalyst)
    - T_post_cat (downstream the catalyst)
    - T_oil (thermocouple installed in the oil sump)
- GPS recorder: "Navi lock" model: NO NL 302V for
    - Vehicle speed [km/h]
    - Latitude [deg]
    - Longitude [deg]
    - Altitude [m]

Figure 16-97 shows some photos of the tested vehicles, equipped with the instrumentation to monitor and record the above mentioned operational characteristics. The photos have been taken in the track, which was used to run the tests. The length of the track was chosen 1.5 km, equal to ¼ of the SRC lap.

Figure 16-97: Installation of the monitoring and recording instruments on the tested vehicles

Figure 16-98 shows the track, where the tests have been conducted. The red curve represents the exact route that was available for the JRC tests, while the blue arrows give the direction. The driver was based on the speed meter of the vehicle in order to follow the speed profile of the test. In order to follow the speed trace as close as possible to the theoretical one, the driver was based on a print copy of the distance-based cycle during driving. As mentioned on the previous section, each cycle was divided in 5 laps (6 km) and each lap was divided either to four ¼ sub-laps (1.5 km) or two ½ sub-laps (3 km) (see also Figure 16-95). The length of the track was chosen 1.5 km, in order to be consistent to the smallest sub-lap of each SRC (¼ lap).

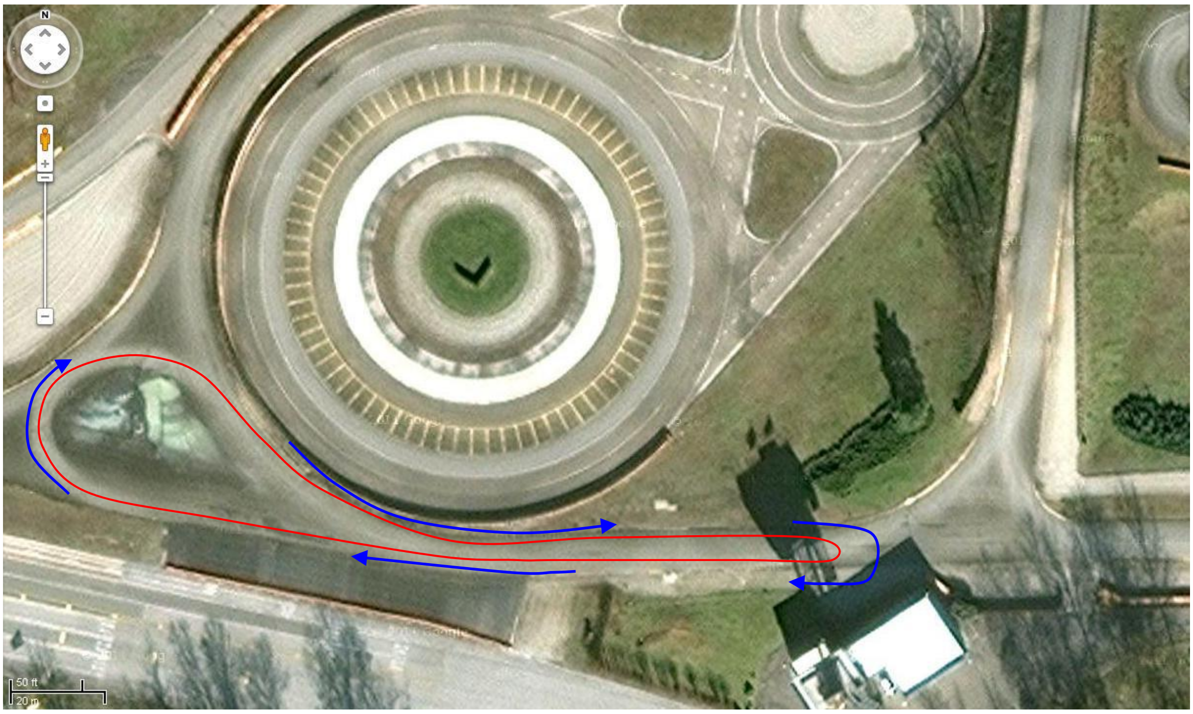


Figure 16-98: The track route used for the tests

Figure 16-99 and Figure 16-100 present comparisons between the theoretical and the real vehicle speed for the two SRC tests, as recorded by the GPS. The first chart refers to vehicle 3, which was tested over the SRC Group 2. The real speed of the vehicle is lower than the theoretical one. This could be attributed to the speed meter of the vehicle used by the driver to control the speed. It is evident that the speed meter overestimates the real speed of the vehicle. In order to avoid such discrepancy, a calibration of the vehicle's speed meter would have been required, either on the roller bench, or on the track (using e.g. instrumentation for measuring speed).

A second problem that was encountered during the tests was the fact that the driver at the end of each sub-lap had to decelerate the vehicle up to around 5-8 km/h, in order to turn the vehicle and start a new sub-lap. This was done due to the shape of the available JRC track. An oval or cycle track, having more open turns, would allow to follow stricter the theoretical speed profile. Using the available track, it was not possible for the driver to follow a ½ sub-lap (3 km), as it was designed for laps 2-4.

The impact of the track is more evident in the test of vehicle 5, which was driven over the SRC group 3. The maximum speed of the theoretical cycle was 100 km/h, while for more than half of the cycle duration a speed of above 80 km/h was required. As it is evident by the real speed trace, recorded by GPS, it was not possible to drive the vehicle with speeds above 80 km/h for an adequate time period.

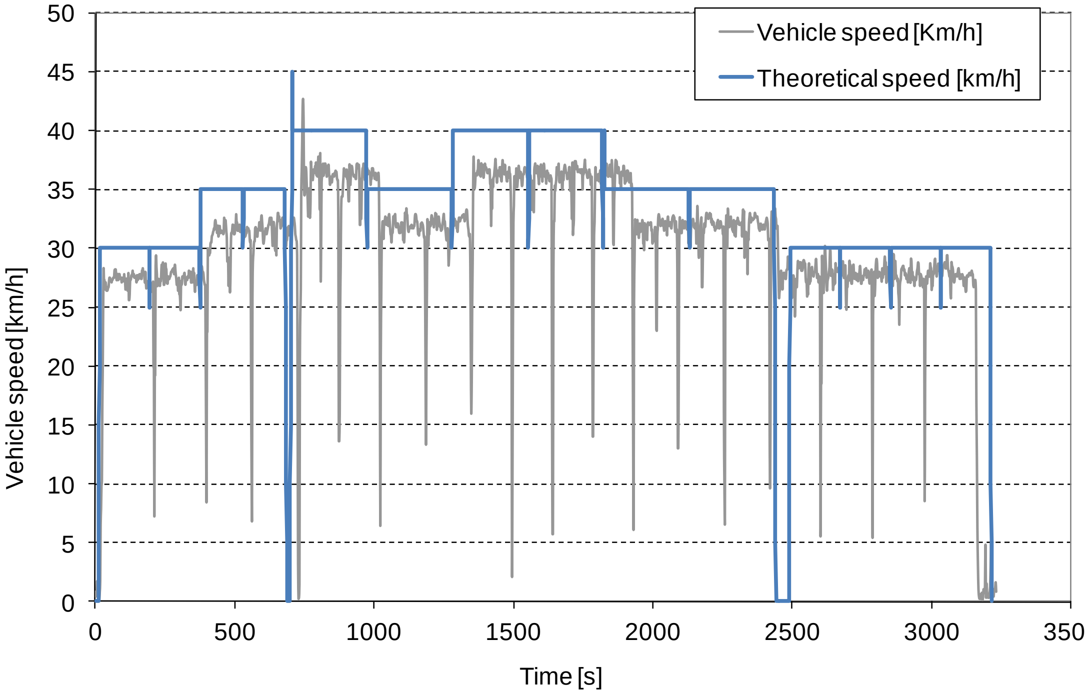


Figure 16-99: Vehicle 3, L1Be, cycle 2, theoretical and real speed profile of the track tests

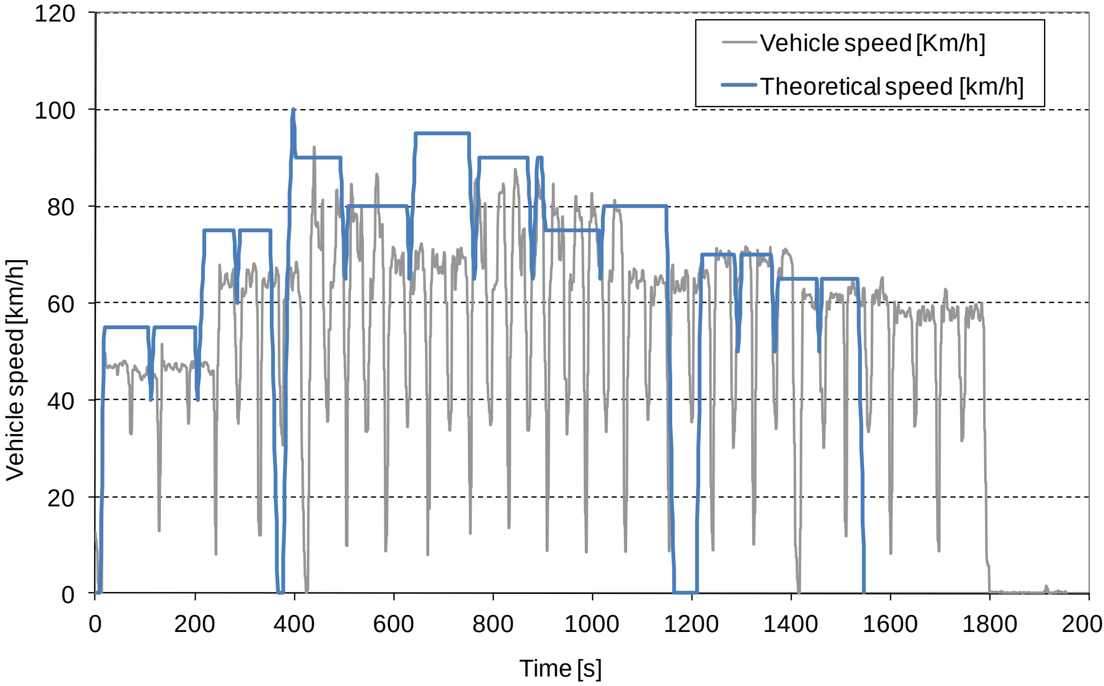


Figure 16-100: Vehicle 5, L3e-A2, cycle 3, theoretical and real speed profile of the track tests

Appendix P Deceleration fuel cut-off (DFCO) points in vehicle T11 (phase 3)

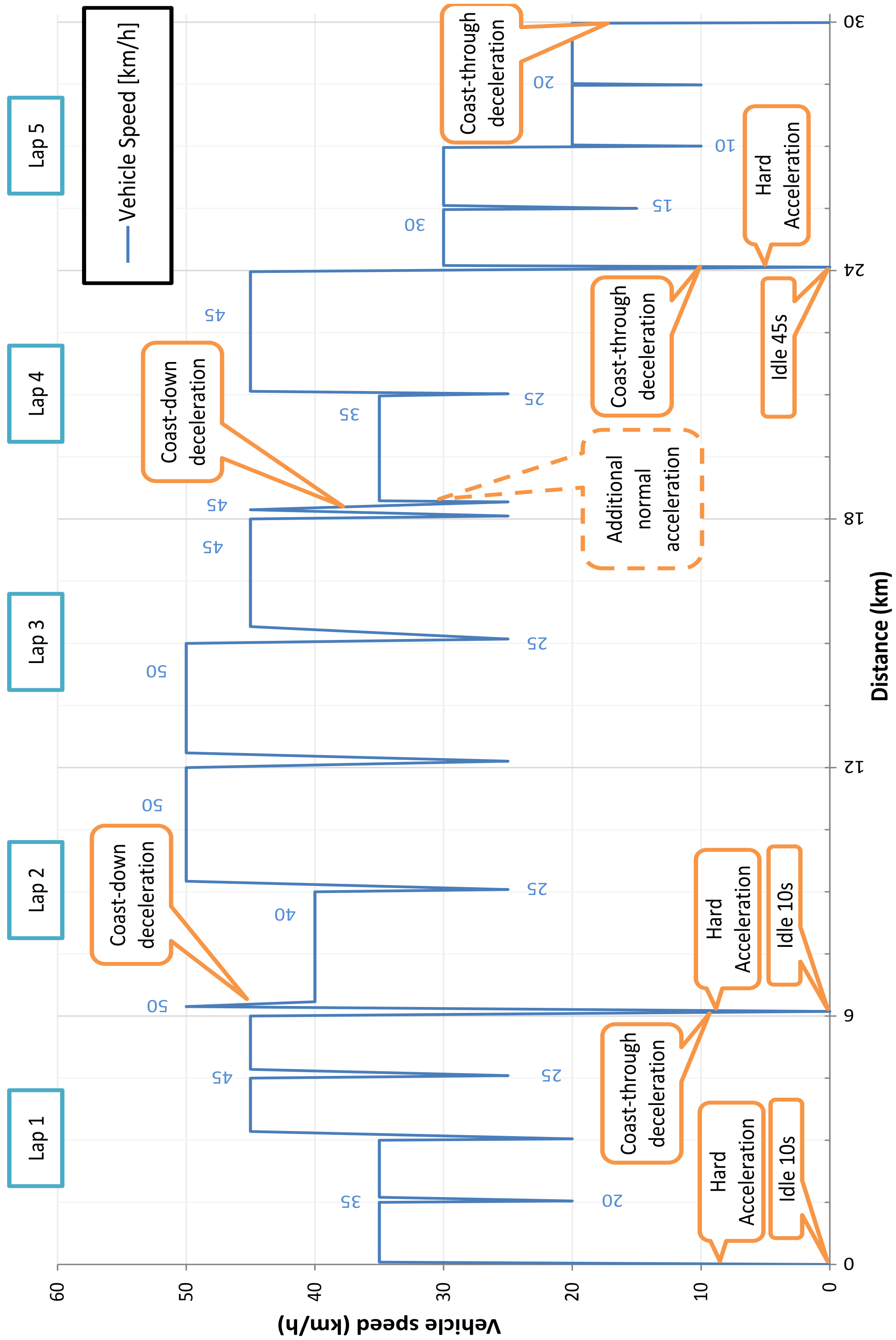
Table 16-20: Vehicle T11: condition of vehicle when DFCO is in effect

Time (s)	Injector time	Rate of change (ms^{-2})	Vehicle speed (km/h)	Engine speed (r/min)	Throttle Position
986	0	-0.88	69.1	3,161	32
987	0	-1.54	63.6	3,217	30
990	0	-1.85	49.0	2,992	29
991	0	-1.60	43.2	2,855	28
1091	0	-0.94	59.2	3,115	27
1092	0	-1.47	53.9	3,036	26
1180	0	-1.65	63.6	3,213	21
1181	0	-0.83	60.6	3,141	28
1182	0	-1.69	54.5	3,061	27
1183	0	-0.81	51.6	2,910	26
1184	0	-1.18	47.3	2,910	20
1185	0	-1.22	42.9	2,910	27
1186	0	-1.22	38.5	2,777	28
1187	0	-1.06	34.7	2,662	20
1320	0	-1.08	62.8	3,218	28
1373	0	-1.29	69.4	3,303	31
1374	0	-1.21	65.0	3,229	26
1375	0	-1.10	61.1	3,055	19
1764	0	-0.86	102.7	4,432	25
1771	0	-1.71	77.0	3,541	20
1772	0	-0.79	74.2	3,421	26

Appendix Q Final SRC-LeCV Durability Cycles

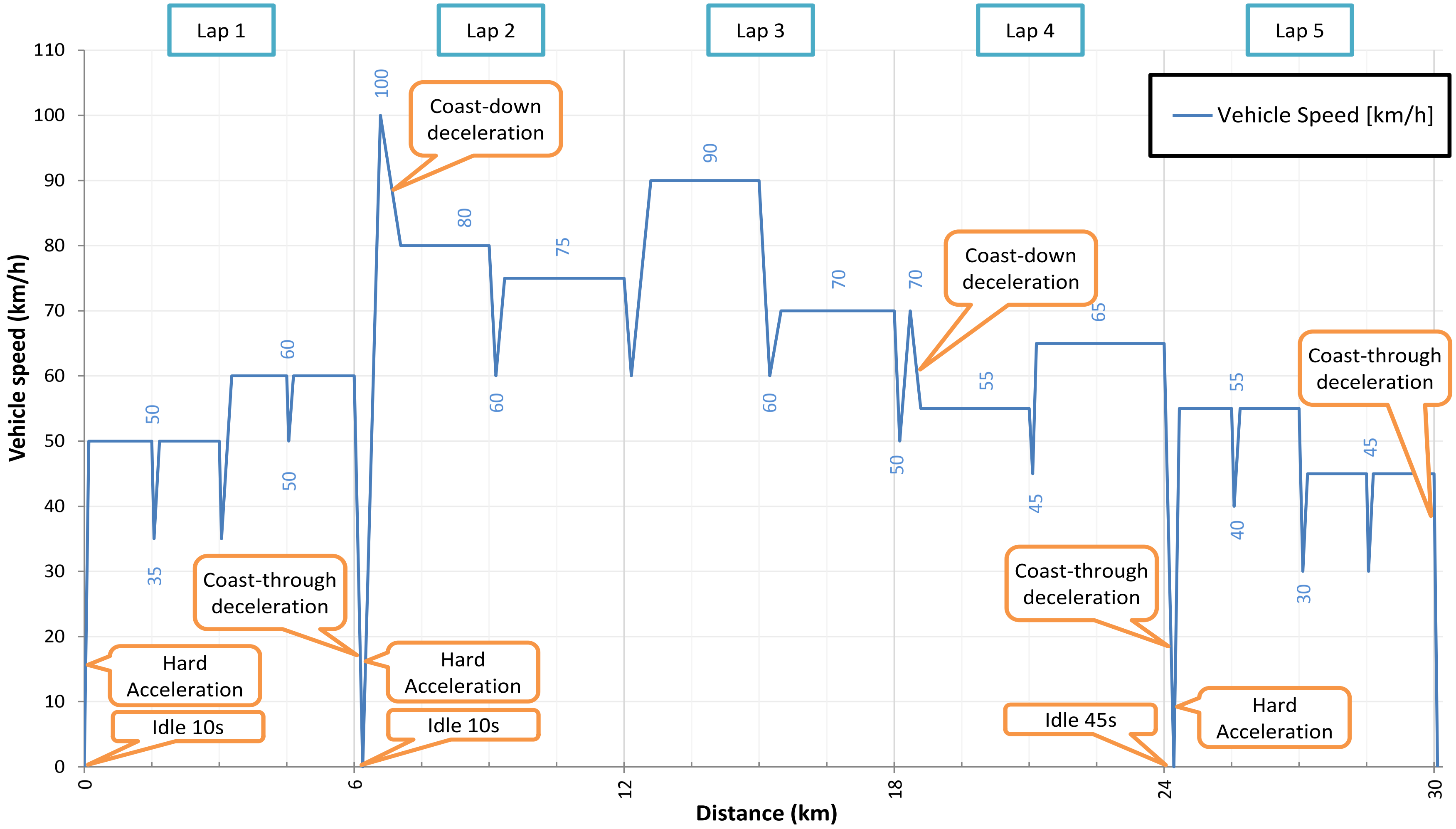
Cycle 1

Unless stated otherwise normal accelerations and decelerations are used



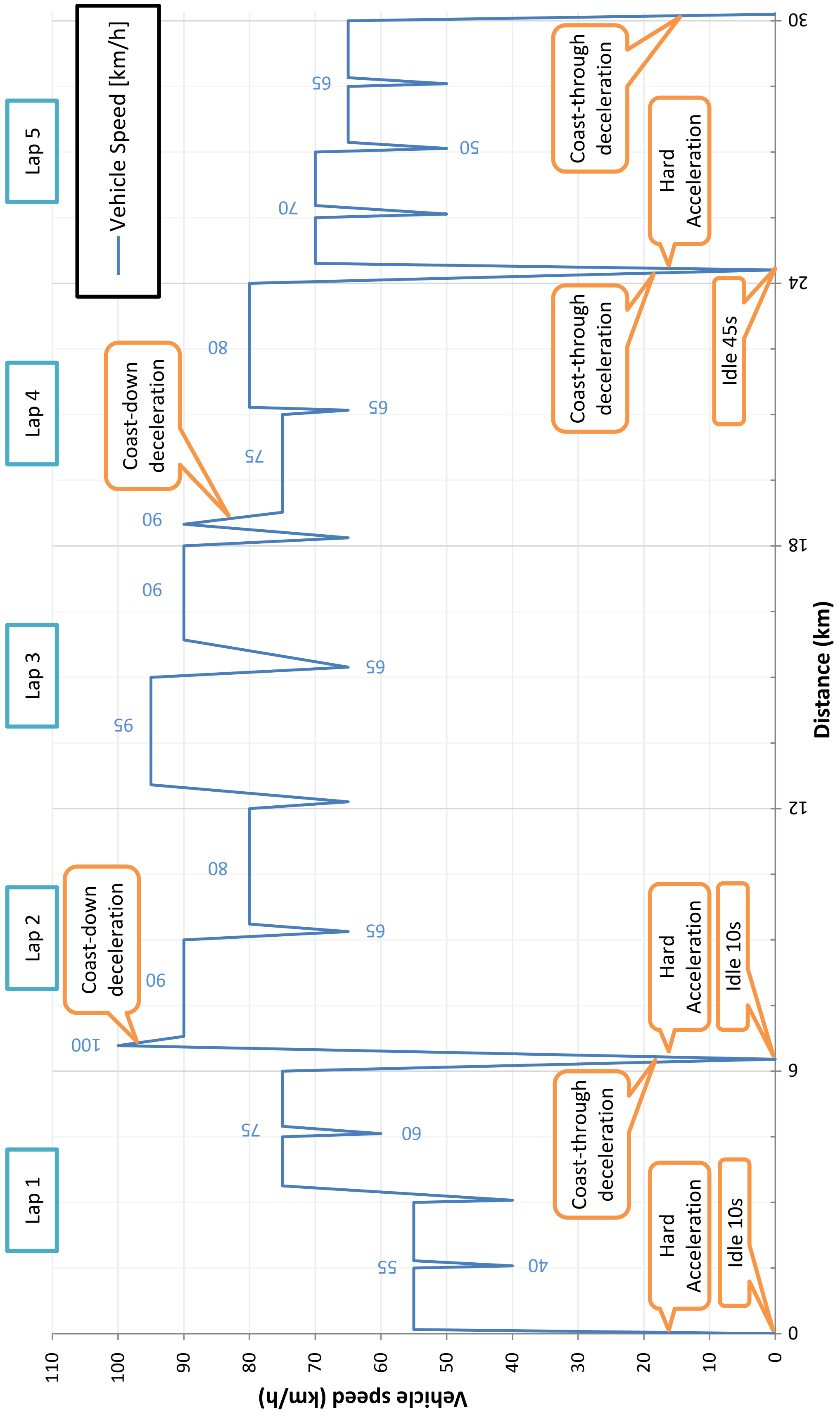
Cycle 2

Unless stated otherwise normal accelerations and decelerations are used



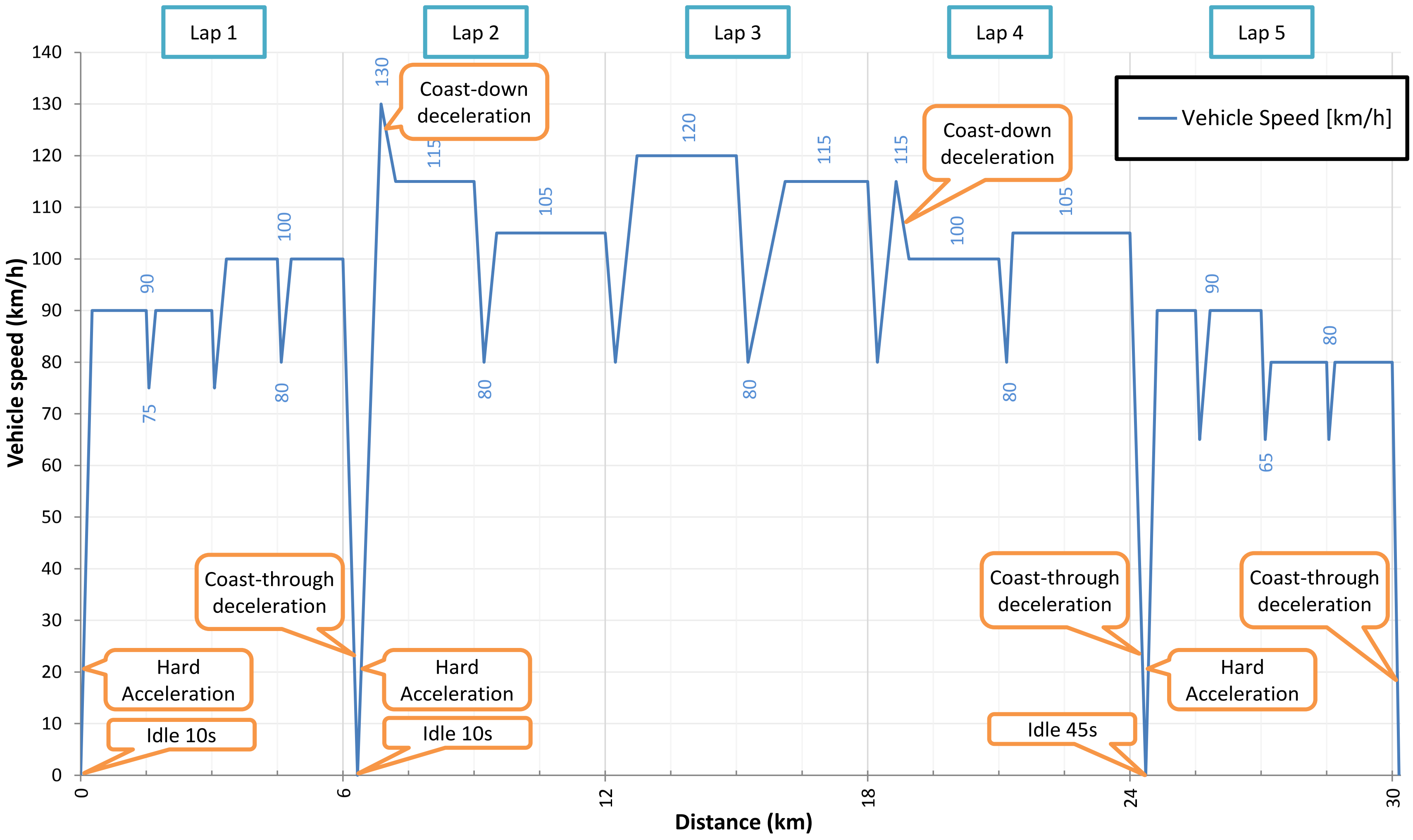
Cycle 3

Unless stated otherwise normal accelerations and decelerations are used



Cycle 4

Unless stated otherwise normal accelerations and decelerations are used



Annex 1

Legislative text

Note: The draft legislative text (Annex V, Test type V requirements: durability of pollution control devices) to become part of the Regulation on the environmental and propulsion performance requirements for the approval and market surveillance of two- or three-wheel vehicles and quadricycles (REPPR), is not included within this version of the report.