Traffic management and air quality: realistic driving cycles for traffic management schemes

Prepared for Charging and Local Transport Division, Department for Transport

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Executive Summary

The Environment Act 1995 requires local authorities in the UK to review and assess air quality in their areas, with the primary objective being to identify locations where the standards set out in legislation are likely to be breached. This review and assessment may result in the declaration of an Air Quality Management Area (AQMA) and the need for a Local Air Quality Action Plan. In most urban areas, road traffic contributes significantly to emissions of the pollutants included in legislation, and is likely to be the most important source of air pollution within many AQMAs. Where hotspots of pollution result mainly from this source, Government guidance suggests traffic management as a method of controlling the emissions. In order to develop Action Plans, local authorities will therefore need to be able to predict the effects of traffic management schemes on vehicle emissions and air quality.

Traffic management can result in a spatial and temporal redistribution of traffic in terms of flow, composition and vehicle operation. The overall impact of any traffic management schemes on local air quality will be related to the combined effects of such changes, and the air quality modelling exercises conducted by local authorities will need to take this into account. For emission measurement and modelling purposes, vehicle operation may be defined in terms of a number of parameters, although it usually relates to engine speed, engine load, gear selection and, most commonly, vehicle speed. It is this vehicle operation aspect of traffic management which is the focus of this report.

For light-duty vehicles (LDVs), real-world operational profiles in relation to traffic management have been recorded in various studies, often for use as the input to emission models. In a small number of studies, LDV operational profiles have been referenced to specific traffic management measures, and subsequently used to develop representative driving cycles for measuring emissions in the laboratory. However, for heavy-duty vehicles (HDVs) very few driving cycles have been developed to specifically represent traffic management schemes, and the emissions performance of such vehicles in relation to traffic management is therefore not well documented.

TRL Limited was commissioned by the Charging and Local Transport (CLT) Division of the Department for Transport (DfT) to undertake a project (UG214) to address the gaps in the understanding of operational profiles and emissions for HDVs. The specific objectives of the project were:

i To identify a range of traffic management schemes for which driving cycles could be developed.

ii To measure operational profiles for a range of vehicles in relation to the schemes identified.

iii To produce generic driving cycles for use in emissions testing.

Driving cycles were developed for seven generic categories of traffic management measure:

- Bus lanes.
- Cycle lanes.
- Traffic calming: road humps.
- Traffic calming: other.
- Mini roundabouts.
- One-way systems.
- Urban traffic control (UTC).

In addition to the above, three control cycles were developed to represent stretches of road with no traffic management.

Examples of each type of traffic management were identified in more than one town or city in the UK to minimise, as far as possible, any site-specific influences on driving patterns. Six sites were chosen in total, each having a substantial number of traffic management measures. These were:

- West London (Kingston/Richmond area).
- Southampton.
- Havant.
- Oxford.
- Gloucester.
- Reading.

At each site a car, a light goods vehicle, a heavy goods vehicle and bus were equipped with a PC-based data logger and a Global Positioning System (GPS), both of which collected continuous vehicle speed data as the vehicles were driven around a set route. In total, forty driving cycles were developed from these measurements. Ten were developed for each vehicle type and within each vehicle type one cycle was developed for each of the seven traffic management measure categories and the three control categories.

The HGV and bus driving cycles produced within the work have been used in a separate TRL project (UG216 - Exhaust Emissions from Heavy Duty Vehicles), also commissioned by CLT Division of DfT.

1 Introduction

1.1 Background

Part IV of the Environment Act 1995 requires local authorities in the UK to review and assess air quality in their areas, with the primary objective being to identify locations where the standards set out in legislation are likely to be breached. This review and assessment may result in the declaration of an Air Quality Management Area (AQMA) and the need for a Local Air Quality Action Plan. In most urban areas, road traffic contributes significantly to emissions of the pollutants included in legislation, and is likely to be the most important source of air pollution within many AQMAs. Where hotspots of pollution result mainly from this source, Government guidance suggests traffic management as a method of controlling the emissions (Defra, 2003). In order to develop Action Plans, local authorities will therefore need to be able to predict the effects of traffic management schemes on vehicle emissions and air quality.

Traffic management can result in a spatial and temporal redistribution of traffic in terms of flow, composition and vehicle operation. The overall impact of any traffic management schemes on local air quality will be related to the combined effects of such changes, and the air quality modelling exercises conducted by local authorities will need to take this into account. For emission measurement and modelling purposes, vehicle operation may be defined in terms of a number of parameters, although it usually relates to engine speed, engine load, gear selection and, most commonly, vehicle speed. It is the vehicle operation aspect of traffic management which is the focus of this report.

1.2 Characterising vehicle emissions: operational profiles and driving cycles

All new light-duty vehicle models and heavy-duty engine models sold in the UK must be type approved with respect to exhaust emissions. Type approval tests are conducted in accordance with European Union Directives. The pollutants included in the legislation are carbon monoxide (CO), hydrocarbons (HC), oxides of nitrogen (NO_x) and, in the case of diesel vehicles, total particulate matter (PM). Since their first introduction, changes have been made to the Directives to include more pollutants, to reduce the emission limits, and to improve the test procedures. Light-duty vehicles (LDVs) are tested using a standard European test cycle on a chassis dynamometer. The driving cycle used in the type approval test is, however, not particularly representative of actual urban driving conditions. For this reason, various research projects have been undertaken to establish ‘real-world’ driving cycles.

For LDVs, operational profiles in relation to traffic management have been recorded in various studies, often for use as the input to emission models. In Copenhagen, for example, Krawack (1993) recorded operational profiles for cars during peak and off-peak traffic periods, and investigated the effects of green waves at three signalised junctions. A study carried out in Graz, Austria (Sturm *et al.*, 1994) considered the impact of the reduction of speed limits in the city from 50 km/h to 30 km/h on vehicle emissions, with real-world driving behaviour having been recorded for approximately 170 journeys. In Havant, Hampshire, Cloke *et al.* (1999) examined the environmental effects of the installation of various accident reduction schemes in the local area. Speed profiles were measured along selected roads before and after the implementation of traffic calming schemes. The pattern of accelerations and decelerations changed considerably after the installation of the schemes.

In other studies, LDV operational profiles have been referenced to specific traffic management measures, and subsequently used to develop representative driving cycles for measuring emissions in the laboratory (*e.g.* Boulter *et al*., 1999, Boulter *et al*., 2001). However, for heavy-duty vehicles (HDVs) very few driving cycles have been developed to specifically represent traffic management schemes, and the emissions performance of such vehicles in relation to traffic management is therefore not well documented.

1.3 Objectives

TRL Limited was commissioned by the Charging and Local Transport (CLT) Division of the Department for Transport (DfT) to undertake a project (UG214) to address the gaps in the understanding of operational profiles and emissions with respect to traffic management. The specific objectives of the project were:

i To identify a range of traffic management schemes for which driving cycles could be developed.

ii To measure operational profiles for four vehicles: two LDVs - a car and a light goods vehicle (LGV), and two HDVs - a heavy goods vehicle (HGV) and a bus. The profiles would be measured in relation to the schemes identified.

iii To produce generic driving cycles for use in emissions testing.

The HGV and bus driving cycles produced within the work have been used in a separate TRL project (UG216 - Exhaust Emissions from Heavy Duty Vehicles), also commissioned by CLT Division of DfT.

2 Data collection method

This chapter of the report details the types of traffic management measure that were included in the study, and describes how the vehicle operation data were collected.

2.1 Overview

Driving cycles were developed for seven generic categories of traffic management measure:

- Bus lanes.
- Cycle lanes.
- Traffic calming: road humps.
- Traffic calming: other.
- Mini roundabouts.
- One-way systems.
- Urban traffic control (UTC).

The selection of measures for inclusion was primarily based on their general popularity (in terms of how many had already been implemented by local authorities in the UK). The 'traffic calming: road humps' category included any measure that resulted in a vertical deflection of vehicle path, including road humps, speed cushions and raised junctions. The 'traffic calming: other' category included horizontal deflection measures such as traffic islands, sheltered parking, build outs, pinch points (plus gateways) and road markings. The 'UTC' category consisted of signalised junctions, whereby systems such as SCOOT are used to control the traffic signals to optimise traffic flow.

In addition to the above, three control cycles were developed to represent stretches of road with no traffic management. The control cycles were classified as:

- Urban congested.
- Urban non-congested.
- Suburban.

The suburban cycle was developed from data collected on residential roads, and was designed as a control for the two cycles for traffic calming. In contrast, the driving cycles for the five remaining categories of traffic management were developed from vehicle operation profiles recorded on major town and city centre routes.

Examples of each type of traffic management were identified in more than one town or city in the UK to minimise, as far as possible, any site-specific influences on driving patterns. Six sites were chosen in total, each having a substantial number of traffic management measures. These were:

- West London (Kingston/Richmond area).
- Southampton.
- Havant.
- Oxford.
- Gloucester.
- Reading.

At each site a route was selected which incorporated as many traffic management measures as possible. The route was divided into a number of sections, with each section being further divided into links by the identification of node points (easily identifiable points along the route, usually junctions, selected to allow the route to be broken up into a number of links). Each node point was numbered, enabling each link to be uniquely identified during the data analysis stage. Instrumented vehicles were used to collect the operational profiles along each route, and classified traffic counts were also obtained for each site to provide information on the volumes of traffic using the routes that were driven. This traffic data was used to give a local impression of traffic conditions associated with the driving patterns during peak and off-peak periods. The sites and routes are described in Chapter 3.

2.2 Test vehicles

At each site four vehicles were instrumented to record operational profiles. These were a car, a light goods vehicle, a heavy goods vehicle and a bus. The car logging was undertaken using two different 2000 model Ford Mondeos, and the LGV logging was undertaken using a 2000 model Ford Transit 100 (semi-high roof) 75PS 2000cc turbo-diesel. For the recording of HGV operational profiles, a 17-tonne Ford Cargo 150 rigid flat-bed vehicle was used at each location. The vehicle was semi-laden to a weight of approximately 12 tonnes. For the recording of bus operation profiles at each site a bus, typical of the fleet used in the local area, was hired from a local operator. Table 1 gives details of all the buses used.

The drivers were selected according to the vehicle type. For the car and LGV logging, TRL employees were used. The HGV was driven by a professional driver hired locally at each site, and the bus drivers were hired from the same company that supplied the bus at each location. During the logging sessions a TRL employee was present to navigate and operate the equipment.

2.3 Vehicle instrumentation

Each test vehicle was equipped with two systems to collect speed data: a PC-based data logger and a Global Positioning System (GPS). The buses were also equipped with a video camera to record the logging routes. It was not possible to secure the video camera in the HGV due to excessive vibration, or in the car or LGV due to the absence of any secure fastening points. However, the considerable quantity of video footage recorded during the bus phase of the work provided an adequate record of the routes.

2.3.1 Global positioning system

The GPS System was used to record the speed and the location of each test vehicle. The equipment comprised a hand-held GPS receiver (GARMIN GPS12XL), an aerial and a PC to log the output from the receiver. Where possible, the aerial was attached to the highest point of the vehicle, using either a magnet or a suction cup, in order to reduce the interruption of the signal from the satellites by buildings and other vehicles.

Table 1 Details of the buses hired to carry out logging work

Site	*Single/double decker*	*Model*	*Engine*	*Seating capacity*	*Weight (unladen)*
London	Single	Dennis	Cummins	36	6694 kg
Havant	Double	Volvo Olympian	Volvo 9.6l	68	10 800 kg
Southampton	Single	Dennis Dart	Cummins	35	Not Available
Oxford	Single	Volvo B10B LE	Volvo	39	10 300 kg
Gloucester	Single	Dennis Dart	Cummins 6BT	28	6500 kg
Reading	Single	Excel	Cummins 5.9l	39	8640 kg

A GPS system determines its position based on the time taken for signals to reach the receiver from orbiting satellites (the positions of which are known at a fixed time). There is no requirement for an external calibration of the receiver. According to the manufacturer's specification, the horizontal position accuracy of the receiver used in the project was ±15m. As well as giving the position, the receiver also estimates the position error, and in general the error has been observed to be less than 5m. Indeed, subsequent analysis of the data showed that when routes repeatedly followed the same section of road, the plotted position data follow the same path. The accuracy of the speed (based on the change in position) was 0.2 km/h.

A communications program was developed to allow the data to be collected from the receiver and stored on the PC. The GPS receiver produced data in ASCII, structured as sentences in a standard format as specified by the USA's National Marine Electronics Association (NMEA). The date and time output from the GPS receiver were not precise enough for use in the experiment, and so the data were time stamped as the PC received each sentence. As well as the date and time, the GPS receiver provided data on vehicle position and speed.

However, the GPS receiver was not found to work reliably under all conditions. Firstly, the signal received by the GPS unit was sensitive to obstructions, such as tall buildings and bridges. In addition, a computer program used to read and store the data output from the GPS receiver, which had been developed specifically for this project, was undergoing adjustments during the early stages of the project. In order to ensure continuous speed data were captured it was therefore decided that the data logger method would be used simultaneously.

2.3.2 Data logger

For the HGV and the bus, vehicle speed and engine speed were measured using two light-emitting proximity switches. One was mounted close to the drive shaft to collect data on vehicle speed, and one was mounted close to the engine pulley to collect data on engine speed. Reflective tape was applied to the prop shaft and engine pulley, and the proximity switches sent a signal to the data logger each time the reflective tape came into view. For the car and LGV, the speed signal was taken from the existing speed transducer fitted to the gearbox. For the car only, the engine speed was also recorded by logging the electrical pulses to the fuel injectors (one pulse every power stroke, which equated to 0.5 pulses per revolution). All the methods generated a number of pulses per revolution, and the signals were later calibrated by driving the test vehicle over a known distance.

On board each vehicle the logging system was operated remotely by a navigator using a hand-held control. This comprised an on/off toggle switch used to start and stop the logging at the beginning and end of each route, and a press button to mark the logged file and indicate the positions of predetermined node points along the route.

2.4 Logging procedure

Bus and HGV logging was carried out between May and November 2000, and car and LGV logging between March and July 2001, as shown in Table 2. School holiday periods were avoided, because holiday periods tend not to represent typical working day traffic flows. As testing was being undertaken at six different locations there were a number of restrictions on the quantity of testing which could be undertaken at each location. For each vehicle and at each location speeds were logged continuously for three

Table 2 Timetable of surveys for each vehicle type

2000	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue
May	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31						
										London							London							London													
June				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30				
																	London							Havant							Havant						
July						1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
										So'ton														Oxford													
Aug		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31					
Sept					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30			
																															So'ton						
Oct							1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
																	Oxford							Gloucester													
Nov			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30					
			Gloucester														Reading														Reading						

2001	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue
March				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31			
										Havant							Reading							So'ton							London						
April							1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
										Oxford																					Gloucester						
May		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31					
			London														Reading							Oxford													
June					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30			
										London							So'ton							Havant							Gloucester						
July							1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
																	London																				

Bus Logging   HGV Logging   Car Logging   LGV Logging consecutive days, from Tuesday to Thursday, between 07:00 and 11:00, and between 15:00 and 19:00. This provided speed profile data for morning and evening peak and off peak periods. The use of Fridays or Mondays as one of the three test days was avoided as the traffic flows during the Monday morning peak and the Friday afternoon peak periods may differ from normal mid-week traffic flows. The buses used for logging were out of service and made brief stops of approximately 5 seconds at bus stops at all sites except Havant, where the majority of the route was not a usual bus route. The bus driving cycles therefore have a greater number of stops than the driving cycles developed for the other vehicle categories.

Log sheets were completed for each run. The information noted included the date, the start and end times of the run, the data logger and GPS file numbers, the route travelled, the distance covered, and any unusual traffic conditions (accidents, road works, *etc*).

3 Site details

This chapter of the report gives details of each of the six sites at which vehicle operation data and traffic data were collected, including the routes driven and the location of all traffic management schemes on these routes.

3.1 Site 1 - West London

The logging in west London was carried out on a 44 km route passing mainly through the Boroughs of Richmond-upon-Thames and Kingston-upon-Thames. Figure 1 shows the route that was driven, and all of the traffic management measures that were located along it. The extra section highlighted as only being logged by the bus was omitted for the other vehicles due to extensive roadworks.

The bus logging started from Wimbledon Chase (south east corner of route) due to its proximity to the bus depot. The logging for the other three vehicle types started from

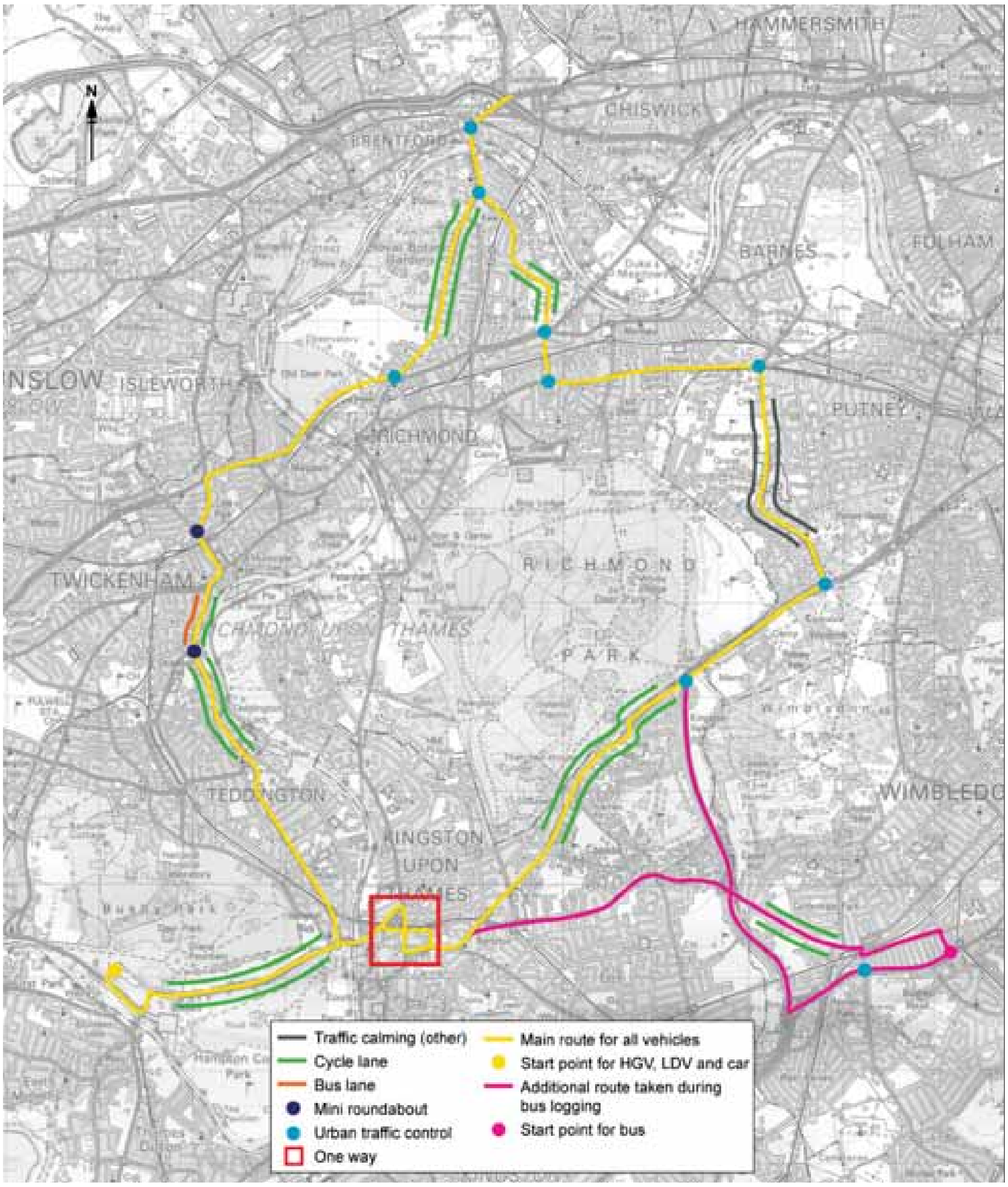


Figure 1 Traffic management measures on the west London route

Hampton Court car park (south west corner of route) as this was the nearest starting point from TRL. The circuit was driven in anti-clockwise and clockwise directions on alternate days, in order to cover the traffic management measures on both sides of the road. This route was far longer than those at the other five sites, and so the logging was carried out over a two weeks period in order to produce a sufficient amount of data.

3.2 Site 2 - Havant

Havant is situated in Hampshire to the north-east of Portsmouth. The area studied was Leigh Park, which is a housing estate in the northern part of the borough. This was chosen because numerous traffic safety measures have been installed as part of the Leigh Park Area Safety Scheme, and also because the safety scheme has been studied previously by TRL (Cloke *et al.*, 1999). Figure 2 shows the route that was driven.

The traffic management measures featured on the routes are also detailed in Figure 3. Four different routes were driven, two following the roads around the edge of Leigh Park (Purbrook Way and Middle Park Way) and two including Dunsbury Way and Botley Drive through the centre of the area. The two routes were followed in both clockwise and anti clockwise directions. The routes were driven in a pre-set order, and the first route driven at the start of each session was changed each day so that any peak traffic flows were encountered on different routes. The route was altered for the HGV due to access restrictions.

3.3 Site 3 - Southampton

Southampton was chosen as a study location due to the implementation of a number of measures to encourage public transport use. This included bus lanes, bus priority, and bus-access-only routes in the city centre. The route driven incorporated as many of these measures as practical (Figure 4).

The route started from either the north or the east of the city on alternate days to ensure peak traffic flows were encountered on different parts of the route. Due to access restrictions and bus-only areas the car, LGV and HGV could not be driven through the centre of the city. The detours from the main route taken by the bus are shown in Figure 4.

3.4 Site 4 - Oxford

As part of its transport strategy the city of Oxford has introduced a large number of traffic management schemes. These have comprised 700 park and ride spaces on the city's perimeter, new bus lanes, bus priority features, new cycle routes, and general improvements to encourage through traffic to use the ring road rather than the city centre.

The route driven was between three park-and-ride sites to the north, south and west of the city (Figure 5) and was

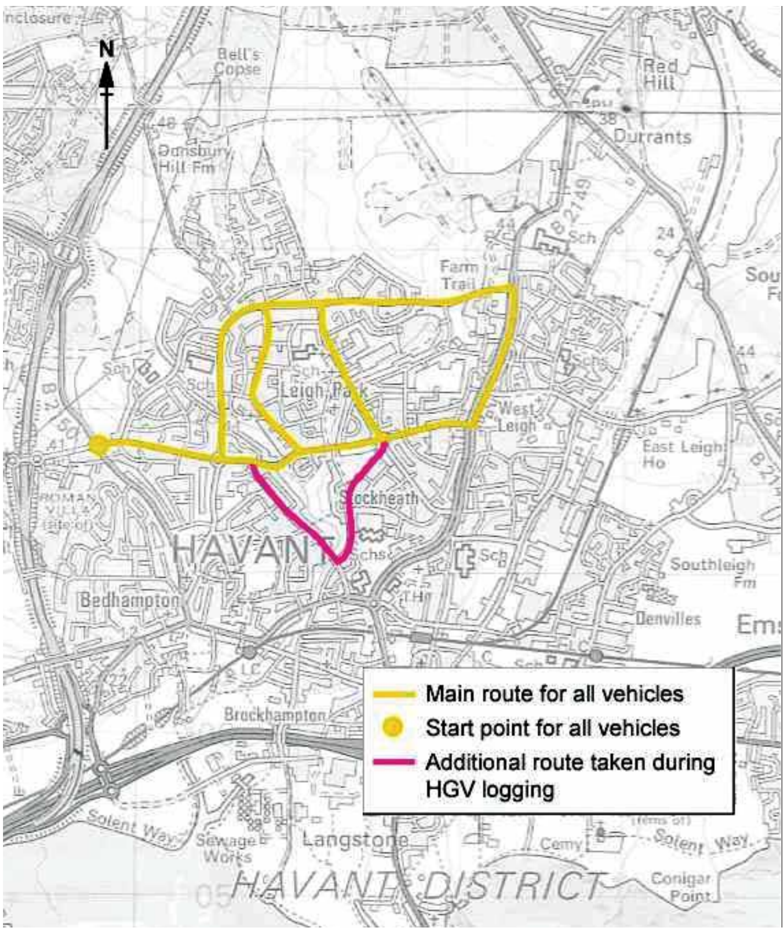


Figure 2 Havant logging route

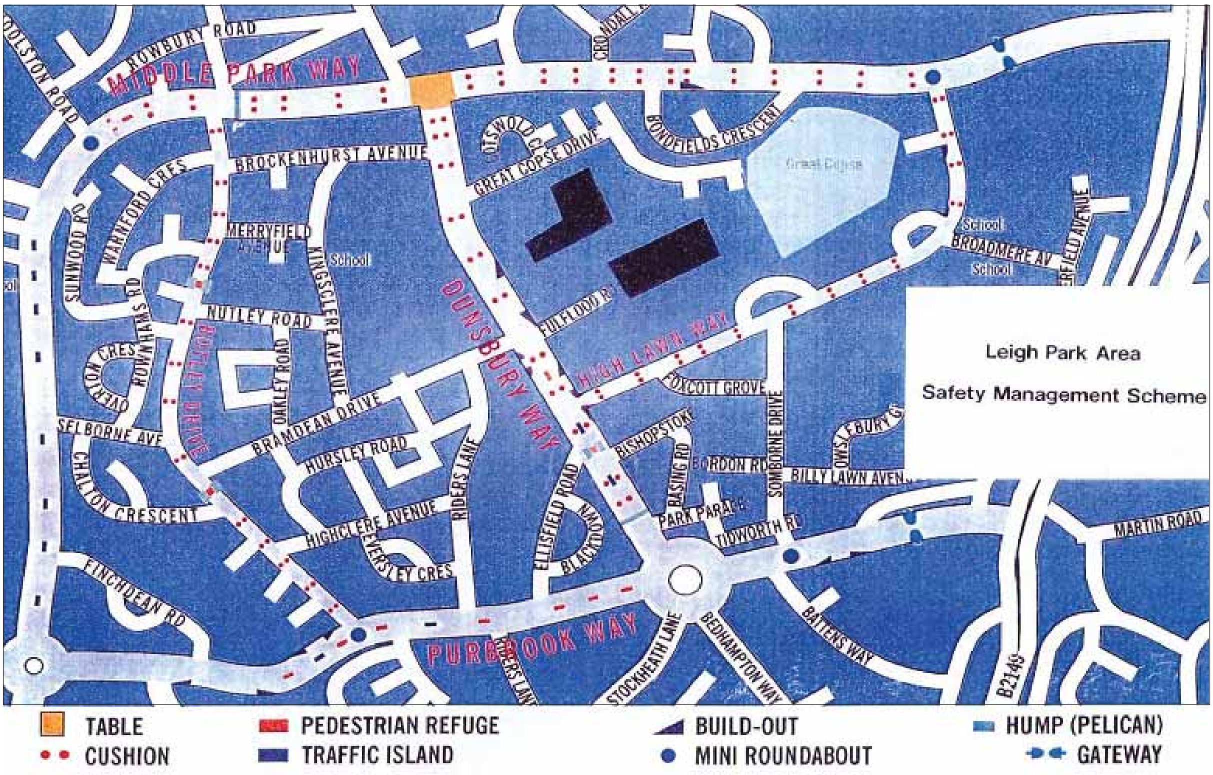


Figure 3 Traffic management measures on the Havant route

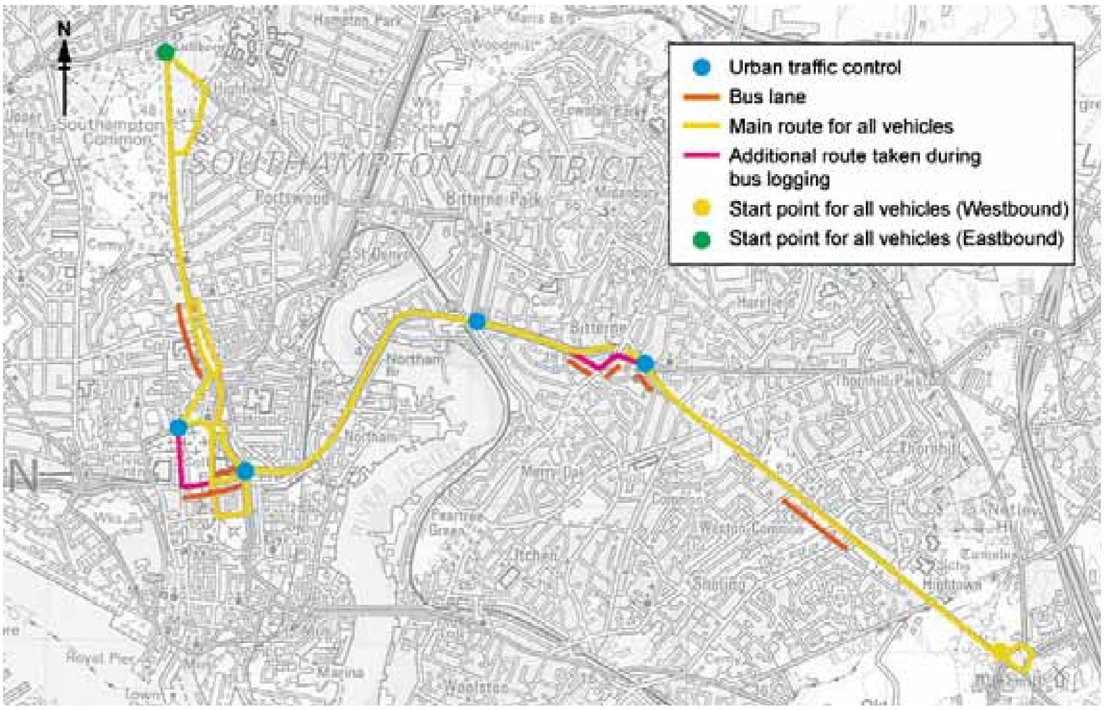


Figure 4 Traffic management measures on the Southampton route

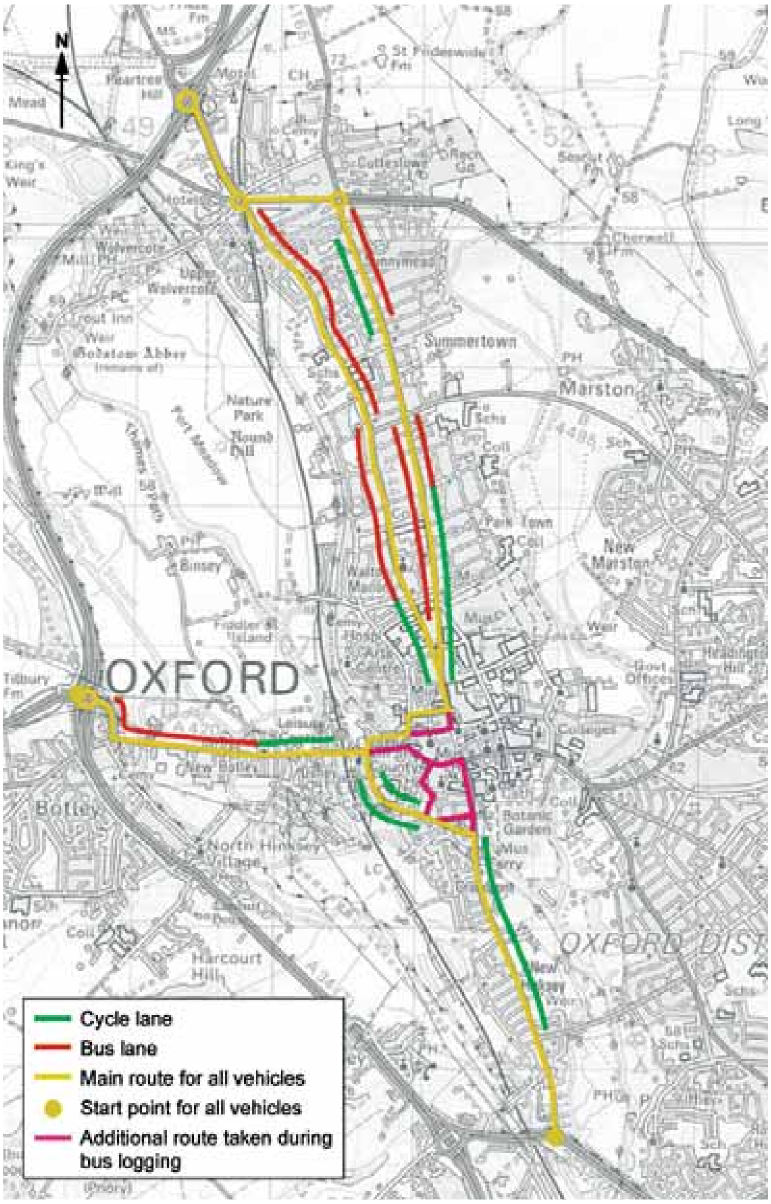


Figure 5 Traffic management measures on the Oxford route

split into six separate routes for ease of analysis. Access to the city centre is restricted, and only the bus was able to gain access to this area. Each day the logging was started from a different location, once from each of the three park-and-ride sites, so as to encounter peak traffic flows at different points on the route.

3.5 Site 5 - Gloucester

In December 1995 the City of Gloucester was chosen by DfT to take part in a 'Safe Town Initiative', subsequently renamed the Gloucester Safer City project. The objective of this project was to reduce the number of road casualties by implementing a range of actions for road safety including traffic management measures.

The route driven can be seen in Figure 6, and included as many areas as possible where the measures had been introduced. In addition to these, the route incorporated several examples of urban traffic control (UTC).

3.6 Site 6 - Reading

Reading has a wide range of traffic management schemes in operation. Reading Borough Council's Local Transport Plan includes the promotion of bus use and improving bus access to the town centre. Road humps have also been introduced in some residential areas to curb traffic speeds. The route driven can be seen in Figure 7. The bus route was different to that defined for the other vehicles due to the ability to access the town centre.

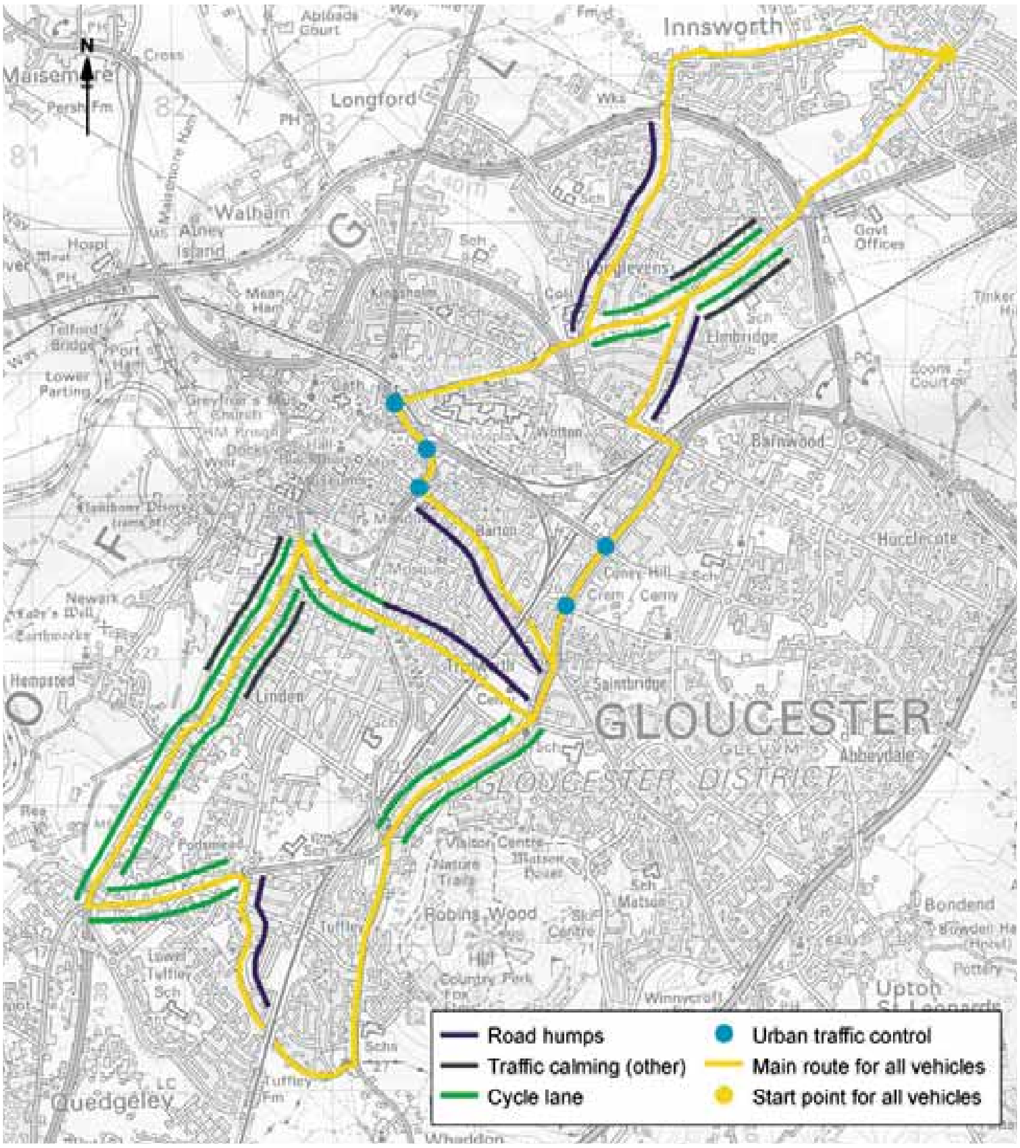


Figure 6 Traffic management measures on the Gloucester route

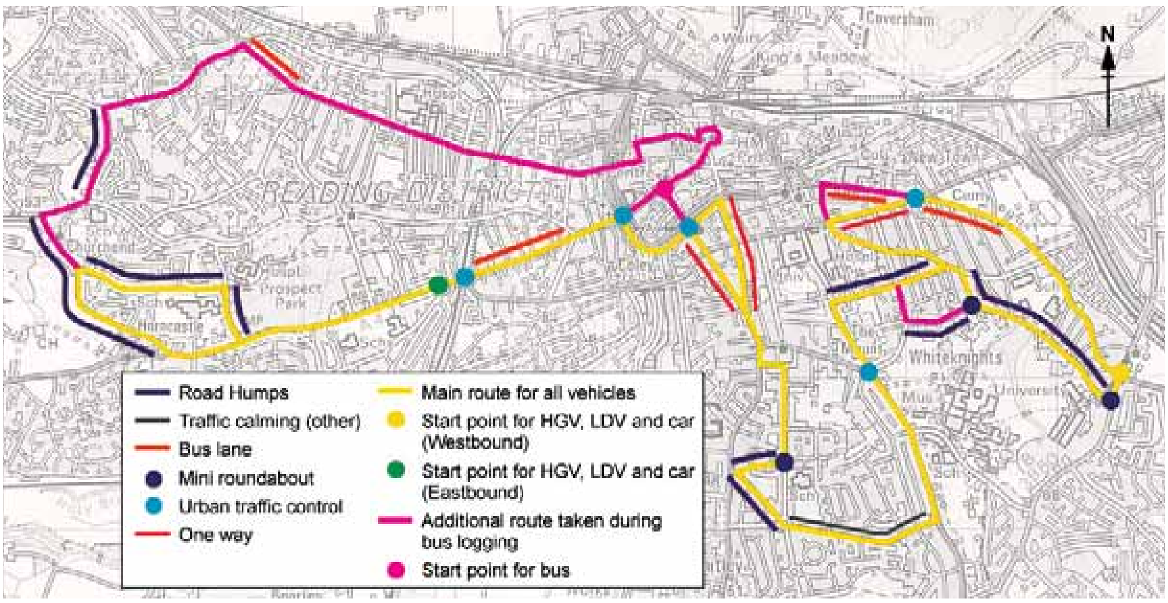


Figure 7 Traffic management measures on the Reading route

4 Driving cycle development

The development of the driving cycles followed three distinct stages:

i The conversion of the raw speed data into second by second speed profiles.

ii The extraction of sections of the speed profiles (links) to compile databases of traffic-management-specific speed profiles for each vehicle.

iii The development of the final cycles.

The stages are described in the following Sections.

4.1 Data conversion

For each vehicle the logging work produced two sources of speed data, one from the GPS unit and one from the data logger. Both sets of data required conversion to a useable format before further analysis could take place.

The logged GPS data were processed using a program which was developed to interpret the NMEA sentences, extract the appropriate parts of the data, convert the data into meaningful units, and store the processed data in a spreadsheet. The processed GPS data spreadsheets included vehicle position, speed and height above sea level. An example of the processed data, showing vehicle position and speed, is shown in Table 3. As well as being used in the data extraction process detailed below, one speed profile from each of the six sites was used to calibrate the speed pulse data collected by the data logger.

The speed data collected by the data logger consisted of pulses per second recorded from the proximity switch mounted in the engine. In order to convert the pulse rates into speed units, a calibration factor was needed in the form of the number of pulses recorded per kilometre. The GPS speed profiles were recorded directly in kilometres per hour, and so by using logger data and GPS data recorded simultaneously it was possible to obtain a calibration factor.

A separate calibration factor was obtained for each vehicle, and this was used to convert the pulse information of all the logger data for that vehicle into kilometres per hour. Any acceleration or deceleration spikes caused by data collection errors were also identified at this stage. Any excessive spikes in the data could therefore be identified and smoothed out by taking an average of the data point on either side. These files were then saved in a spreadsheet, with additional calculated information including distance covered and the numbered node point positions.

4.2 Link extraction

Figure 8 shows an example of a raw speed profile from a route in Reading. The profile is annotated to show where different traffic management measures or sections suitable for control cycles (in this case the suburban cycle) fall. In order to develop specific cycles all these sections, or links, had to be extracted and separated into traffic management specific and vehicle specific databases.

For each of the six sites the majority of the speed measurements were extracted from just one of either the GPS data or the logger data. The speed profiles from the two collection methods were in very good agreement as can be seen in Figure 9, which demonstrates the validity of collecting data using the GPS unit.

The decision as to which data source was used depended mainly upon equipment performance at the particular site with the equipment producing the most complete data set being used in the extraction process. Exceptions to this were the extraction of the urban traffic control and mini roundabout links. These were extracted almost exclusively from the GPS data, as the node points marked in the logger data were located in the middle of the majority of the mini roundabouts and UTC junctions.

The positional information obtained from the GPS receiver was used to extract the required sections of the speed profiles. The longitude and latitude co-ordinates were used to extract the speed data from between two defined points. This method was extremely flexible as it allowed any point on the route to be identified, and so it was possible to extract any section of the route rather than being restricted to designated node points. The speed profiles extracted were

Table 3 Processed GPS data showing position and vehicle speed

PC Time	Trip Time	Latitude	North/Sou	Longitude	East/West	Sentence
14:42:08.07	0.00	51.40782	N	0.215417	W	GPGLL
14:42:08.56	0.49	51.40782	N	0.21545	W	GPRMC
14:42:08.78	0.71	51.40779	N	0.215467	W	GPGGA
14:42:09.22	1.15	51.40779	N	0.2155	W	GPGLL
14:42:09.83	1.76	51.40778	N	0.21555	W	GPRMC
14:42:10.10	2.03	51.40778	N	0.215567	W	GPGGA
14:42:10.54	2.47	51.40776	N	0.215617	W	GPGLL
14:42:11.03	2.96	51.40775	N	0.215667	W	GPRMC
14:42:11.25	3.18	51.40775	N	0.215683	W	GPGGA
14:42:11.75	3.68	51.40771	N	0.21575	W	GPGLL
14:42:12.35	4.28	51.4077	N	0.2158	W	GPRMC
14:42:12.57	4.50	51.40768	N	0.215833	W	GPGGA
14:42:13.07	5.00	51.40767	N	0.215883	W	GPGLL
14:42:13.56	5.49	51.40765	N	0.215967	W	GPRMC
14:42:13.78	5.71	51.40763	N	0.215983	W	GPGGA
14:42:14.22	6.15	51.40762	N	0.216033	W	GPGLL
14:42:14.88	6.81	51.4076	N	0.216133	W	GPRMC
14:42:15.10	7.03	51.40759	N	0.21615	W	GPGGA
14:42:15.54	7.47	51.40755	N	0.216233	W	GPGLL

PC Time	Trip Time	Speed	Sentence
14:42:08.56	0.49	17.9644	GPRMC
14:42:09.83	1.76	20.372	GPRMC
14:42:11.03	2.96	23.15	GPRMC
14:42:12.35	4.28	25.928	GPRMC
14:42:13.56	5.49	30.3728	GPRMC
14:42:14.88	6.81	32.5952	GPRMC
14:42:16.09	8.02	34.4472	GPRMC
14:42:17.35	9.28	41.8552	GPRMC
14:42:18.56	10.49	42.4108	GPRMC
14:42:19.88	11.81	42.596	GPRMC
14:42:21.09	13.02	43.1516	GPRMC
14:42:22.35	14.28	43.522	GPRMC
14:42:23.56	15.49	43.7072	GPRMC
14:42:24.87	16.80	43.522	GPRMC
14:42:26.08	18.01	43.7072	GPRMC
14:42:27.40	19.33	43.522	GPRMC
14:42:28.55	20.48	46.3	GPRMC
14:42:29.87	21.80	47.4112	GPRMC
14:42:31.08	23.01	49.078	GPRMC

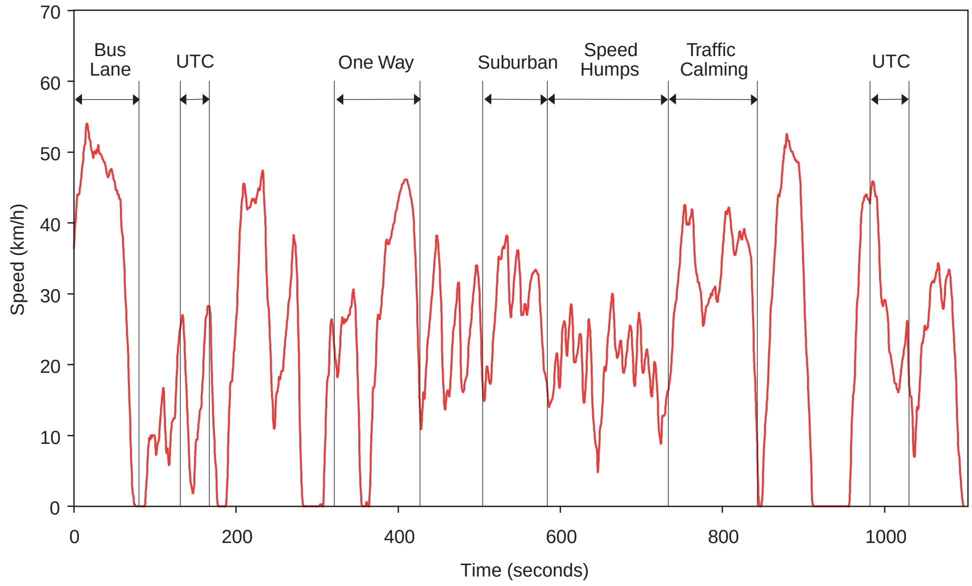


Figure 8 Processed speed profile highlighting sections of traffic management

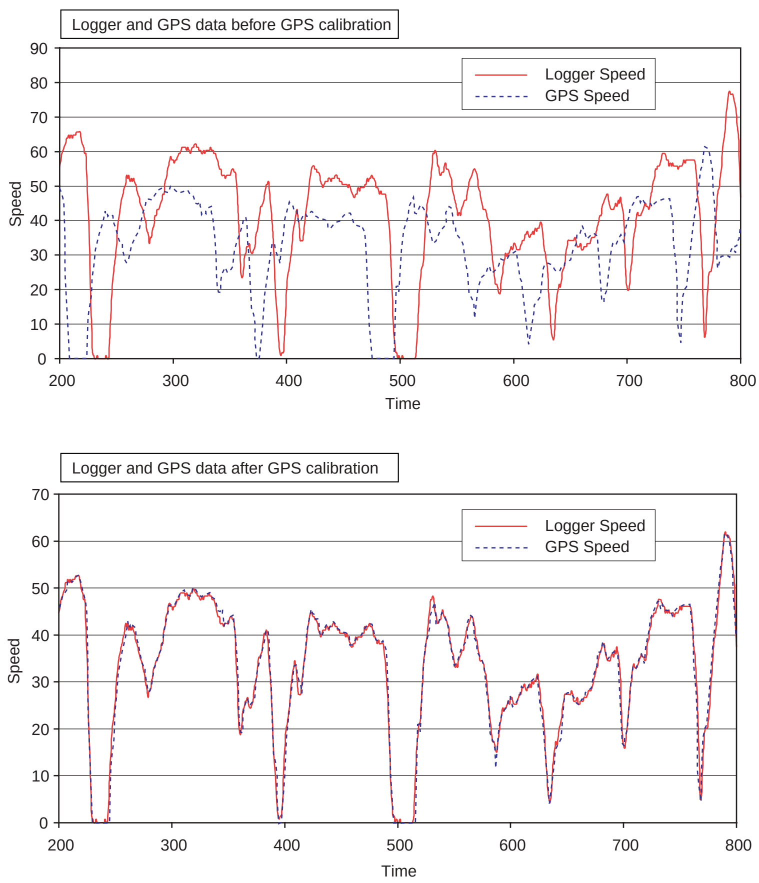


Figure 9 Speed profile agreement between GPS and logger

automatically saved to designated files corresponding to the type of traffic management represented in the link being extracted, and to the vehicle type.

As described earlier, a hand-held control was used to mark the locations of predetermined node points on the data logger files as the routes were being driven. These node points coincided with junctions, roundabouts, the start of bus or cycle lane. In order to extract the correct speed profile sections it was essential that the node points separating the links were correctly recorded. To verify the node points their positions were assessed graphically as a function of distance. Any errors (for example, if the navigator had missed a node point or had recorded it in the wrong place) could be identified and corrected.

Once this process had been completed, the data were extracted from specific links identified by the node points at either end. As with the GPS data these were automatically saved to a file corresponding to the type of traffic management being extracted. Unlike with the GPS data, this data extraction could only be undertaken between specified links.

4.3 Production of driving cycles

Once the data had been modified and the required links had been extracted, a database of speed profiles was available for each vehicle type, for each of the seven traffic management scheme types, and for the control conditions (suburban and urban). These links had been extracted from multiple sites and each link had a number of recorded vehicle operation profiles associated with it due to the repeated driving of the designated routes. From these links a single driving cycle of between 900 and 1200 seconds was derived for each type of traffic management scheme and for each vehicle type as a second-by-second speed profile. The following paragraphs describe how the driving cycles were developed.

For each vehicle type, the individual scheme-specific driving cycles were developed by joining together selected vehicle operation profiles from the six measurement sites. In order to ensure that the final driving cycles were representative of all the operational profiles measured, profiles which were typical of each link were identified, based on the average speed. For each link the average speed was calculated for each of the operation profiles. The overall average of these statistics was then calculated for all the profiles measured over that single link. The operation profiles with the closest average speed to the overall average speed were selected. As a refinement of the selection process, further checks were undertaken of the selected profiles using additional statistics (trip duration, minimum and maximum speed, and average, minimum and maximum acceleration) and by plotting each of the profiles. The number of individual profiles incorporated in a given driving cycle was dependent on the number of examples of each type of traffic management that were covered by the measurement work, and the length of the link from which the profiles were derived. For example, there were fewer examples of mini roundabouts on the routes driven than other traffic management measures and the link lengths were short. This resulted in a large number of profiles from any given link being used in the final driving cycle.

The speed data of the chosen profiles were joined together and, if necessary, the links were joined with a few seconds of manually entered data to provide a smooth transition between one section and the next. This process is illustrated in Figure 10. Once the chosen sections had been joined into single driving cycles, a final check was carried out to ensure all the cycles were representative of the whole data set from which each was derived. This was done by comparing the average speed and average positive acceleration of the driving cycle with that of the whole data set (i.e. the average statistics for all of the links, at all of the sites, for a given vehicle and traffic management type). The average speeds of all the driving cycles were found to be within 1.5 km/h of the data set and the average positive acceleration within 0.1 m/s^2.

To provide a cycle that was driveable on a chassis dynamometer it was necessary to smooth the majority of the driving cycles once they had been constructed. This was achieved by taking an average of each data point with the data points one second either side. This had little affect on the overall cycle but removed any undriveable spikes.

When the speed profiles for the bus lane, cycle lane and one way links were being examined the range of average speeds found within a single link indicated that there were two distinct types of profile: one in congested traffic and one in free-flowing traffic. To reflect these two driving conditions these driving cycles were split into non-congested and congested portions. The average speed data for each operation profile were used to split the profiles into the two different categories. Profiles with an average speed of less than 15 km/h were classified as congested, and profiles with an average speed of more than 20 km/h were classified as non-congested. The few links falling in between these categories or falling close to the boundaries were examined more closely by plotting the speed profiles. These were then either categorised correctly or, for the few links that did not clearly fit into either category, were not categorised although remained in the data set for the purpose of calculating the overall statistics. The buses were not subjected to congestion on the bus lanes and so the bus lane cycle was split into off-peak and peak sections, with peak times taken as 07:30-09:30 and 16:30-18:00. The development of these split cycles followed the same method as described above, other than that each half was developed separately. For example, a non-congested cycle of approximately 500 to 600 seconds was developed and compared to the overall statistics of all the non-congested data. This was then joined to the congested cycle and as a final check the whole cycle was compared with the statistics of the whole data set.

4.4 Link information

This section contains maps showing the location of each link that was used in the final driving cycles. Each link is numbered allowing the links used to make up the final driving cycles to be identified. There are also photographic

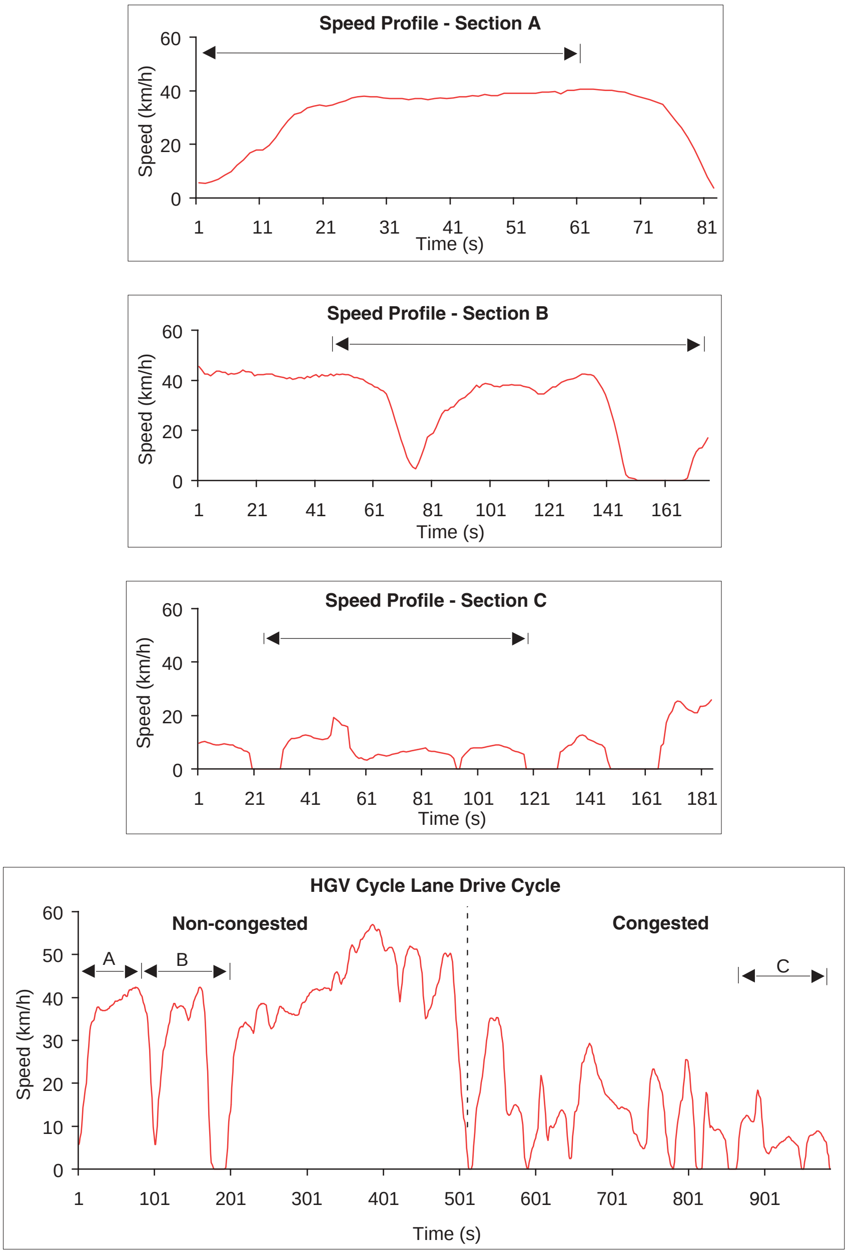


Figure 10 An example of driving cycle development

examples of a selection of links and a summary of traffic count data from a selection of links. The photographs were taken from the video recording that was on board the bus during the logging periods.

In addition to the information contained within this section the video footage recorded during the bus logging was used to produce four CD-ROMs. One video from each route was modified into a movie MPEG file and each of the links marked on the maps in this section have been highlighted on the video images.

4.4.1 West London

Figure 11 shows the links used from the west London route. The route driven was split into three sections and the start points for each of these sections are also labelled on Figure 11. Figure 12 shows a selection of stills from the video footage of links used along the route.

The traffic count data for west London were collated from counts undertaken by the London Borough of Richmond-upon-Thames. The data are presented in Table 4. All the data were collected between 07:00 and 19:00. The counts on links 8 and 9 were undertaken in April 1997 and the count on link 14 in April 1998. The data for the other links were collected more recently. The counts for links 3 and 4 were carried out in September 2001 and for links 1 and 2 in November 2001. Where no LGV data were available, the counts were included with the car/taxi data.

Even though the traffic count data for the different links were collected at different times of year and in different years, the data still give an indication of the proportion of vehicles using the different routes. However, a comparison of vehicle numbers across the links may not be very accurate given the large time gap between counts. The two most recent counts for links 1 to 4 cover links containing

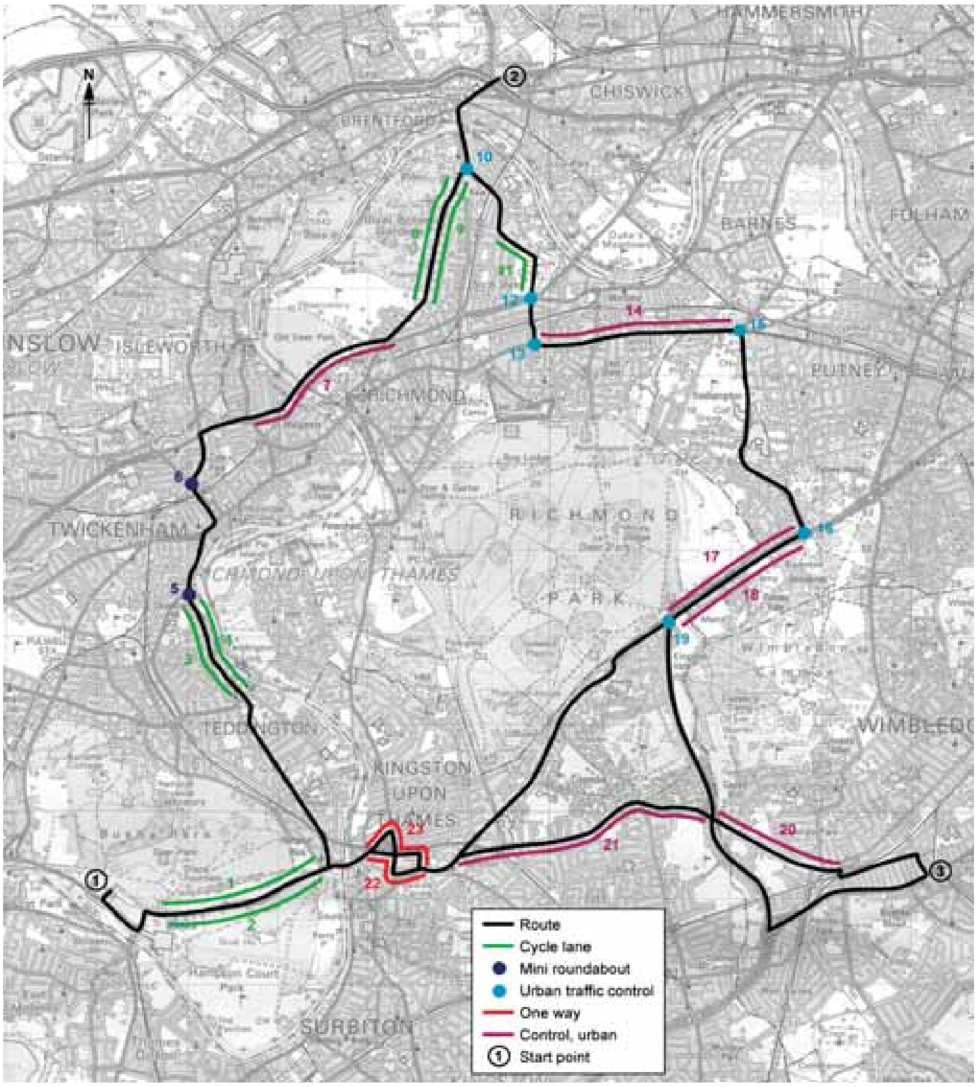


Figure 11 West London links used for cycle development

Table 4 Number and percentage of each vehicle type at a selection of links – West London

Vehicle category	*Link 1 (CL)*		*Link 2 (CL)*		*Link 3 (CL)*		*Link 4 (CL)*		*Link 8 (CL)*		*Link 9 (CL)*		*Link 14 (UC)*	
	No.	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*
HGV	342	4.4	282	3.9	205	3.9	147	2.8	252	3.4	277	3.7	698	6.2
Bus	194	2.5	172	2.4	65	1.2	56	1.1	111	1.5	101	1.4	252	2.3
LGV	–	–	–	–	–	–	–	–	636	8.5	784	10.5	1233	11.0
Car / Taxi	7084	90.1	6542	91.2	4617	88.4	4728	90.0	6129	82.0	5868	78.7	8526	76.3
Motorcycle	172	2.2	121	1.7	133	2.5	115	2.2	169	2.3	230	3.1	250	2.2
Pedal cycle	68	0.9	57	0.8	202	3.9	206	3.9	181	2.4	192	2.6	215	1.9
Total	7860		7174		5222		5252		7478		7452		11174	

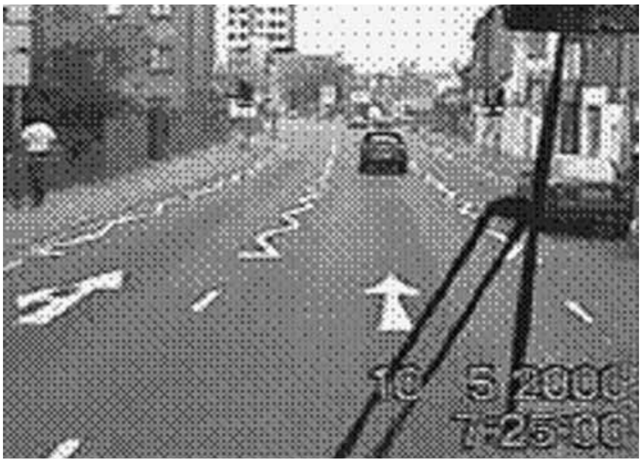
CL - Cycle lane.
UC - Urban control.

Cycle lane – Link 1

Cycle lane – Link 3

Cycle lane – Link 8

Urban control – Link 14



One way – Link 22

Urban control – Link 21

Figure 12 Examples of traffic management measures in west London cycle lanes. Pedal cycles on links 3 and 4 made up almost 4% of the traffic but on links 1 and 2 they made up less than 1%. The other major difference is that link 14 has the largest proportion of HGVs. This was likely to be due to deliveries to a number of shops and restaurants on this link.

4.4.2 Havant

The links in Havant used for driving cycle development are shown in Figure 13. Figure 14 shows photographic examples of six links. The traffic count data for Havant in Table 5 were collected from 07:00 to 19:00 on 13th February 2001.

As all the data were collected on the same day it is possible to compare traffic numbers as well as the proportion of vehicle types on the links. Table 5 shows that the highest percentage of buses was seen on links 18, 19, 20 and 21. These roads were not the main routes through the housing estate. They were therefore less frequented by through traffic but were served by local bus services.

4.4.3 Southampton

Figure 15 shows the links from the Southampton route used to develop the final driving cycles. Figure 16 presents video stills from a selection of links.

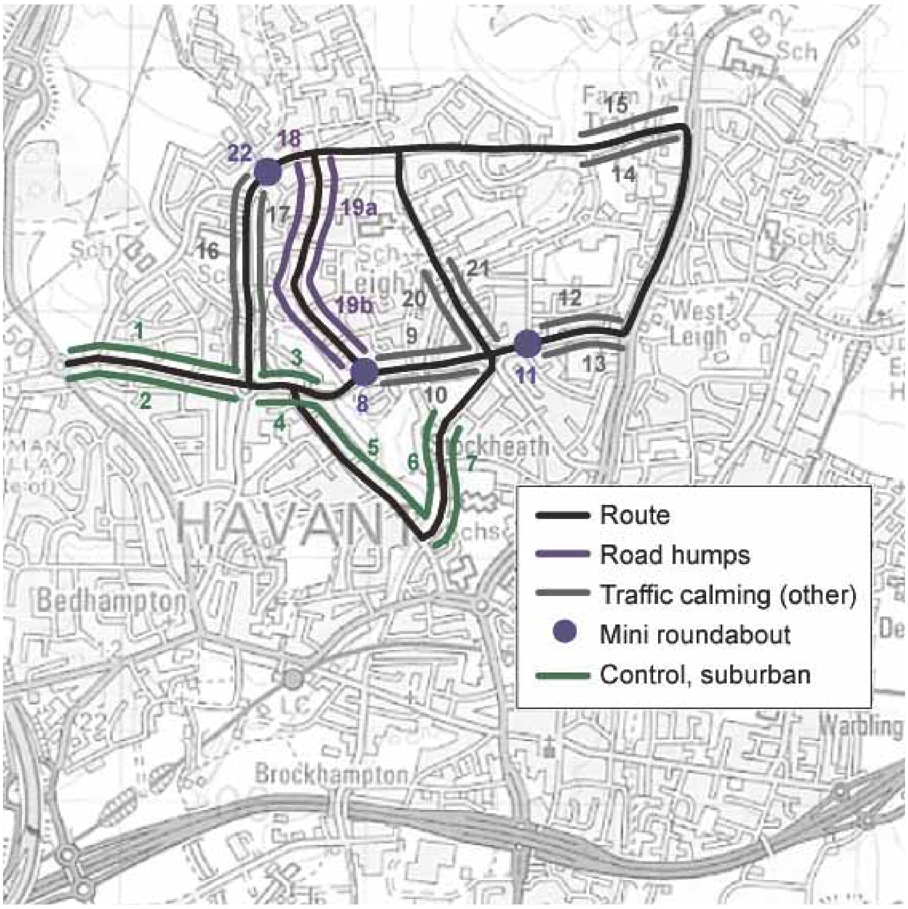


Figure 13 Havant links used for cycle development

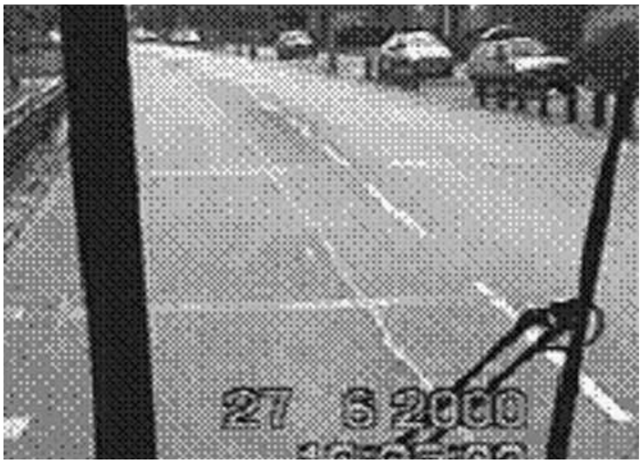
Table 5 Number and percentage of each vehicle type at a selection of links – Havant

Vehicle category	*Link 12 (TC)*		*Link 13 (TC)*		*Link 14 (TC)*		*Link 16 (TC)*		*Link 17 (TC)*		*Link 18 (RH)*		*Link 19 (RH)*		*Link 20 (TC)*		*Link 21 (TC)*	
	No.	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*
HGV	104	2.3	113	2.4	83	5.0	97	3.5	81	3.1	44	8.9	44	8.2	36	3.6	54	4.0
Bus	65	1.5	98	2.1	61	3.6	32	1.2	14	0.5	49	9.9	59	11.1	102	10.3	146	10.9
LGV	556	12.5	683	14.3	247	14.7	299	10.9	316	12.2	72	14.6	73	13.7	73	7.4	134	9.9
Car / Taxi	3550	80	3730	78.3	1266	75.5	2245	81.9	2163	83.3	335	67.7	342	64.0	754	75.9	964	71.7
Motorcycle	39	0.9	38	0.8	17	1.0	36	1.3	24	0.9	4	0.8	9	1.7	11	1.1	5	0.4
Pedal cycle	146	3.3	123	2.6	23	1.4	53	1.9	21	0.8	12	2.4	28	5.2	38	3.8	63	4.7
Total	4439		4764		1676		2741		2598		495		534		993		1345	

TC - Traffic calming (other).

RH - Road humps.

Control cycle, suburban – Link 3

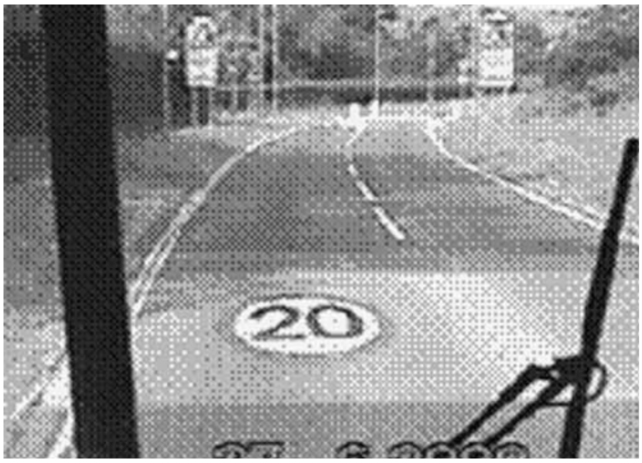


Control cycle, surburban – Link 2

Mini roundabout – Link 11

Road humps – Link 19a

Traffic calming (other) – Link 16



Traffic calming (other) – Link 20

Figure 14 Examples of traffic management measures in Havant

The traffic count data for Southampton presented in Table 6 was collected between 07:00 and 19:00. Links 1, 2, 3, 5 and 6 were collected in September 2001 and link 10 was collected in June 2001. All counts were carried out on Thursdays during school term time. Table 6 shows that the proportion of vehicle types at each of the five urban control links are fairly similar. The reason for the difference in total counts is that links 5 and 6 are one of the main routes eastbound out of the city as traffic is restricted to only a few river crossing points. This exit route then splits at link 4, resulting in the total traffic counts on links 1, 2 and 3 being considerably reduced. The only obvious difference in the proportion of vehicles counted at each of these urban control links is that links 5 and 6 have a greater proportion of buses. On link 10 a greater proportion of cars were counted compared to the other links. This may therefore be a stretch of road used more by local traffic than by goods vehicles accessing the city centre.

4.4.4 Oxford

Figure 17 shows the links used from the Oxford route for the final driving cycle development. The route driven was split into a number of sections and the start points for each of these sections are also labelled on Figure 17. Figure 18 presents video stills from a selection of links.

The traffic count data for links 2, 3, 5 and 6 presented in Table 7 were collected on two weekdays during May 2000. The count for link 8 was carried out mid week in November 2000 and the counts for links 9 and 10 were carried out mid week in October 2000. All counts were undertaken between 07:00 and 19:00. The main difference between this data set and the traffic counts for all the other sites are the large numbers of bicycles. This is not unexpected due to the counts being undertaken during university term time. The proportion of vehicle types counted at each link doesn't change greatly other than links 9 and 10 having a greater proportion of cars and a lower proportion of pedal cycles.

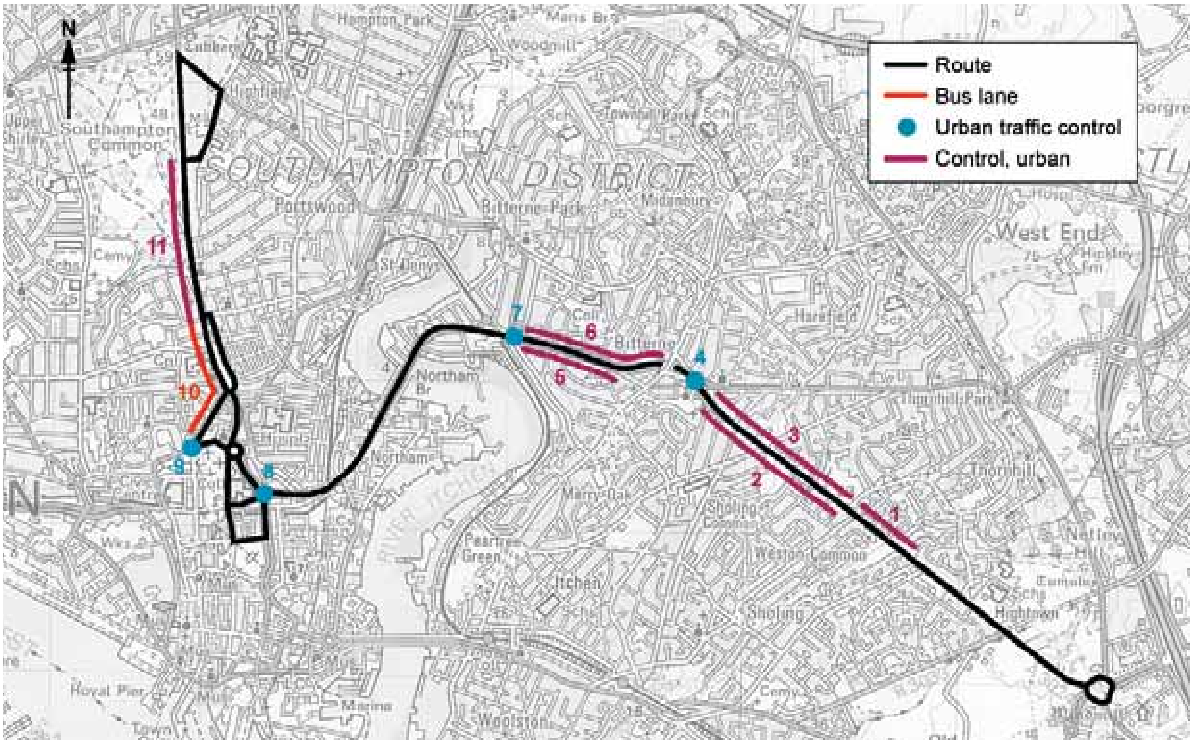


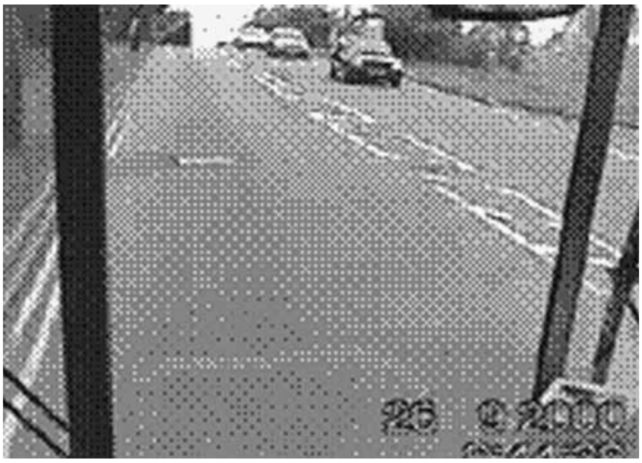
Figure 15 Southampton links used for cycle development

Table 6 Number and percentage of each vehicle type at a selection of links – Southampton

Vehicle category	Link 10 (BL)		Links 1 and 3 (UC)		Link 2 (UC)		Link 5 (UC)		Link 6 (UC)	
	No.	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*
HGV	618	6.5	808	12.2	813	9.6	1139	8.6	1174	8.1
Bus	167	1.8	34	0.5	63	0.7	363	2.7	301	2.1
LGV	714	7.5	695	10.5	1016	12.1	1653	12.5	1723	12.0
Car / Taxi	7857	82.8	4980	75.0	6395	75.9	9651	73.0	10827	75.1
Motorcycle	94	1.0	109	1.6	118	1.4	293	2.2	291	2.0
Pedal cycle	38	0.4	11	0.2	21	0.2	124	0.9	92	0.6
Total	9488		6637		8426		13223		14408	

BL - Bus lane.

UC - Urban control.



Control cycle, urban – Link 3

Control cycle, urban – Link 6

Bus lane – Link 10

Control cycle, urban – Link 11

Figure 16 Examples of traffic management measures in Southampton

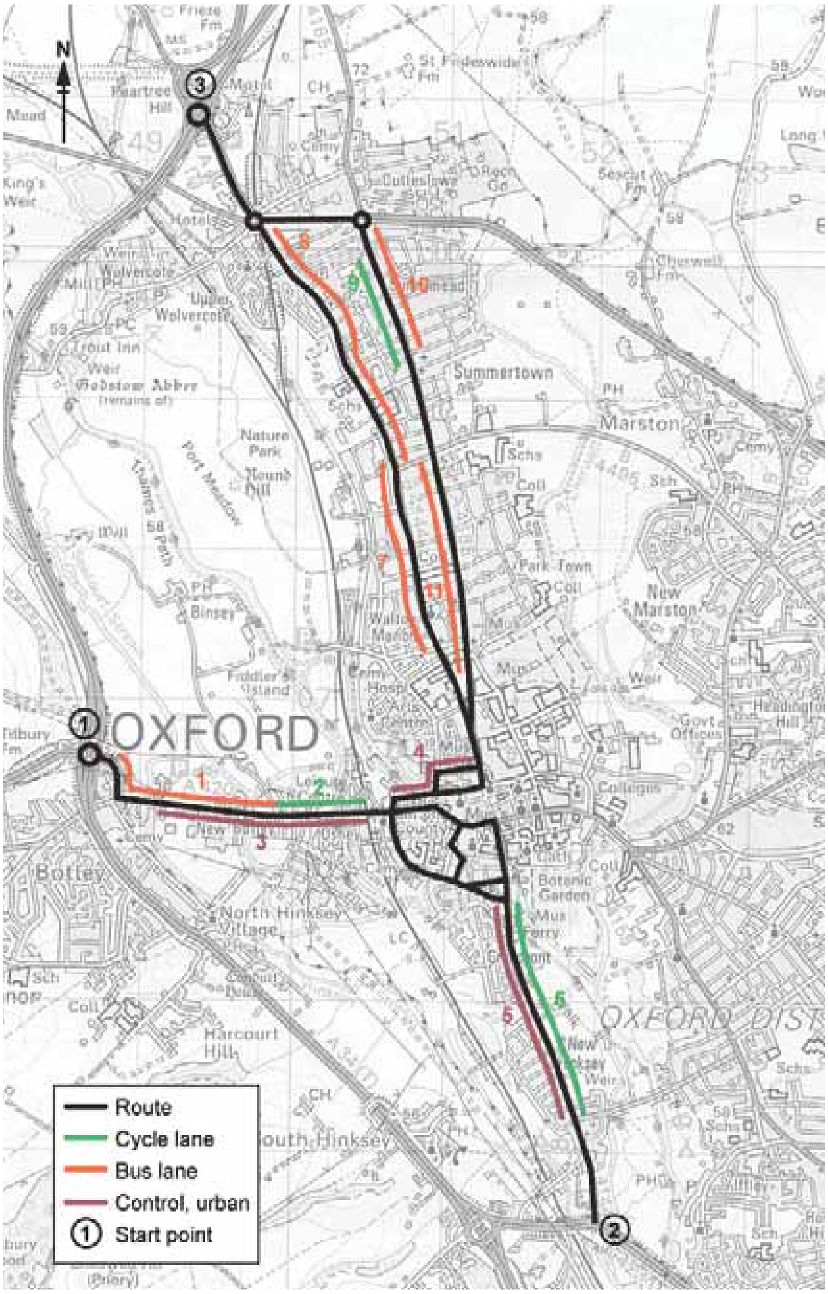


Figure 17 Oxford links used for driving cycle development

Table 7 Number and percentage of each vehicle type at a selection of links – Oxford

Vehicle category	*Link 2 (CL)*		*Link 3 (UC)*		*Link 5 (UC)*		*Link 6 (CL)*		*Link 8 (BL)*		*Link 9 (CL)*		*Link 10 (BL)*	
	No.	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*
HGV	282	3.7	300	3.7	254	3.0	289	3.7	277	3.7	180	2.5	268	4.1
Bus	327	4.3	295	3.6	394	4.7	359	4.6	281	3.7	360	5.0	333	5.0
LGV	893	11.7	1091	13.5	848	10.2	764	9.9	616	8.2	760	10.6	663	10.0
Car / Taxi	5075	66.2	5335	65.9	5689	68.1	5287	68.4	5878	77.9	5450	76.1	5076	76.9
Motorcycle	144	1.9	157	1.9	136	1.6	177	2.3	96	1.3	107	1.5	104	1.6
Pedal cycle	942	12.3	918	11.3	1031	12.3	848	11.0	397	5.3	303	4.2	155	2.3
Total	7663		8096		8352		7724		7545		7160		6599	

CL - Cycle lane.

UC - Urban control.

BL - Bus lane.

Bus lane – Link 1

Cycle lane – Link 2

Control cycle, urban – Link 3

Control Cycle, urban – Link 5

Bus lane – Link 11

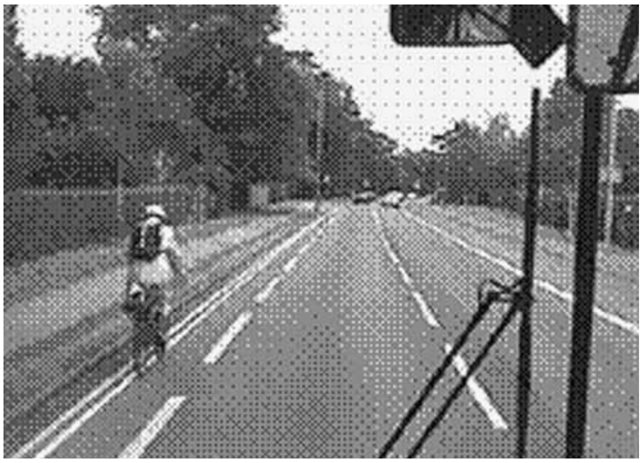

Cycle lane – Link 9

Figure 18 Examples of traffic management measures in Oxford

4.4.5 Gloucester

Figure 19 shows the links from the Gloucester route used to develop the final driving cycles. Figure 20 presents video stills of a selection of the links.

The traffic counts for Gloucester presented in Table 8 were all carried out on in March 2001 between 07:00 and 19:00. Table 8 shows that the highest proportion of LGVs and HGVs are seen on links 10 and 11. These are two main routes into and around the city for all traffic plus, to the east of link 10, there is an industrial estate and there are a large number of industrial processes along the west side of the road. The lowest proportion of HGVs is seen along the road covered by links 15 and 16. Although this is a residential road it is possible to use it is as a short cut between the two major roads entering the city. As part of the Gloucester Safer City Project, however, the road has had speed humps installed.

4.4.6 Reading

Figure 21 shows the links from the Reading route used to develop the final driving cycles. Figure 22 presents video stills of a selection of the links used.

The traffic count data for Reading was collated from counts undertaken by Reading Borough Council over the last few years. The counts for links 10, 11, 12 and 13 presented in Table 9 were undertaken during peak traffic periods only (07:00-10:00 and 16:00-19:00) mid week during 1999. The data for all the other links were collected between 07:00 and 19:00. The link 20 data were collected during November 1999, link 21 during June 2000, and links 26 and 27 during June 2000.

Even though the traffic count data for the different links were been collected at different times of year spanning a few years, the data still give an indication as to the proportion of vehicles using the different routes. A comparison of vehicle numbers may not be quite so accurate given the large time gap between counts. Table 9 shows that links 20 and 21 have the highest proportion of public service vehicles whereas links 26 and 27 have the highest proportion of HGVs. Links 26 and 27 are on the road that leads out to the M4 and are, therefore, more likely to carry a larger proportion of HGVs.

5 Driving cycles

All 40 driving cycles developed during the project are presented in Appendices A to D. Each cycle is annotated to show the separate component links that were used to make the whole cycle. This is demonstrated in the car driving cycle developed for cycle lanes which is shown in Figure 23. Each link is labelled to correspond to the maps in Chapter 4, for example G11 refers to Gloucester link 11, O2 to Oxford link 2 etc.

The figures in the appendices are also annotated to show where the driving cycles have been developed from congested and non-congested, or peak and off-peak operation profiles. The raw second-by-second speed data for each driving cycle is not included within this report but at the time of publication was available from the TRL website (http://www.trl.co.uk/1024mainpage.asp?page=760).

The specifications for each of the forty driving cycles are presented in Tables 10 to 13. A comparison is also made between the derived cycle and the whole data set for average speed and average positive acceleration (the average positive acceleration is often used to describe the level of dynamics of a cycle). This demonstrates that the average speeds of all the cycles were within 1.5 km/h of their corresponding data set and the average positive accelerations were all within 0.1 m/s^2.

The data in Table 14 show that, as would be expected, for the majority of the cycles the car and LGV have higher average speeds than the bus and HGV cycles. There are, however, exceptions to this. The congested sections of each cycle demonstrate similar average speeds across all vehicles ranging from 10.26 km/h to 13.77 km/h. The non-congested sections of the HGV cycles for the bus lane, cycle lane and control cycle show similar average speeds to the equivalent car and LGV cycles. The equivalent bus non-congested cycles have an average speed that is between 8.4 km/h to 16.3km/h slower than the other three vehicle types. This is due to the fact that the bus cycles include stops and bus stops.

Other than for the non-congested cycles already mentioned, a similar level of variation is seen between the bus and HGV cycles except for the cycle lane driving cycle which demonstrates a difference of 6.1 km/h. Again this is due to the bus stops reducing the average speed for the bus driving cycle. Those cycles where the bus average speed is greater than the HGV are those made from links that did not feature bus stops (i.e. mini roundabouts and UTC). Between the car and LGV cycles there is a small variation in average speed across the two vehicle types but by no more than 4km/h as seen in the non-congested bus lane.

Another point to note is that the bus lane cycle for buses has a similar average speed for both the peak and off-peak sections. This was as expected due to the purpose of a bus lane being to allow public transport to flow freely in areas which are subject to congestion. The off peak section of the bus lane driving cycle for the bus shows a lower average speed than the non-congested bus lane cycles for the three other vehicle types. Again this is due to the bus stopping at bus stops.

At the time of publication, the bus and HGV cycles were being used within another TRAMAQ research project, namely UG216 - Exhaust Emissions from Heavy Duty Vehicles. A pilot study had been completed which, among other objectives, examined the driveability of the heavy-duty vehicle driving cycles developed within this project. The ten cycles for both vehicle types were driven on a chassis dynamometer and no problems of driveability were encountered. The difference between the engine speeds of two runs of each driving cycle was also compared to assess the repeatability of the cycles. These showed that the UG214 driving cycles had a good level of repeatability. The emissions results obtained from UG216 are to be used in the development of a traffic management emissions model. Also, within the scope of the TRAMAQ programme, UG218 is developing a specification to use the car driving cycles to obtain emission data for a range of traffic management schemes.

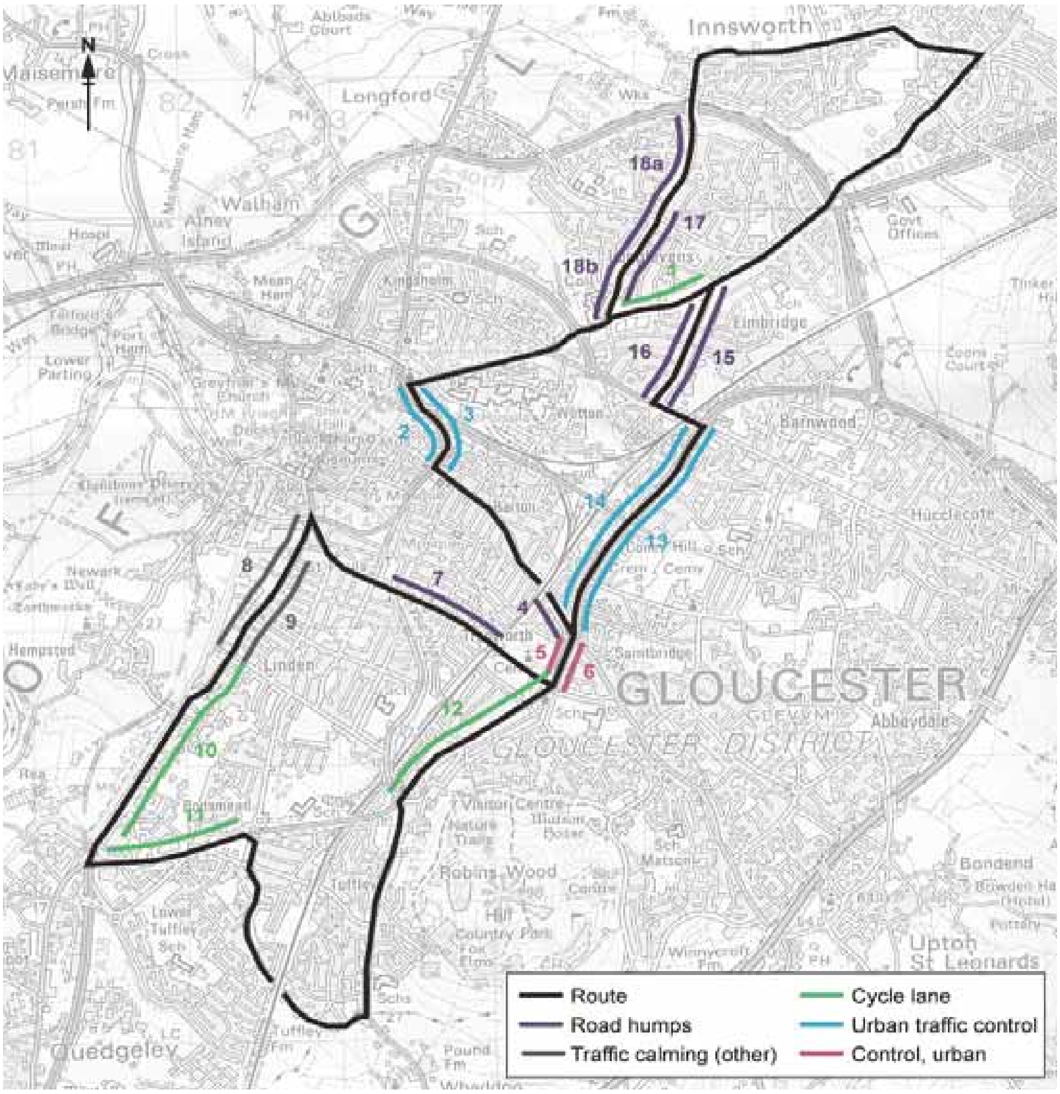


Figure 19 Gloucester links used for driving cycle development

Table 8 Number and percentage of each vehicle type at a selection of links – Gloucester

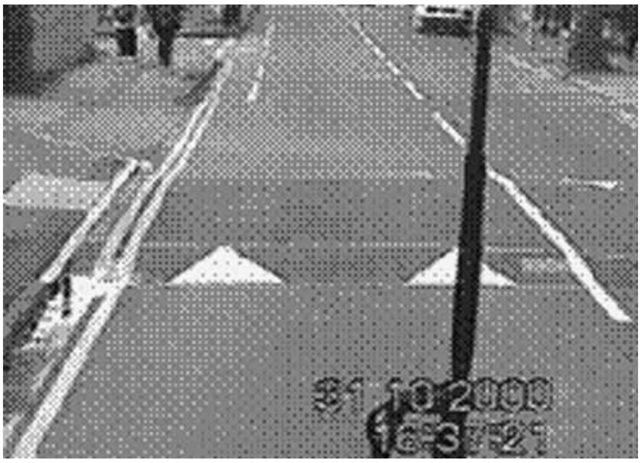
Vehicle category	*Link 1 (CL)*		*Link 4 (RH)*		*Link 10 (CL)*		*Link 11 (CL)*		*Link 15 (RH)*		*Link 16 (RH)*		*Link 17 (RH)*		*Link 18b (RH)*	
	No.	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*
HGV	177	3.4	170	3.5	727	7.7	710	7.6	42	2.0	34	2.2	92	4.1	98	3.8
Bus	132	2.5	209	4.3	156	1.7	46	0.5	19	0.9	23	1.5	19	0.9	14	0.5
LGV	494	9.4	564	11.5	1436	15.2	1239	13.2	198	9.3	151	9.7	220	9.9	251	9.7
Car / Taxi	4298	81.9	3844	78.3	6911	73.2	7242	77.4	1768	82.7	1230	78.9	1799	81.0	2103	81.6
Motorcycle	43	0.8	33	0.7	85	0.9	82	0.9	17	0.8	15	1.0	13	0.6	15	0.6
Pedal cycle	102	1.9	92	1.9	130	1.4	36	0.4	95	4.4	105	6.7	79	3.6	95	3.7
Total	5246		4912		9445		9355		2139		1558		2222		2576	

CL - Cycle lane.

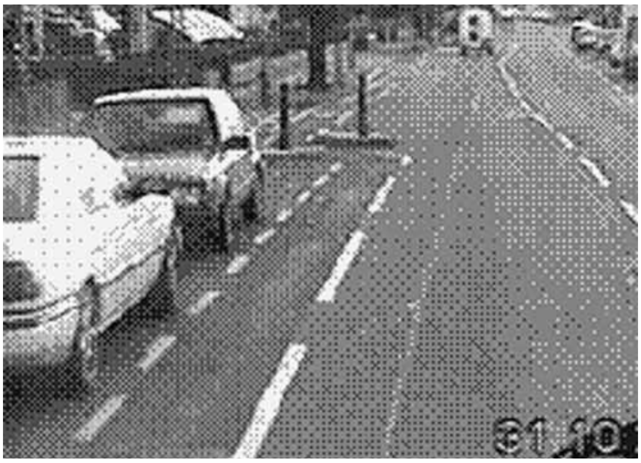
RH - Speed humps.

Cycle lane – Link 1

Control cycle, urban – Link 6



Road hump – Link 7



Traffic calming (other) – Link 9

Cycle lane – Link 12

Road hump – Link 18a

Figure 20 Examples of traffic management measures in Gloucester

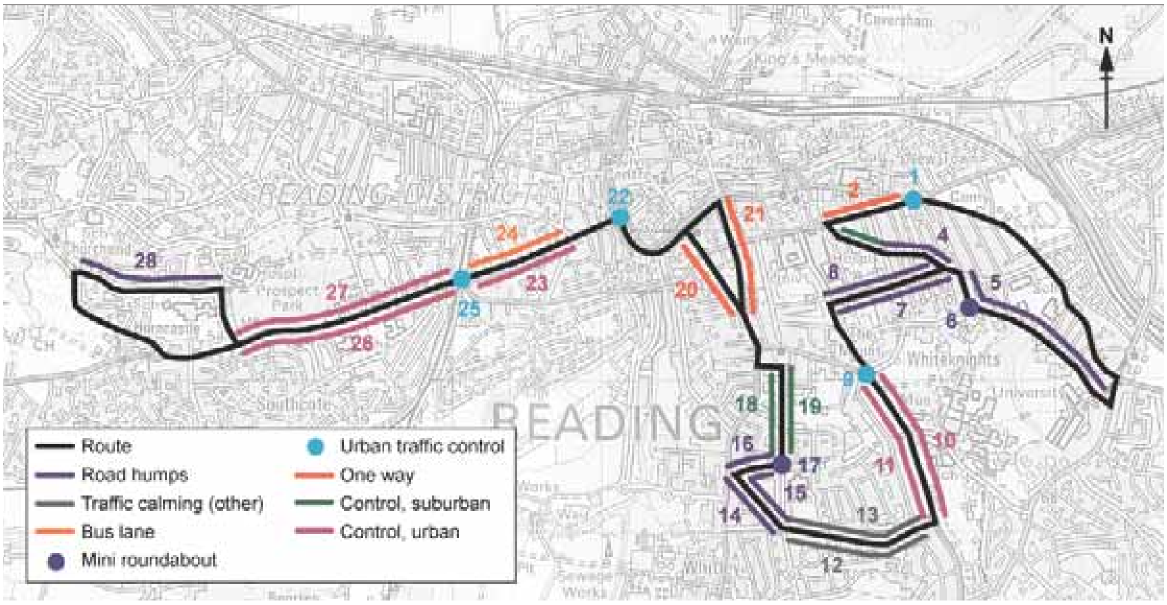


Figure 21 Reading links used for driving cycle development

Table 9 Number and percentage of each vehicle type at a selection of links – Reading

Vehicle category	*Link 10 (UC)*		*Link 11 (UC)*		*Link 12 (TC)*		*Link 13 (TC)*		*Link 20 (OW)*		*Link 21 (0W)*		*Link 26 (UC)*		*Link 27 (UC)*	
	No.	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*
HGV	59	2.2	84	2.8	30	1.6	29	2.5	306	3.3	224	2.6	520	5.3	589	5.7
Bus	77	2.8	68	2.2	20	1.1	20	1.7	320	3.4	488	5.6	121	1.2	127	1.2
LGV	207	7.6	261	8.6	203	11.1	121	10.3	1114	11.9	1019	11.7	976	10.0	1088	10.5
Car / Taxi	2328	85.3	2586	84.7	1555	85.3	1002	84.9	7435	79.3	6682	77.0	7903	80.9	8252	80.0
Motorcycle	24	0.9	17	0.6	7	0.4	5	0.4	63	0.7	72	0.8	130	1.3	115	1.1
Pedal cycle	34	1.2	36	1.2	9	0.5	3	0.3	135	1.4	192	2.2	114	1.2	147	1.4
Total	2729		3052		1824		1180		9373		8677		9764		10318	

UC - Urban control.
TC - Traffic calming (other).
OW - One way.

Control cycle, urban – Link 11

Traffic calming (other) – Link 12

Road hump/mini roundabout – Links 16/17

One way (plus narrowing) – Link 20

Bus lane – Link 24

Road hump – Link 28

Figure 22 Examples of traffic management measures in Reading

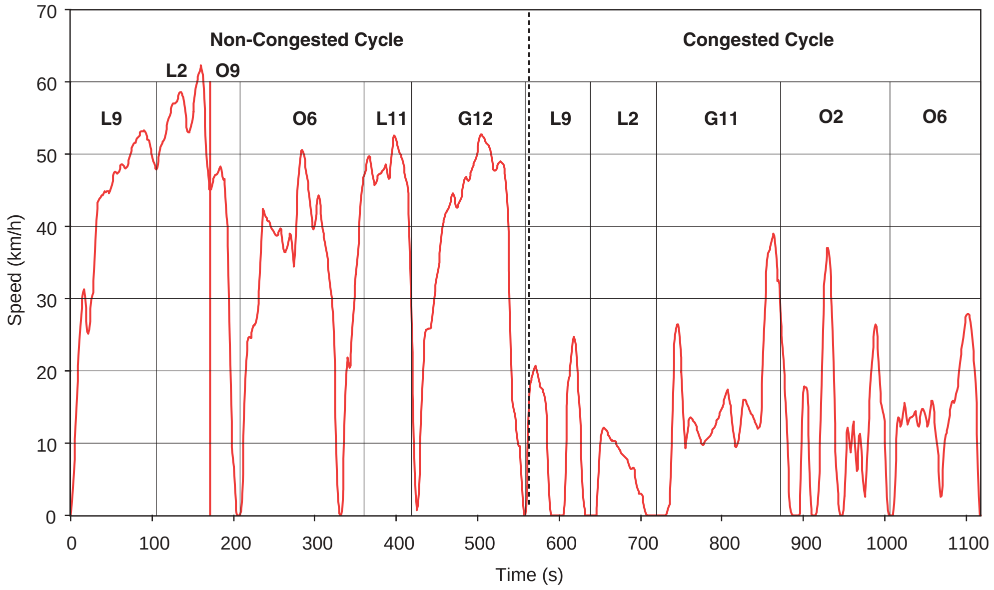


Figure 23 Example driving cycle

Table 10 A statistical summary of the HGV cycles and sub cycles

HGV cycles	*Distance (km)*	*Duration (s)*	*Average speed (km/h) Derived cycle*	*Average speed (km/h) All data*	*Max. speed (km/h)*	*Average positive accel. (m/s^2) Derived cycle*	*Average positive accel. (m/s^2) All data*	*Max. accel. (m/s^2)*
Road hump	5.75	1010	20.49	21.18	34.2	0.29	0.39	0.86
Traffic calming (other)	6.70	885	27.26	27.32	38.31	0.30	0.40	1.26
Cycle lane (CL)	6.83	985	24.93	25.08	57.04	0.34	0.30	1.14
CL: Non-congested	*5.21*	*513*	*36.53*	*36.93*	*57.04*	*0.30*	*0.29*	*1.12*
CL: Congested	*1.62*	*472*	*12.29*	*13.23*	*35.33*	*0.38*	*0.30*	*1.14*
Bus lane (BL)	6.56	930	25.37	24.21	52.19	0.33	0.33	1.68
BL: Non-congested	*4.80*	*472*	*36.64*	*35.79*	*52.19*	*0.29*	*0.29*	*0.96*
BL: Congested	*1.76*	*458*	*13.77*	*12.62*	*43.21*	*0.37*	*0.36*	*1.68*
One way (OW)	4.02	947	15.26	15.21	43.71	0.37	0.46	1.11
OW: Non-congested	*3.07*	*535*	*20.64*	*21.17*	*43.71*	*0.35*	*0.42*	*1.11*
OW: Congested	*0.95*	*412*	*12.67*	*9.26*	*34.52*	*0.40*	*0.43*	*1.04*
Mini-roundabouts	5.80	927	22.51	23.87	48.39	0.34	0.44	1.05
Urban traffic control	5.07	954	19.11	20.52	45.47	0.40	0.42	1.22
Control, congested	2.51	835	10.84	12.09	48.52	0.37	0.42	1.33
Control, non-congested	8.81	875	36.22	34.85	66.69	0.34	0.34	1.28
Control, suburban	5.12	790	23.31	24.44	51.10	0.36	0.43	0.96

Table 11 A statistical summary of the bus cycles and sub cycles

Bus cycles	*Distance (km)*	*Duration (s)*	*Average speed (km/h)*		*Max. speed (km/h)*	*Average positive accel. (m/s²)*		*Max. accel. (m/s²)*
			Derived cycle	*All data*		*Derived cycle*	*All data*	
Road hump	5.31	944	20.25	21.34	43.26	0.43	0.37	1.28
Traffic calming (other)	5.94	855	24.97	26.35	45.25	0.37	0.29	1.45
Cycle lane (CL)	5.65	1080	18.82	20.05	45.02	0.47	0.44	3.08
CL: Non-congested	*4.12*	*542*	*27.31*	*28.46*	*45.02*	*0.52*	*0.46*	*3.08*
CL: Congested	*1.53*	*538*	*10.26*	*11.65*	*31.20*	*0.41*	*0.42*	*1.19*
Bus lane (BL)	8.34	1192	25.17	23.48	39.94	0.46	0.55	1.73
BL: Off peak	*4.12*	*611*	*25.00*	*23.86*	*39.94*	*0.48*	*0.56*	*1.73*
BL: Peak	*3.93*	*581*	*24.31*	*23.09*	*38.77*	*0.44*	*0.53*	*1.53*
One Way (OW)	4.36	941	16.65	17.01	41.42	0.52	0.56	1.99
OW: Non-congested	*2.80*	*471*	*21.35*	*21.17*	*41.42*	*0.51*	*0.57*	*1.55*
OW: Congested	*1.56*	*470*	*11.92*	*12.84*	*39.45*	*0.53*	*0.56*	*1.99*
Mini-roundabouts	7.88	1076	26.33	25.09	46.45	0.38	0.41	1.28
Urban traffic control	5.41	894	21.76	22.09	49.56	0.50	0.44	1.79
Control, congested	3.08	1051	10.53	11.51	38.20	0.39	0.49	1.19
Control, non-congested	7.61	983	27.82	28.89	47.68	0.49	0.55	1.80
Control, suburban	6.39	886	25.95	27.42	48.00	0.40	0.50	1.43

Table 12 A statistical summary of the car cycles and sub cycles

Car cycles	*Distance (km)*	*Duration (s)*	*Average speed (km/h)*		*Max. speed (km/h)*	*Average positive accel. (m/s²)*		*Max. accel. (m/s²)*
			Derived cycle	*All data*		*Derived cycle*	*All data*	
Road hump	6.80	804	30.41	29.79	47.09	0.42	0.42	1.47
Traffic calming (other)	7.99	824	34.87	34.31	57.81	0.38	0.38	1.60
Cycle lane (CL)	7.92	1117	25.52	24.97	62.22	0.41	0.41	1.62
CL: Non-congested	*6.04*	*556*	*39.07*	*37.65*	*62.22*	*0.35*	*0.38*	*1.41*
CL: Congested	*1.88*	*561*	*12.02*	*12.42*	*38.98*	*0.47*	*0.44*	*1.62*
Bus lane (BL)	7.84	1067	26.42	25.61	57.30	0.51	0.51	1.88
BL: Non-congested	*6.02*	*524*	*41.31*	*39.73*	*56.18*	*0.44*	*0.46*	*1.88*
BL: Congested	*1.81*	*543*	*12.07*	*11.49*	*57.30*	*0.56*	*0.66*	*1.81*
One way (OW)	5.94	1051	20.31	20.00	47.78	0.47	0.47	1.69
OW: Non-congested	*4.24*	*543*	*28.05*	*28.15*	*47.78*	*0.45*	*0.54*	*1.69*
OW: Congested	*1.70*	*508*	*12.02*	*11.86*	*37.24*	*0.51*	*0.56*	*1.36*
Mini-roundabouts	6.90	808	30.71	30.77	48.22	0.47	0.47	1.53
Urban traffic control	7.04	914	27.75	26.55	67.50	0.51	0.57	2.32
Control, congested	3.66	1057	12.44	12.30	47.44	0.47	0.47	1.60
Control, non-congested	9.92	950	37.75	36.89	62.80	0.39	0.40	1.66
Control, suburban	8.26	805	36.88	37.47	60.64	0.45	0.45	1.72

Table 13 A statistical summary of the LGV cycles and sub cycles

LGV cycles	*Distance (km)*	*Duration (s)*	*Average speed (km/h)* *Derived cycle*	*All data*	*Max. speed (km/h)*	*Average positive accel. (m/s²)* *Derived cycle*	*All data*	*Max. accel. (m/s²)*
Road hump	8.02	1027	28.10	27.53	45.86	0.35	0.43	1.19
Traffic calming (other)	8.49	909	33.59	32.98	47.53	0.33	0.38	1.45
Cycle lane (CL)	8.87	1195	26.69	25.61	67.65	0.42	0.0.37	1.55
CL: Non-congested	*6.91*	*596*	*41.70*	*39.65*	*67.65*	*0.39*	*0.35*	*1.36*
CL: Congested	*1.95*	*599*	*11.73*	*11.17*	*40.08*	*0.45*	*0.38*	*1.55*
Bus lane (BL)	7.73	1168	23.81	23.54	53.53	0.38	0.42	1.43
BL: Non-congested	*6.10*	*588*	*37.23*	*36.57*	*53.53*	*0.33*	*0.40*	*1.21*
BL: Congested	*1.64*	*580*	*10.18*	*10.51*	*45.09*	*0.47*	*0.44*	*1.43*
One way (OW)	6.33	1155	19.71	20.60	46.81	0.47	0.51	1.52
OW: Non-congested	*4.42*	*528*	*30.08*	*29.52*	*46.81*	*0.45*	*0.50*	*1.52*
OW: Congested	*1.91*	*627*	*10.97*	*11.67*	*37.78*	*0.49*	*0.52*	*1.25*
Mini-roundabouts	7.30	842	31.16	30.52	51.12	0.43	0.44	1.40
Urban traffic control	6.73	1006	24.06	24.23	54.43	0.50	0.51	1.52
Control, congested	3.26	1142	10.28	9.66	42.77	0.45	0.53	1.45
Control, non-congested	10.65	1016	37.69	37.29	59.26	0.38	0.45	1.77
Control, suburban	8.81	881	35.98	36.04	51.56	0.38	0.39	1.45

Table 14 A comparison of the average speeds of all cycles and sub cycles

	Average Speed (km/h)				*Difference in Speed (km/h)*	
Driving cycles	*HGV*	*Bus*	*Car*	*LGV*	*HGV - Bus*	*Car - LGV*
Road hump	20.49	20.25	28.1	30.41	0.24	2.31
Traffic calming (other)	27.26	24.97	33.59	34.87	2.29	1.28
Cycle lane (CL)	24.93	18.82	26.69	25.52	6.11	-1.17
CL: Non-congested	*36.53*	*27.31*	*41.7*	*39.07*	*9.22*	*-2.63*
CL: Congested	*12.29*	*10.26*	*11.73*	*12.02*	*2.03*	*0.29*
Bus lane (BL)	25.37	25.17	23.81	26.42	0.2	2.61
BL: Non-congested / Off peak	*36.64*	*25*	*37.23*	*41.31*	*11.64*	*4.08*
BL: Congested / Peak	*13.77*	*24.31*	*10.18*	*12.07*	*-10.54*	*1.89*
One way (OW)	15.26	16.65	19.71	20.31	-1.39	0.6
OW: Non-congested	*20.64*	*21.35*	*30.08*	*28.05*	*-0.71*	*-2.03*
OW: Congested	*12.67*	*11.92*	*10.97*	*12.02*	*0.75*	*1.05*
Mini-roundabouts	22.51	26.33	31.16	30.71	-3.82	-0.45
Urban traffic control	19.11	21.76	24.06	27.75	-2.65	3.69
Control, congested	10.84	10.53	10.28	12.44	0.31	2.16
Control, non-congested	36.22	27.82	37.69	37.75	8.4	0.06
Control, suburban	23.31	25.95	35.98	36.88	-2.64	0.9

6 Summary

The Environment Act 1995 requires local authorities in the UK to review and assess air quality in their areas, with the primary objective being to identify locations where the standards set out in legislation are likely to be breached. This review and assessment may result in the declaration of an Air Quality Management Area (AQMA) and the need for a Local Air Quality Action Plan. In most urban areas, road traffic is an important consideration when drawing up an Action Plan due to its large contribution to emissions of some pollutants. Government guidance suggests traffic management as a method of controlling emissions from traffic and thus improving air quality. Local authorities therefore need to be able to predict the effects traffic management schemes may have on vehicle emissions.

The emissions performance of vehicles in relation to traffic management, particularly heavy-duty vehicles, is not well documented. To address this gap in research TRL Limited (TRL) was commissioned by CLT Division of the Department for Transport (DfT) to undertake a study to assemble a database of vehicle operation profiles for a range of vehicles (car, LGV, HGV and bus) and a range of traffic management schemes. The specific objectives were:

i To identify a range of traffic management schemes for which driving cycles could be developed.

ii To measure operational profiles for a range of vehicles in relation to the schemes identified.

iii To produce generic driving cycles for use in emissions testing.

Driving cycles were developed for seven generic categories of traffic management measure:

- Bus lanes.
- Cycle lanes.
- Traffic calming: road humps.
- Traffic calming: other.
- Mini roundabouts.
- One-way systems.
- Urban traffic control (UTC).

In addition to the above, three control cycles were developed to represent stretches of road with no traffic management.

Examples of each type of traffic management were identified in more than one town or city in the UK to minimise, as far as possible, any site-specific influences on driving patterns. Six sites were chosen in total, each having a substantial number of traffic management measures. These were:

- West London (Kingston/Richmond area).
- Southampton.
- Havant.
- Oxford.
- Gloucester.
- Reading.

At each site a car, a light goods vehicle, a heavy goods vehicle and bus were equipped with a PC-based data logger and a Global Positioning System (GPS), both of which collected continuous vehicle speed data as the vehicles were driven around a set routes. All data collection was undertaken from 07:00-11:00 and 15:00-19:00 from a Tuesday to a Thursday. This provided data for morning and evening, peak and off peak periods. It was also all undertaken during school term time to avoid the fluctuating flows of school holiday traffic. Classified traffic counts were also obtained for each site to provide information on the volumes of traffic using the routes that were driven.

Once the data had been collected three distinct stages were followed to produce the final driving cycles. These were the modification of the data into second by second speed profiles, the extraction of sections of the profiles to compile databases of traffic management specific operation profiles for each vehicle and finally the development of the final cycles.

In total forty driving cycles were developed. Ten cycles were developed for each vehicle type: one cycle was developed for each of the seven traffic management measure categories and the three control categories.

The HGV and bus driving cycles produced within the work have been used in a separate TRL project (UG216 - Exhaust Emissions from Heavy Duty Vehicles), also commissioned by CLT Division of DfT.

7 Acknowledgements

Thanks are due to the staff at the six bus companies (namely London Central Bus Company, Goldline Travel in Reading, Boomerang Bus Company in Tewkesbury, First Southampton, Stagecoach South Ltd in Havant and The Oxford Bus Company).

8 References

Boulter P G, Latham S, and Ainge M (1999). Driving cycles for measuring passenger car emissions on roads with traffic calming measures. The Science of the Total Environment, *Elsevier Science*. 235, pp. 77-89.

Boulter P, Hickman A J, Latham S and Layfield R, Davison P and P Whiteman (2001). *The impacts of traffic calming measures on vehicle exhaust emissions.* TRL Report TRL482. Crowthorne: TRL Limited.

Cloke J, Webster D, Boulter P, Harris G, Stait R, Abbot P and Chinn L (1999). *Traffic calming: Environmental assessment of the Leigh Park area safety scheme*. TRL Report TRL397. Crowthorne: TRL Limited.

DEFRA (2003). *Part IV of the Environment Act 1995, Local Air Quality Management, Policy Guidance, LAQM. PG(03).* Retrieved: 2003, from www.defra.gov.uk.

Krawack S (1993). Traffic management and emissions. *The science of the total environment*, 1993, 134 306-314.

Sturm P, Almbauer R A and Kunz R (1994). Air quality study for the city of Graz, Austria. *Urban Air Pollution. Vol 1.* (Ed H Power, N Moussiopouloh and C A Brebbia) Computational Mechanics Publications 1994.

Appendix A: HGV driving cycles

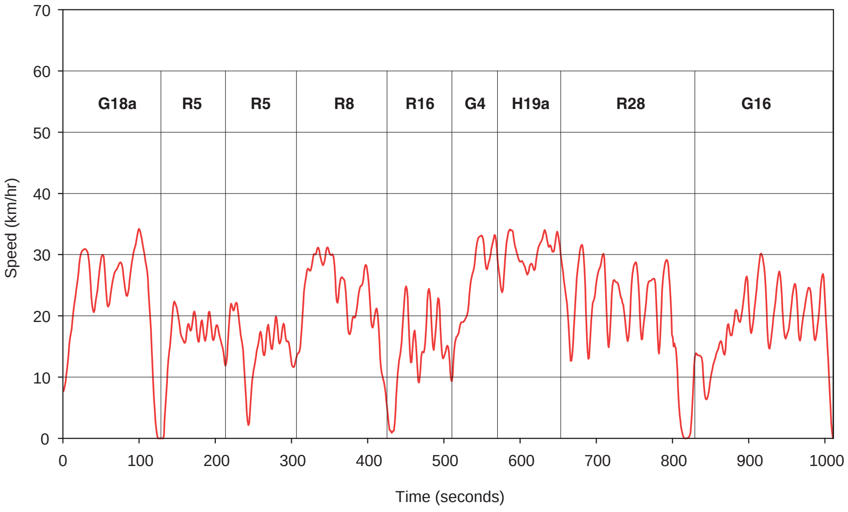


Figure A1 HGV driving cycle 1: road hump cycle

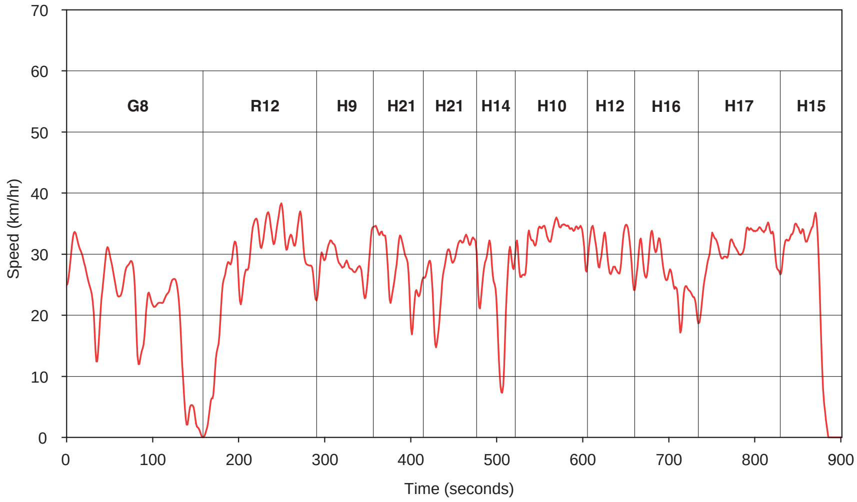


Figure A2 HGV driving cycle 2: traffic calming (other) cycle

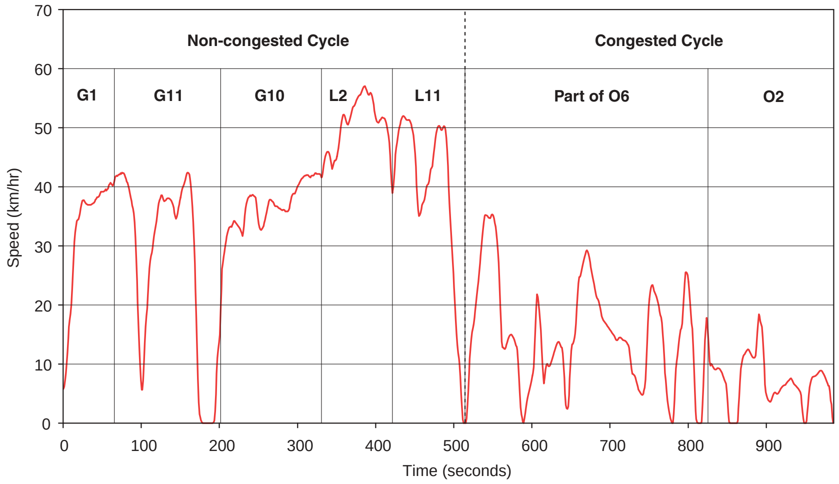


Figure A3 HGV driving cycle 3: cycle lane cycle

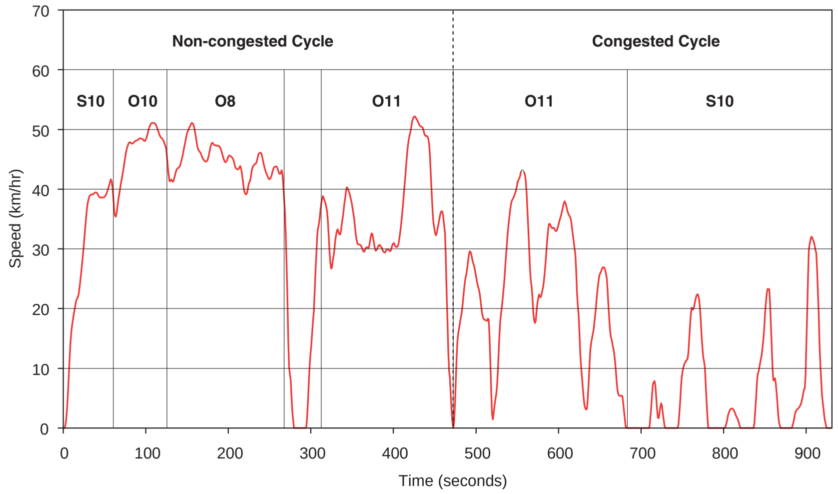


Figure A4 HGV driving cycle 4: bus lane cycle

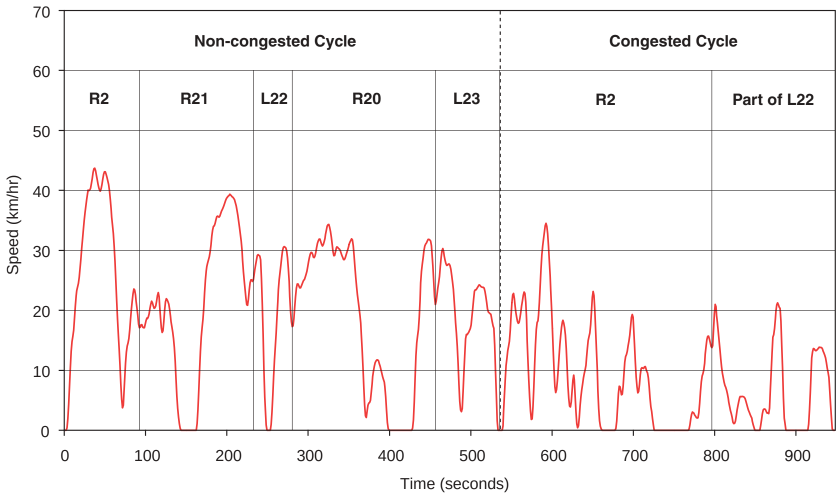


Figure A5 HGV driving cycle 5: one way cycle

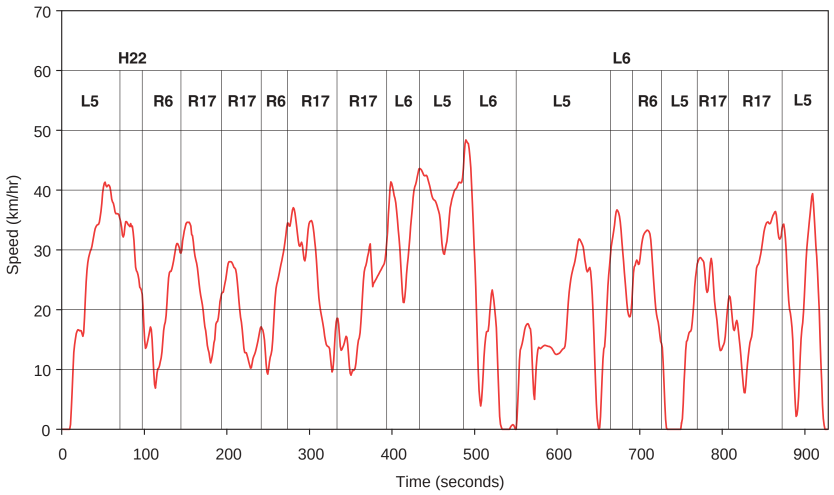


Figure A6 HGV driving cycle 6: mini-roundabout cycle

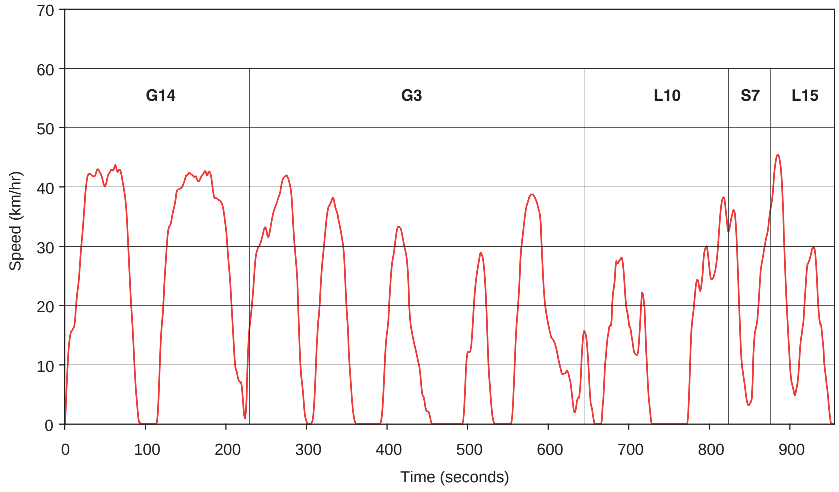


Figure A7 HGV driving cycle 7: urban traffic control (UTC) cycle

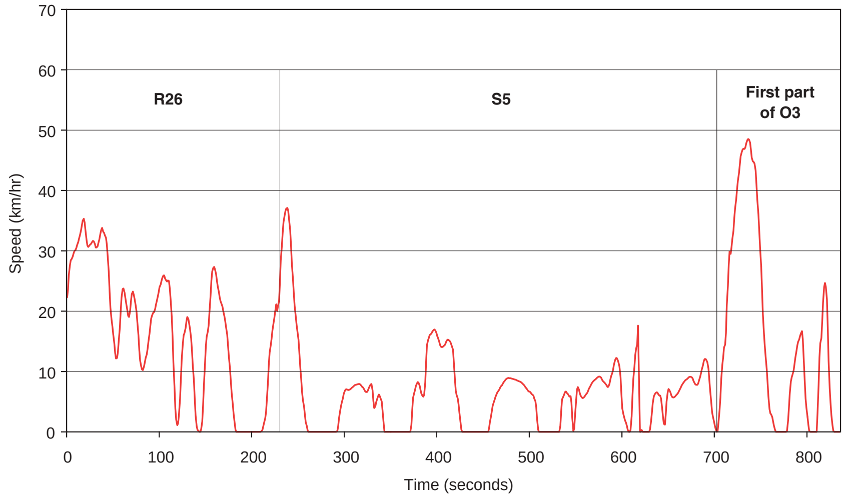


Figure A8 HGV driving cycle 8: congested control cycle

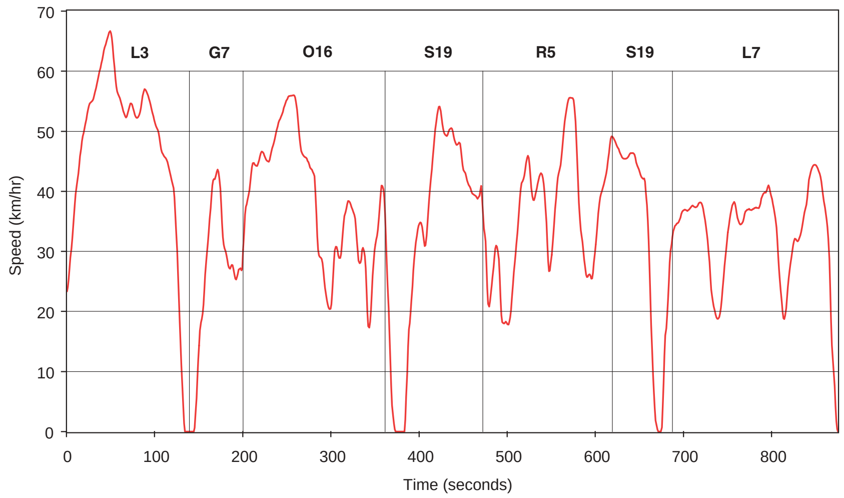


Figure A9 HGV driving cycle 9: non-congested control cycle

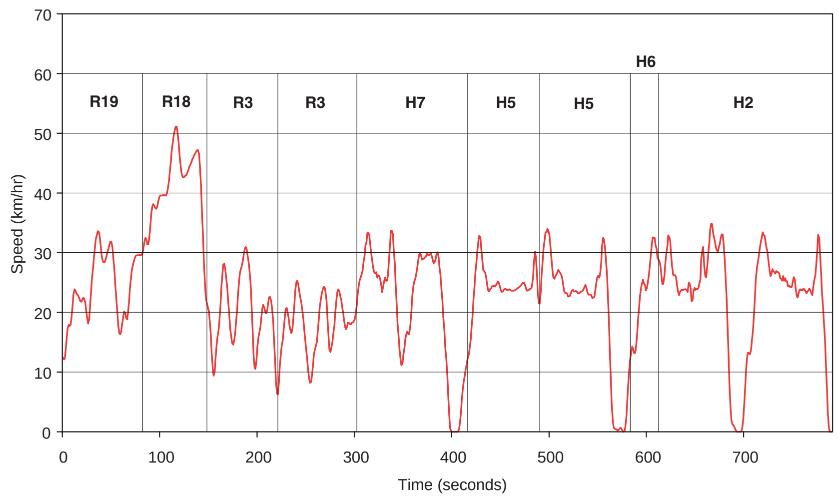


Figure A10 HGV driving cycle 10: suburban control cycle

Appendix B: Bus driving cycles

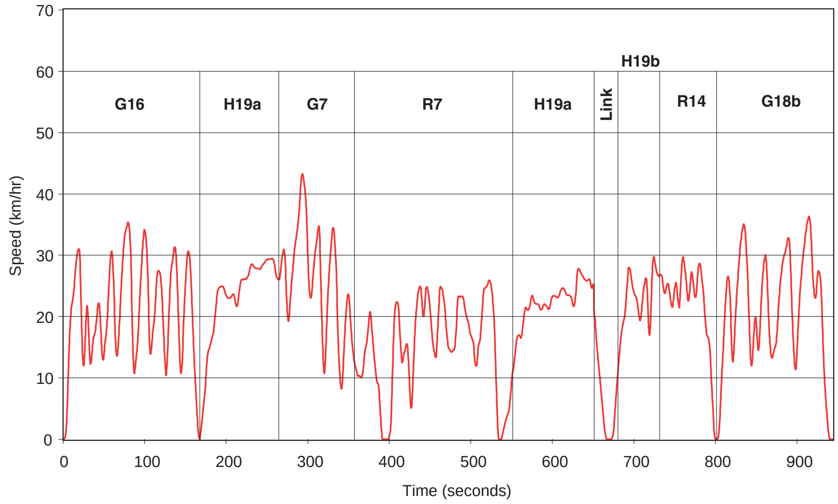


Figure B1 Bus driving cycle 1: road hump cycle

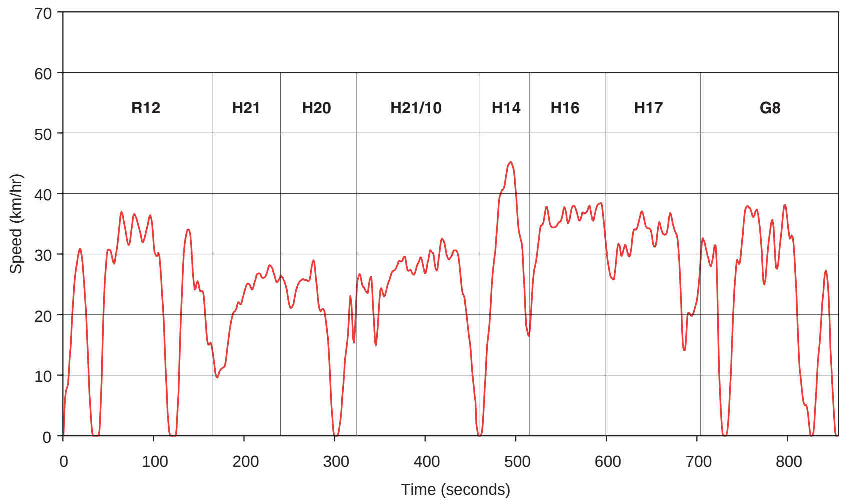


Figure B2 Bus driving cycle 2: traffic calming (other) cycle

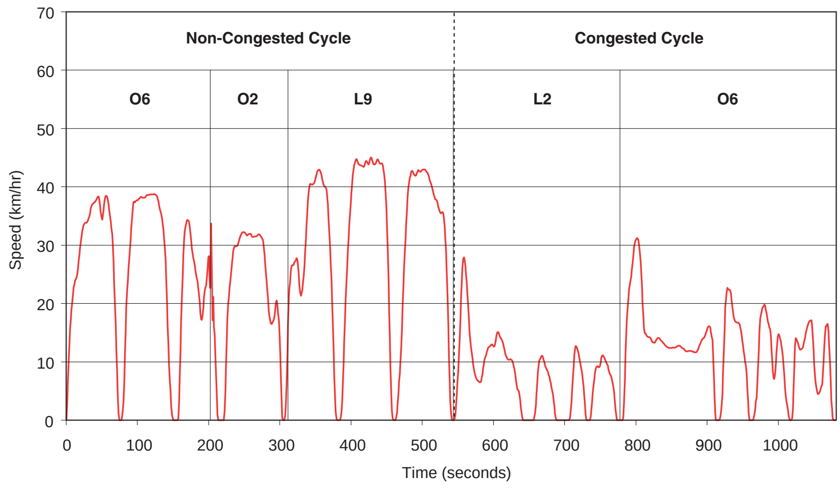


Figure B3 Bus driving cycle 3: cycle lane cycle

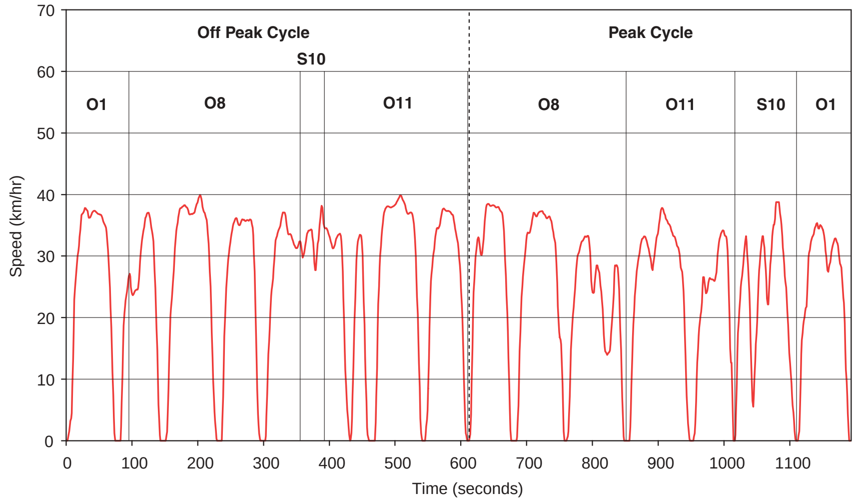


Figure B4 Bus driving cycle 4: bus lane cycle

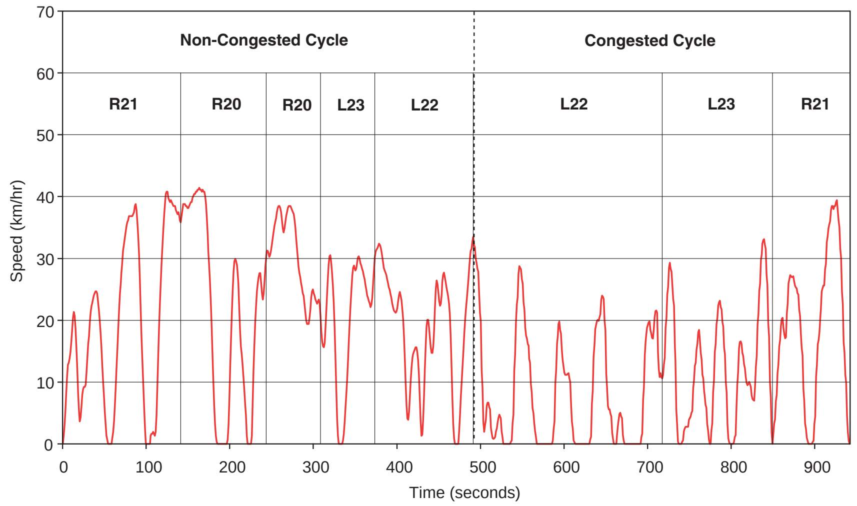


Figure B5 Bus driving cycle 5: one way cycle

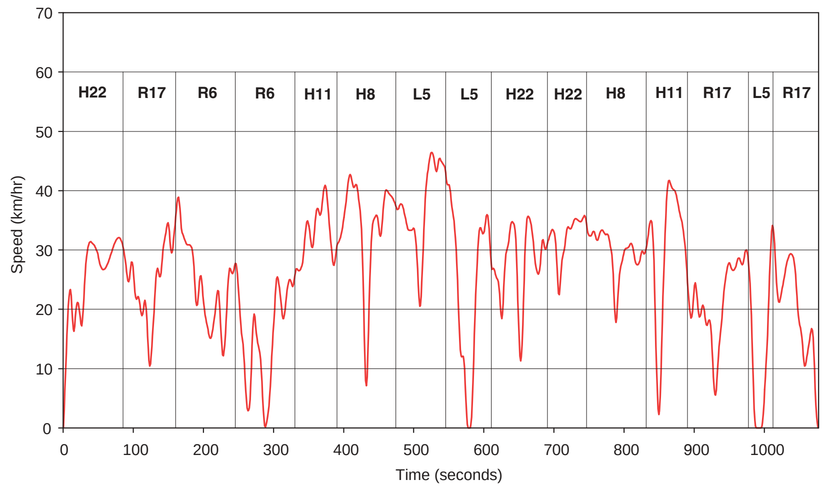


Figure B6 Bus driving cycle 6: mini roundabout cycle

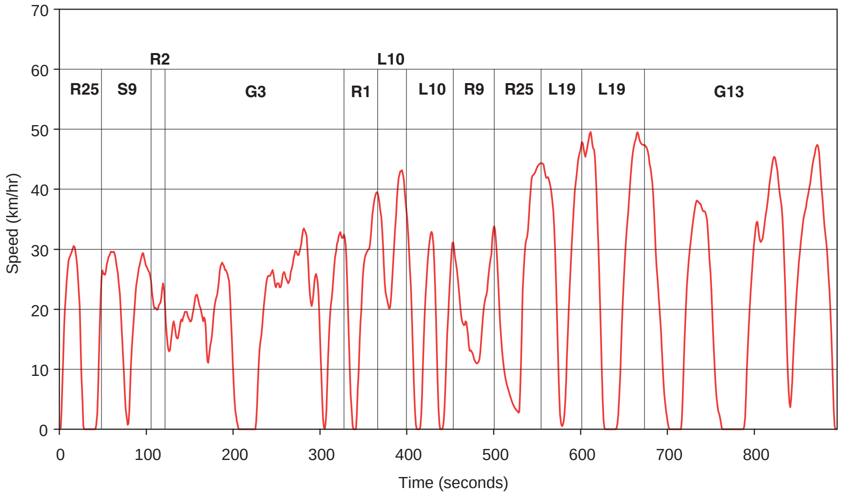


Figure B7 Bus driving cycle 7: urban traffic control (UTC) cycle

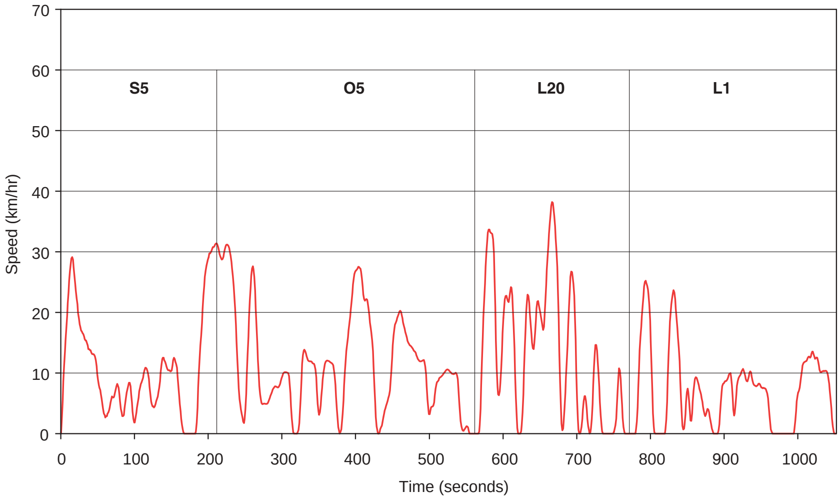


Figure B8 Bus driving cycle 8: congested control cycle

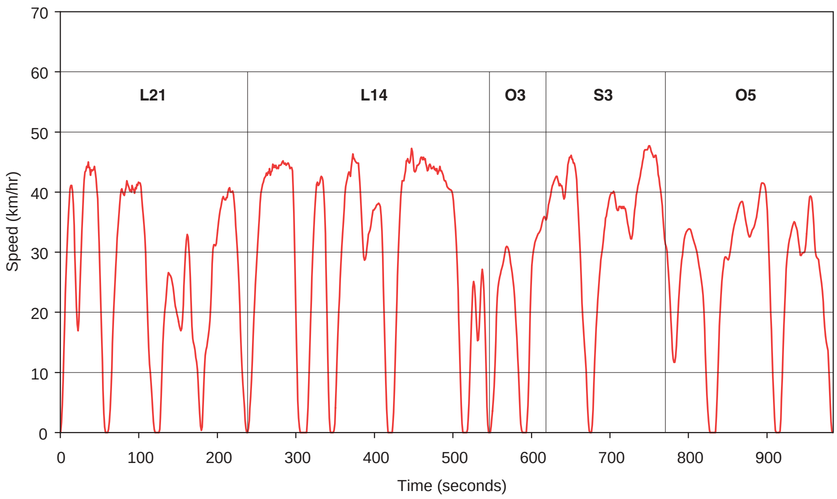


Figure B9 Bus driving cycle 9: non-congested control cycle

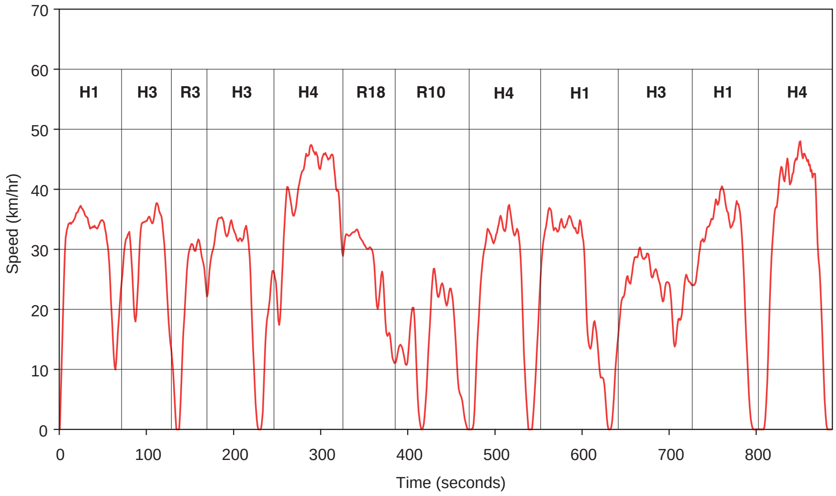


Figure B10 Bus driving cycle 10: suburban control cycle

Appendix C: Car driving cycles

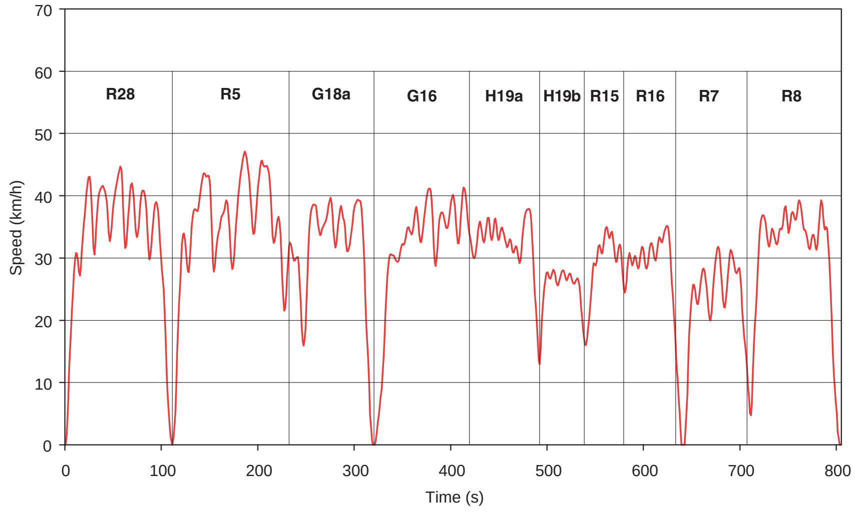


Figure C1 Car driving cycle 1: road hump cycle

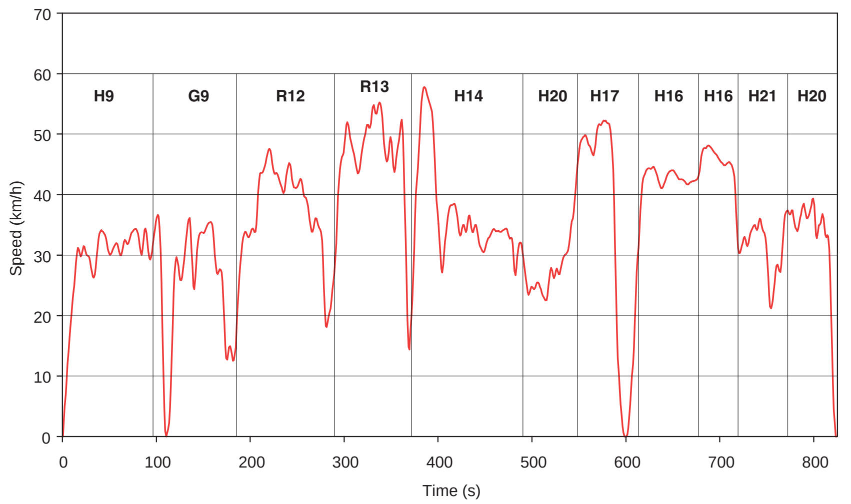


Figure C2 Car driving cycle 2: traffic calming (other) cycle

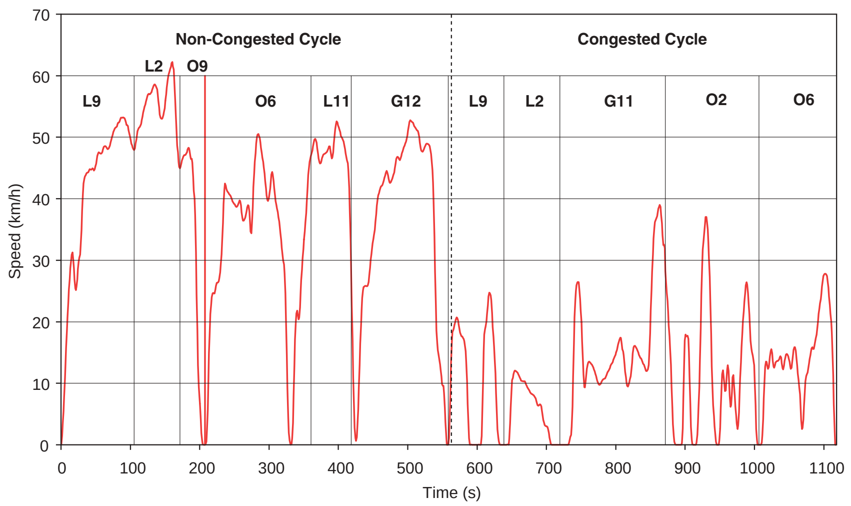


Figure C3 Car driving cycle 3: cycle lane cycle

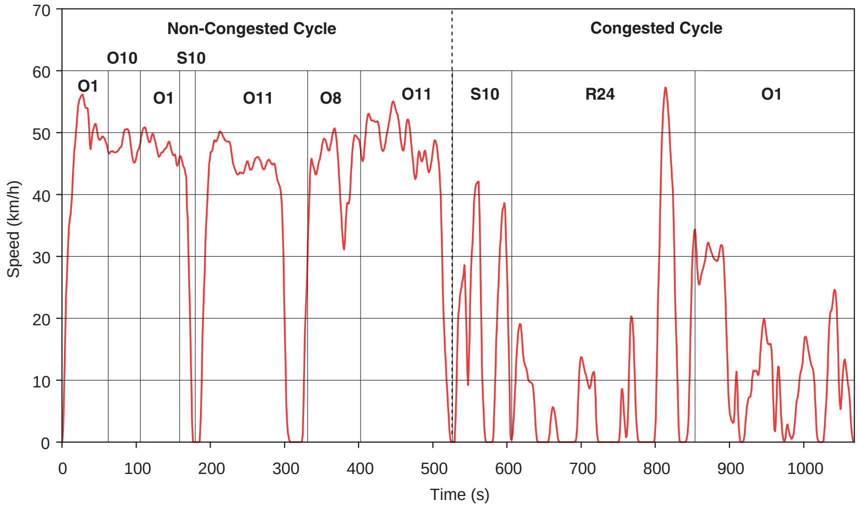


Figure C4 Car driving cycle 4: bus lane cycle

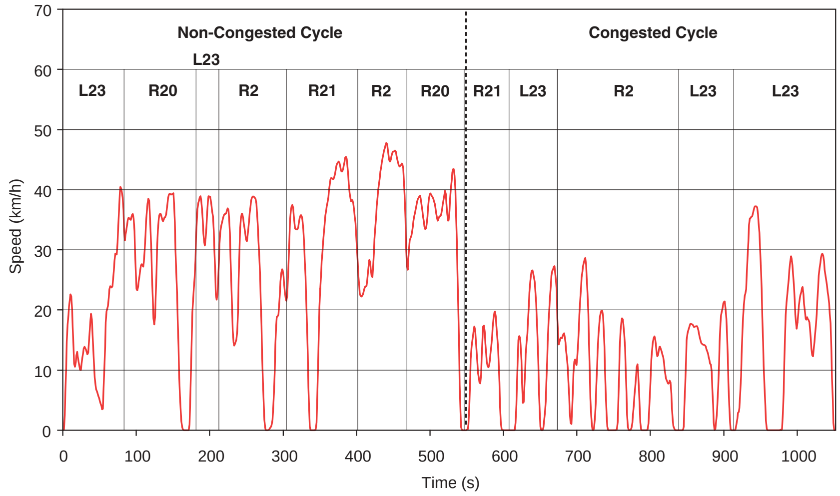


Figure C5 Car driving cycle 5: one way cycle

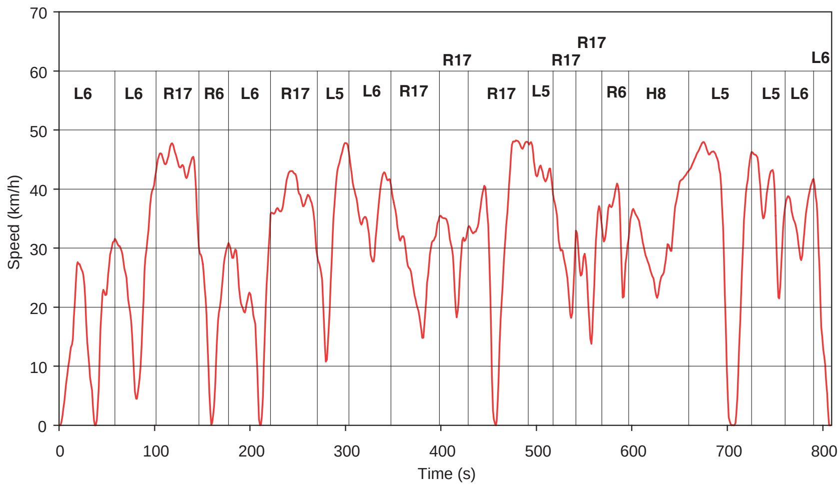


Figure C6 Car driving cycle 6: mini roundabout cycle

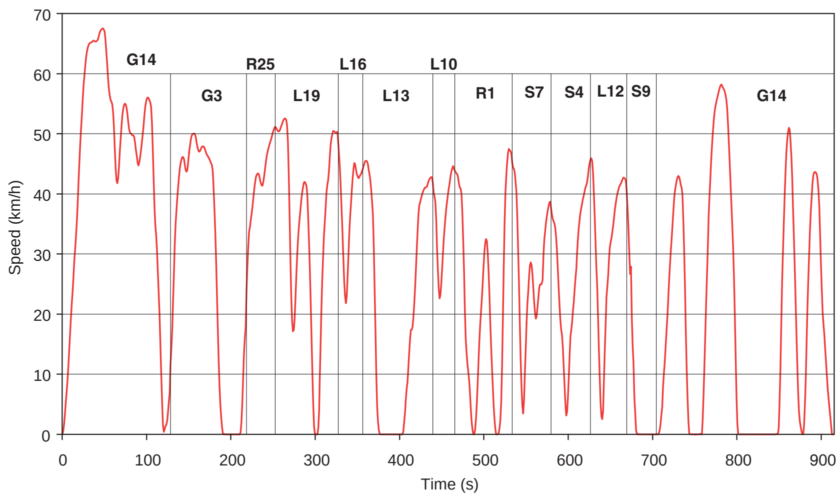


Figure C7 Car driving cycle 7: urban traffic control (UTC) cycle

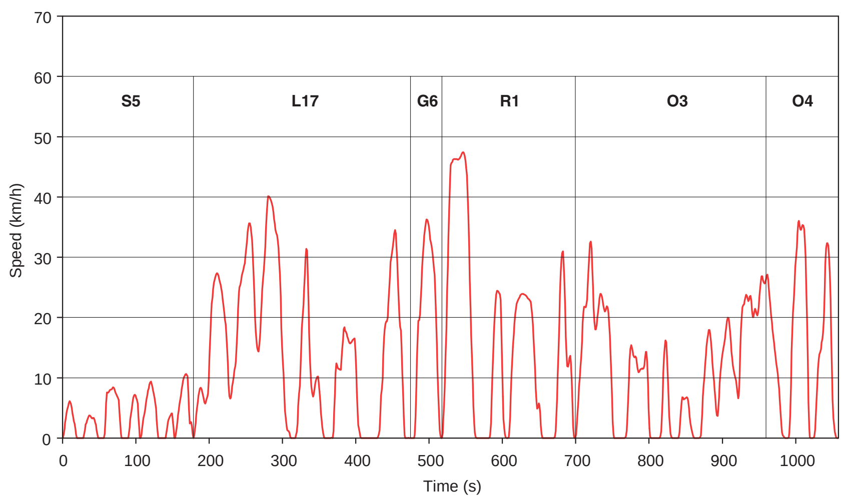


Figure C8 Car driving cycle 8: congested control cycle

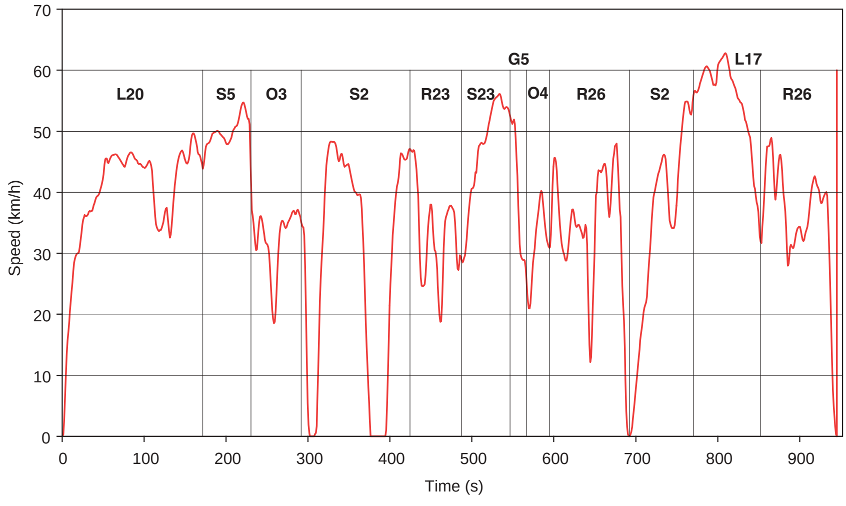


Figure C9 Car driving cycle 9: non-congested control cycle

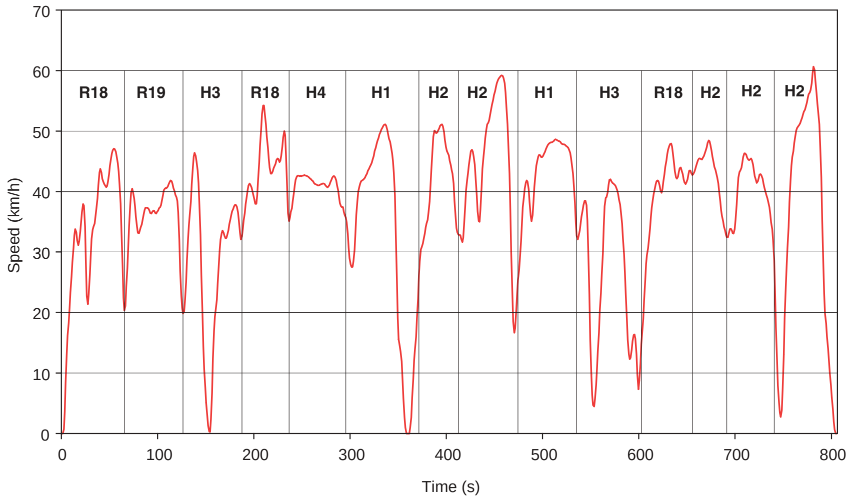


Figure C10 Car driving cycle 10: suburban control cycle

Appendix D: LGV driving cycles

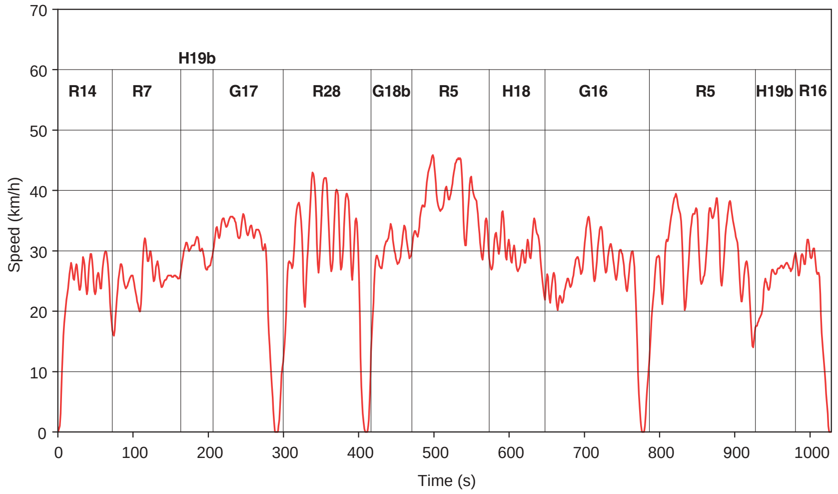


Figure D1 LGV driving cycle 1: road hump cycle

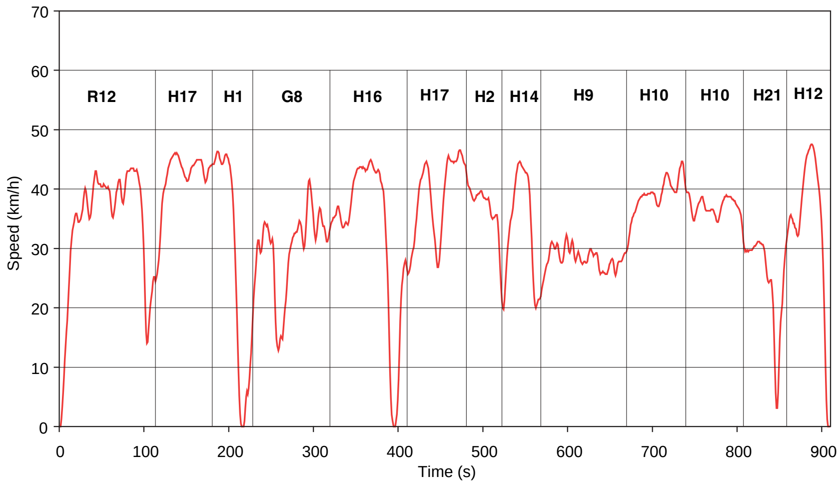


Figure D2 LGV driving cycle 2: traffic calming (other) cycle

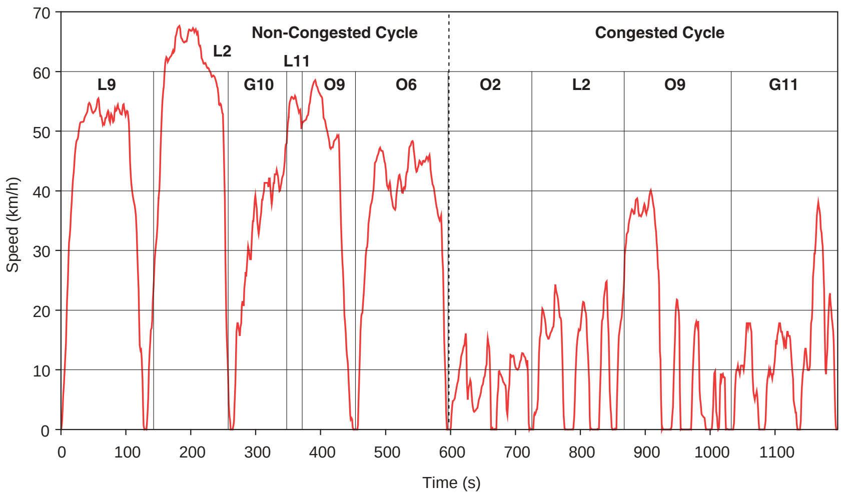


Figure D3 LGV driving cycle 3: cycle lane cycle

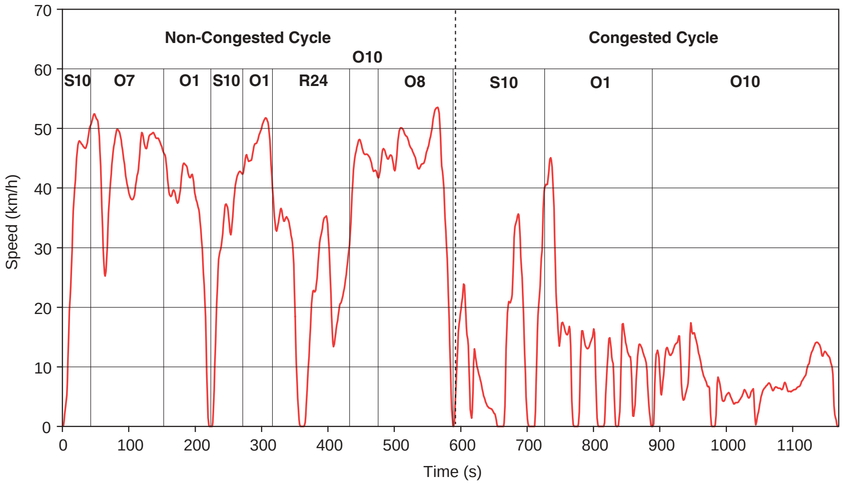


Figure D4 LGV driving cycle 4: bus lane cycle

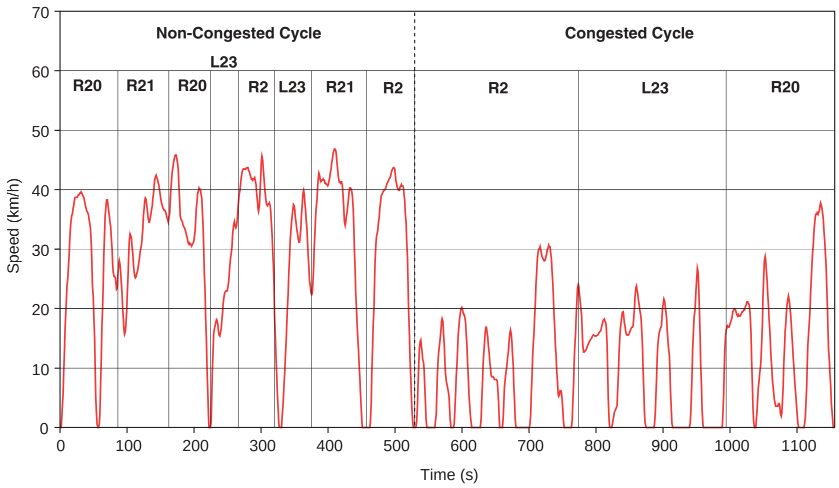


Figure D5 LGV driving cycle 5: one way cycle

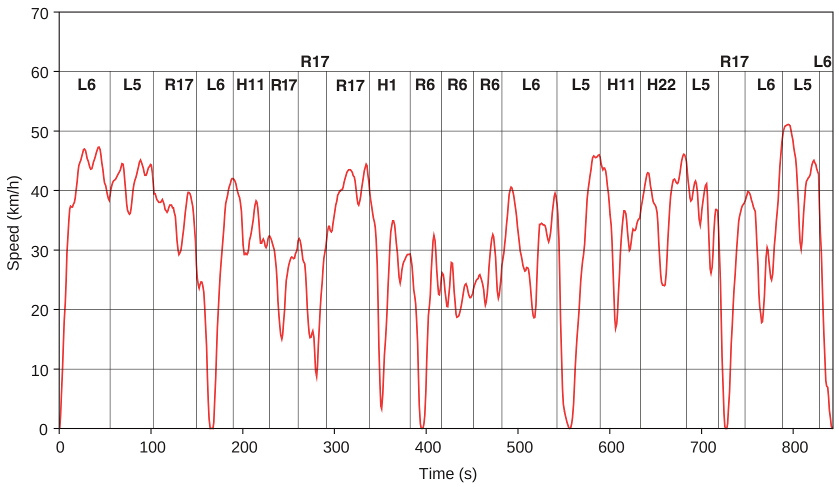


Figure D6 LGV driving cycle 6: mini roundabout cycle

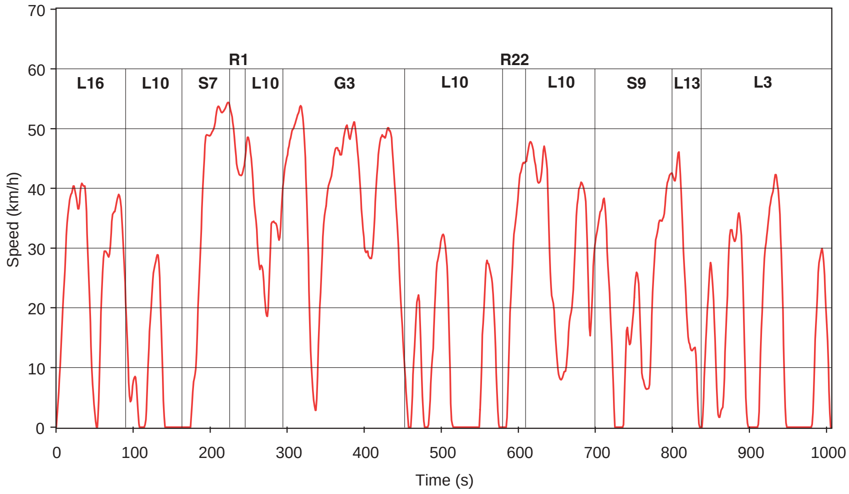


Figure D7 LGV driving cycle 7: urban traffic control (UTC) cycle

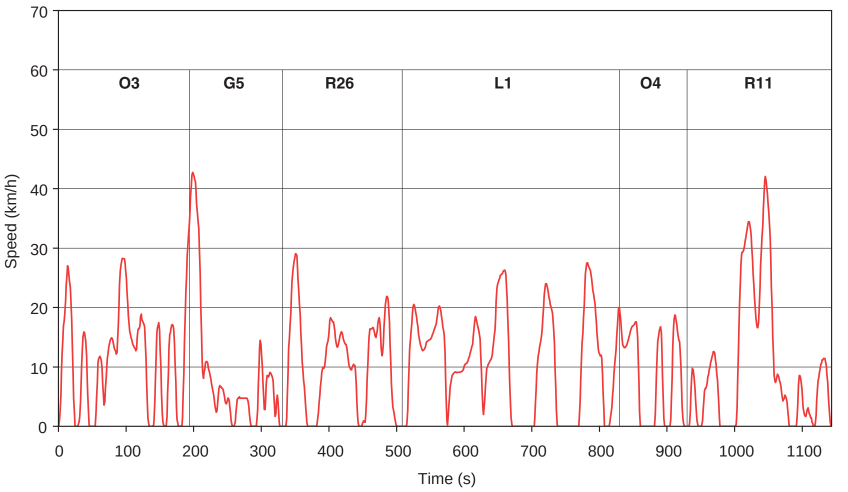


Figure D8 LGV driving cycle 8: congested control cycle

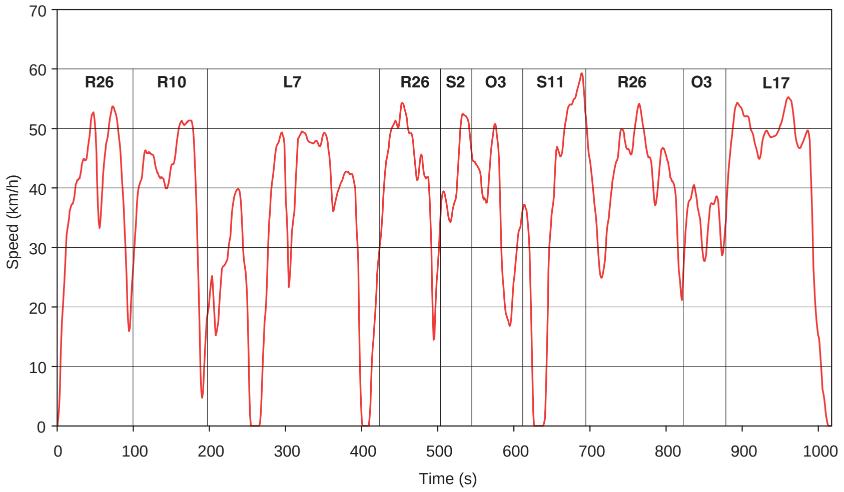


Figure D9 LGV driving cycle 9: non-congested control cycle

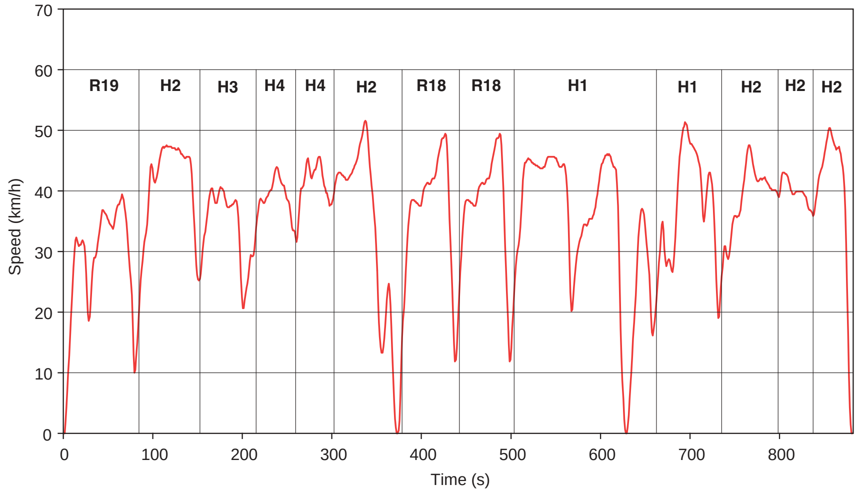


Figure D10 LGV driving cycle 10: suburban control cycle

Abstract

A database of 40 vehicle driving cycles, for the purpose of measuring vehicle emissions in the laboratory, has been developed for a range of traffic management schemes and a range of vehicle types. The driving cycles were developed from real-world operational profiles which were measured for a car, a light goods vehicle, a bus and a heavy goods vehicle. At six locations the four vehicles were driven over set routes which featured a selection of the following traffic management schemes: bus lane, cycle lane, road humps, other traffic calming, one way system, mini roundabout and urban traffic control. Speed data were collected using both a PC-based data logger and a Global Positioning System (GPS). The GPS was used to record both vehicle speed and location. The driving cycles were developed by extracting sections from the raw speed profiles relevant to the traffic management schemes of interest. Ten driving cycles were developed for each vehicle type: seven traffic management cycles and three control cycles. Emission measurements relating to some of these driving cycles are being conducted in a separate TRL project.

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