WLTP DHC subgroup	
Date	**30/10/09**
Title	**Draft methodology to develop WLTP drive cycle**
Working paper number	**WLTP-DHC-02-05**

1.0. Introduction

This paper sets out the methodology that will be used to generate the world harmonized light duty driving test cycle (WLTC).

This methodology was developed and agreed following a full discussion at the 1st DHC subgroup meeting (held in September 2009). An outline methodology, including details on developing a data weighting matrix and gearshift points, is presented here.

1.1. Terminology

Term	Description
Drive cycle	The speed–time trace that defines how a vehicle will be "driven" during the WLTC test
Drive cycle phase (phase)	Part of a drive cycle; the WLTC will have three phases representative of urban, rural and motorway driving
Drive cycle sub phase (sub phase)	Part of a drive cycle phase; the WLTC might have an urban phase divided into two sub phases (e.g. congested and non-congested)
Short trip (ST)	Any period of driving cycle from standing start to next vehicle stop.
Regional weighting factor	Weighting factor, determined by total number of vehicle hours per region, used to weight data from regions when creating the unified distributions[1]
Driving conditions weighting factors	Weighting factors referring to driving period, road type
Driving period	Peak, off-peak, weekend
Region	Geographical region represented by each Contracting Party
Traffic volume	Number of vehicles

[1] At the 1st DHC meeting India and China raised objections to determining regional weighting factors based on current vehicle hours in each region. It was agreed to note these objections. For the purposes of developing a draft methodology, it is assumed that regional weighting factors will be determined as stated in table 1.1 with the proviso that the method for determining these weighting factors may be changed at a later stage if required.

2.0. Overview of proposed drive cycle development

Figure 2.1 gives an outline of the steps involved in the development of the WLTC. The work comprises four work streams:

a. In-use data collection

b. Determination of weighting factors

c. Data analysis and drive cycle development

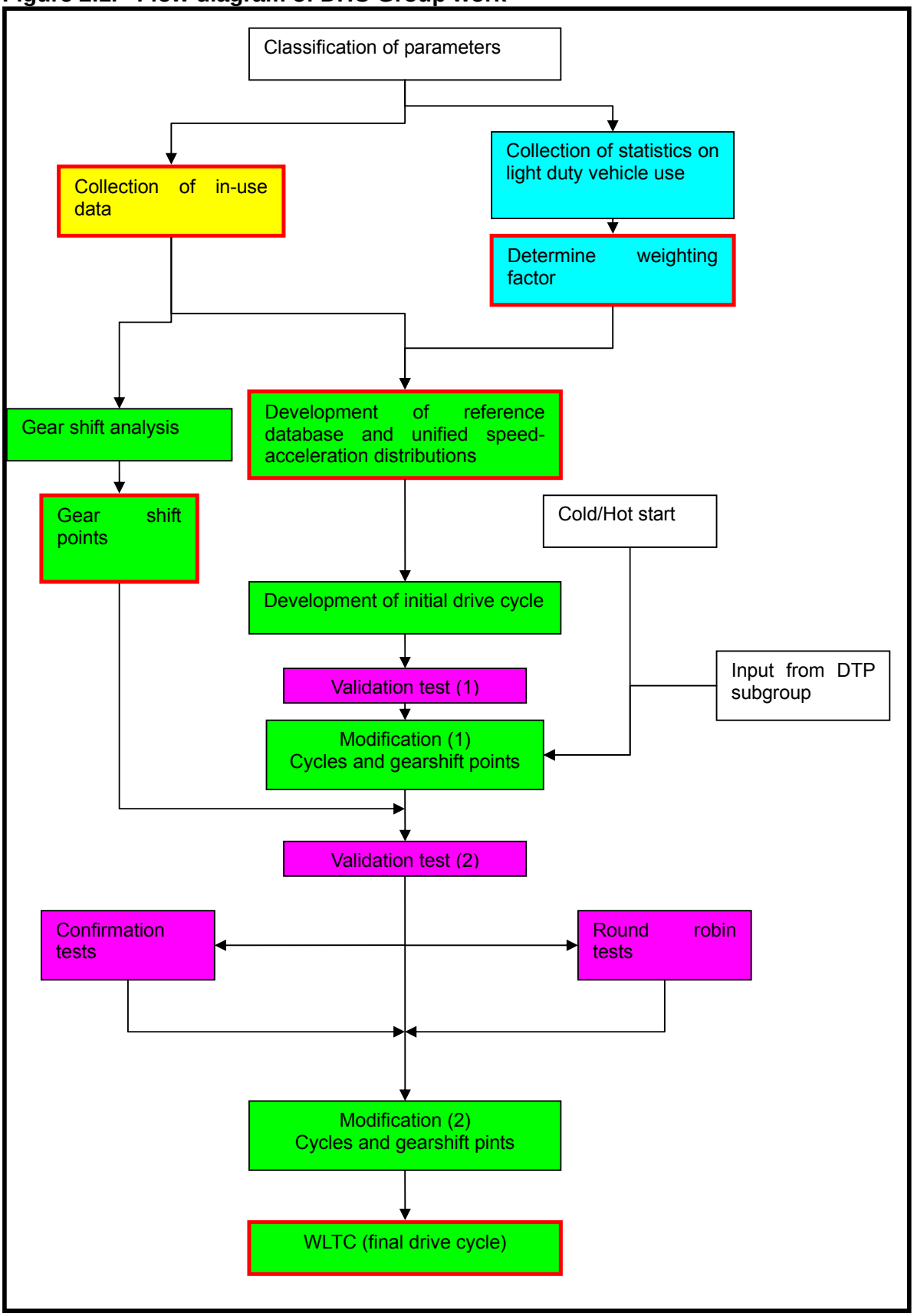
d. Validation/confirmation testing

Work streams c and d will be an iterative process; validation/confirmation testing will undoubtedly result in modifications being made to the early versions of the drive cycle until the final drive cycle is agreed.

Input will be required from the Development of Test Procedure (DTP) subgroup. A joint meeting is scheduled between the DHC and DTP subgroups in June 2010. After that, the Chairpersons of the DHC and DTP subgroups will coordinate further joint meetings as necessary based on the progress made in each subgroup.

Guidelines for in-use data collection are being developed in parallel to developing the data analysis and cycle development methodologies. See paper WLTP-DHC-01-06 for more details on data analysis guidelines.

Figure 2.1. Flow diagram of DHC Group work



3.0. Method for developing drive cycle

The WLTC drive cycle will be developed based on combination of collected in-use data and suitable weighting factors. It is proposed to follow the method used in developing the worldwide harmonized motorcycle emissions certification procedure (WMTC), i.e., aggregating in-use data according to road type (urban, rural and motorway) and processing data pertaining to these road types separately in order to produce drive cycles phases that are road type specific. These drive cycle phases will then be combined to yield the final drive cycle.

Real world in-use data will be collected from a range of Contracting Parties in the following regions:

- China,
- EU,
- India,
- Japan,
- South America,
- South Korea,
- USA,

and a reference database of short trips developed. Raw in-use data will be weighted and aggregated to produce unified speed-distributions (again based on road type). Analysis will be undertaken to determine the average short trip durations and idling times which will then be used to determine the number of short trips that should be included in each drive cycle phase. Short trips (selected from the reference database) will then be combined to develop the final drive cycle.

3.1. In-use data

All Contracting Parties will be required to supply raw in-use data, collected at a frequency of at least 1 Hz.

When vehicle acceleration is not measured during in-use data collection, it will be calculated from consecutive vehicle speed samples using the following equation:

$$a_{\mathrm{i}} = \frac{\left(\upsilon_{\mathrm{i}+1} - \upsilon_{i-1}\right)}{\left(t_{\mathrm{i}+1} - t_{i-1}\right)} \Big/ 3.6$$

where

a = acceleration (m s^{-2})

ν = velocity (km/hour)

t = time (s).

3.2. Initial data analysis

In-use data will be combined to generate a short trip database and an idle database. Combinations of short trips and idle periods will be used to develop candidate drive cycle phases (see section 3.4).

Raw in-use data will initially be analysed according to road type (urban, rural and motorway) and region (e.g. Japan, Europe, India, etc), i.e. all urban data from Japan will be analysed independently to all urban data from India. A global unified distribution will be developed for each road type by combining the appropriate regional in-use data with the appropriate weighting factors (see section 4.0 for more detail regarding weighting factors). Initially, it is proposed to generate unified speed–acceleration distributions and to use these to compare the representativeness of the drive cycle phases. However, it has been agreed that other unified distributions and averages will also be considered; these include (but are not limited to):

- Maximum speed
- Maximum acceleration
- Cruise speed
- Relative positive acceleration.

3.3. Determination of test cycle length

It will be necessary to decide the length of the final drive cycle. WMTC is comprised of three sections relating to urban, rural and motorway driving; each section is of equal length (600 s). The worldwide heavy duty certification procedure (WHDC), EPA Urban Dynamometer Driving Schedule (UDDS), New European Driving Cycle (NEDC) and JC08 are not divided into sections and have total durations of 1800, 1371, 1180 and 1204 s, respectively.

For WLTC, it is proposed to follow the WMTC method and develop a drive cycle that contains individual phases relating to urban, rural and motorway driving. As a first step, it will be necessary to decide the length/duration of each drive cycle phase. The number of short trips and idle periods in each section will be determined by the average short trip and idle period durations, as determined from analysis of the in-use data.

3.4. Development of the drive cycle

Drive cycle phases will be compiled for the three different road types and these combined to yield the overall drive cycle.

The first step will be to identify short trips and idle periods that will be considered for the drive cycle. Cumulative frequency graphs based on the short trip and idle databases will be derived and from these it will be possible to select short trips and idle periods of suitable length (distance/time) to be included in the drive cycle phase. It is agreed that all drive cycle phases will begin and end with an idle period.

Selected short trips and idle periods will be combined to develop candidate drive cycle phases. The speed–acceleration distributions of these candidate drive cycle phases will be compared with the relevant unified speed–acceleration distributions using a chi-squared analysis. The final drive cycle phase will be chosen as the combination of short trip and idle periods that minimises the difference between the speed–acceleration distributions of the drive cycle phase and the unified distribution.

Of course it is possible to use other statistical analyses to compare the unified distributions and the speed–acceleration distribution (or indeed other unified distributions/averages) of the candidate drive cycle phases. Use of these different statistical analyses and distributions/averages can be considered as data analysis progresses. As a starting point, we will proceed as outlined above to develop the preferred drive cycle phases. These will then be compared using other statistical analyses and making use of other unified distributions/averages.

3.5. Validation, modification and confirmation

The overall drive cycle as described above in section 3.4 will be subject to validation and confirmation testing. The outcome of such testing is likely to lead to modification of the drive cycle as factors such as driveability, repeatability etc. are accessed. The result will be a somewhat iterative process of validation and modification in order to develop the final WLTC drive cycle.

4.0. Weighting factor matrix

Previous studies to develop driving cycles have weighted in-use data according to a number of different factors:

- Region
- Road type
- Vehicle category
- Power to mass ratio.

These factors were combined to produce classification matrices with weighting factors based on either the distance or time driven. Driving duration was used to derive the weighting matrix for WHDC, while driving distance was used for WMTC. In development of JC08, both average vehicle speed and driving duration were used.

4.1. Weighting factors

This section provides an overview of how weighting factors will be applied to the raw data to develop the drive cycle. This outline method was agreed at the 1st DHC meeting; however, it was also agreed to retain flexibility regarding the weighting of data. Therefore, this outline methodology will be reviewed to assess its appropriateness as data are analysed.

At the 1st DHC subgroup it was agreed to consider the following parameters when developing weighting factors:

- Region
- Road type (urban, rural, motorway)
- Driving period (peak, off-peak, weekend)
- Vehicle category (passenger car, light duty commercial vehicle[2]).

It was also agreed to assign weighting factors on a time basis.

Weighting factors will be applied to the raw data collected during the in-use data collection exercise before these data are added to the unified distributions. Weighting is needed to ensure that the unified distributions are representative of world-wide driving patterns and that these distributions are not dominated by those contacting parties that might be able to supply more in-use data than others.

The weighting factors discussed in this paper only relate to generating of the drive cycle. As WLTP progresses, it may become appropriate to weight certain parts of the drive cycle during emissions testing; this additional weighting should be considered as part of the test procedure development and thus is not considered here.

It is important to note that because all contacting parties are required to submit raw data, it will be possible to change our approach to weighting during the data analysis stage. The method presented in this paper thus represents a general framework for weighting that can be modified at a later stage if required.

4.1.1. Different types of weighting factors

For the purposes of drive cycle development, there are two types of weighting factor: regional weighting factors and driving condition weighting factors.

Table 4.1. Summary of weighting factors

Weighting factor	Description
Regional weighting factor	Determined by the total number of vehicle hours in a region[3]
Driving condition weighting factors	Determined on a regional basis for the following parameters: road type (urban, rural, motorway), driving period (peak, off-peak, weekend)

[2] Vehicle category may be further subdivided depending on the in-use data collected.
[3] See footnote 1 of table 1.1.

Weighting factors are generated using statistical data collected in each region. There are several methods for generating these factors and these are discussed in more detail below (see section 4.2).

Regional weighting factors

Regional weighting factors are needed to allow data from different regions to be combined when generating the overall unified distributions. At the 1st DHC meeting it was agreed, initially, that these weighting factors should be based on the total number of vehicle hours (for light duty vehicles) in each region. As data analysis progresses it may become necessary to revisit the generation of regional weighting factors.

Driving condition weighting factors

Driving condition weighting factors are required for the following parameters: road type (this will be used when developing the test procedure), driving period and vehicle classification (passenger car, or light duty commercial vehicles). These weighting factors will be determined on a regional basis using statistical data (see section 4.2).

When developing the driving condition weighting factors it will be necessary to define driving conditions. Each Contracting Party should define the following parameters according to the driving patterns observed in their region:

- Road type
  - Urban
  - Rural
  - Motorway
- Driving period
  - Peak
  - Off-peak
  - Weekend

Table 4.2 provides some suggested definitions for road types; however, it is expected that these definitions may not be suitable for each region and thus Contracting Parties may choose to use their own definitions.

Table 4.2. Suggested definitions of road types

Road type	Definition
Urban	Paved roads in urban areas with a speed limit ≤ 50 km/hour
Rural	Paved non-motorways outside and inside urban areas with a speed limit between 50 and 100 km/hour
Motorway	Paved multilane roads specifically constructed and controlled for fast traffic

Contracting Parties should clearly define road types and driving periods and

provide these definitions when submitting raw data[4]. In addition, it is also important to ensure that the same definitions for road type and driving period are used when collecting in-use data.

4.1.2. Applying weighting factors: an overview

The different weighting factors will be applied at different stages of the data analysis to generate unified distributions (e.g. unified speed–acceleration or average speed, etc). Figures 4.1 and 4.2 provide an overview of how the weighting factors will be applied to raw data.

The raw data from Contracting Parties will be split according to road type and driving period. Driving condition weighting factors will then be applied to the aggregated raw in-use data on a regional basis to generate unified distributions that are specific to each region. These regional unified distributions can then be combined with regional weighting factors to develop the overall unified distribution (note that overall unified distributions will be generated for each road type).

Table 4.3. Regional unified distributions

Regional unified distribution	Road type	Driving period
U	Urban	Peak
		Off-peak
		Weekend
R	Rural	Peak
		Off-peak
		Weekend
M	Motorway	Peak
		Off-peak
		Weekend

[4] It was agreed at the 1st DHC meeting that Contracting Parties should endeavour to collect photographic/videographic evidence to support road type classification.

Figure 4.1. Applying weighting factors to generate a regional urban unified distribution

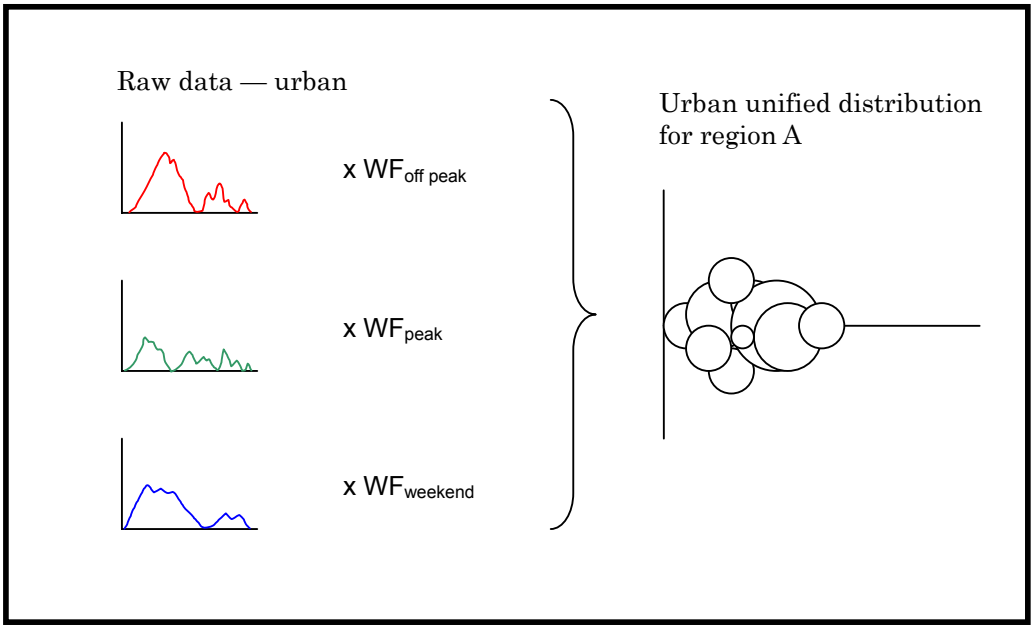
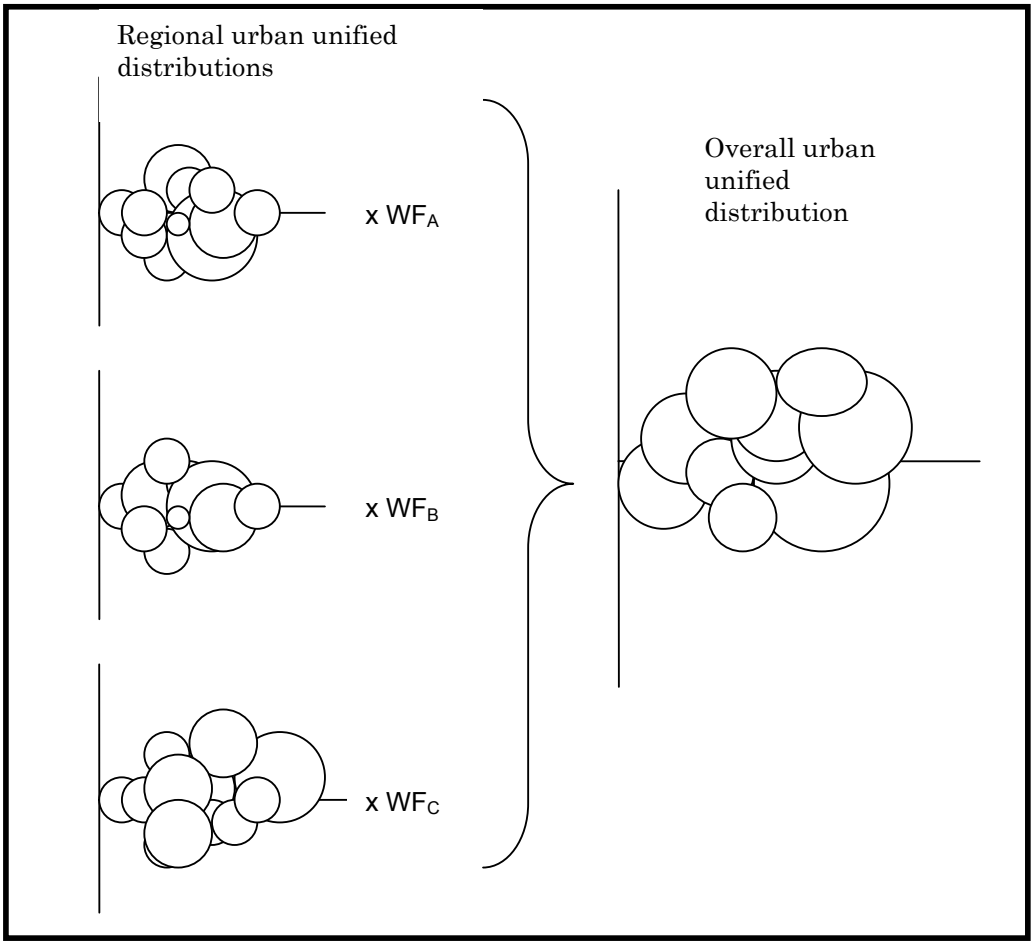


Figure 4.2. Applying the regional weighting factors to generate the overall urban unified distribution



4.2. Generating weighting factors

Regional weighting factors
These will be based on the total number of vehicle hours in each region. Contracting Parties should provide statistical estimates of the total number of vehicle hours in their region based on latest available data.

Driving condition weighting factors
Four methods are possible for generating weighting factors. These are (in order of decreasing preference):

- Full traffic census
- Partial traffic census combined with statistical data
- Partial traffic census combined with survey
- Survey

Driving condition weighting factors will be applied on a regional basis to develop the regional unified distributions thus allowing Contracting Parties to choose which weighting factor generation method is best suited to their region.

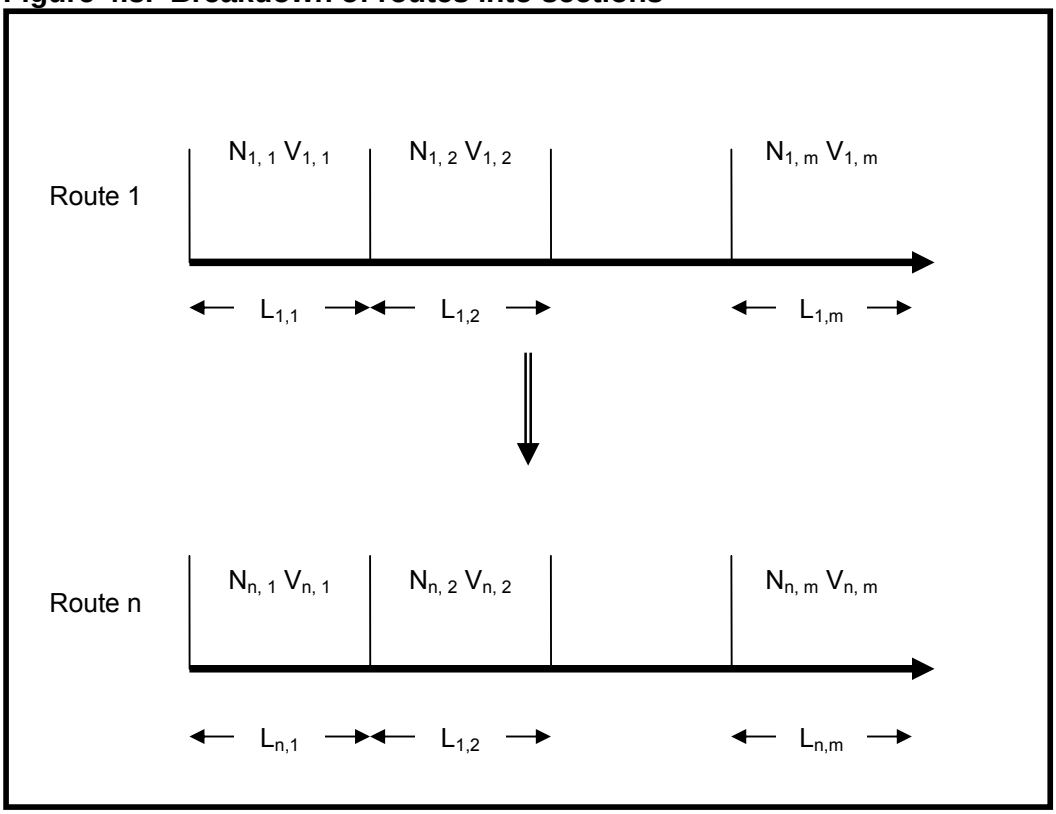
4.2.1. Full traffic census

A full traffic census can be conducted to measure the volume of traffic for each driving condition (road type, driving period) and for each vehicle category (car, light duty commercial vehicle). Whilst this method is time consuming, it will yield the most accurate weighting factors.

Data collection takes place over a number of different routes coving all road types. Automated detection allows the number of vehicles travelling on each section of the route to be counted and the average vehicle speeds to be determined. These data can then be analysed to determine the number of vehicles travelling during the different driving periods (i.e. peak, off-peak and weekend).

The actual data on traffic volume (number of vehicles) measured between two points is then combined with the average vehicle speed to determine the number of vehicle hours for that section of road. Data can then be collated for all similar sections of road and driving period. Figure 4.3 shows how different routes can be broken down into sections; measurements are made of the number and vehicle category passing through these sections.

Figure 4.3. Breakdown of routes into sections



The total number of vehicle hours is then calculated using the following equation:

$$T = \sum_{i=1}^{n} \left(\sum_{j=1}^{m} \frac{L_j \times N_j}{V_j} \right)$$

where

T = Number of vehicle hours
L = distance of section (km)
N = number of vehicles (traffic volume)
V = average speed (km/hour)
i = route number
j = section number

4.2.2. Partial traffic census combined with statistical data

A partial traffic census can be used to measure the traffic volume on given road types during different driving periods. It is necessary to ensure that measurements are taken on parts of the road network that are representative of the region. It is recommended that the traffic census measurement period is not less than two weeks in duration.

Automated sensors (or other methods) are employed to measure the number of vehicles passing the measurement points, differentiated according to vehicle category (passenger car/light duty commercial vehicle) over different driving periods (peak/off-peak/weekend). Existing statistical data are then used to determine the total network distance for each road type and these are combined with the measured data to determine the number of vehicle hours for each combination of vehicle category, road type and driving period.

Table 4.4 gives and example of how the urban weighting factors would be calculated. The same method would be used to calculate the weighting factors for rural and motorway driving.

Table 4.4. Example calculation for determining weighting factors using a partial traffic census combined with existing statistical data

Traffic volume (number of vehicles)			
	Urban		
	Weekday		**Weekend**
	Peak	**Off-peak**	
Passenger car	5000	2000	2500
Light duty commercial vehicle	2000	1000	500
Total network distance (derived from statistical data)	80 000km		
Average vehicle speed (derived from traffic census data or in-use data)	20 km/hour		
Weighting factor (see equation below)			
Passenger car	20,000,000	8,000,000	10,000,000
Light duty commercial vehicle	8,000,000	4,000,000	2,000,000
Weighting factor (normalised)			
Passenger car	10	4	5
Light duty commercial vehicle	4	2	1

Where,

$$\text{Weighting factor} = \frac{\text{traffic volume} \times \text{network distance}}{\text{average vehcile speed}}$$

4.2.3. Partial traffic census combined with survey

This method can be used when there are no statistical data available on a region's total road network distance. A survey of vehicle users can be carried out to estimate the average distance travelled on each road type (urban, rural and motorway). Traffic volumes during different driving periods can be measured by a partial traffic census (as detailed above) and these data combined to yield weighting factors as per the calculation used in Table 4.

4.2.4. Survey

This is the least favoured method for generating driving condition weighting factors. A survey can be conducted of an appropriate proportion of vehicle users in the region. The questionnaire will need to collect the following data:

- Vehicle category (passenger car/light duty commercial vehicle
- Number of hours driven in each of the following road type/driving period combinations —

Combination	Road type	Driving period
1	Urban	Peak
2	Urban	Off-peak
3	Urban	Weekend
4	Rural	Peak
5	Rural	Off-peak
6	Rural	Weekend
7	Motorway	Peak
8	Motorway	Off-peak
9	Motorway	Weekend

When using this method, you must ensure that the survey population size is sufficiently large to be representative of driving behaviour in your region.

The survey data is collected and the number of total number of vehicle hours in each combination of vehicle category/road type/driving period is added up. The ratio of these vehicle hours is equal to the weighting factor (see table 4.5).

Table 4.5. Example calculation for determining urban weighting factors by survey

Urban				
	Peak	**Off-peak**	**Weekend**	
Passenger car	12000	6000	8000	Total number of vehicle hours
Light duty commercial vehicle	10000	2000	4000	
Passenger car	6	3	4	Weighting factor
Light duty commercial vehicle	5	1	2	

4.3. Generating the weighting factor matrix

Statistical data on light duty vehicle use, as described by the factors outlined in section 4.1, should be gathered from each region. These data will then be analysed, aggregated according to road type, and a suitable weighting matrix developed. Table 4.6 provides an outline of the proposed weighting matrix.

Table 4.6. Outline of weighting factor matrix

Vehicle category[1]	Urban										Rural	Motorway
	China			EU			India	Japan	South America	USA	…	…
	Peak (week day)	Off-peak (week day)	Off-peak (weekend)	Peak (week day)	Off-peak (week day)	Off-peak (weekend)	…	…	…	…	…	…
Passenger car							…	…	…	…	…	…
Light duty commercial vehicle							…	…	…	…	…	…

[1]Vehicle category may be subcategorised to allow differentiation between different passenger car categories (e.g., GVW, engine displacement, power:mass, etc.) and van categories (small, medium, large van, etc.).

5.0. Gear shift point analysis

In developing the WLTC, it will be necessary to prescribe gear shift points. Data on gear shift points will be collected during the in-use data collection exercise.

Gear shift points are mostly influenced by traffic condition, vehicle specification and vehicle conditions (e.g. laden weight). The in-use data collection exercise will seek to collect data which cover a range of these conditions.

It is proposed to apply the gear shift analysis method used in the development of JC08. A separate paper discussing this method has been circulated to DHC members.