energy technologies institute

An ETI Insights Report

HGV USE IN THE UK

Contents

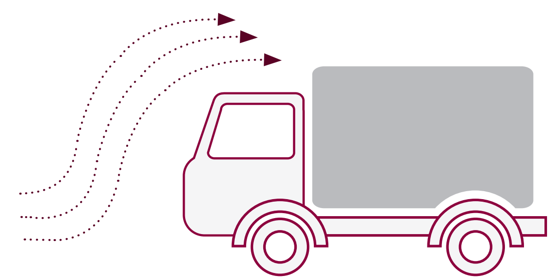
For the UK to meet its **climate change goals** under the 2008 Climate Change act, **significant emission reductions** will be required in transport.

HGVs could contribute around 15% of total UK CO_2 emissions by 2050.

The ETI has developed **36 statistically distinct archetypes** to accurately assess **HGV usage in the UK.**

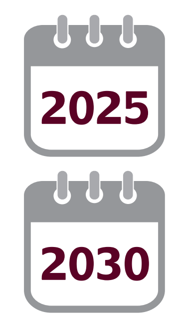
HGV USE IN THE UK

With more **complex** telematics solutions **HGV OEMs** will be well placed to assess the effectiveness of new technologies in the **real world.**



Further **research** is needed to accrue and **populate data** for the remaining 24 of the **36** archetypes.

HGV OEMs will be able to track their own carbon emissions from individual vehicles and their **whole fleet** against **2025** and **2030** targets.



INTRODUCTION

For the UK to meet its legal obligation under the 2008 Climate Change Act, significant emission reductions will be required in all parts of the transport sector. Heavy duty vehicles (HDVs) comprise around a third of UK domestic transport emissions, equalling 8% of all UK domestic emissions. Whilst this is a relatively small proportion now, this contribution could grow as other sectors decarbonise. In some scenarios, HDVs could contribute as much as 30% of the overall Green House Gas (GHG) emissions in 2050. The sector is therefore coming under increasing pressure to reduce CO_2 emissions and fuel usage[1]. This pressure will increase with the ambition to move to "net zero" by 2050.

In 2010, the ETI started a £40m HDV efficiency programme targeting a 30% reduction in GHG emissions across a range of vehicles representing the UK HDV fleet. The HDV efficiency programme generated computer models and drive cycles for a range of HDVs to which fuel saving technologies were applied to improve fuel efficiency. Heavy Goods Vehicles (HGVs) form a large part of the UK land HDV fleet with GHG emissions at around 47% and as such formed a key element of this work[2].

During the HGV modelling work to determine the most promising fuel saving technology combinations, it became apparent that the fuel efficiency benefit and the technology solutions chosen were particularly sensitive to how the vehicles were used[2]. Therefore, it was necessary to understand how HGVs are actually operated in the UK and consequently that the drive cycles selected were representative when assessing the impact of different technology solutions.

There remains no publicly available information on how HGVs are used in the UK - such as typical drive cycles, average fuel consumption, daily mileage ranges and payload carried.

In parallel to the ETI HDV efficiency programme the European Commission has been developing a model, which uses drive cycles, to legislate HGV CO_2 emissions in the EU[3] called VECTO (Vehicle Energy Consumption Calculation **TO**ol). Prior to this tool being developed by the EU, typical engine use cycles have been used to certify engines on a test bed for criteria pollutant emissions from Euro standard I to VI[4]. The cycles used for engine certification have been elevated to vehicle based cycles for vehicle modelling and have been utilised by the ETI in the HGV modelling ETC/FIGE (European Transient Cycle) and WHVC (World Harmonised Vehicle Cycle). At the start of the HDV efficiency programme, drive cycles developed for VECTO, which would be representative of HGVs used in Europe, had not been made publicly available.

To address the lack of publicly available data the ETI leveraged existing infrastructure and hardware in the telematics market in a project lead by Element Energy with Microlise and the International Council on Clean Transportation (ICCT). The aim of the project was to assess how HGVs are used in the UK and if vehicle parameters such as aerodynamic drag and payload could be accurately derived from available in use data.

This insight sets out to address how HGVs are used in the UK, how this compares to cycles used to inform legislation, and if meaningful performance characteristics can be inferred from investigating service use.

[1] Source: BEIS – 2016 UK Greenhouse Gas Emissions, Final Figures – 06/02/2018
[2] ETI Insight – Land Based Heavy Duty Vehicle Efficiency at the ETI
[3] European Commission – Proposal for a Regulation of the European Parliament and of the Council setting CO2 emission performance standards for new heavy-duty vehicles
[4] https://www.dieselnet.com/standards/eu/hd.php

HDVs could contribute as much as 30% of the overall GHG emissions in 2050.

UK ON-HIGHWAY HGVS AND METHOD FOR COLLECTING DATA

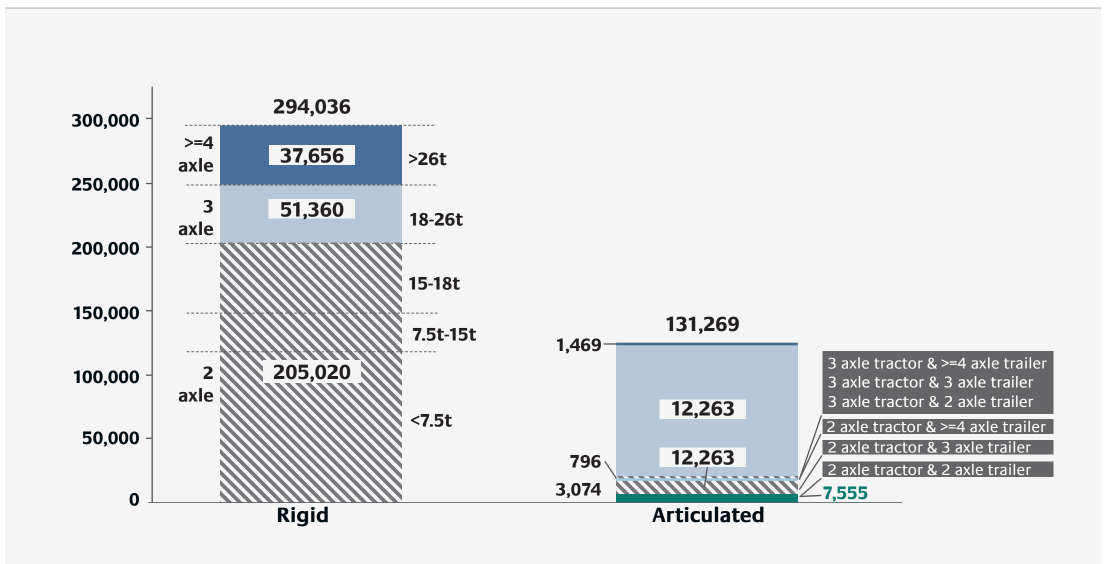
The UK Department for Transport (DfT) offers high-level statistics for HGVs registered in the UK. Over 400,000 HGVs are registered in the UK which can be split between Articulated and Rigid HGVs and further defined by wheel plan and gross vehicle weight (GVW) (Figure 1). Collecting data from all of the vehicles in the HGV fleet is not currently practical, hence statistically representative samples should be used for each vehicle archetype.

The ETI conducted a project that leveraged a smaller sample of data than the DfT statistics, collected from those HGVs already fitted with telematic devices. This data had been collected to provide information on vehicle use and driver behaviour to the vehicles operators and owners. The previously collected data was event based data, collected at set intervals (1 per minute or 1 per mile) or at set driver triggered events collecting numerous vehicle parameters such as GPS location, vehicle speed, engine RPM and fuel used.

Over 400,000 HGVs are registered in the UK.

Figure 1

Total number of HGVs licenced in the UK in 2016 broken down by axle configuration and vehicle weight (for rigid vehicles only)[5,6]



10,364 vehicles were in the sample, which contained three months of vehicle tracking between September and December 2016 (around 500,000 days of HGV driving data). The data was used to characterise how vehicles in the UK HGV fleet were actually used during real world driving. A subset of the data was selected which was of higher quality and where the company and vehicle types could be readily established. The vehicle types in the sample were broad but it was particularly skewed towards heavier articulated vehicles with an under representation in the rigid vehicles, especially for 3 and 4 axle rigid HGVs[7]. This was largely due to the vehicle types being from two OEMs fitted with telematic devices during manufacture.

Figure 2 shows the distribution of daily driving distances and Figure 3 shows the distribution of fuel economy based on the wheel plan of the vehicles in the whole data set.

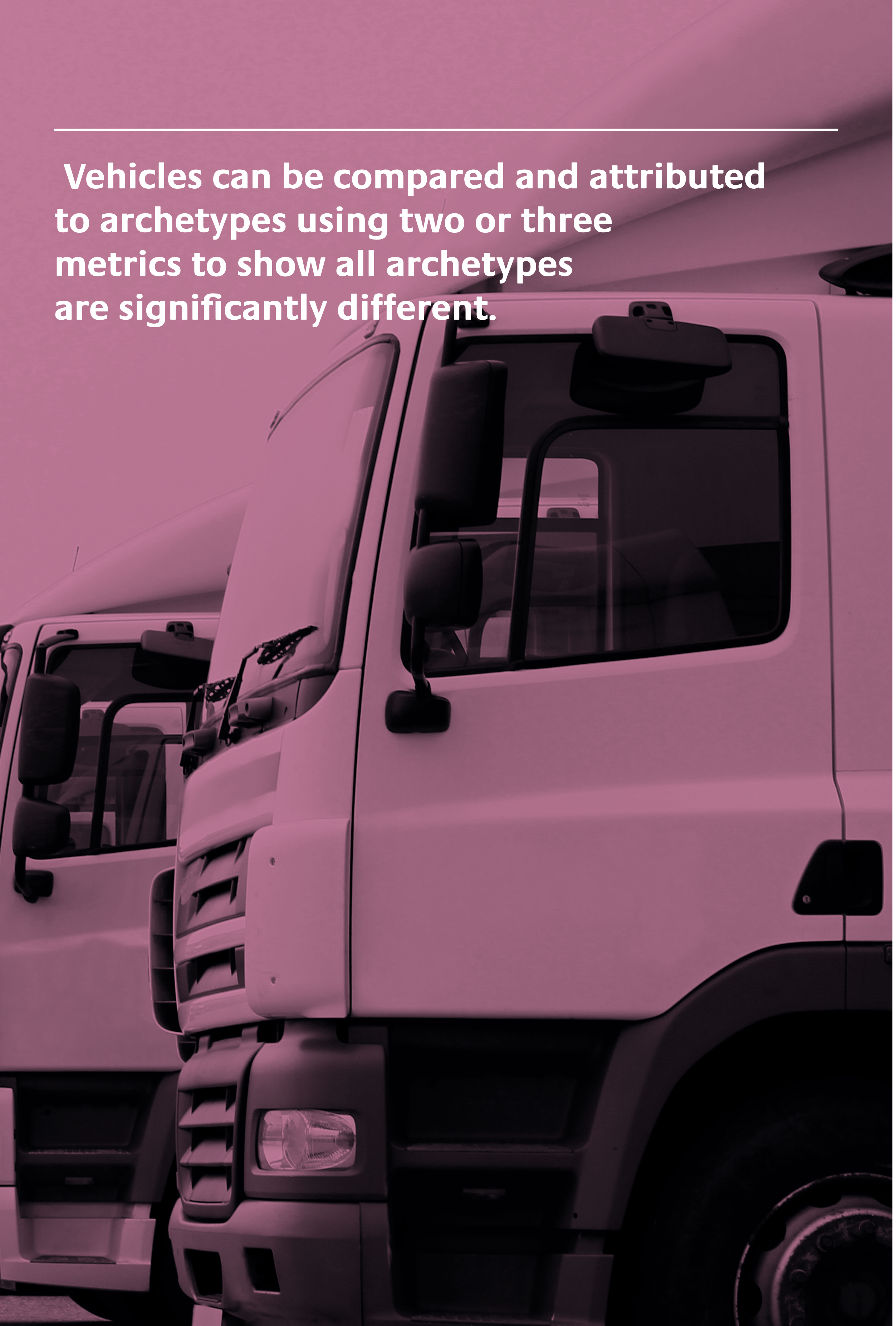
Vehicles within the 10,364 were able to be grouped into archetypes based on commonly available vehicle metrics that aligned with statistical reporting and policy making. Type of operation (daily distance driven, fuel consumption and speed distribution) and vehicle size are delineators for creating archetypes. The resulting grouping of vehicles matches well with the work conducted by legislators at the European Commission for VECTO.

Table 1 shows the thirty six archetypes generated from the 10,364 vehicles in the sample; how many vehicles are in each archetype and how many vehicles are needed within each archetype for it to be statistically representative of the population. Some vehicles can be characterised as 'generic' in that they are attributed to a truck dealership, vehicle hire, or it was not possible to find the company. These cannot be reliably assigned to a particular archetype. From the 10,364 vehicles, 1,176 could be attributed to the specific archetypes in Table 1. Note that data is not evenly distributed between company types and wheel plans.

[5] The axle configuration of the trailer is taken from the vehicle licensing agency's statistics which reflect the information given for the vehicle by the owner in the registration documents. It is assumed that this reflects the most common trailer configuration used but other trailer configurations could be used on some journeys

[6] Weight breakdown of rigids assumes a very small proportion of the fleet is registered to pull a drawbar trailer and that a very small proportion of vehicles are registered in a weight category lower than the maximum category allowed for the axle configuration and that these cases can therefore be ignored

[7] 4 axle rigid HGVs, which are typically used for construction and typically have a GVW of 30-32 tonnes, are not presented in the dataset and would add to the 36 categories presented in table 1.



Vehicles can be compared and attributed to archetypes using two or three metrics to show all archetypes are significantly different.

Figure 2
Distance driven per day broken down by vehicle wheel plan

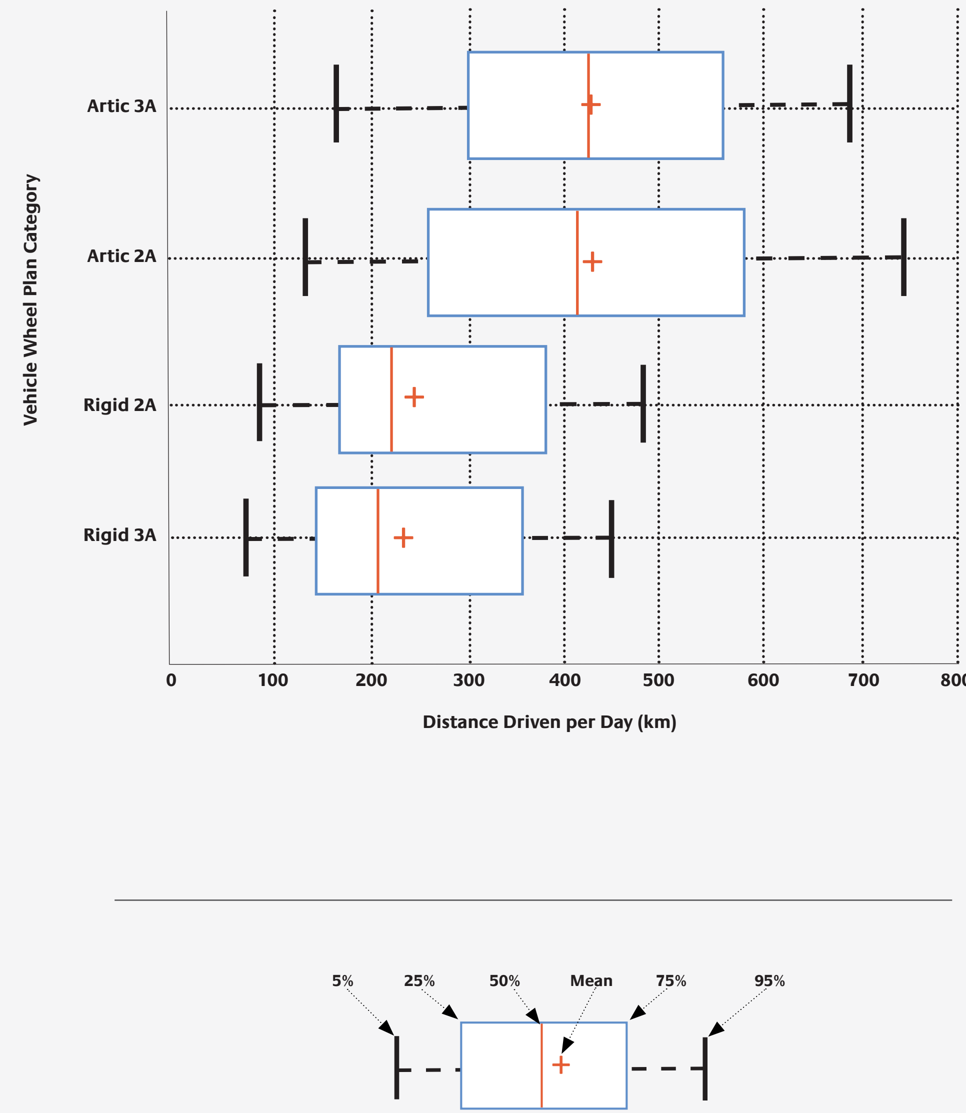
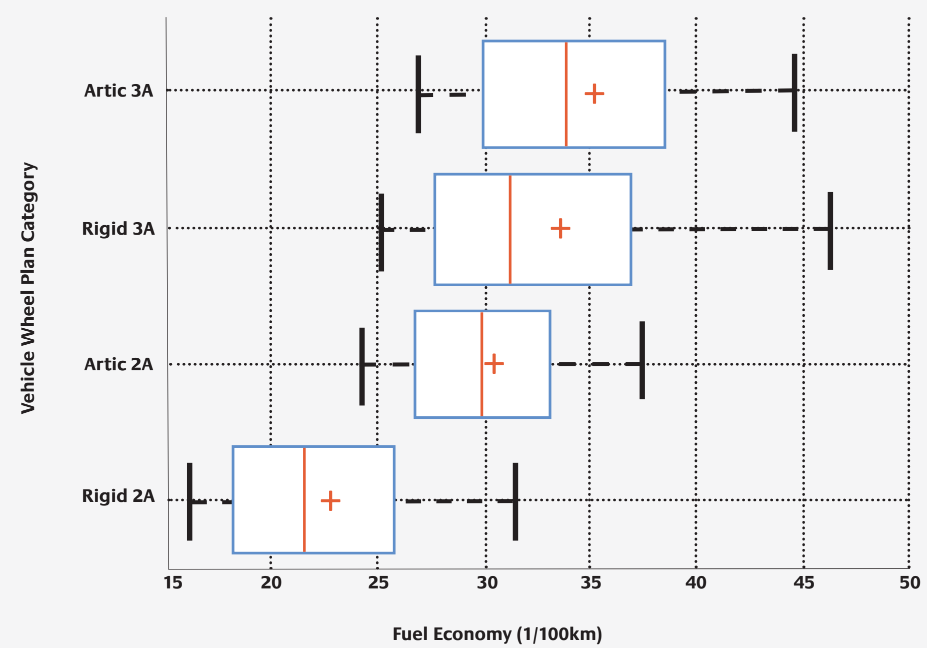


Figure 3
Fuel economy broken down by vehicle wheel plan



When archetypes are compared by a single metric, such as daily driving distance, some archetypes present little or no statistical differences. However, when archetypes are compared based on two or three metrics all archetypes are significantly different.

Across the thirty six different archetypes, the event based data shows there are key characteristics across four speed bands:

- At low speeds (less than 15km/h) the speed distribution either drops very rapidly or displays a wider peak with a significant amount of time spent at less than 10 km/h. It is expected that the speed distributions that drop very quickly represent vehicles where most of their idle time occurs at the depot. Whereas vehicles with a wider peak at low speeds are either stopping at multiple locations throughout the day or travelling through stop-start traffic in congested city centre locations.
- At the medium speed band (45-55 km/h) some vehicles show a small peak. This peak represents cruising in urban/suburban areas at the speed limit (in uncongested traffic).
- At the medium/high speed band (65-75 km/h) vehicles either have or do not have a small peak. This peak represents cruising in suburban/rural areas at the speed limit (in uncongested traffic).
- At the high-speed band (over 80 km/h) all vehicles either have a medium or large peak representing cruising on motorways. Vehicles with shorter distances driven per day have a smaller motorway peak, it is expected that this corresponds to motorway driving around a city's periphery to visit depots. Vehicles with a high daily distance with a higher proportion of high speed driving are expected to be travelling across the country between cities from depot to depot.

Table 1
Number of vehicles in the dataset for that category / sample size needed for statistical validity based on the margin of error method - Colour coded by the number of vehicles available in the dataset (Green, enough vehicles are available. Orange, approximately enough vehicles are available. Red, too few vehicles are available)

Rigid Company type / Wheel plan	2 Axle Rigid	3 Axle Rigid	2 Axle Artic	3 Axle Artic
Parcel Delivery (PD)	-	2 / 124	2 / 201	97 / 100
Haulage (H)	49 / 84	13 / 120	75 / 84	219 / 136
Liquid Haulage (LH)	1 / 55	-	-	86 / 158
Container Haulage (CH)	4 / 45	-	-	24 / 98
FMCG[8] Haulage (FMCG)	-	-	-	104 / 83
Retail Haulage (RH)	58 / 31	4 / 130	37 / 85	-
Food Haulage (FH)	64 / 80	106 / 79	53 / 65	92 / 125
Construction (C)	6 / 15	-	-	77 / 150
Municipal (M)	-	-	-	-

The speed profiles of each of the twelve archetypes where sufficient data exists (i.e. the green and orange cells in Table 1) are shown in Figure 3, Figure 4 and Figure 5.

These 36 archetypes represent the majority of HGV activity types, while limiting the number so that the output remains useful and the archetypes are statistically distinct.* 4 axle rigid HGV's would be in addition to these 36.

The use of event based data is limited because of its slow update rate which means it cannot be used to study driving transients. The value of event based data is that it is easy to collect for a large number of vehicles over a long time period meaning it is very useful to generate summary statistics for the UK HGV fleet as a whole.

[8]FMCG - Fast Moving Consumer Goods – goods sold in high volume at a relatively low price (processed food, pharmaceuticals, toiletries)

Figure 4
Speed profile for all rigid archetypes[9]

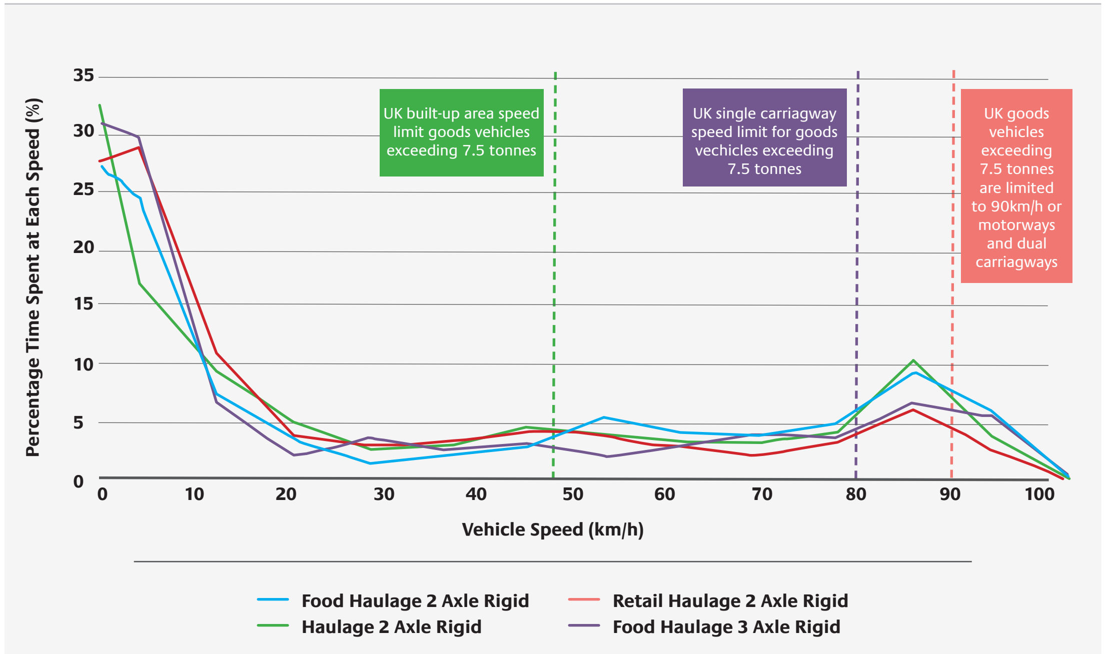


Figure 5
Speed profile for all articulated vehicles with a low proportion of motorway cruising time[6]

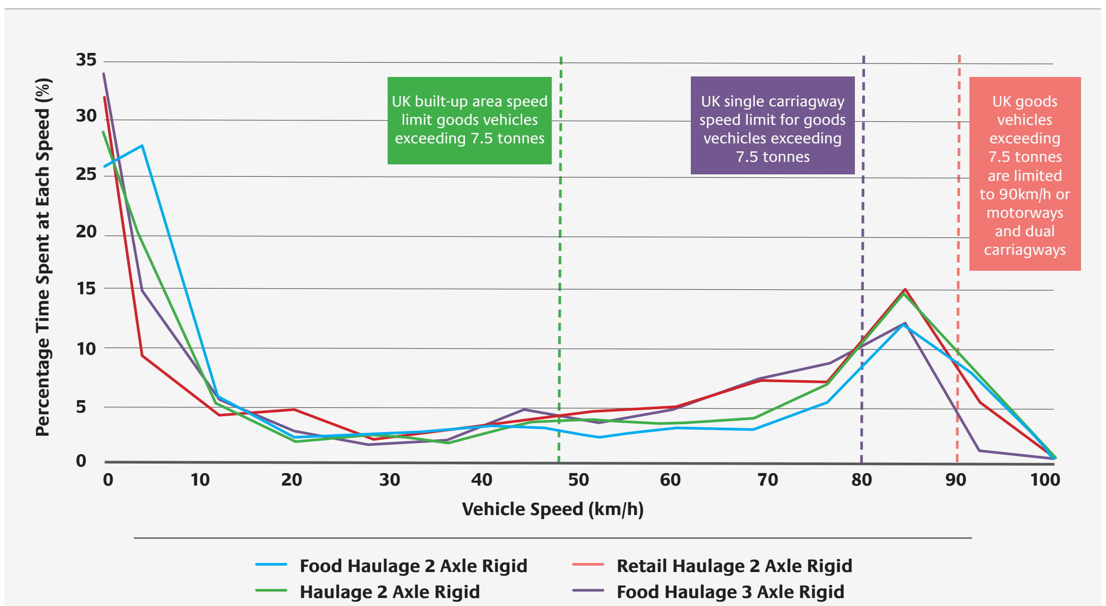
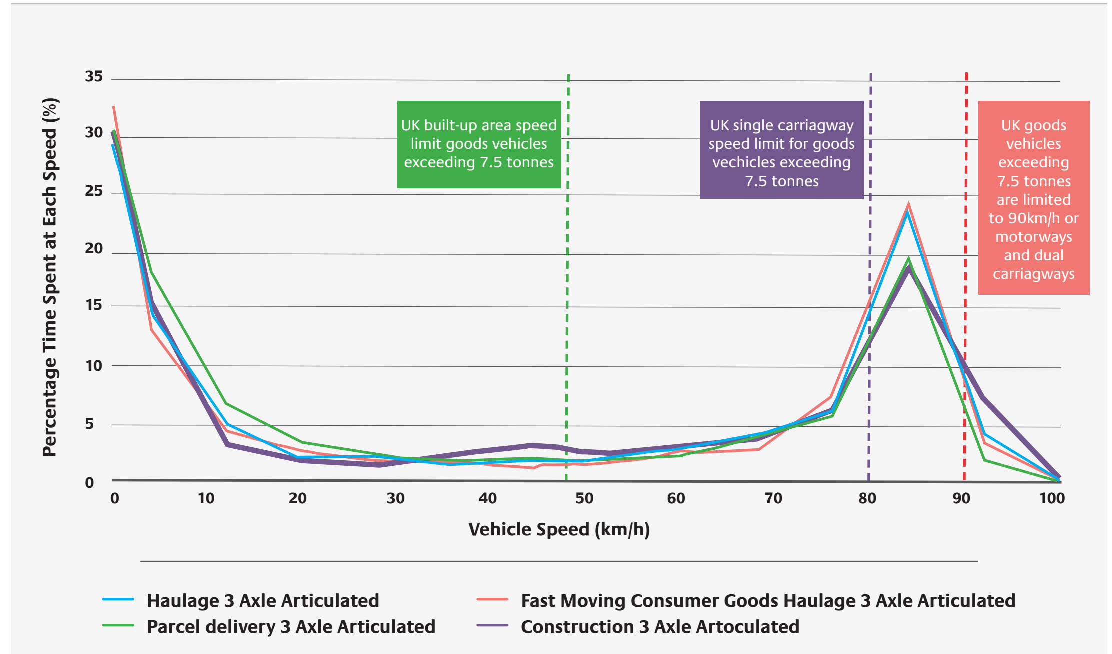


Figure 6
Speed profile for all articulated vehicles with a high proportion of motorway cruising time[6]



Creating archetypes and archetype statistics that represent the UK HGV fleet provides significant value for governments and Non-Governmental Organisations (NGOs). Providing summary statistics provides an adequate level of data fidelity when considering a national fleet of vehicles. For archetypes that are statistically representative these summary statistics have been presented. However, there is no data available for 14 of the archetypes, and insufficient data for a further 10 (red cells in Table 1). It is recommended that future work should be undertaken to populate these as well as increasing the available data for the 12 which are populated.

[9]ICCT – Heavy-Duty Vehicle Fuel-Efficiency Simulation: A Comparison of US and EU Tools – April 2015

DERIVING HGV PERFORMANCE PARAMETERS

To delve deeper than the summary statistics requires a methodology for deriving vehicle performance parameters and representative time-based drive cycles. Any such methodology requires more detailed data with a shorter time step than the event based data used to characterise the UK HGV fleet. There is a high cost associated with collecting large quantities of data, which means high time step data is often only available from a small sample of vehicles. It is expected that, given the advancements in telematics and the reduction of hardware and data transfer costs, higher frequency data will become more readily available in the future. Higher frequency data, collected at time intervals at or below 1 sample per second for each parameter, can be utilised to derive vehicle performance parameters such as overall vehicle mass (and effective cargo mass), and to a lesser degree rolling resistance and aerodynamic resistance information. These are important "real world" parameters to understand because they are key parameters that govern the fuel efficiency of an HGV. Hence, these parameters often form the inputs to mathematical models of the type being used for CO_2 emission reduction and/or regulation.

Legislative models (for example VECTO), and most vehicle models, use static factors for vehicle mass, rolling resistance coefficient and the aerodynamic drag coefficient. To produce representative results this is adequate as long as a range of factors are used that represent real world use. Collecting and analysing instantaneous data offers a way to resolve how some of these parameters vary in real use and how they can change over the course of a journey and by the operation of the vehicle.

The ETI collected two datasets; one dataset from the ETI HDV efficiency programme and a second dataset by fitting additional telematic logging capability to five HGVs. Five HGVs from a single operator were selected to be equipped with additional logging equipment for one month (3 Mercedes Actros and 2 Scania R440 – all 3 axle articulated HGVs from the FMCG archetype).

High frequency data was collected from a single HGV in the HDV efficiency programme, this included fitting additional sensors to collect data from the powertrain and vehicle that are not readily available from standard vehicle telematic systems. Performance parameters were derived from 49 vehicle journeys using the data from the HGV, a DAF XF105:

- 37 journeys were on the UK road network and can be considered a reasonable representation of normal HGV driving; being comparable to the 3 Axle Artic archetype results with a high proportion of motorway cruising.
- 2 controlled test runs were conducted at Millbrook proving ground to derive vehicle performance parameters – i.e. rolling resistance coefficient and aerodynamic drag coefficient.

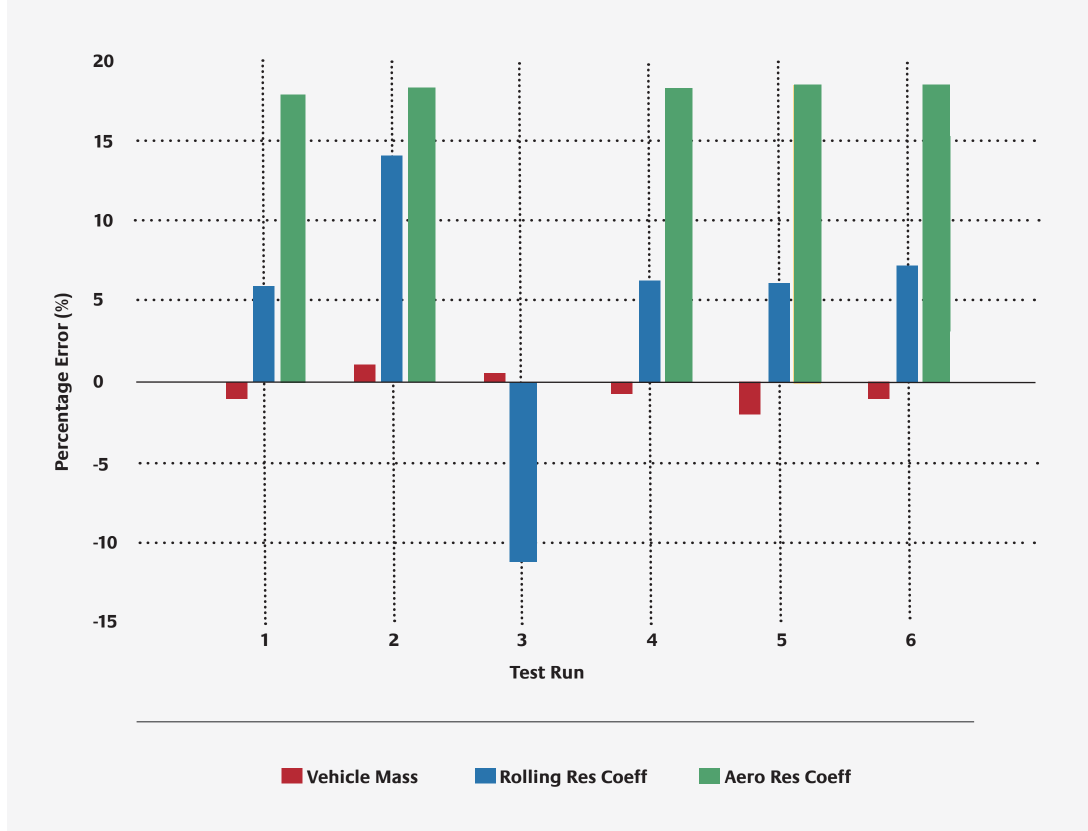
Data collected from the HGV was used to validate the methodology that was then used to derive the vehicle performance parameters from the sample of five HGVs.

The HGV data was used as the 'baseline vehicle', with known parameters established through the 12 controlled tests, to establish the accuracy of predicting each variable (vehicle mass, rolling resistance and aerodynamic drag) over several acceleration and coast down test runs. The analysis shows that the accuracy in predicting each of the vehicle mass, rolling resistance coefficient and aerodynamic drag coefficient varies significantly with the vehicle mass being impacted the least (Figure 7).

Utilising mathematical models to derive these parameters after the data had been collected also relies on external data to ensure adequate data processing is possible. Two parameters, GPS accuracy and Engine torque, have a significant reliance on external data. The accuracy of these also have a significant impact on the overall quality and accuracy in deriving the performance parameters.

Poor GPS data can result in significant elevation errors, whereas poor engine torque estimates can result in large errors in the estimates of rolling resistance and aerodynamic performance. GPS accuracy on the vehicle, although every 1s, compromised the overall results. Additional processing is required to ensure all vehicle GPS points are on a road. In general, the accuracy of commercial GPS systems could mean that a recorded point is for example on an embankment at the side of the road. This causes issues when accurate gradient data is sought for every GPS point to resolve mathematical models, in some cases this causes the elevations to change significantly.

Figure 7
Algorithm error at predicting vehicle mass and resistance coefficients using engine power



Accurate on road GPS data is required to create accurate elevation data which is crucial to solve vehicle models. Commercial mapping data was not available to provide elevation data for this work; therefore, the best publicly available elevation data was utilised supplied from the Environment Agency LIDAR data for the UK.

Commercial mapping data is utilised by most HGV Original Equipment Manufacturers (OEMs) and it is used on board vehicles for navigation systems and features such as predictive cruise control would overcome the issues experienced. In any commercial application, it is perceived that highly accurate GPS data would not be an issue.

Outputs of engine torque are available from an HGV's electronic control unit (ECU) using the vehicle diagnostic system. This torque figure is an estimate set by the OEM based upon a further estimate of the fuel injected into the engine. Therefore, the accuracy of this estimate is subject to many noise factors and variances between manufacturers. This inability to determine engine torque accurately enough leads to very large errors in the aerodynamic and rolling resistance coefficients (+/-20%) under certain conditions with the possibility of systematic bias for which it is not possible to correct.

The sample of five vehicles, which fall into the category of an FMCG 3-axle articulated archetype, were studied over a one month period between March and May 2017, during which large amounts of instantaneous data was collected. All of the journeys taken by the five vehicles were primarily on the UK strategic road network, shown in Figure 8.

Figure 8
Algorithm error at predicting vehicle mass and resistance coefficients using engine power.

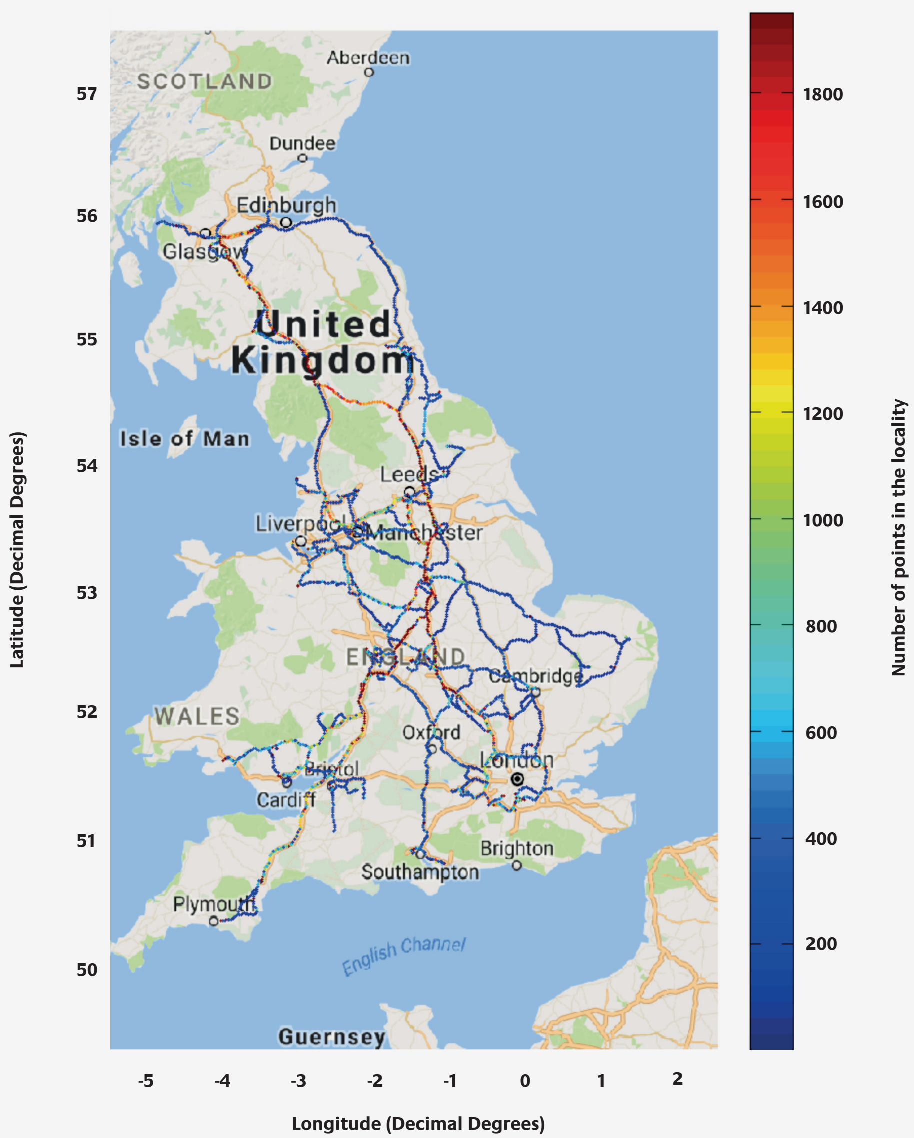
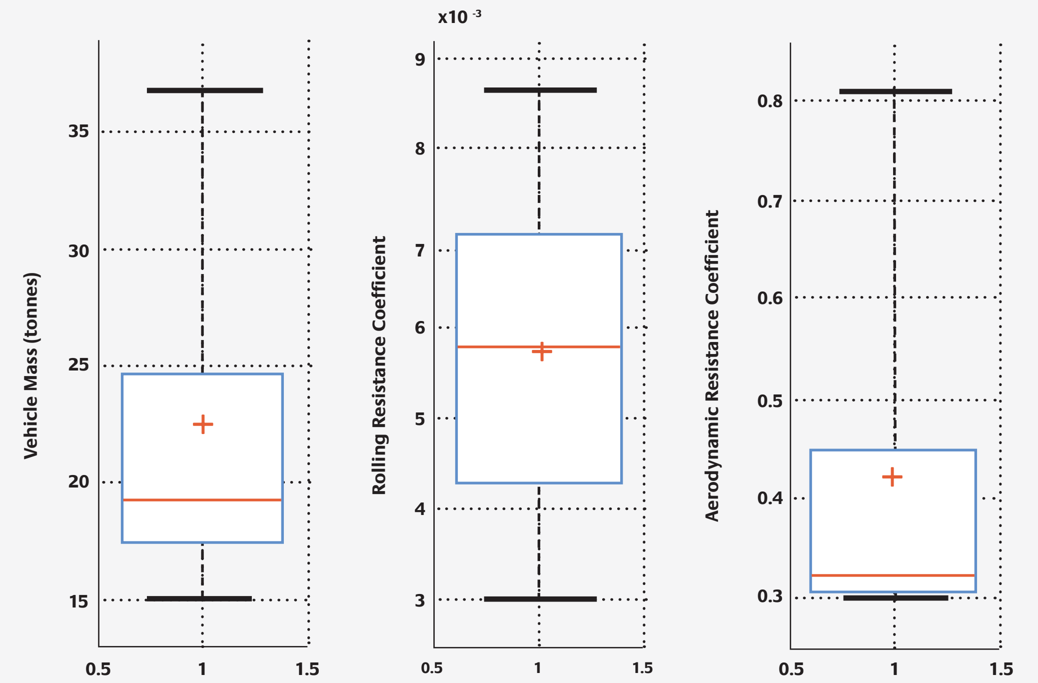


Figure 9
Vehicle performance parameter results.



In practice vehicles are loaded and unloaded throughout the day. The vehicle mass therefore changes significantly, and there is no single correct vehicle mass. Averaging the mass over a set of vehicles will provide some high level statistics but the vehicle powertrain requires optimising to operate across a range of vehicle weights rather than an average.

With the technology available today, deriving HGV parameters in real time is achievable. Advancements in the telematics market with vehicle OEMs now fitting most of the telematics devices mean higher fidelity data is becoming available for real time use. Access to other vehicle systems, such as navigation, would mean some of the problems experienced in acquiring accurate GPS and subsequent elevation data in addition to accurate engine torque data are relatively straightforward to overcome.

COMPARISONS TO LEGISLATIVE MODELS AND CYCLES

Performance parameters and cycles used in VECTO can be compared to the performance parameters and drive cycle derived from five FMCG HGVs driving around the UK and duty cycle derived from the event based data. While the data from VECTO doesn't need to be identical, the results should be within a range that is close enough that they represent real world use for the 3 axle artic HGV.

VECTO establishes the CO_2 emissions for a vehicle by modelling four different freight weights over two different vehicles cycles in the UK:

- Regional Delivery Cycle – 2.6 tonnes and 12.9 tonnes.
- Long Haul Cycle – 2.6 tonnes and 19.3 tonnes.

If an unloaded vehicle and trailer weight of around 17.3 tonnes was assumed this would equate to a total laden vehicle mass of:

- Regional Delivery Cycle – between 20.2 tonnes and 30.2 tonnes with a mean of 27.6 tonnes (when weighting factors are considered).
- Long Haul Cycle – between 20.2 tonnes and 36.6 tonnes with a mean of 31.1 tonnes (when weighting factors are considered).

The lower vehicle weights attributed to the VECTO cycles compare well to the type of vehicles in the sample (FMCG 3 Axle Artic) where the 2nd quartile (bottom) of the box plot aligns. There are significant differences at the higher weights of both cycles which is far beyond most of the vehicle weights from the type of vehicle in the sample. This skews the average weight into the upper quartile of the data collected from the sample of FMCG 3 Axle Artic vehicles.

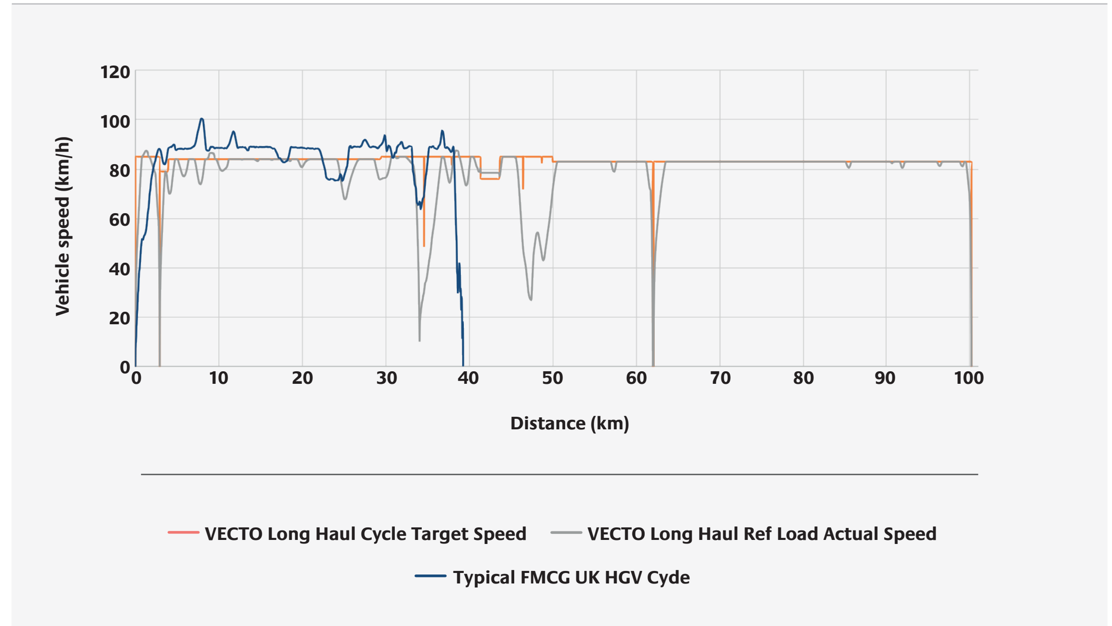
More data from other categories on vehicle weights is required to draw conclusions on whether the weights used in VECTO are relevant for all categories. However, the data collected from FMCG vehicles suggests there are large differences in vehicle weights when a vehicle is at capacity. In the case of the FMCG vehicle sample they are volume limited rather than weight limited.
VECTO utilises a target speed based cycle in which the simulated vehicle aims to achieve a given speed over a distance based cycle. VECTO uses a speed and gradient profile provided by the ACEA (European Automobile Manufacturers Association)[10].

The long haul cycle currently used in VECTO is 100km in length and has a very steady state speed profile target.

Using the VECTO model to run a vehicle over this cycle (the VECTO cycle) shows how the actual speed of the vehicle will vary compared to the target speed. This can be compared to a drive cycle of actual speeds which represent the five vehicles tracked on over 800 journeys (Figure 10) which are representative of the FMCG 3-axle articulated archetype.

[10]ICCT – Heavy-Duty Vehicle Fuel-Efficiency Simulation: A Comparison of US and EU Tools – April 2015

Figure 10
VECTO Long Haul Cycle vs UK HGV Cycle

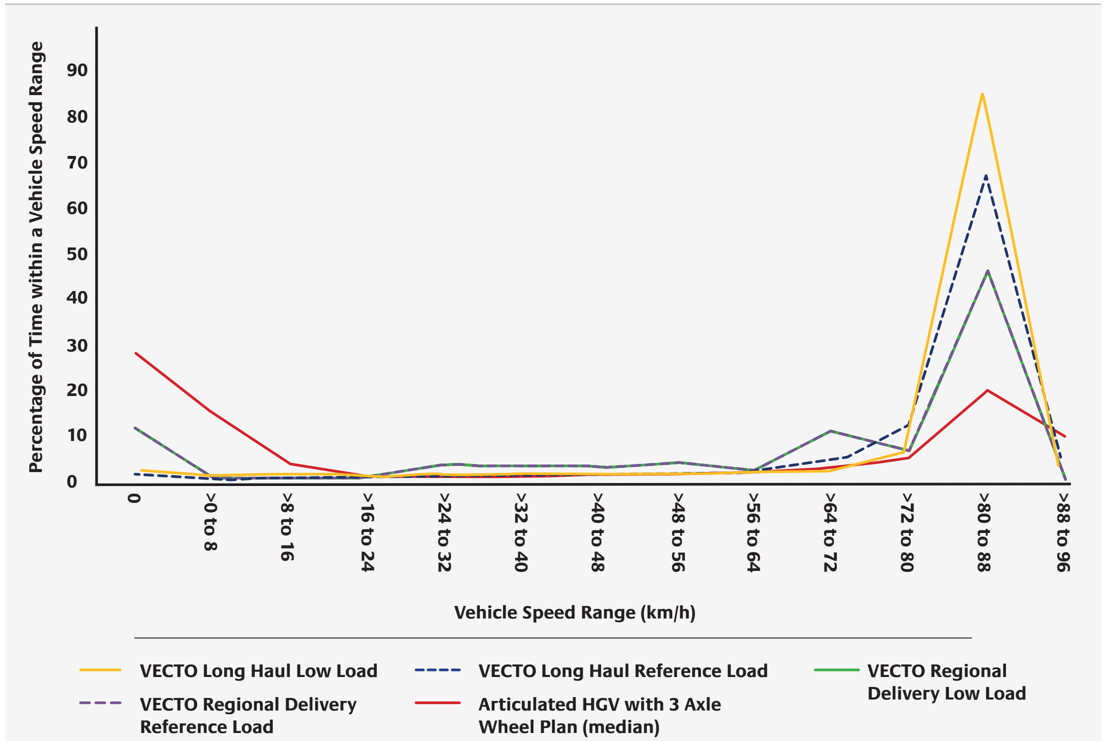


VECTO targets steady state speeds (83, 84 and 85kph), which is below UK limited speed for HGVs of 90kph and the steady state speeds seen in the instantaneous and event based data. In addition to the speed profile, road elevation profile data has a large effect on the overall results of any vehicle simulation. There is currently no data available (publicly or under acceptable licencing terms) at sufficient resolution and coverage to create an elevation profile (and thus gradient profile) to compare UK HGVs to the legislative cycle used in VECTO. Publicly available LIDAR data has recently become available from the Environment Agency (EA), but coverage of the UK is incomplete (≈75% of England is covered), while the resolution is adequate. This data was created to assess flood risks and the highest resolution data is around coastal areas while the 'blackspot' coverage areas are likely to be near the strategic road network.

Figure 10 presents the VECTO long haul cycle (outputs from VECTO for an example HGV over the long haul cycle) as a speed histogram compared to the speed histograms established from the 4,451 vehicles used to characterise the UK HGV fleet. A clear distinction is evident between the theoretical VECTO cycle and real world data. For 93% of the VECTO cycle, the vehicle is assumed to be operating between 80 and 88kph. This is much higher than the real world data, and significantly underestimates the stationary (idling) and low speed portions of real drive cycles.

Figure 11

VECTO cycles as duty cycles against the characterised duty cycles from 10,370 UK HGVs



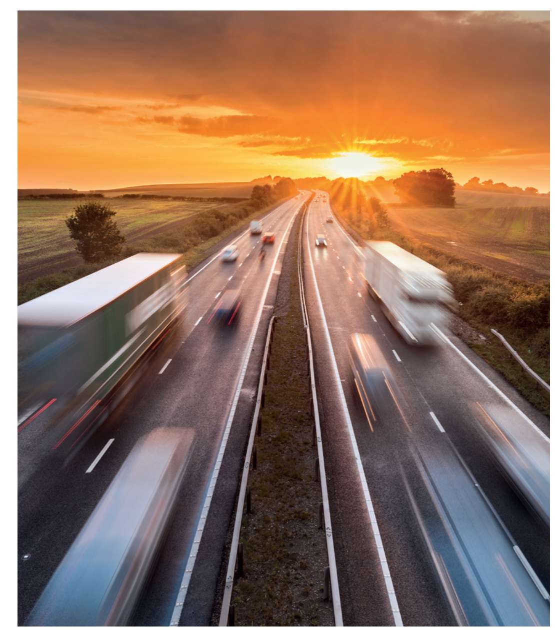
CONCLUSIONS

Through profiling an HGV's use by common metrics such as speed distribution, daily distance driven, and fuel consumption, a number of archetypes have been created to represent the UK HGV fleet. Thirty six statistically distinct archetypes exist in the data sample used in the ETI Data Analysis project. However, the data set contains enough data to be statistically representative in only twelve of the thirty six. Data sets for some archetypes could not be created at all due to there being no data from these vehicles (4 axle Rigid HGVs) in the samples used, whereas others had too few data points to be statistically representative. Further work is required to accrue and populate data from the missing archetypes from the sample of data used here to create the usage picture for the entire HGV fleet in the UK. The breadth and challenges faced by the ETI in acquiring data for the ETI project highlights some of the expected challenges in acquiring this further data.

The twelve archetypes which have been statistically characterised were compared to the drive cycles used in VECTO. There are significant differences between the VECTO drive cycle and the twelve archetypes' duty cycles, especially at higher cruising speeds. This has the potential to lead to significant differences between the certified and labelled fuel efficiency and CO_2 emissions predicted by VECTO and those seen in real operations of HGVs in the UK. This could affect confidence in the VECTO approach for UK operators.

Accurately calculating the mass of a vehicle is achievable with currently available systems. More accurate data is required in other areas, specifically around topography and engine torque, in order to accurately predict rolling resistance and aerodynamic drag coefficients. HGV OEMs are developing ever more complex telematic solutions in each new iteration of vehicle. These solutions could alleviate some of the challenges in deriving performance parameters, i.e. collecting engine torque data of sufficient quality and road gradient data (HGV OEMs are already purchasing this data for predictive cruise control and navigation systems). HGV OEMs, who own much of this data, will be equipped in the near term to predict rolling resistance and aerodynamic drag coefficients, and will be well placed to assess the effectiveness of new technologies in real world use.

OEMs should, in turn, be able to assess their own vehicle real world fuel consumption and CO_2 emissions to compare to the modelling outputs. This could also mean that OEMs would know how they are doing against the 2025 and 2030 targets in real use. There is provision in the legislation for the European commission to monitor in service emissions, but how this can be achieved in practice has yet to be defined[11].



[11] European Commission – Proposal for a Regulation of the European Parliament and of the Council setting CO2 emission performance standards for new heavy-duty vehicles

ABOUT THE AUTHOR

Matthew Joss
Principal Engineer

Matthew Joss is a Principal Engineer at the ETI. He was ETI's Strategy Analyst from 2013 – 2017.

Thanks...

The ETI would like to thank Element Energy, Microlise and the ICCT for carrying out the Data Analysis project which provided the basis for this ETI Insight.

Reports and data from this project have been made available with this insight. These are available to download from the Knowledge Zone of the HDV programme area on the ETI website.

Energy Technologies Institute
Charnwood Building
Holywell Way
Loughborough
LE11 3AQ

01509 202020
eti.co.uk
info@eti.co.uk
@the_ETI