Why the VECTO black box needs to be opened up

Analysis of the input parameters

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1. Introduction

The VECTO simulation tool is developed to predict the fuel consumption/CO_2 of HDV's as accurately as possible in various boundary conditions such as mission profile, vehicle loading, configuration, etc. To achieve an acceptable level of accuracy of the model output, there are two important requirements:

1. The model architecture should match the complexity of all components that play a dominant role in the determination of actual fuel consumption/CO2
2. Sufficiently detailed input data is required on those components that play a dominant role in the determination of actual fuel consumption/CO2

As it is often said amongst simulation modelers, '**the quality of the model is as good as the quality of the input data**'. On the delivery of quality input data there is a potential conflict between on the one hand the level of detail required to feed the model, and the confidentiality of these data on the other hand.

This paper is intended as a first analysis of the main input parameters of VECTO, to give some better understanding of what these parameters represent and how they can be measured. Furthermore it will be discussed if the parameter should be classified as 'confidential' or not. For the evaluation of confidentiality we use the evaluation method outlined in our discussion paper[1].

2. Input data

There are 6 main components identified for VECTO: Engine, air drag, axles, transmissions, tyres and auxiliaries. For each of these components we will first identify the input parameter which is likely the most sensitive one in terms of confidentiality, and describe how this parameter can be measured.
Notes:

- Manufacturers will have different options for the determination of the input parameters, which range from using default values to performing detailed measurements. In this analysis we assume that data is determined at the highest detail level.
- For most of the engine and drivetrain related components the parameter may be different when the vehicle is still warming up. This effect is not included in VECTO, which might be justified by the assumption that it is negligible for vehicles driving most of the day.

2.1 Engine

Main input parameter: Fuel efficiency map

What it represents: The fuel rate of the engine as a function of engine torque and engine speed.

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[1] Discussion paper on confidential input data for VECTO, I.J. Riemersma and W. Todts, Transport & Environment, 12 May 2015 http://www.transportenvironment.org/sites/te/files/publications/26.05.2015%20Input%20paper%20on%20confidentiality_final-1.pdf

Measurement method: The engine is placed on an engine dynamometer in the emission laboratory, and the fuel rate is measured for 80 to 100 engine points (combinations of engine torque and engine speed). The efficiency of the engine in each engine point can be found by dividing the fuel rate by the engine power.
Other parameters: Torque curve, idle speed, rated engine speed, etc.

Remark: The fuel consumption/CO2 simulated by VECTO is determined through the following steps:
- the speed/inclination cycle is translated into second-by-second engine points
- the second-by-second fuel consumption/CO2 is derived by linear interpolation of the measured engine points (referred to as a quasi-stationary calculation method)
- a transient correction is applied, which is found by dividing the transient WHTC CO2 result by the quasi-stationary calculation of the WHTC (similar to the previous bullet point)

2.2 Air drag

Main input parameter: Air drag coefficient C_d

What it represents: The aerodynamic resistance of the vehicle body, expressed as the ratio between the air drag of the vehicle body and the air drag of a flat object with the same frontal area

Measurement method: The vehicle is driven at a constant speed with torque meters installed at the wheel hubs. By measuring the torques at the two different vehicle speeds, and assuming that air drag correlates with the quadratic vehicle speed, the air resistance can be broken down from the total resistance. Dividing this by the frontal area of the vehicle, it delivers the air drag coefficient.

Other parameters: Air drag of trailers, and influences (both positive and negative) of additional equipment attached externally to the vehicle body.

Remark: Alternative methods to derive the air drag coefficient are the vehicle coast down method (predominant method for light-duty vehicles), wind tunnel measurements or CFD simulation. A small quadratic vehicle speed influence might also be related to the tires.

2.3 Axles

Main input parameter: Axle efficiency

What it represents: The power losses in the axle as a function of axle load, torque and rotational speed
Measurement method: The axle is placed on a dynamometer, and the torques at all shaft ends are measured at varying rotational speeds. The efficiency of the axle can be found by dividing power at the wheel shafts by the power of the driveshaft (power = torque x rotational speed).

Other parameters: final ratio, axle load distribution

Remark: This procedure applies to driven axles. Non-driven axles also have an efficiency, related to the losses in the axle bearings. These efficiencies are better than those of driven axles.

2.4 Transmissions

Main input parameter: transmission efficiency

What it represents: The power losses in the transmission as a function of torque and rotational speed in each gear

Measurement method: The transmission is placed on a dynamometer, and the torques at the shafts are measured at varying rotational speeds in all gears. The efficiency of the transmission can be found by dividing power at the driveshaft by the power of the engine shaft (power = torque x rotational speed).
Other parameters: gear ratios

2.5 Tyres

Main input parameter: Tire rolling resistance coefficient

What it represents: The losses due to tire deformation, expressed as the ratio between resistance force (opposite to the vehicle speed direction) and the vertical gravitation force on the tire.

Measurement method: The tire is pressed against a large spinning roller. The torque that is applied to the roller to maintain its rotational speed is calculated into a resistance force at the tire.

Other parameters: Tire load distribution

Remark: There is an official regulation for tire rolling resistance labelling in place (EC 1222/2009) with a test procedure for rolling resistance determination and an alignment method to compensate for internal friction in the measurement equipment. The actual values of the test procedure are proposed to serve as the basis for this input parameter.

2.6 Auxiliaries

Main input parameter: auxiliary power

What it represents: The amount of mechanical or electrical power absorbed by any of the auxiliary systems, e.g. engine cooling fan, alternator, air compressor, steering pump, A/C compressor

Measurement method: In a dedicated test procedure the absorbed power will be determined as a function of the rotational speed (if applicable)

Other parameters: Depending on the type of auxiliary system a use factor may need to be determined
Remarks: only those auxiliary systems that are installed on the actual vehicle need to be considered.

3. Evaluation of confidentiality

According to our discussion paper[2] on confidential input data for VECTO, input data would not classify as being confidential if any of the following scenarios apply:

- There is no knowledge included in them;
- The data can be measured or easily reverse engineered;
- There is no competitive risk to disclose the information.

An evaluation table was introduced for these three aspects to indicate what would be considered to be a low or a high level, see the table below.

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[2] Discussion paper on confidential input data for VECTO, I.J. Riemersma and W. Todts, Transport & Environment, 12 May 2015

	Low	*High*
Data knowledge level	Just values or general know-how is included	Data contains detailed know-how resulting from design, engineering or calibration work
Data protection level	Data is easily measured or reverse engineered	Not possible to trace for third parties without excessive research or measurements
Data disclosure risk level	No competitive risk of disclosure or risk is diminished by full transparency	Clear competitive risk of disclosure

Table 1 – Data evaluation table to evaluate the confidentiality

Since for a number of these risks the ranking was seen higher than 'low' but lower than 'high', a third level was introduced ('average').

For each of the main input parameters the confidentiality can now be checked on the three relevant aspects i.e. knowledge, protection and disclosure risk.

3.1 Engine

Knowledge: The engine is controlled by a sophisticated control unit. This is programmed to define relevant engine parameters (such as fuel amount per cycle, injection timing, profile and pressure) within the operating envelope of engine torque and speed. The calibration of this control unit needs to ensure that the engine is capable of running in different ambient conditions (ambient temperature, pressure, altitude) and at the same time optimizes the engine for low fuel consumption, good drivability and low pollutant emissions. These operational objectives may lead to conflicts and trade-offs in , for instance a low fuel consumption also leads to a high engine-out NOx emission and vice versa.

This means that the manufacturer will apply alternative strategies in different parts of the engine map. For areas which are often frequented during the type approval test procedure the manufacturer may choose to optimize for low pollutants in order to meet the emission limits, while a low fuel consumption may be chosen as the main objective for less frequented areas. This calibration process is complex and time consuming. It is to a great extent depending on the engine and after treatment technology applied, as well as the strategy chosen by the manufacturer to meet the pollutant emission limits while the engine is also efficient in fuel consumption.

For the VECTO input it is proposed to use the fuel efficiency map, which is based on measuring 100 points within the operating envelope of engine torque and speed. This will provide a fairly accurate description of the fuel consumption. Although the fuel efficiency map does not reveal the exact details of applied calibration strategies (e.g. control algorithms). It does show the result of all engineering and calibration efforts. It doesn't however reveal which engine parameters were exactly manipulated to achieve the fuel efficiency which would suggest low levels of knowledge are 'hidden' in the fuel map.

On the other hand, analyzing the fuel map may provide a hint on where the manufacturer chose to optimize the engine for low fuel consumption or low NOx within the operating envelope of the engine map. So it some ways it does provide a picture of how the engine was optimized although this is a rather blurred picture.
In summary, the fuel efficiency map can provide some general information on which optimization strategy was chosen during the calibration process, but will not reveal through which parameters that optimization was obtained. Therefore the knowledge level is seen as low to average.

Protection: It is not easy to measure the fuel efficiency map of an engine on a dynamometer without the assistance of the manufacturer. Alternatively, the engine could be measured while it is still mounted in the vehicle, but that would reduce the accuracy of the measurement. The protection level is seen as high.

Disclosure risk: Competitor manufacturers might benefit from the general information on which optimization strategy was chosen during the calibration process , by using it to identify a calibration that roughly brings the same result. Also the information on fuel efficiency throughout the engine map might work as a benchmark. Of course, the efficiency map does not show *how* this efficiency was obtained, only what the achieved level of efficiency is. The disclosure risk is considered to be average.

3.2 Air drag

Knowledge: The air drag coefficient C_d does not contain any knowledge, it is only showing the result of the combined engineering and design efforts to create a low aerodynamic resistance. The knowledge level is considered to be low.

Protection: An accurate measurement of the C_d in a wind tunnel is very costly, but a coast down test on a track could be executed relatively simply. Without detailed information from the manufacturer the C_d cannot be simulated by CFD. The protection level is seen as average.

Disclosure risk: Competitor manufacturers cannot benefit much from knowing the C_d of a particular vehicle. The only competitive disadvantage would be that it is relatively easy to determine which manufacturer is identified as 'best of class', and to see which aerodynamic aspects on that vehicle have contributed to that low drag coefficient. The disclosure risk is considered to be low.

3.3 Axles and transmissions

Since input data and measurement principle of axles and transmissions are very similar, this analysis will be combined.

Knowledge: From the efficiency of an axle or a transmission it cannot be learned what engineering efforts were taken to achieve this level of efficiency. Hence, there is no knowledge attached to the efficiency, and the knowledge level is considered to be low.

Protection: For an accurate measurement of the efficiency and the relation with torque and speed it will be necessary to dismount the transmission or axle, and test it at a dynamometer. Especially for automatic transmissions that may prove to be complicated, though not impossible. The protection level is judged to be average or high.

Disclosure risk: Competitor manufacturers cannot benefit much from knowing the efficiency of an axle or transmission. The only competitive disadvantage would be that it is relatively easy to determine which manufacturer is identified as 'best of class', and to find out by dismantling the axle/transmission which engineering aspects contribute to that low high efficiency. The disclosure risk is considered to be low.

3.4 Tires

Knowledge: From the rolling resistance coefficient of a tire it cannot be learned what engineering efforts were taken to achieve a low RRC. Hence, there is no knowledge attached to the RRC and the knowledge level is considered to be low.

Protection: A tire RRC can be measured at each of the aligned European test facilities. But that is not really necessary as the RRC value for tires is already known by the labelling system effective in the EU. It is also common practice that the vehicle manufacturer will specify the maximum RRC for the tires that he wants to be fitted to the vehicle. The protection level is low.

Disclosure risk: Since the tires are already labelled in classes and the tire manufacturer has to specify the RRC to the vehicle manufacturer anyway, there is clearly a low risk for disclosure. Having said that, it seems that there are still some administrative and legislative hurdles to overcome as there is no official information channel available for the RRC.

3.5 Auxiliaries

Knowledge: The power needed to drive any of the auxiliary systems does not contain any knowledge. For some auxiliaries where the output power can be measured this can be translated into an efficiency, but that still does not reveal how this efficiency was obtained. The knowledge level for all auxiliaries is seen to be low.

Protection: Since auxiliaries are separate systems, they can easily be taken out of the vehicle and driven on a dynamometer to derive the power consumption. For auxiliaries which are manufactured by the supplier industry, this information will be available as an information. The protection level is low.
Disclosure risk: Competitor manufacturers would not benefit much from knowing the power consumed by auxiliary systems. The risk of disclosure is therefore seen as low.

4. Summary

The table below summarizes this confidentiality analysis. The last column shows the overall evaluation of the confidentiality level for the components.

Component	Knowledge level	Protection level	Disclosure risk level	**Confidentiality level (overall)**
Engine	Average	High	Average	**Average**
Air drag	Low	Average	Low	**Low**
Axles & Transmissions	Low	High	Low	**Low**
Tyres	Low	Low	Low	**Low**
Auxiliaries	Low	Low	Low	**Low**

Table 2 – Component input data evaluation

According to this data evaluation, only the fuel efficiency map of the engine would qualify as average confidential input data.

Discussion items

- The competitive risk of disclosure is higher if it only concerns one of the market players. In this case all of the manufacturers that serve the European market have to provide transparency on their input data, hence the risk of disclosure is considerably less.

- Disclosure of input parameters may also have positive effects: manufacturers would not like to be 'worst in class' with their components, and will make improvements to achieve better performance.
- Following the same principle, manufacturers of components that are 'best in class' may attract more attention from their competitors to see how this result was obtained. In this way, transparency of the input parameters may prove to be an effective driver for innovation.
- Next issue will be to address the options to make confidential input parameters available to third parties while safeguarding them from being exposed to a wider public (encrypted data, independent input data management bureau, local storage at manufacturer with restricted access, etc.)

Further information

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