Support Preparation of Legislation on Trailers Certification

Procedure no: CLIMA.C.4/SER/2019/0003

Task 3: Development of the IT tool to be used for certification

Task 4: Validation of the IT tool to be used for certification

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Acronyms and abbreviations

Acronym	Meaning
CFD	Computational Fluid Dynamics
CIF	Customer Information File
GUI	Graphical User Interface
HDV	Heavy Duty Vehicles
MRF	Manufacturer's Records File
OEM	Original Equipment Manufacturer
S&M	Support and Maintenance
TPMLM	Technically Permissible Maximum Laden Mass
VECTO	Vehicle Energy Consumption calculation TOol
xEV	Vehicles with electrified powertrains
XML	Extensible Markup Language (file format)

Definitions

Term	Definition
Efficiency ratio	Ratio of two CO_2-values as results from VECTO Trailer Tool for specific (semi-)trailers in the nominator and the results for the corresponding reference trailer in the denominator
Reference ratio	Ratio between two CO2 emission values simulated with a generic towing vehicle, coupled to the reference trailer as defined for each trailer vehicle group and coupled to the standard trailer as defined for the towing vehicle group in Regulation (EU) 2017/2400
CO_2-value	Result from the simulation tool for vehicles in the units [g/km], [g/pass.-km],[g/t-km] or [g/m³-km]
DA	Code for semi-trailer according to Regulation (EU) 2018/858 (revision of 2007/46/EC), Annex I, Part C, (5).
DB	Code for Drawbar trailer according to (EU) 2018/858 (revision of 2007/46/EC), Annex I, Part C, (5).
DC	Code for Centre-axle trailer according to (EU) 2018/858 (revision of 2007/46/EC), Annex I, Part C, (5).
HDV	Vehicles with type approval according to Regulation (EC) 595/2009 and its amending Regulations"
LDV	Vehicles with type approval according to Regulation (EC) 715/2007 and its amending Regulations". These are officially called "Light Passenger and Commercial vehicles"
Lorry	A vehicle that is designed and constructed exclusively or principally for conveying goods which may also tow a trailer according to Regulation (EU) 2018/858 (revision of 2007/46/EC), Annex I, Part C, (4). Lorries cover chassis-cab HDVs, vans and tractors.
Rigid Lorry	A lorry that is not designed or constructed for the towing of a semi-trailer and that is not a van; according to point (17) in Article 3 of the upcoming amendment of regulation (EU) 2017/2400
Tractor	A towing vehicle that is designed and constructed exclusively or principally to tow semi-trailers according to Regulation (EU) 2018/858 (revision of 2007/46/EC), Annex I, Part C, (4)
Trailer	Any non-self-propelled vehicle on wheels designed and constructed to be towed by a motor vehicle, that can articulate at least around a horizontal axis perpendicular to the longitudinal median plane and around a vertical axis parallel to the longitudinal median plane of the towing motor vehicle
Semi-trailer	means a towed vehicle in which the axle, or axles are positioned behind the centre of gravity of the vehicle (when uniformly loaded), and which is equipped with a connecting

Term	Definition
	device permitting horizontal and vertical forces to be transmitted to the towing vehicle
Light Lorry	N1 and N2 not exceeding 5 tons maximum mass with engine type approval according to Regulation (EU) 595/2009 and a reference mass exceeding 2610 kg
Medium Lorry	N2 exceeding 5 tons and not exceeding 7.4 tons maximum mass with engine type approval according to Regulation (EU) 595/2009 and a reference mass exceeding 2610 kg
Heavy Lorry	N2 exceeding 7.4 tons maximum mass and N3 with engine type approval according to Regulation (EU) 595/2009
Primary Lorry	Lorry with complete chassis, engine, transmission, axles, tyres and auxiliaries but with standard body or semi-trailer for declaration of the vehicles CO_2-value
Complete(d) Lorry	Lorry with its final body and equipment for declaration of the CO_2-Factor
Final body and equipment	Body, auxiliaries and any other equipment mounted to a Primary Lorry or a Primary Bus until the final stage, which changes weight, aerodynamics or auxiliary power consumption in the input data of the simulation tool.
Standard body or trailer	Body, trailer or semi-trailer defined in Appendix 4 to Annex VIII with standardised dimensions for air drag testing of lorries and with generic mass as input for the CO_2 calculation tool

Executive Summary

Overall Context and objectives

This report is part of the work developed in the project *Support Preparation of Legislation on Trailers Certification,* for DG CLIMA under the contract CLIMA.C.4/SER/2019/0003.

The aim of this project is to develop a detailed certification methodology for determining heavy-duty vehicles (HDV) CO2 emissions, fuel and energy consumption with regards of their bodies and trailers, on the basis of technical properties of their components, such as engine, transmission, tyres and also aerodynamic drag, together with an extension of VECTO (Vehicle Energy Consumption calculation Tool). To achieve this, the project aims to:

- **Define a classification system** for O3 O4 category vehicles and rigid lorry bodyworks for their effect on the CO_2 emissions and fuel consumption of the towing vehicle / base vehicle.
- **Define a certification methodology** including the development of test requirements for determining the necessary inputs for the IT tool(s) used for CO_2 emissions / fuel consumption calculations and the definition of the algorithms, standard values and generic equations to be used for the CO_2 emissions / fuel consumption calculations.
- **Develop and validate the required IT tool**.
- **Provide support** throughout the project concerning the content of the technical annexes of a draft regulation.

This document describes the work carried out and methods developed in

- Task 3: Development of the IT tool to be used for certification and
- Task 4: Validation of the IT tool to be used for certification

specific for the application on trailers. As a general convention in this report, the term "trailers" includes semitrailers, drawbar trailers and centre axle trailers.

❖ Task 3: Development of the IT tool(s) to be used for certification

The development of the tool - hereinafter referred to as the VECTO Trailer Tool - was driven by the following requirements:

(1) it shall be based on the existing VECTO methods and algorithms as constantly being further developed in the framework of Regulation (EU) 2017/2400

(2) it shall be easy to maintain

(3) the tool shall allow both small manufacturers with only a few produced units per year as well as large manufacturers to determine the official performance parameters of their vehicles efficiently

(4) it shall adopt the existing methods from Regulation (EU) 2017/2400 for data integrity ("hashing") also for the information flow within the framework of trailer certification.

(5) the software shall be licenced under the EUPL v1.2.

The implementation approach chosen for the VECTO Trailer Tool was to embed the additional trailer specific routines into VECTO and handle the trailers as a separate vehicle category in the same way as heavy buses. This specific implementation allows for easy maintenance of the VECTO Trailer Tool, because e.g. bug fixes in the VECTO simulation core, which are carried out in the course of the maintenance of the motor vehicle VECTO, can be easily merged with the existing trailer specific routines.

For future extensions of the trailer legislation, e.g. to include e-axles, this implementation also offers ideal boundary conditions. For this purpose, a further developed VECTO version including xEV powertrain models can be used in the simulation core. Adjustments would only have to be made in the declaration data adapter which generates the VECTO run data (with additional generic towing vehicles) and the input module to reflect the trailer regulation specific methods, e.g. which types of e-axles can be configured, what specific input data are requested (input of XMLs for electric components as certified under Regulation (EU) 2017/2400) and what boundary conditions should be considered in the simulation.

As a code repository CITnet – the platform used for the motor vehicle VECTO - was used. The obvious choice was to use CITnet platform also for the distribution of the trailer specific official tool versions (the "official distribution platform").

For the official operation of the tool in the context of the Regulation, it still has to be decided whether the official support and maintenance process should also be handled via CITnet JIRA, or whether a simpler process (e.g. email platform) should be used due to the large number of potential users.

In order to meet the requirements of point (3) for SMEs, the features described below were implemented into the software:

- Graphical User Interface which allows for manual operation of the tool also for official purposes
- A background worker which enables a simple automation of the start and execution of simulation runs
- An automated generation of a formatted pdf for the Customer Information File (CIF)

For trailer manufacturers with larger production numbers, the tool furthermore offers the possibility to fully automate the process of generating the official values.

Regarding data integrity measures ("hashing"), the trailer regulation makes use of four trailer specific file formats (trailer input data XML, trailer MRF XML, trailer CIF XML certified aerodynamic device input XML). The related relevant hashing

functions were implemented into the VECTO Trailer Tool and the VECTO hashing tool.

- **Task 4: Validation of the IT tool(s) to be used for certification**

In Task 4 the software developed under Task 3 has been validated, tested and a user guide and software documentation have been elaborated. The good operation of the tools and the comprehensibility of the documents and methods have been tested first by running the applications within the consortium and then by collecting feedback from stakeholders in several test phases. Based on the feedback, further improvements to the tools have been implemented.

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1 Introduction

This report is part of the work developed in the project *Support Preparation of Legislation on Trailers Certification,* for DG CLIMA under the contract CLIMA.C.4/SER/2019/0003.

The aim of this report is to summarize the work done in Task 3 (Development of the IT tool to be used for certification) and Task 4 (Validation of the IT tool to be used for certification) specific for the application on trailers. As a general convention in this report, the term "trailers" includes semitrailers, drawbar trailers and centre axle trailers.

Task 3 aims to develop the IT tool necessary for certification for trailers with consultation and agreement with the Commission, covering the design, programming and testing of:

- The interfaces from users to the tool (GUI) and between the tool and VECTO.
- Reading input data for the base vehicle (PIF, Primary Vehicle Information File).
- Reading input data for the specific trailer.
- Calculation routines for the CO_2 – Factor and for the CO_2 – Ratio methods with VECTO in the loop.
- Writing results files for the specific trailer.
- Extension of the VECTO Hashing Tool for trailers.

This software has been tested and validated in Task 4 to eliminate bugs and a user guide and software documentation were developed.

2 Task 3: Development of the IT tool to be used for certification

The objective of this task was to develop the IT tool - hereinafter referred to as the VECTO Trailer Tool - necessary for certification of trailers.

2.1 Requirements

The requirements for the VECTO Trailer Tool, as identified based on the service request, own analysis and input from stakeholders, were identified to be as follows:

(1) it shall be based on the existing VECTO methods and algorithms as constantly being further developed in the framework of Regulation (EU) 2017/2400

(2) it shall be easy to maintain

(3) the tool shall allow both small manufacturers with only a few produced units per year as well as large manufacturers to determine the official performance parameters of their vehicles efficiently

(4) it shall adopt the existing methods from Regulation (EU) 2017/2400 for data integrity ("hashing") also for the information flow within the framework of trailer certification.

(5) the software shall be licenced under the EUPL v1.2.

2.2 General software architecture

2.2.1 VECTO Trailer Tool simulation approach

After a detailed analysis of the options resulting from the above-mentioned requirements (1) and (2), the implementation approach chosen for the VECTO Trailer Tool was to embed the additional trailer specific routines into the VECTO project and handle the trailers as a separate vehicle category in the same way as heavy buses. In order to explain this implementation, the architecture and steps to create a simulation run of the "motor vehicle" VECTO is briefly explained below and then, in a second step, the trailer specific adaptations as applied by the VECTO Trailer Tool is described.

In Figure 1 the architecture and process to create the simulation runs and reports in the official simulation for motor vehicles is depicted.

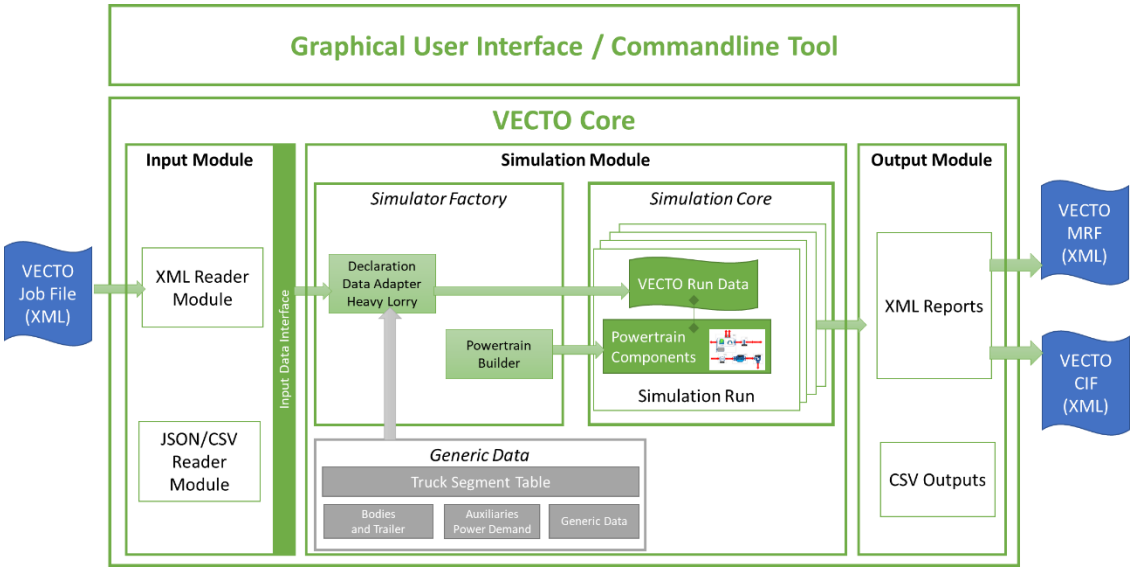


Figure 1: Software Architecture – motor vehicle VECTO

VECTO uses a flexible software architecture. Individual modules are decoupled via interfaces so that a certain module can be adapted or replaced and thus the functionality changes. The three main modules are the *input module*, the *simulation module* and the *output module*. The input module reads the model parameters from different input sources (currently JSON/CSV and XML are supported) and provides the model parameters via dedicated interfaces to the *simulation module*. The *simulation module* itself consists of additional sub-modules. In the *simulator factory*, the *declaration data adapter* uses the model parameters provided by the input module via the *input data interface* and *generic data* to create the model parameters for a simulation run in a *VECTO run data* object. Based on the input parameters, the vehicle is allocated to a certain vehicle group (Truck Segment Table). The vehicle group defines which generic values for the body and potential trailer, auxiliary power demand, etc. are applicable and which mission profiles and payloads need to be simulated. A separate instance of *VECTO run data* is created for each combination of mission profile and payload. The *VECTO run data* object contains the model parameters for every powertrain component (i.e., tyres, vehicle mass and air drag, transmission, combustion engine, etc.) during the simulation. This is an internal representation of the model parameters from the input and generic data. For example, the single input value of the declared air-drag coefficient is used to generate a look-up table of speed-dependent influence of the air-drag, considering the vehicle height and cross-wind influence.

The powertrain builder uses the *VECTO Run Data* and instantiates all necessary components of the drivetrain (vehicle, wheels, retarder, transmission, combustion engine, etc.), connects the components with each other and creates the Simulation Run objects. The *Simulation Core* then performs the simulation of all simulation runs in parallel. A *simulation run* handles everything related to the simulation itself. All components are initialized at the beginning. The simulation is split into simulation intervals of about 0.5 seconds. Every simulation step is split into two phases. The first phase is the request-phase. The simulator issues a new

request for the simulation step to find a valid operating point of the whole powertrain. Depending on the driving action this means that either the vehicle's acceleration is varied so that the engine operating point is within or on the full-load curve, or the braking power is adapted to reach a certain deceleration. More details on the VECTO basic simulation approach can be found in section 4.3.2.3 in [1]. The second phase is the commit-phase. Every component updates its internal state to be ready for the next simulation step.

All simulation results are collected in the output module. The output module creates the XML reports (manufacturer's record file, customer information file) among others.

The trailer specific routines have now been integrated into this existing system as shown in Figure 2. The architecture and simulation approach are exactly the same as in the VECTO simulation tool. Changes were made in the input module and the data adapter. In addition, the data adapter uses additional generic data.

The input module contains new interfaces and new classes for reading the input XML for trailers. The *Declaration Data Adapter* is specific for trailer simulations. But the *VECTO Run Data* instances are exactly the same as in VECTO. Moreover, the powertrain builder and VECTO Simulator remain unchanged.

The Declaration Data Adapter uses additional generic data tables. Based on the input, the trailer is allocated to a certain vehicle group. The vehicle group defines the generic towing vehicle to be used in the simulation, the mission profiles and payloads to be simulated, etc. The generic towing vehicle defines the vehicle category of the towing vehicle and thus the auxiliary power demands and other truck-specific generic values to be used in the simulation.

The input parameters of the trailer mainly influence three different model parameters of the *VECTO Run Data* instance. The dimensions of the trailer and the aerodynamic features have an influence on the aerodynamic drag curve, the masses influence the total vehicle mass, and the axles and tyres have an influence on the rolling resistance. The simulation of the simulation runs itself is exactly the same as for the VECTO for motor vehicles.

The output module contains new classes to write the trailer-specific manufacturer's record file and customer information file in XML format.

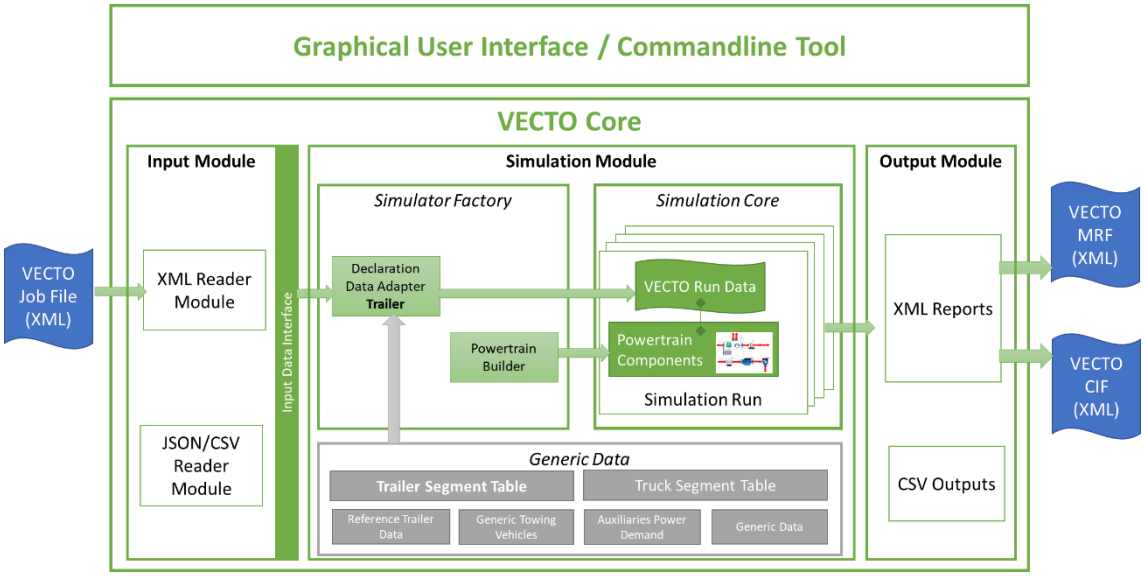


Figure 2: Software architecture – VECTO Trailer Tool

This specific implementation allows for easy maintenance of the VECTO Trailer Tool, because e.g. bug fixes in the VECTO simulator core, which are carried out in the course of the maintenance of the motor vehicle VECTO, can be easily merged into the existing trailer specific routines.

For future extensions of the trailer legislation, e.g. to include e-axles, this implementation also offers ideal boundary conditions. For this purpose, a further developed VECTO version including xEV powertrain models can be used in the simulation core. Adjustments would only have to be made in the declaration data adapter which generates the VECTO run data (with additional generic towing vehicles) and the input module to reflect the trailer regulation specific methods, e.g. which types of e-axles can be configured, what specific input data are requested (input of XMLs for electric components as certified under Regulation (EU) 2017/2400) and what boundary conditions should be considered in the simulation.

The Graphical User Interfaces (GUI) can be used to generate and modify the XML input data and may start the simulation.

The new functionality for reading trailer XML files, creating the VECTO Run Data instance with correct values as well as trailer-specific generic data is covered by several unit tests.

2.2.2 Programming environment, support and maintenance

As can be concluded from the software architecture described above, CITnet – the platform used for the motor vehicle VECTO - was used as a code repository for the VECTO Trailer Tool. The obvious choice was to use the CITnet platform also for the distribution of the trailer specific official tool versions (the "official distribution platform").

What has not yet been created for the VECTO Trailer Tool on the JRC CITnet platform is the registration of official users and a dedicated separate "Project",

i.e. a subsection of the platform where VECTO Trailer Tool-specific bugs can be noted and maintenance is organised. This feature was not required so far because the large number of testers in the stakeholder feedback phase made it impractical to have each tester registered on CITnet. Instead, feedback and bugs were collected via a "Feedback Excel" during the test phase (details see task 4).

For the official operation of the tool in the context of the Regulation, there are still some decisions or arrangements to be made in this regard:

- Does it make sense to have all official users of the tool registered on CITnet JIRA? Consultants view: yes, but such must be clarified with the capacities of CITnet JIRA (maximum number of users which can be configured by the JRC and the related requirements from the process licence)

- If answer to above is “no”: What does an alternative form of organisation look like with regard to notifications about updates, bug reporting etc.? An option could be simple email distribution list centrally managed by DG CLIMA.[1]

- For the smooth operation of the motor vehicle VECTO, contracts are awarded for support and maintenance of the tool. The task is to deal with any problems or questions that arise during the official use of the tool and, if necessary, to carry out bug fixes and updates to the tool. It is assumed that this will be also necessary for the smooth operation of the VECTO trailer tool. The effort required in this regard is very difficult to estimate. The trailer specific algorithms are much less sophisticated than the VECTO simulation core itself, but also the fact of much more and less trained users’ needs to be taken into consideration. As the trailer specific routines are embedded into the overall VECTO code library it is recommended to have motor vehicle and trailer specific support and maintenance activities covered in a single contract. Otherwise it will be difficult to decide which of the contracts applies for which ticket and double resources might be required for fixing of single issues.

2.3 VECTO Trailer Tool features

In order to meet the requirements of point (3), the features described below were implemented into the software. These features are also to a large extent the result of extensive stakeholder feedback during the testing phase as described in task 4.

❖ **Graphical User Interface (GUI)**

In contrast to the VECTO version currently used in Regulation (EU) 2017/2400, with the VECTO Trailer Tool it is possible to generate the input XML required for the official process purely via the GUI. This makes it much easier for small companies without in-depth IT knowledge (e.g. on how to deal with XML schemas) to carry out the official process for determining the official efficiency

[1] Nevertheless, from TUG's point of view, CITnet/Jira should be used for development and as an issue tracker (even if requests come in by email - it is easier to keep track of what has been changed, what is still open, changelog, ...). As mentioned above, a separate "project" should be created for the VECTO Trailer tool in CITnet/Jira.

related properties.[2] Component XMLs received from suppliers (tyre manufacturers, aero device manufacturers) can easily be added to the trailer configuration via a browse function. The tool GUI can be used to generate the XML input data as well as to call the actual calculation.

- **Background worker**

One requirement raised by stakeholders during the first test phase of the tool in 2021 was the implementation of a "background worker". This function enables a simple automation of the start and execution of simulation runs. The background worker periodically searches a directory specified by the user for new input XMLs. If such a file is available, a calculation is automatically started in the background and, after completion, the input XML and result files are stored in another directory to be specified.

- **Automated generation of a formatted pdf for the Customer information file (CIF)**

Another requirement frequently mentioned by stakeholders in the course of tool development was the option for automated generation of a formatted printable output of the customer information file. Such is generated by the tool in the form of a pdf file in a neutral format, if the corresponding tool option is set accordingly. Such a function is not provided in the motor vehicle VECTO. So far as is known for motor vehicles, each manufacturer uses its own, manufacturer-specific layout for the customer results. It can therefore be assumed that the automated function in anonymous layout in the trailer tool will rather be used by smaller manufacturers.

- **Further options for automation**

The process of determining the official efficiency ratios for trailers can of course also be fully automated. The following two steps are necessary for this:

1) Independent generation of the input XML, e.g. from a manufacturer-specific product database. For programming the corresponding script, the XML schema files are delivered with the trailer tool.

2) Start the simulation with the command line tool `vectocmd.exe`, e.g. `vectocmd.exe -q <XML-File>`

For the automated start of the calculation, there is also the basic possibility of executing this via an OEM-specific IT solution or application.

- **User Guide and Tool documentation**

Following the breakdown of deliverables in the service request, the user guide and the software documentation are described in the report section for Task 4.

[2] Due to the significantly higher complexity of the input data (scope and variety) for motor vehicles, such a function would not make much sense for those. However, such a function was added in the course of the work on the 2nd amendment for bus body manufacturers, among which there are also many SMEs and for whom only a limited number of parameters need to be entered.

2.4 Hashing

The trailer regulation makes use of four trailer specific file formats for which data integrity measures ("hashing") are required. These files are:

1) Trailer input data XML
2) Trailer MRF XML
3) Trailer CIF XML
4) Certified aerodynamic device input XML

The following functions required in the context of trailer regulation were implemented in the VECTO tools:

- The trailer input XML is hashed before the simulation and the hash is written to the MRF.
- The hash of the trailer MRF is calculated and written to the CIF.
- The hash of the trailer CIF is calculated and output at the end of the CIF.
- A certified aerodynamic device input XML can be component hashed via the VECTO hashing tool.
- The validity of the hash of the certified aerodynamic device input XML can be checked via the VECTO hashing tool.

3 Task 4: Validation of the IT tool to be used for certification

In Task 4 the software developed under Task 3 has been validated, tested and a user guide and software documentation have been elaborated. The good operation of the tools and the comprehensibility of the documents and methods have been tested first by running the applications within the consortium and then by collecting feedback from stakeholders in several test phases. Based on the feedback, further improvements to the tools have been implemented. This section documents the work performed in these regards.

3.1 Validation approach

For the validation and safeguarding of the methods applied by the trailer Regulation – this comprises both the methods for determining the input data and the accuracy of simulation tool - it is advisable to proceed in a step by step process with the following elements:

i. Validation of the “VECTO approach” as applied in Regulation (EU) 2017/2400

ii. Validation of trailer specific methods

iii. Verification of the correct function of the VECTO Trailer Tool

iv. Plausibility checks of the input data to the VECTO Trailer Tool

The “classical” validation elements i. and ii. are explained in this section. A further holistic validation of the overall approach "in one step" by means of a comparison between measurement and simulation seems hardly feasible in practice[3] and also not necessary on the basis of the considerations made here. Items iii. and iv. are discussed in the following sections 3.2 and 3.3.

3.1.1 Validation of the “VECTO approach” as applied in Regulation (EU) 2017/2400

The core of the method for determining the impact of trailers on CO_2 emissions and fuel consumption of the towing vehicle is the "VECTO method" as developed and applied for Regulation (EU) 2017/2400. This procedure consists of two parts:

- firstly, the specific determination of vehicle parameters (e.g. vehicle mass, aerodynamic drag by means of Constant Speed Test (CST), engine characteristics from engine dynamometer tests), and

- secondly, the simulation of energy consumption or fuel consumption and CO_2 emissions of the entire vehicle using the simulation model VECTO.

This overall approach has already been tested and validated in several measurement series. The most extensive of these investigations ("proof of concept") is described in (Fontaras, 2014)[4]. The fuel consumption of vehicles in five different HDV categories was measured in road and chassis dynamometer measurements and was compared with VECTO simulation results. In the study it was concluded that "the simulated fuel consumption of on-road real world operation was calculated always within a +/-3% range from the real world measurement, and in several cases even closer than that". This observed accuracy can be transferred 1 to 1 to simulations in which the trailer is the subject of the investigation, since the same parameters of the entire vehicle (mass, air resistance and rolling resistance) are influenced and modelled.

[3] In order to directly validate the "efficiency ratios" as determined under the new legislation, the mission profiles as stored in VECTO would have to be exactly driven on a test track under absolutely identical environmental conditions for the reference trailer and the specific trailer. The towing vehicle would have to be close to the specifications of the generic vehicle defined for VECTO and the reference trailer would have to correspond exactly to the defined reference trailer of the trailer regulation. This validation would need to be carried out for trailers with the different technical features.
It is estimated here that, due to limitations in the practical execution of such validation measurements, the uncertainties of such a validation are significantly higher than the potential uncertainties of the trailer methodology.

[4] Fontaras G., Rexeis M., Hausberger S., Kies A., Hammer J., Schulte L., Anagnostopoulos K., Manfredi U., Carriero M., Dilara P.: Development of a CO_2 certification and monitoring methodology for Heavy Duty Vehicles – Proof of Concept report. JRC report 87799, Europe-an Union 2014, ISBN 978-92-79-35146-4, doi: 10.2790/12582.

3.1.2 Validation of the trailer specific methods

Building on this basic methodology, the approach developed for the trailer legislation additionally applies elements used to either generate trailer specific input data (like CdxA) to the simulation and/or to establish a reference for rating of results. Those elements are:

- Generic towing vehicles
- Reference trailers
- An approach to determine air drag for a specific combination of towing vehicle and trailer
- An approach to consider liftable and steered axles

The functioning of these methods including the derivation of the approaches and data for validation are described in detail in the Task 2 report.

The methods for taking vehicle mass and rolling resistance into account are not listed here, because in this respect no elements are used that go beyond the methods already used in Regulation (EU) 2017/2400.

In the validation context, the following facts should be pointed out in particular:

- The final evaluation of a trailer according to the Regulation developed in this project is based on a ratio factor, the "efficiency ratio" (ratio of CO_2 emissions of the specific trailer to a reference trailer, both simulated with the generic tractor vehicle). This means that different trailers within a vehicle group can be easily compared on the basis of this key value. Since only simple[5] vehicle characteristics (mass, air resistance, rolling resistance + bonus factors for liftable and steered axles) are evaluated, this approach can be considered very robust.

- If trailers from different vehicle groups are compared (e.g. investigating whether a volume-oriented trailer is better suited than a standard trailer for a specific transport application), the absolute values for fuel consumption and CO_2 emissions as well as the characteristic values from the simulation (payload and transportable volume) must be used.[6] Also for this application, the method can be considered at least as robust as the motor vehicle regulation as long as only the comparably simple trailer characteristics are considered by the Regulation.

As soon as more complex technologies are included in the evaluation of trailer regulation (e.g. e-axles in different system designs), the robustness of the methods or an explicit validation will need to be analysed again.

3.2 Testing of the VECTO Trailer tool

As foreseen in the project's work plan, the VECTO Trailer Tool was subjected to a comprehensive test programme on several levels:

[5] "Simple" in comparison to the "complex" features evaluated by the motor vehicle regulation (e.g. different powertrain technologies, vehicle controls)
[6] A direct comparison based on the efficiency ratios is not possible because the reference retailers differ in the denominator of the factor.

- The first level included basic testing in the actual software development, including the creation of unit tests in the code.

- The second level comprised "internal tests" carried out by personnel not involved in the programming of the software code.

- The third level comprised "external testing" by future users and stakeholders or at stakeholders premises.

Within the scope of the project, the VECTO Trailer Tool essentially underwent four major development cycles:

A first functional version was subjected to internal tests from November 2020 on. However, this version was not distributed externally because in January 2021 it was decided to change the basic approach for calculating the efficiency ratio (reference trailer instead of standard trailer).

The second version was also subject to internal testing only, as it was already clear at this time that further modifications will need to be implemented due to the extensive activity of the trailer certification task force (e.g. updates in the classification matrix).

The third version of the VECTO Trailer tool was tested internally in June 2021 and handed over to stakeholders – accompanied by two stakeholder workshops (presentation on June 1st 2021, Q&A workshop on July 14th 2021) - for external testing.

A fourth development cycle of the VECTO Trailer Tool took place in the winter of 2021/2022, in which the changes in the Regulation since the summer of 2021 were to be incorporated and the feature requests of the stakeholders from the first external test phase were incorporated. The final tool version was presented to stakeholders in April 2022 with a feedback period during May 2022.

After this test phase, only minor changes and bug fixes were made.

The activities carried out in the internal and external tests are described below, and the feedback from the stakeholders from the latter is documented.

3.2.1 Internal testing

The following test cases or use cases were carried out and analysed in the internal tests:

- Test cases for all vehicle groups and technologies.

- Comparison of interim results (e.g. determined CdxA values, determined total vehicle mass for simulations, applied simulation settings) with the correct values as specified by the “Master Excel”.

- Extensive checks regarding the ease of use of the GUI including checks that possible input errors in both the GUI and/or input XMLs are detected and a clear error message is created accordingly.

- Checks that both the GUI and XMLs (both input and output XMLs) are in line with the Annexes e.g. naming of the parameters or that certain input parameters are shown/hidden depending on the defined trailer, and also that internal algorithms like the allocation of a specified trailer to the corresponding trailer group work correctly.

- Plausibility checks regarding the impact on overall fuel consumption for different technology combinations like axle feature combinations, aerodynamic devices and trailer characteristics like mass or dimensions.

- Checks regarding the correct calculation of the efficiency ratios and overall plausibility of the results

Generic input data sets were created from the test cases, which are also distributed as examples with the VECTO Trailer Tool.

3.2.2 Test phase with users

A test phase with the involvement of future users is essential to ensure that the software functions work as smoothly as possible in the official application. As already described above, two external test phases were carried out in the project. The focus of the tests was both on improving usability (first and second test phase) and identifying errors in the code (second test phase).

User feedback was collected in an Excel format.[7] These tables are presented in Appendix B (first external test phase) and Appendix C (second external test phase). It should be noted that, for the sake of completeness, to-do items identified within the consortium were also documented on these lists. These lists thus represent the complete work plan for the elaboration of the fourth version of the tool (April 2022) and the final version (June 2022).

3.3 Plausibility checks of the input data

This element is not part of a classical validation but should nevertheless be mentioned here. To safeguard the official results generated within the framework of trailer regulation, it is also beneficial to take measures to check the plausibility of the input data into the tool. This seems particularly useful because, as already described above, it is to be expected that small manufacturers operate the tool via manual inputs - and not via an automated and uncertified process. Also, during the testing phase, the stakeholders suggested that plausibility checks should be included for this purpose. After coordination within the task force, the checks of the input data as listed in Table 1and Table 2 were built into the VECTO Trailer Tool.

[7] As already described under task 3, the organisation via the CITnet JIRA platform was not used here in order to simplify the process with many beta testers.

Table 1: Overview of plausibility checks implemented in the tool – Part 1

IF	THEN
Number of Axles = 1	No Type DB allowed
Trailer Type = DB + Number of Axles = 2	Axle 1: steered and not liftable Axle 2: not liftable and not steered
Trailer Type = DB + Number of Axles = 3	Axle 1: steered and not liftable Axle 2: not steered Maximum 1 axle is liftable
Trailer Type = DC + Number of Axles = 1	Legislative Category = O3
Trailer Type = DA + Number of Axles = 1	
Trailer Type = DC + Number of Axles = 1	Axle 1: not liftable and not steered
Trailer Type = DC + Number of Axles = 2	Axle 1: not steered
Trailer Type = DC + Number of Axles = 3	Axle 1: not steered Axle 2: not liftable and not steered
Trailer Type = DA + Number of Axles = 1	Axle 1: not liftable
Trailer Type = DA + Number of Axles = 2	Axle 1: not steered
Side covers short	No Side covers long
Side covers long	No Side covers short
Trailer Type = DB	No Side covers long
Trailer Type = DC	No Side covers long
Rear flaps short	No Rear flaps long
Rear flaps long	No Rear flaps short
Trailer Type = DC	TPMLM Axle Assembly ≤ TPMLM Trailer
Trailer Type = DA	TPMLM Axle Assembly < TPMLM Trailer

Table 2: Overview of plausibility checks implemented in the tool – Part 2

Parameter	Requirements
VIN	17 characters
Mass in running order, TPMLM Trailer and TPMLM Axle Assembly	>1.000kg
External width of the body	1000 mm< x ≤ 2.600mm
Total Height of the Trailer	1000 mm< x ≤ 4.000mm
External height of the body	< Total height of the Trailer
External length of the body	< Max. length per type: Body DA ≤ 14.000mm Body DC ≤ 12.000mm Body DB ≤ 12.000mm

In this context, it is pointed out that these checks can only catch gross implausibilities in the inputs to the tool. More subtle errors, e.g. typos in the numbers, in the input will remain undetected. In any case, within the scope of the official application of the tool, the user of the tool must be responsible for the

correctness of the entries. Compliance with the corresponding quality standards is the subject of the process certification according to Annex II of the regulation.

3.4 Tool documentation

The documentation of the VECTO Trailer Tool comprises the following parts:

- Methodical documentation of the developed algorithms (e.g. determination of C_dxA for a specific trailer, influence of steered or liftable axles, efficiency ratio calculation etc.) in the **report on Task 2** of this project.
- Formal documentation of the input data into the tool in **Annex III of the trailer Regulation**.
- Formal documentation of the official output data of the tool in **Annex IV of the trailer Regulation**.
- IT documentation of input and output files as **XML schemas (*xsd)** distributed with the tool
- **User Guide** with graphical instructions on how to use the tool and an overview of other relevant sources of information (see next section below).
- The **VECTO Trailer Tool Masterexcel** is a complete and partly interactive documentation of all trailer specific parameters and functions. The Masterexcel played a central role in the development of the tool and exchange of data and methods with stakeholder experts (also see separate section below).

3.4.1 User Guide

The User Guide is designed in a slide layout and can be directly accessed from the tool's graphical user interface. The User Guide comprises the following content:

- References to information in Technical Annexes of the Trailer Regulation
- VECTO Trailer Tool
    - Software package
    - JobFiles GUI
    - Options GUI
    - Background worker
    - How to create or edit trailer job
    - Result files
    - What is the "Efficiency ratio"?
    - What is the "Reference ratio"?

- Generation of input XML for a certified aero device
- Overview content of VECTO Trailer Tool Masterexcel

The User Guide can be found in Annex A of this report.

3.4.2 VECTO Trailer Tool Masterexcel

The VECTO Trailer Tool Masterexcel is an integral part of the tool documentation and fulfils the following functions:

- Documentation of the classification matrix used internally in the tool, which is more detailed than the classification according to Annex I;
- Documentation of all generic data stored in the tool (e.g. mission profile and payload allocation, specifications of reference trailers, standard values for reduction rates of aerodynamic devices etc.);
- Documentation of the formulas for calculating the air drag for the various combinations of generic towing vehicles and trailers
- Documentation of bonus factors for liftable and steered axles

The content of the individual sheets is described in Table 3 below.

Table 3: Content VECTO Trailer Tool Masterexcel

Excel sheet	Description
Classification	General information stored in the tool for each trailer configuration • Vehicle group acc. to Annex 1 • Information on the allocated generic towing vehicle • Mission allocation + weighting for aggregated results • Payload and axle weight shares per mission
Generic CAD vehicle	Main dimensions and air drag values of the generic CAD models used as a starting point to calculate the air drag of trailers with different dimensions (could be the reference- or the specific trailer)
Reference Trailer	Information on the reference trailers for each trailer configuration • Curb mass and cargo volume • Tyre specifications • Main external dimensions to calculate the air drag

Excel sheet	Description

	• Indication on which aero corrections are applied to which trailer configuration
	  • „1“ means aero correction is applied
	  • „0“ means aero correction is not applied

Specific trailer	Information on technologies that may be present on a specific trailer
	• Bonus factors for liftable and steered axles depending on trailer configuration, mission and payload
	  • These factors are to be understood as reduction factors on overall fuel consumption / CO_2
	• Indication on which aero corrections are applied to which trailer configuration
	  • „1“ means aero correction is applied
	  • „0" means aero correction is not applied The individual aero correction formulas can be viewed in the “Reference/Specific Trailer Aero" sheet and are documented in detail in Task 2 report section 2.4.5.
	• Aero reduction values for standard aerodynamic devices acc. to sheet „Combination Add-ons DX*“

Standard Trailer	Information on the standard trailers also used in Regulation EU 2017/2400 to calculate the reference ratios
Reference (Specific) Trailer Aero	Main dimensions and air drag values of the generic CAD models used as a starting point to calculate the air drag of trailers with different dimensions (Reference/Specific trailer) Step by step calculation process on how to apply the individual aero corrections to get the final air drag values for a reference/specific trailer In the columns AN to AX, the aero-relevant data can be entered for the individual trailer groups. The results for CdxA(0) as well as the polynomial coefficients of the polar can then be found in the columns DU and EC to EE.

Excel sheet	Description
Combination Add-ons DX*	Air drag reduction in % for the specific combination of standard aerodynamic devices (the reduction values can also be found in the sheet „Specific Trailer“
Efficiency Ratios - DA	Example on how the individual and weighted efficiency ratios are calculated based on a DA trailer

*DX... Placeholder depending on trailer type
DA... Semi trailer
DB... Drawbar trailer
DC... Centre axle trailer

4 Bibliography

[1] M. Rexeis, M. Quaritsch, S. Hausberger and et.al, “VECTO tool development: Completion of methodology to simulate Heavy Duty Vehicles' fuel consumption and CO2 emissions: Upgrades to the existing version of VECTO and completion of certification methodology.,” 2017.

[2] B. R. McAuliffe and A. S. Wall, *Aerodynamic Performance of Flat-Panel Boat-Tails and Their Interactive Benefits with Side Skirts,* SAE International Journal of Commercial Vehicles, 2016.

[3] J. M. Ortega and K. Salari, “Investigation of a Trailer Underbody Fairing for Heavy Vehicle Aerodynamic Drag Reduction,” in *Commercial Vehicle Engineering Congress & Exhibition*, 2008.

[4] DG CLIMA, Bodies and trailers – development of CO2 emissions determination procedure. Procedure Number CLIMA/C.4/SER/OC/2018/0005, 2019.

[5] European Comission, COMMISSION REGULATION (EU) No 1230/2012 of 12 December 2012, 2012.

[6] UN/ECE, Regulation No 73 Revision1, 2004.

[7] European Comission, COMMISSION REGULATION (EU) 2019/1892 of 31 October 2019, 2019.

[8] European Comission, COMMISSION REGULATION (EU) 2017/2400 implementing Regulation (EC) No 595/2009 of the European Parliament, 12 December 2017.

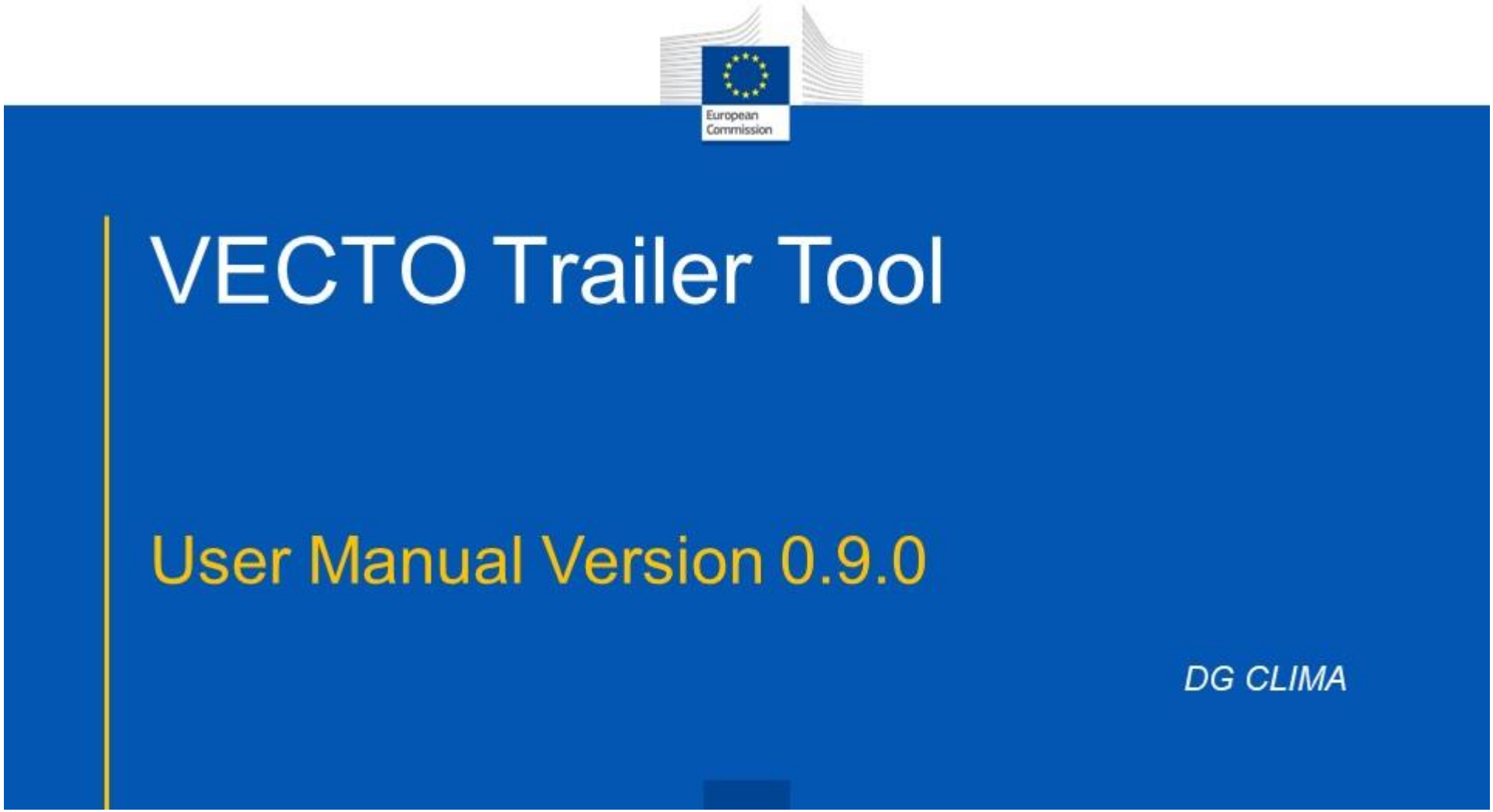
[9] N. Zacharof, A. Tansini, I. Prado and T. Grigoratos et al, “A Generalized Component Efficiency and Input-Data Generation Model for Creating Fleet-Representative Vehicle Simulation Cases in VECTO,” 2019.

[10] S. van Zyl, S. van Goethem, S. Kanarachos, M. Rexeis, S. Hausberger and R. Smokers, “Study on Tyre Pressure Monitoring Systems (TPMS) as a means to reduce LightCommercial and Heavy-Duty Vehicles fuel consumption and CO2 emissions,” 2013.

Annex A – User Guide

This Annex contains the User Guide as it is distributed as a pdf with the tool and can be accessed directly from the application via the Help button.

This report considers the current status (13th July 2022) of the VECTO trailers tool. Even if the tool suffers further modifications, the information in this document (user guide attached in the following pages) will not be updated.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VECTO Trailer Tool
User Manual Version 0.9.0
DG CLIMA

About this release version

- This release is a feature complete version of the VECTO Trailer Tool for the first implementation of the Regulation as regards the performance of heavy-duty trailers with regard to their influence on the CO_2 emissions, fuel consumption, energy consumption and zero emission range of motor vehicles and amending Implementing Regulation (EU) 2020/683
- **This is not yet an official version**, as the standard values for ΔCdxA reduction rates for aero features on DB and DC trailers are still not fixed.
- In this respect, placeholder values are implemented in the present version (details see slides 38 and 39).
- **Any official calculations carried out after the regulation has come into force must be carried out with subsequent official releases!**

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Content

- References to information in Technical Annexes of the Trailer Regulation
- VECTO Trailer Tool
  - Platform requirements and installation options
  - Software package
  - JobFilesGUI
  - OptionsGUI
  - Background worker
  - How to create or edit trailer job
  - Result files
  - What is the "Efficiency ratio"?
  - What is the "Reference ratio"?
  - Hashing
  - Plausibility checks
  - Options for automation
- Handling of aerodynamic devices
  - Generation of input XML for a certified aero device
  - Standard aerodynamic devices: Reduction values and allowed configurations
- Handling of liftable and steered axles
  - Bonus factors
  - Rules for multiple liftable and/or steered axles
- Overview content of VECTO Trailer Tool Masterexcel

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References to information in Technical Annexes of the Trailer Regulation

Annex Number	Title	Further Explanation
Annex I	Classification of vehicles in vehicle groups	Required definitions and classification system for trailers covered by the Regulation
Annex II	Requirements and processes for the operation of the simulation tool	Requirements for the process to be able to determine the official values within the framework of trailer regulation by means of the VECTO Trailer Tool
Annex III	Input information about the characteristic of the vehicle	Definitions and precise description of the input parameters into the tool and how to determine them
Annex IV	Template of the Manufacturer's Records file and of the Customer Information file	Definition of content and structure of the Manufacturer's Records file (MRF) and the Customer Information file (CIF)
Annex V	Vehicle's air drag data	Defines the procedures how the features of aerodynamic devices shall be determined, either via virtual testing using CFD or by applying standard reduction rates for aerodyanmic devices fulfilling certain minimum properties

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Platform requirements

Hardware Requirements

- Microsoft Windows PC running Microsoft Windows 7 or later

Software Requirements

- Microsoft .NET Framework 4.8

Software Requirements to use the pdf function of the tool

- Microsoft Visual C++ Runtime must be installed. If this is not the case for your computer, it can be downloaded free of charge from the following links:
  - 32 bit: https://aka.ms/vs/17/release/vc_redist.x86.exe
  - 64 bit: https://aka.ms/vs/17/release/vc_redist.x64.exe

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Installation Options

VECTO Trailer Tool is distributed as a portable application. This means you can simply unzip the archive and directly execute it. This, however, requires write and execute permission for the VECTO Trailer Tool application directory.

In case you do not have execute permissions, please ask your system administrator to install VECTO Trailer Tool into an appropriate directory (e.g. under `C:\Program Files`). Installing VECTO Trailer Tool requires the following two steps:

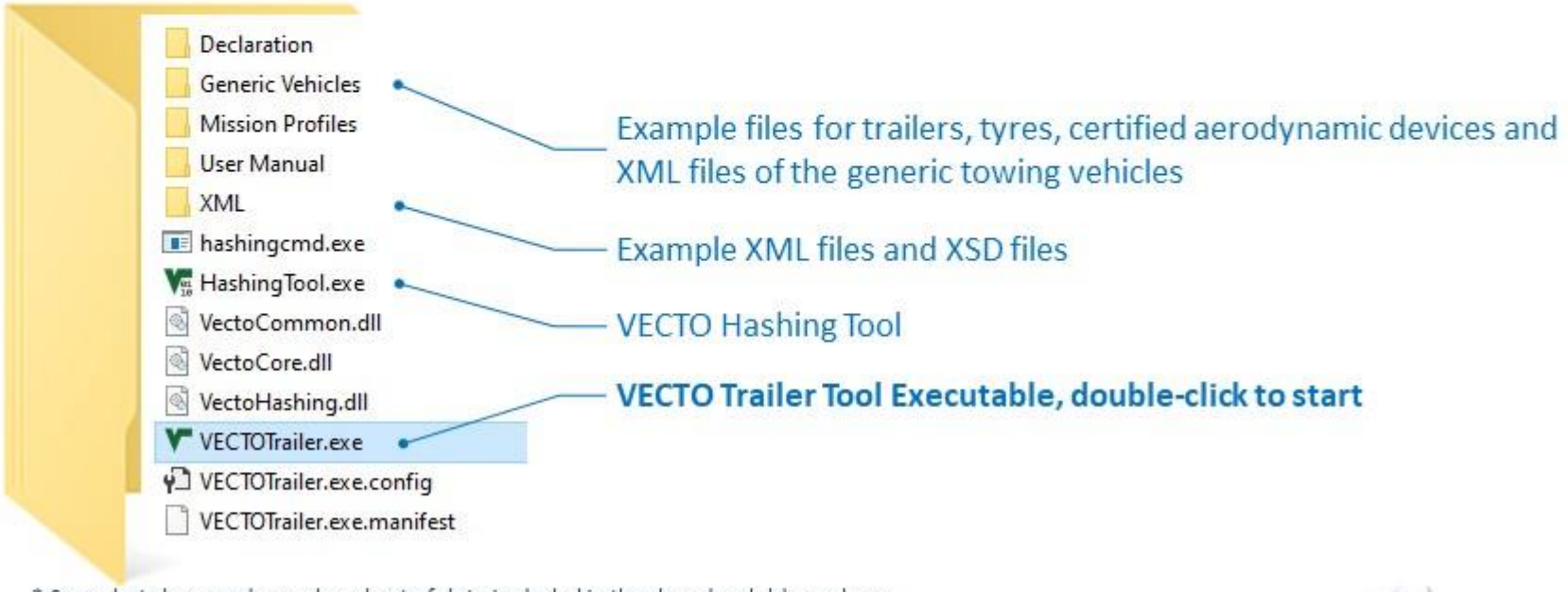
- Copy the VECTO Trailer Tool directory and all its files and subdirectories to the appropriate location where the user has execute permissions
- Edit the file `install.ini` and remove the comment character (#) in the line containing `ExecutionMode = install`

If the ExecutionMode is set to install (this is also possible when running VECTO Trailer Tool from an arbitrary directory), VECTO Trailer Tool does not write its configuration files and log files to the application directory but to the directories `%APPDATA%` and `%LOCALAPPDATA%` (usually `C: \User\<username>\AppData\Roaming` and `C: \User\<username>\AppData\Local`).

Important: If the ExecutionMode is set to install it is necessary that you copy the generic VECTO Trailer Tool models distributed with VECTO Trailer Tool to a location where you have write permissions as VECTO Trailer Tool writes the results to the same directory as the job files

VECTO Trailer Tool – Software package

Content of VECTO Trailer Tool package as downloaded from JRC server can be copied to any place on a PC/server*



* Snapshot shows only a reduced set of data included in the downloadable package

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VECTO Trailer Tool – What to do if tool doesn't start

Such a behaviour has been observed in cases where the VECTO Trailer Tool software package was unpacked with the Windows Explorer and marked the executables and dlls as unsafe (because loaded from the internet).

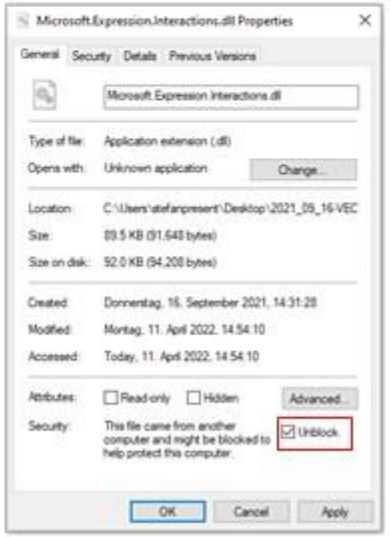
How to fix this?

Option 1:

Check all exe and dlls and mark them as "safe" → explorer → right click properties and then in the lower area tick the box that says "Unblock" (see Snapshot to the right)

Option 2:

Unpack VECTO Trailer Tool with another software ("7zip" for example)



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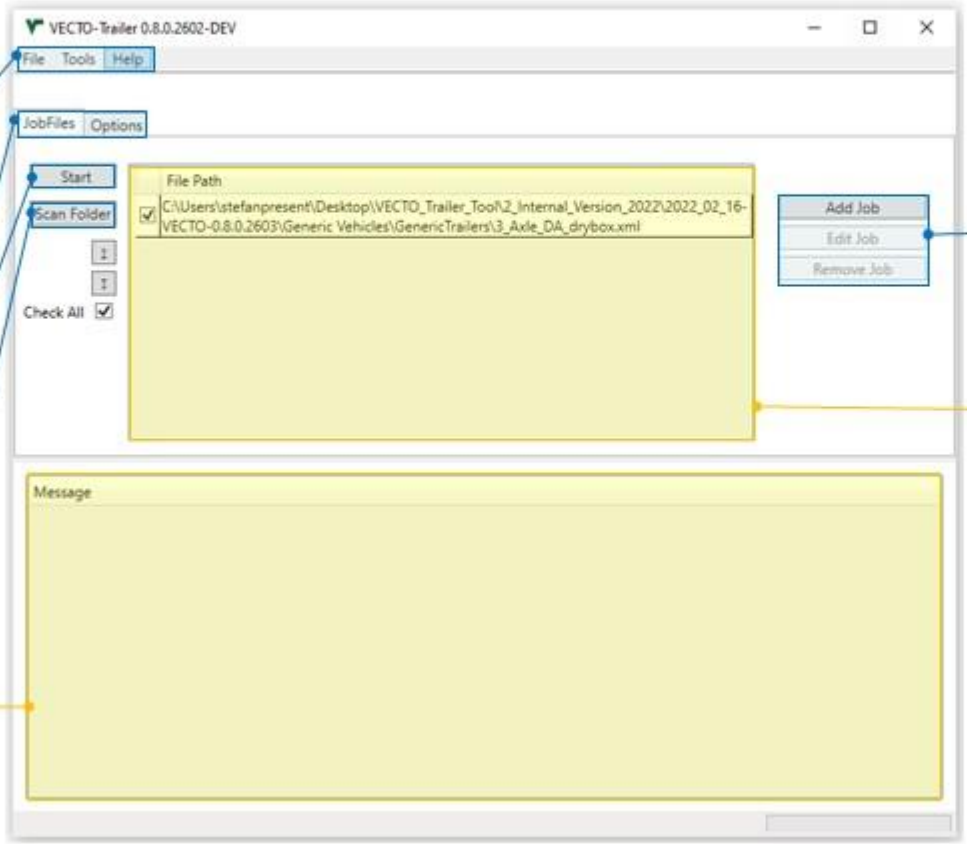
VECTO Trailer Tool – JobFiles GUI



Toolbar with common controls like
- add new Job
- search for Job files
- open User Manual
- etc.

Switch between "Job Files" and "Options" tab

Start button to simulate active Jobs

Button to activate/stop background worker

Message window showing the calculation status

Buttons to handle Job files
- Add new Jobs
- Edit existing Jobs from Job window
- Delete Jobs from Job window

Job window that shows all loaded Job files

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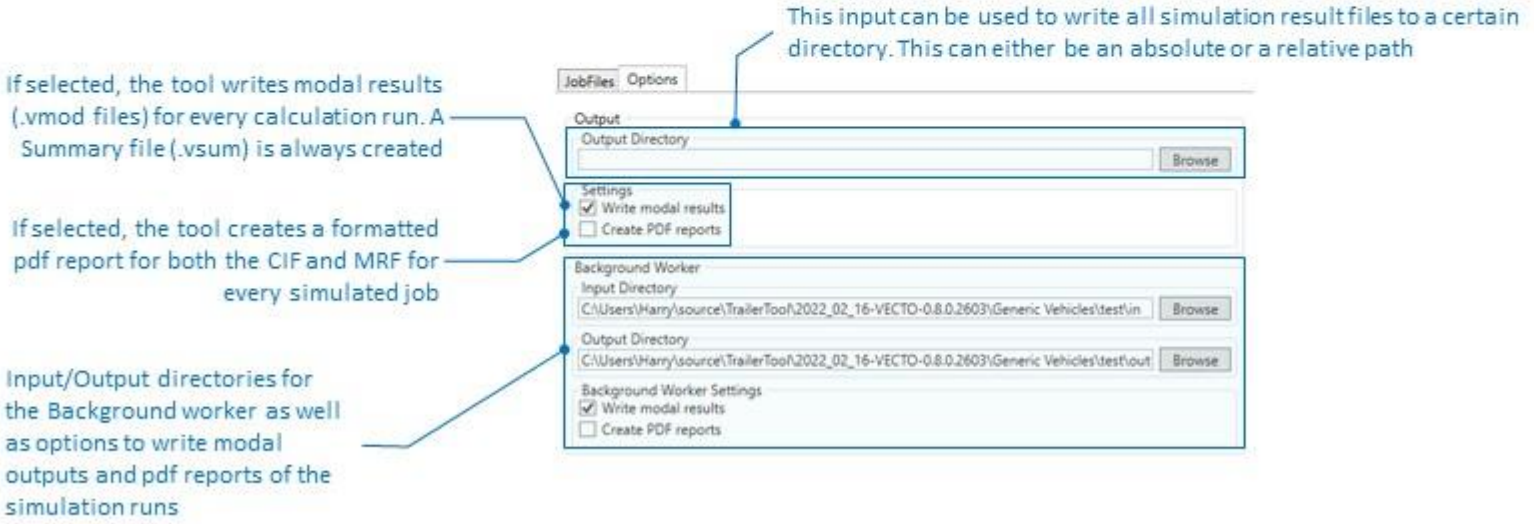
VECTO Trailer Tool – Options GUI

- At first program start it is recommended to define the default output directory and check the settings for writing modal results and creating formatted pdf reports
- Settings only affect the handling of input data or results, but do not influence the official results.



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VECTO Trailer Tool - Background worker

Enables a simple automation of simulation runs

1. The background worker periodically (i.e. every 4 seconds) searches a directory specified by the user for new input XMLs (Input Directory)
2. If a new file is available, a calculation is automatically started in the background
3. After completion, the result files are stored in another directory to be specified by the user (Output Directory)*

- Important boundary conditions / information on using the Background worker
  - Input and Output Directory **must be** different folders
  - In case an erroneous file is read from the Input directory, the tool will display an error message but still simulate the remaining valid Job files

*The background worker has to be initiated for a certain input/output directory by pressing the „Scan Folder" button under „JobFiles"

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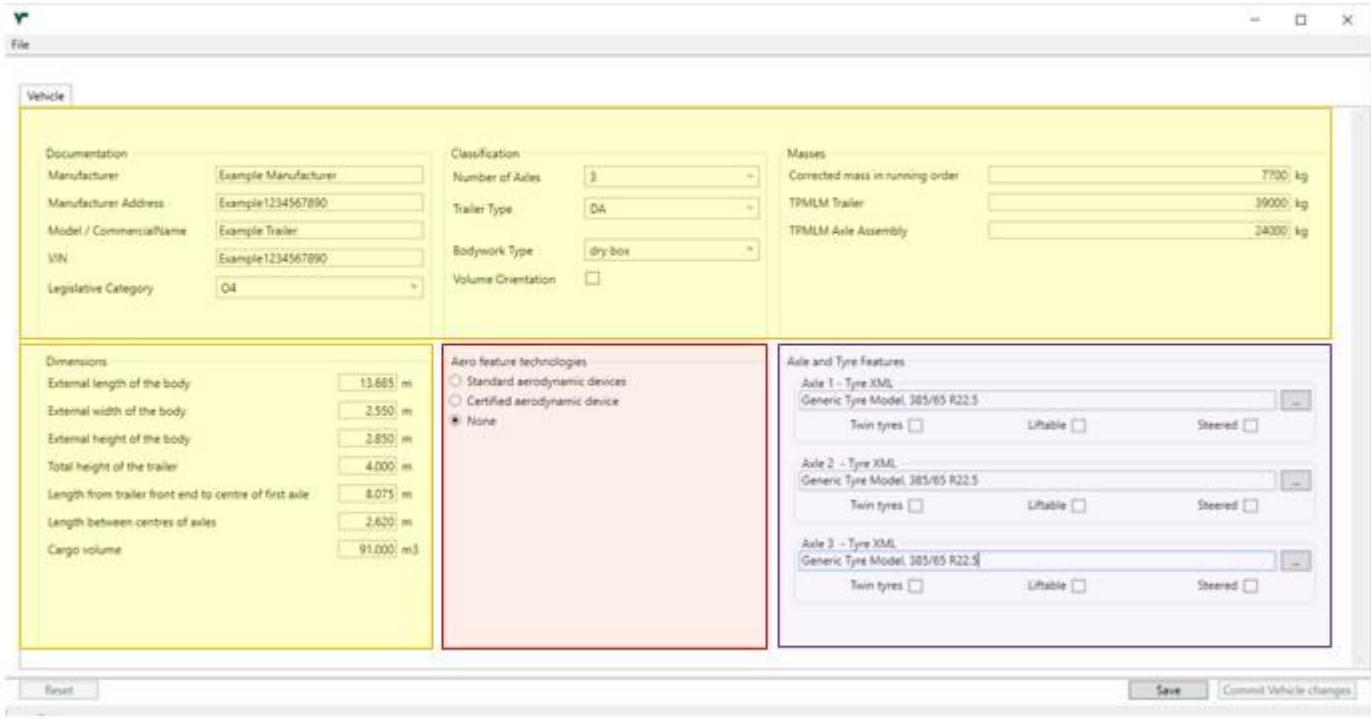
VECTO Trailer Tool – Create or edit trailer job (1/6)

1. Open window via
   - "Edit Job" or
   - Right click on Job window → "Create Trailer Job"

2. Define main trailer specifications

3. Define Aero feature technologies

4. Define Axle and Tyre features



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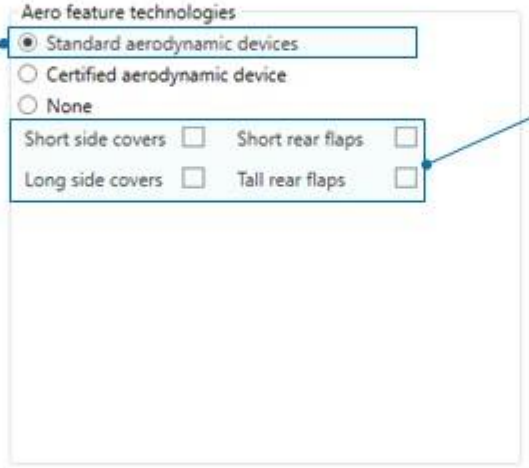
VECTO Trailer Tool – Create or edit trailer job (2/6)

3. Define Aero feature technologies

Select if standard values for reduction rates from aero devices are to be applied

Standard values as automatically allocated by the VECTO Trailer Tool are documented in:

- Masterexcel sheet „Combination Add-ons" or „Specific Trailer" column Y to BH
- Specific_trailer.csv in the Declaration folder
- Task 2 report



Checkbox to declare applicable standard aerodynamic device(s)
Note that not all combinations are valid → see also:

- Masterexcel sheet „Combination Add-ons"
- Trailer_combination_addon.csv in the Declaration folder
- Task 2 report

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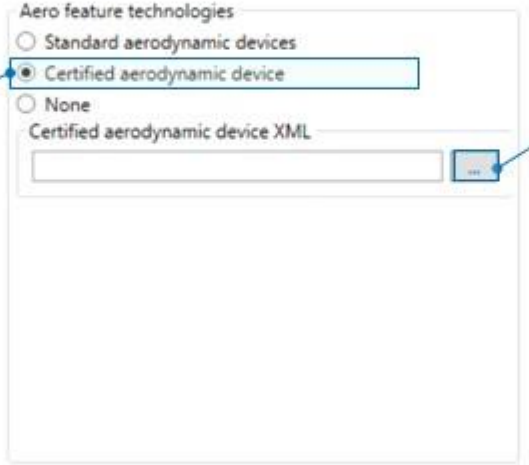
VECTO Trailer Tool – Create or edit trailer job (3/6)

3. Define Aero feature technologies

Select if certified reduction rates from aerodynamic devices are to be applied



Brows button to browse for the XML file of the certified aerodynamic device

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VECTO Trailer Tool – Create or edit trailer job (4/6)

3. Define Aero feature technologies

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VECTO Trailer Tool – Create or edit trailer job (5/6)

4. Define Axle and Tyre features

Checkbox to declare applicable tyre/axle features

Effects as automatically considered by the VECTO Trailer Tool for liftable/steered axles are documented in:

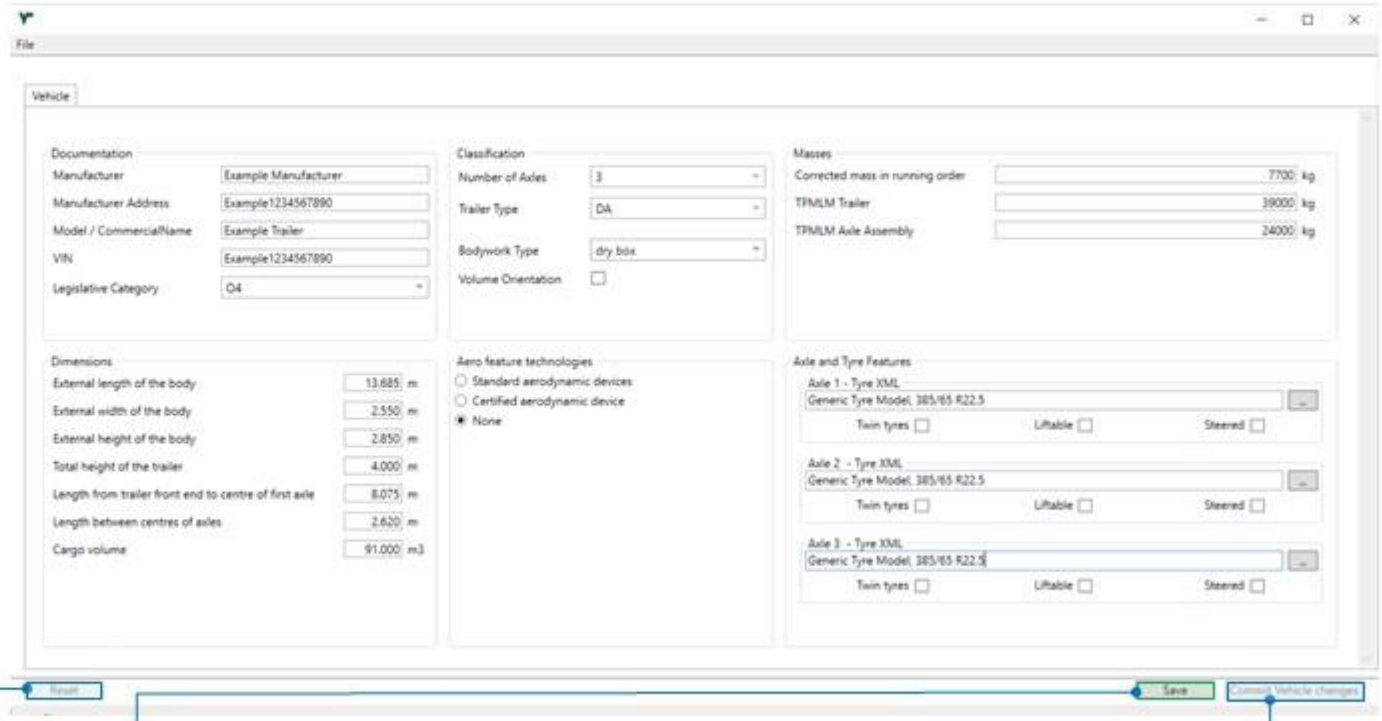
- Masterexcel
  - sheet „Specific Trailer" column E to P
- Specific_trailer.csv in the Declaration folder,
- Task 2 report

Browse button to search for tyre XMLs

VECTO Trailer Tool – Create or edit trailer job (6/6)

5. Save Job file

6. Press "Start" in Job file editor to start simulation of active Jobs



Button to reset all input fields to the last committed state

When the Job-file is saved, a message window will pop up if any errors are detected in the inputs

Button to commit changes made to the input fields. However, in order to permanently commit the changes it is necessary to save the file (closing the file without saving will reset the changes)

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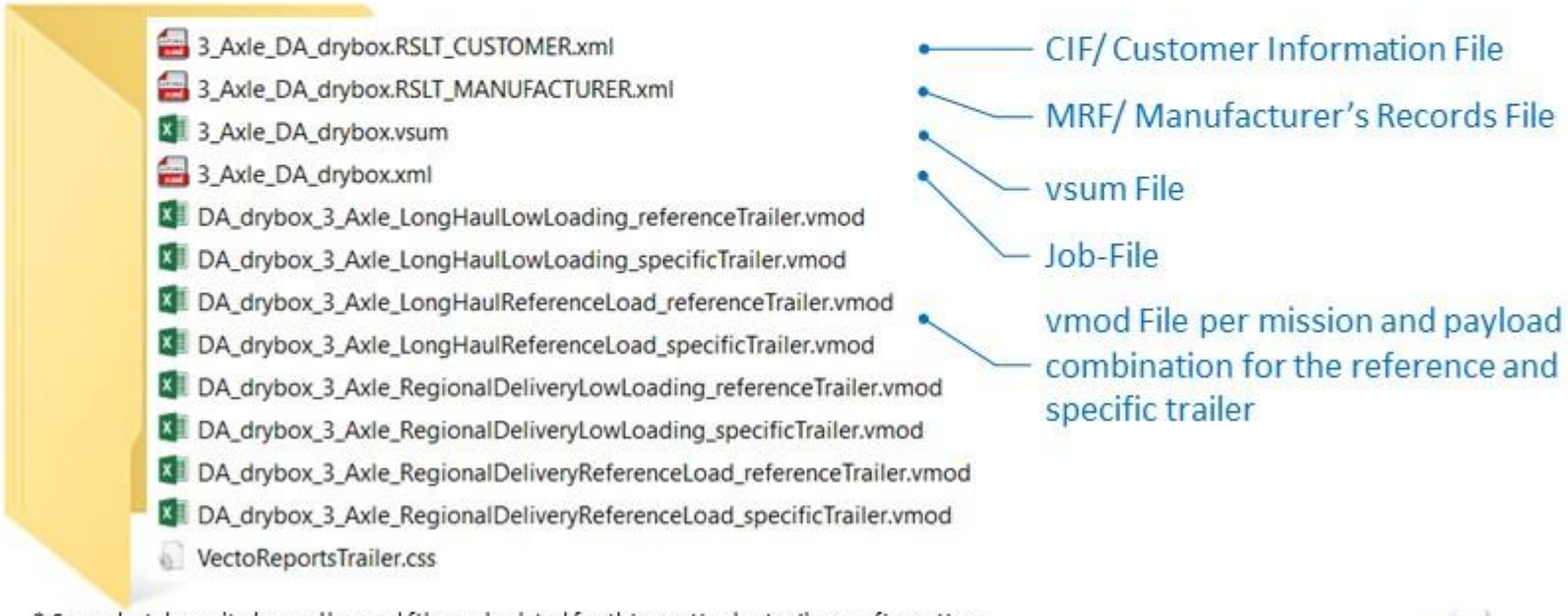
VECTO Trailer Tool – Result files (1/2)

Outputs created by the VECTO Trailer Tool including the corresponding Job file*



* Snapshot doesn't show all .vmod files calculated for this particular trailer configuration

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VECTO Trailer Tool – Result files (2/2)

Result file	Description
Manufacturer's Records File (MRF)	**Output for regulatory purpose in XML format** a file produced by the simulation tool which contains manufacturer related information, a documentation of the input data and input information to the simulation tool, and the performance of the vehicle with regard to its influence on the CO2 emissions and fuel consumption of motor vehicles, and which takes the form of the template laid down in Annex IV, Part I
Customer Information file (CIF)	**Output for regulatory purpose in XML format** a file produced by the simulation tool which contains a set of vehicle related information and the performance of the vehicle with regard to its influence on CO2 emissions, fuel consumption, of motor vehicles, and which takes the form of the template laid down in Annex IV, Part II
Pdf-output	Formatted printable output of the customer information file
vsum-file*	Output for engineering purposes in csv-format. Single line of results per each simulated combination of trailer, mission profile and payload with aggregate and or average values
vmod-file*	Output for engineering purposes in csv-format. Single file per each simulated combination of trailer, mission profile and payload with time-resolved simulation results from the VECTO core.

* A documentation of the results contained in the vsum and vmod files can be found in the help file for the VECTO calculation core (help.html), which is also included in the VECTO Trailer Tool release.

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What is the "Efficiency Ratio"? (1/2)

The Efficiency Ratio (ER) is a dimensionless characteristic value for the rating of a (semi-)trailer with regard to its influence on CO_2 emissions, fuel emissions and energy consumption of the towing vehicle.

$$\textbf{Efficiency Ratio} = \frac{CO_{2,\,spec(S)T}}{CO_{2,\,ref(S)T}}$$

Where:
$CO_{2,\,spec(S)T}$ ... CO_2 emissions with the generic towing vehicle and the **specific** (semi-)trailer
$CO_{2,\,ref(S)T}$ ... CO_2 emissions with the generic towing vehicle and a **reference** (semi-)trailer

Accordingly, an ER of 0.95 indicates that CO_2 emissions are 5% lower with the specific (semi-)trailer than with the reference trailer.

ERs are provided:

- For CO_2 emissions in the units "grams per km", "grams per ton-km" and "grams per m^3-km"
- For each relevant mission profile and payload combination and for the weighted-mix of mission profiles and payloads

Reference (semi-)trailers are defined for all vehicle groups currently covered by the Regulation and represent typical configurations (mass, dimensions, rolling resistance) as of approx. the year 2020. The specifications of these reference (semi-)trailers are documented in the VECTO Trailer Tool Masterexcel. However, their knowledge is not essential for the interpretation of the ERs.

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What is the "Efficiency Ratio"? (2/2)

Further information for individual use of the results from the VECTO Trailer Tool:

- Since fuel consumption and CO_2 emissions correlate linearly, the results as indicated by the ERs also apply to fuel consumption. For energy consumption of fully electric vehicles, at least similar trends apply.
- If (semi-)trailers in different groups are to be compared with each other (e.g. a standard variant with a volume-oriented variant), this cannot be done using the ER, as the reference (semi-)trailers are different. Such a comparison can be made using the results for fuel consumption (lit./100km, g/km) or CO_2 emissions (g/km). For a direct comparison, it must be ensured that the assigned generic towing vehicles are also identical on the basis of Annex I.
- Results for fuel consumption in the units lit./100km, g/km and CO_2 emissions in the unit g/km can be interpolated or extrapolated to other payload conditions in a specific mission profile in a very good approximation via the linear trend established by the results for the two fixed payloads as provided by the VECTO Trailer tool.

What is the "Reference Ratio"? (1/4)
Basics

- The "reference ratio" is the ratio between two CO_2 emission values simulated with a generic towing vehicle, once coupled to the reference trailer as defined for each trailer vehicle group and once coupled to the standard trailer as defined for the towing vehicle group in Regulation (EU) 2017/2400.

$$\text{Reference Ratio} = \frac{CO_{2,\,ref(S)T}}{CO_{2,\,stand(S)T}}$$

Where:
$CO_{2,\,ref(S)T}$ ... CO_2 emissions with the generic towing vehicle and the **reference** (semi-)trailer
$CO_{2,\,stand(S)T}$ ... CO_2 emissions with the generic towing vehicle and a **standard** (semi-)trailer

- The reference ratio is a numerical value that allows a vehicle operator to combine the results from the motor vehicle VECTO for the towing vehicle with the results from the VECTO Trailer Tool for the trailer to produce specific results for the combination of both. How this is done is explained on the following slides.
- The reference ratio is a fixed numerical value per trailer vehicle group, mission profile and payload and completely independent of the inputs for a specific trailer.
- The reference ratio is purely a "service" for a vehicle operator and has yet no application within the framework of a Regulation.

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What is the "Reference Ratio"? (2/4)
Basics

Calculation of fuel consumption and CO_2 emissions for a specific vehicle combination for which VECTO results for both the towing vehicle and for the (semi-)trailer are available:

$$\text{FC or } CO_2 = \text{FC or } CO_2 \cdot \text{Reference Ratio} \cdot \text{Efficiency Ratio}$$

For the specific vehicle combination	VECTO result for the specific towing vehicle	VECTO Trailer Tool results for the specific (semi-)trailer
Units: lit./100km; g/km	Units: lit./100km; g/km	

The following constraints need to be considered:

- The towing vehicle must be of the same vehicle group (e.g. "9") as the generic towing vehicle defined in Annex I for the (semi-)trailer.
- The calculation must be carried out separately for each combination of mission profile and paylaod.
- The calculation can only be performed for the units specified above. For the Efficiency Ratio the "kilometre-based" value is to be used.

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What is the "Reference Ratio"? (3/4) Application example

- Vehicle configuration: **Group 9 lorry** with **drawbar trailer**

				Results motor vehicle VECTO	Results VECTO Trailer Tool		
Mission profile	**Vehicle configuration as in VECTO for motor vehicles**	**Vehicle configuration as in VECTO Trailer Tool**	**Payload**	**FC (l/100km) towing vehicle**	**Reference ratio**	**Efficiency ratio**	**FC (l/100km) specific combination**
Long haul	**Specific group 9 lorry** + T2 standard trailer (type DC)	Generic group 9 lorry + **specific DB trailer**	low	26.8	0.929	0.973	24.2
			rep.	34.8	0.949	0.965	31.9
Regional delivery	**Specific lorry as "rigid solo"**	Generic group 9 lorry + **specific DB trailer**	low	20.1	1.282	0.976	25.1
			rep.	23.5	1.368	0.972	31.2

Other mission profiles are not of relevance (urban delivery is not simulated for group 9 vehicles by motor vehicle VECTO, municipal cycle is not relevant for trailers)

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What is the "Reference Ratio"? (4/4)
Background information: Formulas and validation

$$FC \text{ or } CO_2 = FC \text{ or } CO_2 * \text{Reference Ratio} * \text{Efficiency Ratio}$$

FC or CO_2: For the specific vehicle combination. Units: lit./100km; g/km

FC or CO_2: VECTO result for the specific towing vehicle and standard (semi-)trailer. Units: lit./100km; g/km

Reference Ratio * Efficiency Ratio: VECTO Trailer Tool results for the specific (semi-)trailer

Reference Ratio: $\frac{CO_{2,ref(S)T}}{CO_{2,stand(S)T}}$ Efficiency Ratio: $\frac{CO_{2,spec(S)T}}{CO_{2,ref(S)T}}$

$$FC \text{ or } CO_2 = FC \text{ or } CO_2 * \frac{CO_{2,spec(S)T}}{CO_{2,stand(S)T}}$$

FC or CO_2: For the specific vehicle combination. Units: lit./100km; g/km

FC or CO_2: VECTO result for the specific towing vehicle and standard (semi-)trailer. Units: lit./100km; g/km

$\frac{CO_{2,spec(S)T}}{CO_{2,stand(S)T}}$: Correction factor, how much FC / CO2 of the specific towing vehicle changes as the specific trailer and not the standard trailer is coupled

With this approach one does not get exactly the same result as if one would have the specifications of both the specific towing vehicle and the specific trailer available with a single VECTO simulation. The reason is that the "correction factor" (in green, calculated by the VECTO trailer tool via the reference and efficiency ratios) can only be determined based on the specifications of the generic towing vehicle. This results in principle-related deviations, which are also accepted in the factor method used for heavy buses in VECTO.

✓ The calculation example shown on slide 23 was compared with results from a single VECTO simulation for validation purposes. The deviations were below 1%.

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Hashing (1/2)

The following hashing functions are integrated into the automated programme sequence of the VECTO Trailer Tool:

- The trailer input XML is hashed before the simulation and the hash is written to the MRF.
- The hash of the trailer MRF is calculated and written to the CIF.
- The hash of the trailer CIF is calculated and written to the CIF.

→ **This means that in the official application of the tool for calculating the "Performance of new vehicles with regard to their influence on CO_2 emissions and fuel consumption" all steps with regard to hashing are automated. The separate VECTO Hashing Tool is not used.**

Hashing (2/2)

The VECTO Hashing Tool shall be used in the context of certified input XMLs:

- Creation of the component hash
- Verification of the component hash

This process is demonstrated on subsequent slides on the example of certified aerodynamic device input XML.

For tyre input XMLs, the entire process is completely identical to Regulation (EU) 2017/2400.

Plausibility checks for input data

IF	THEN
Number of Axles = 1	No Type DB allowed
Trailer Type = DB + Number of Axles = 2	Axle 1: steered and not liftable Axle 2: not liftable and not steered
Trailer Type = DB + Number of Axles = 3	Axle 1: steered and not liftable Axle 2: not steered Maximum 1 axle is liftable
Trailer Type = DC + Number of Axles = 1	Legislative Category = O3
Trailer Type = DA + Number of Axles = 1	
Trailer Type = DC + Number of Axles = 1	Axle 1: not liftable and not steered
Trailer Type = DC + Number of Axles = 2	Axle 1: not steered
Trailer Type = DC + Number of Axles = 3	Axle 1: not steered Axle 2: not liftable and not steered
Trailer Type = DA + Number of Axles = 1	Axle 1: not liftable
Trailer Type = DA + Number of Axles = 2	Axle 1: not steered
Side covers short	No Side covers long
Side covers long	No Side covers short
Trailer Type = DB	No Side covers long
Trailer Type = DC	No Side covers long
Rear flaps short	No Rear flaps long
Rear flaps long	No Rear flaps short
Trailer Type = DC	TPMLM Axle Assembly ≤ TPMLM Trailer
Trailer Type = DA	TPMLM Axle Assembly < TPMLM Trailer

Parameter	Requirements
VIN	17 characters
Mass in running order, TPMLM Trailer and TPMLM Axle Assembly	>1.000kg
External width of the body	1000 mm< x ≤ 2.600mm
Total Height of the Trailer	1000 mm< x ≤ 4.000mm
External height of the body	< Total height of the Trailer
External length of the body	< Max. length per type: Body DA ≤ 14.000mm Body DC ≤ 12.000mm Body DB ≤ 12.000mm
Length between centres of axles	> 0.000 mm

Important note:

The listed checks can only catch gross implausibilities in the inputs to the tool. More subtle errors, e.g. typos in the numbers, in the input will remain undetected. In any case, within the scope of the official application of the tool, the user of the tool must be responsible for the correctness of the entries. Compliance with the corresponding quality standards is the subject of the process certification according to Annex II of the regulation.

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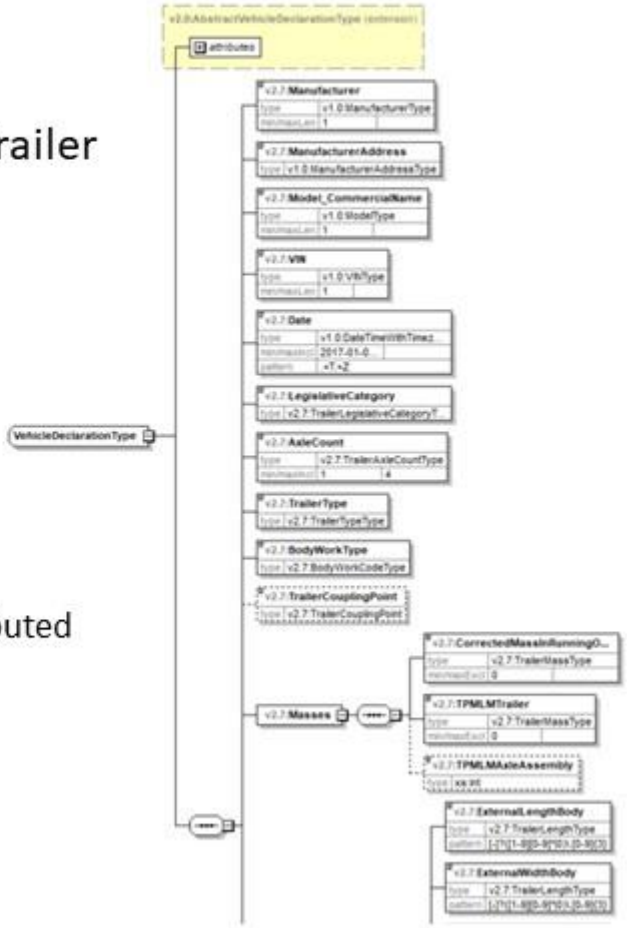
Options for automation

The process for generating official results of the VECTO Trailer Tool can also be fully automated.

- Generation of input XMLs
  - E.g. create it out of your product database system
  - XML schema files are distributed with the tools (see snapshot)
- Running the simulation
  - Use the “background worker” feature as shown in the live demonstration and described in the User Manual
  - Use the command-line tool **`vectocmd.exe`** as distributed with the archive.
    → **`vectocmd.exe -q <XML-File>`**
  - Calling VECTO from your own application is also possible.



Generation of input XML for a certified aero device (1/4)

- The XML needs to be created by the supplier within a separate certification process
- A template of the XML is located in the downloadable VECTO Trailer Tool package in the “Generic vehicles” folder
- The XSD file is located in the downloadable VECTO Trailer Tool package in the “XML” folder

Generation of input XML for a certified aero device (2/4)

- At the start screen click „Hash Component Data“
  - then click the browse button to search for a non hashed XML → XML will be hashed automatically once loaded to the hashing tool

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Generation of input XML for a certified aero device (3/4) Hashing example

```
<?xml version="1.0" encoding="UTF-8"?>
<tns:VectoInputDeclaration xmlns="urn:tugraz:ivt:VectoAPI:DeclarationDefinitions:DEV:v2.7" xmlns:v2.0="urn:tugraz:ivt:VectoAPI:DeclarationDefinitions:v2.0"
xmlns:v2.1="urn:tugraz:ivt:VectoAPI:DeclarationDefinitions:v2.1" xmlns:v2.2="urn:tugraz:ivt:VectoAPI:DeclarationDefinitions:v2.2"
xmlns:v2.7="urn:tugraz:ivt:VectoAPI:DeclarationDefinitions:DEV:v2.7" xmlns:tns="urn:tugraz:ivt:VectoAPI:DeclarationComponent:DEV:v2.7"
 xmlns:di="http://www.w3.org/2000/09/xmldsig#" schemaVersion="2.0" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:schemaLocation="urn:tugraz:ivt:VectoAPI:DeclarationComponent v:\VectoCore\VectoCore\Resources\XSD/VectoDeclarationComponent.xsd">
    <tns:CertifiedAeroReduction >
        <Data xsi:type="CertifiedAeroDataDeclarationType" id="AERO-asdf">
            <Manufacturer>Generic Manufacturer</Manufacturer>
            <Model>Generic Aero Model</Model>
            <CertificationNumber>e12*0815/8051*2017/05T0000*00</CertificationNumber>
            <Date>2022-04-12T11:00:00Z</Date>
            <AeroReductionYawAngle0>1.00</AeroReductionYawAngle0>
            <AeroReductionYawAngle3>2.00</AeroReductionYawAngle3>
            <AeroReductionYawAngle6>3.00</AeroReductionYawAngle6>
            <AeroReductionYawAngle9>4.00</AeroReductionYawAngle9>
            <ApplicableVehicleGroup>132</ApplicableVehicleGroup>
        </Data>
    </tns:CertifiedAeroReduction>
</tns:VectoInputDeclaration>
```

After succesfull hashing of the component XML click „Save Component Data“

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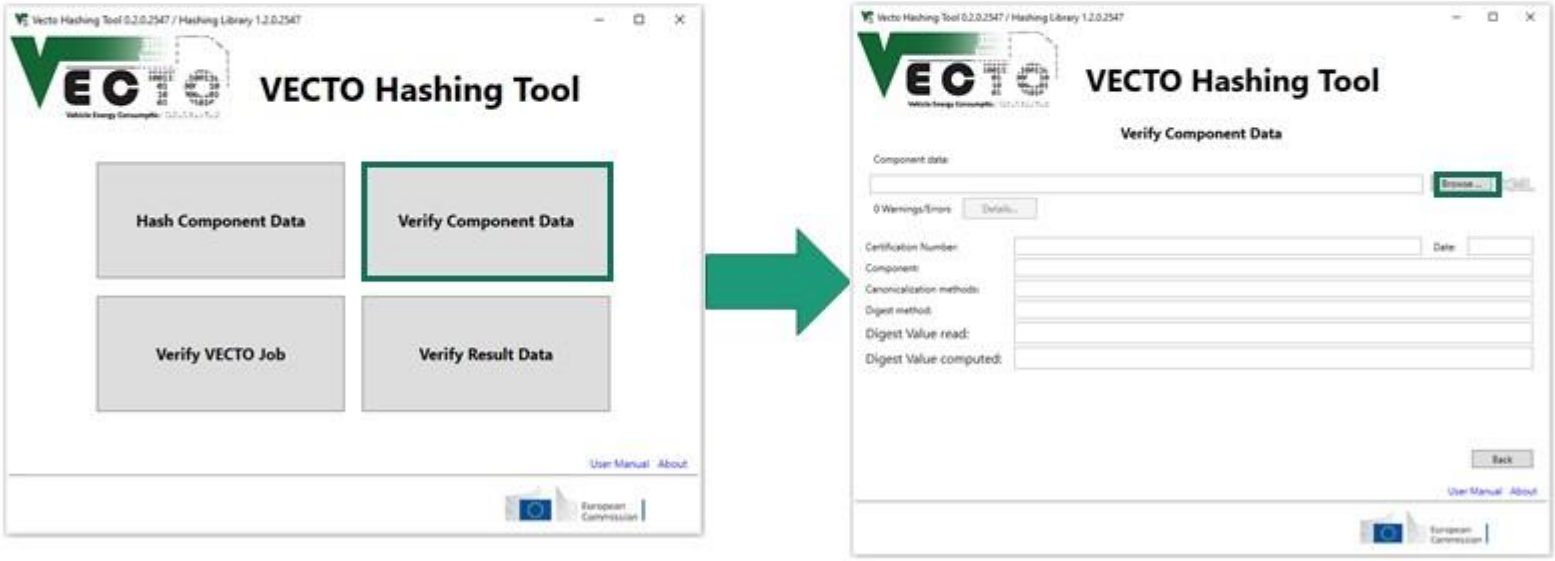
Generation of input XML for a certified aero device (4/4) Hashing example

- Hashed component File

```
<?xml version="1.0" encoding="UTF-8"?>
<tns:VectoInputDeclaration xmlns="urn:tugraz:ivt:VectoAPI:DeclarationDefinitions:DEV:v2.7" xmlns:v2.0="urn:tugraz:ivt:VectoAPI:DeclarationDefinitions:v2.0"
xmlns:v2.1="urn:tugraz:ivt:VectoAPI:DeclarationDefinitions:v2.1" xmlns:v2.2="urn:tugraz:ivt:VectoAPI:DeclarationDefinitions:v2.2"
xmlns:v2.7="urn:tugraz:ivt:VectoAPI:DeclarationDefinitions:DEV:v2.7" xmlns:tns="urn:tugraz:ivt:VectoAPI:DeclarationComponent:DEV:v2.7"
 xmlns:di="http://www.w3.org/2000/09/xmldsig#" schemaVersion="2.0" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:schemaLocation="urn:tugraz:ivt:VectoAPI:DeclarationComponent v:\VectoCore\VectoCore\Resources\XSD/VectoDeclarationComponent.xsd">
    <tns:CertifiedAeroReduction >
        <Data xsi:type="CertifiedAeroDataDeclarationType" id="AERO-asdf">
            <Manufacturer>Generic Manufacturer</Manufacturer>
            <Model>Generic Aero Model</Model>
            <CertificationNumber>e12*0815/8051*2017/05T0000*00</CertificationNumber>
            <Date>2022-04-12T11:00:00Z</Date>
            <AeroReductionYawAngle0>1.00</AeroReductionYawAngle0>
            <AeroReductionYawAngle3>2.00</AeroReductionYawAngle3>
            <AeroReductionYawAngle6>3.00</AeroReductionYawAngle6>
            <AeroReductionYawAngle9>4.00</AeroReductionYawAngle9>
            <ApplicableVehicleGroup>132</ApplicableVehicleGroup>
        </Data>
        <Signature>
            <di:Reference URI="#AERO-asdf">
                <di:Transforms>
                    <di:Transform Algorithm="urn:vecto:xml:2017:canonicalization"/>
                    <di:Transform Algorithm="http://www.w3.org/2001/10/xml-exc-c14n#"/>
                </di:Transforms>
                <di:DigestMethod Algorithm="http://www.w3.org/2001/04/xmlenc#sha256"/>
                <di:DigestValue>Nw1jk22fUPBKP6xEn5OzMeqXx08kC6Qaxd4sJcavxgw=</di:DigestValue>
            </di:Reference>
        </Signature>
    </tns:CertifiedAeroReduction>
</tns:VectoInputDeclaration>
```

Verification of component hash for a certified aero device (1/3)

- At the start screen click „Verify Component Data“
  - then click the browse button to search for a hashed XML → Digest values will only match if nothing was changed after hashing



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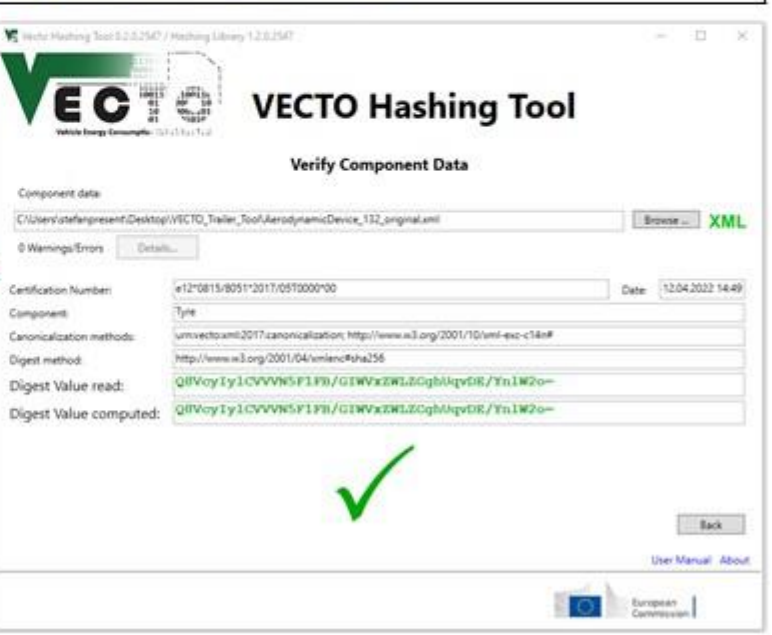
Verification of component hash for a certified aero device (2/3)

- Example verification of an unchanged XML

```
<?xml version="1.0" encoding="utf-8"?>
<tns:VectoInputDeclaration xmlns="urn:tugraz:ivt:VectoAPI:DeclarationDefinitions:DEV:v2.7" xmlns:v2.0="urn:tugraz:ivt:VectoAPI:DeclarationDefinitions:v2.0"
    <tns:CertifiedAeroDevice>
        <v2.7:Data xsi:type="CertifiedAeroDataDeclarationType" id="AERO-asdf">
            <v2.7:Manufacturer>Generic Manufacturer</v2.7:Manufacturer>
            <v2.7:Model>Generic Aero Device Model</v2.7:Model>
            <v2.7:CertificationNumber>e12*0815/8051*2017/05T0000*00</v2.7:CertificationNumber>
            <v2.7:Date>2022-04-13T11:21:11.8581891Z</v2.7:Date>
            <v2.7:AeroReductionYawAngle0>1.00</v2.7:AeroReductionYawAngle0>
            <v2.7:AeroReductionYawAngle3>2.00</v2.7:AeroReductionYawAngle3>
            <v2.7:AeroReductionYawAngle6>3.00</v2.7:AeroReductionYawAngle6>
            <v2.7:AeroReductionYawAngle9>4.00</v2.7:AeroReductionYawAngle9>
            <v2.7:ApplicableVehicleGroups>
                <v2.7:ApplicableVehicleGroup>422</v2.7:ApplicableVehicleGroup>
                <v2.7:ApplicableVehicleGroup>112</v2.7:ApplicableVehicleGroup>
            </v2.7:ApplicableVehicleGroups>
        </v2.7:Data>
        <v2.7:Signature>
            <di:Reference URI="#AERO-asdf">
                <di:Transforms>
                    <di:Transform Algorithm="urn:vecto:xml:2017:canonicalization" />
                    <di:Transform Algorithm="http://www.w3.org/2001/10/xml-exc-c14n#" />
                </di:Transforms>
                <di:DigestMethod Algorithm="http://www.w3.org/2001/04/xmlenc#sha256" />
                <di:DigestValue>Q8VcyIylCVVVN5F1FB/GIWVxZWLZCghUqvDE/YnlW2o=</di:DigestValue>
            </di:Reference>
        </v2.7:Signature>
    </tns:CertifiedAeroDevice>
</tns:VectoInputDeclaration>
```



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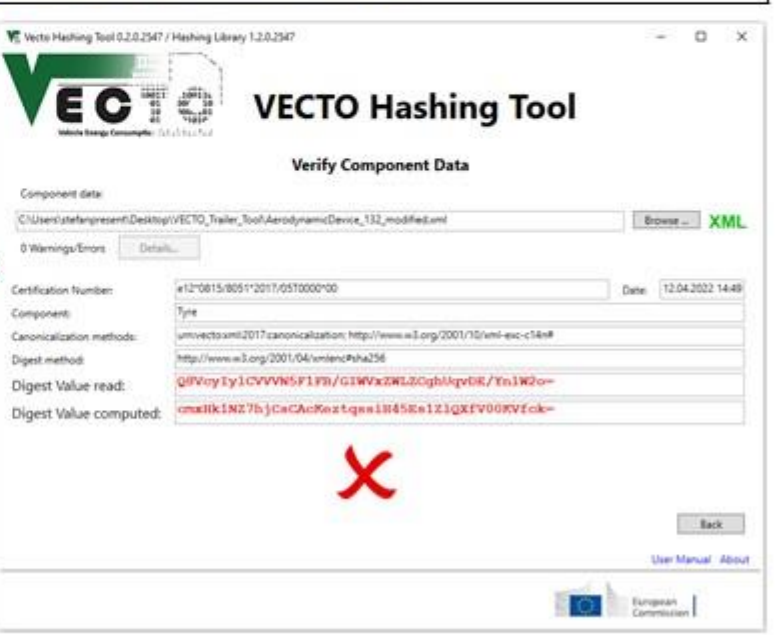
Verification of component hash for a certified aero device (3/3)

- Example verification of a modified XML

```
<?xml version="1.0" encoding="utf-8"?>
<tns:VectoInputDeclaration xmlns="urn:tugraz:ivt:VectoAPI:DeclarationDefinitions:DEV:v2.7" xmlns:v2.0="urn:tugraz:ivt:VectoAPI:DeclarationDefinitions:v2.0"
    <tns:CertifiedAeroDevice>
        <v2.7:Data xsi:type="CertifiedAeroDataDeclarationType" id="AERO-asdf">
            <v2.7:Manufacturer>Generic Manufacturer</v2.7:Manufacturer>
            <v2.7:Model>Generic Aero Device Model</v2.7:Model>
            <v2.7:CertificationNumber>e12*0815/8051*2017/05T0000*00</v2.7:CertificationNumber>
            <v2.7:Date>2022-04-13T11:21:11.8581891Z</v2.7:Date>
            <v2.7:AeroReductionYawAngle0>1.10</v2.7:AeroReductionYawAngle0>
            <v2.7:AeroReductionYawAngle3>2.00</v2.7:AeroReductionYawAngle3>
            <v2.7:AeroReductionYawAngle6>3.00</v2.7:AeroReductionYawAngle6>
            <v2.7:AeroReductionYawAngle9>4.00</v2.7:AeroReductionYawAngle9>
            <v2.7:ApplicableVehicleGroups>
                <v2.7:ApplicableVehicleGroup>422</v2.7:ApplicableVehicleGroup>
                <v2.7:ApplicableVehicleGroup>112</v2.7:ApplicableVehicleGroup>
            </v2.7:ApplicableVehicleGroups>
        </v2.7:Data>
        <v2.7:Signature>
            <di:Reference URI="#AERO-asdf">
                <di:Transforms>
                    <di:Transform Algorithm="urn:vecto:xml:2017:canonicalization" />
                    <di:Transform Algorithm="http://www.w3.org/2001/10/xml-exc-c14n#" />
                </di:Transforms>
                <di:DigestMethod Algorithm="http://www.w3.org/2001/04/xmlenc#sha256" />
                <di:DigestValue>Q@VcyIylCVVVN5F1FB/GIWVxZWLZCghUqvDE/YnlW2o=</di:DigestValue>
            </di:Reference>
        </v2.7:Signature>
    </tns:CertifiedAeroDevice>
</tns:VectoInputDeclaration>
```



Standard aerodynamic devices – for DA trailers

Allowed configurations				
Combination Number	Side cover SHORT	Side cover LONG	Rear flaps SHORT	Rear flaps LONG
0				
1	1			
2		1		
3			1	
4				1
5	1		1	
6	1			1
7		1	1	
8		1		1

ΔCdxA reduction rates [%]			
Yaw 0.0	Yaw 3.0	Yaw 6.0	Yaw 9.0
0.0%	0.0%	0.0%	0.0%
1.4%	2.7%	3.0%	3.7%
4.0%	3.4%	3.5%	4.7%
2.8%	3.2%	3.8%	4.9%
3.9%	4.1%	5.1%	6.0%
3.8%	5.8%	8.3%	8.7%
4.7%	6.8%	9.2%	10.1%
6.5%	6.4%	7.8%	9.4%
7.6%	7.7%	9.2%	10.9%

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Standard aerodynamic devices – for DB trailers

Allowed configurations					ΔCdxA reduction rates [%]			
Combination Number	Side cover SHORT	Side cover LONG	Rear flaps SHORT	Rear flaps LONG	Yaw 0.0	Yaw 3.0	Yaw 6.0	Yaw 9.0
0					0.0%	0.0%	0.0%	0.0%
1	1				N/A	N/A	N/A	N/A
3			1		N/A	N/A	N/A	N/A
4				1	3.4%	4.6%	5.0%	3.9%
5	1		1		N/A	N/A	N/A	N/A
6	1			1	N/A	N/A	N/A	N/A

- Missing values to be completed via CFD in second half of 2022
- The tool version as released in June 2022 applies placeholder dummy values instead.
  THIS IS INTENDED, PLEASE WAIT FOR THE FINAL RELEASE AFTER THE WORK ABOVE HAS BEEN COMPLETED.

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Standard aerodynamic devices – for DC trailers

Allowed configurations					ΔCdxA reduction rates [%]			
Combination Number	Side cover SHORT	Side cover LONG	Rear flaps SHORT	Rear flaps LONG	Yaw 0.0	Yaw 3.0	Yaw 6.0	Yaw 9.0
0					0.0%	0.0%	0.0%	0.0%
1	1				N/A	N/A	N/A	N/A
3			1		N/A	N/A	N/A	N/A
4				1	2.3%	3.7%	5.2%	11.1%
5	1		1		N/A	N/A	N/A	N/A
6	1			1	N/A	N/A	N/A	N/A

- Missing values to be completed via CFD in second half of 2022
- The tool version as released in June 2022 applies placeholder dummy values instead.
  THIS IS INTENDED, PLEASE WAIT FOR THE FINAL RELEASE AFTER THE WORK ABOVE HAS BEEN COMPLETED.

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Bonus factors for liftable and steered axles - Overview

- In order to model the effect of liftable and/or steered axles on fuel consumption and CO_2 emissions, generic bonus factors are applied in the VECTO Trailer Tool.
- The general formula how to apply these factors ("bf_{lift}", "bf_{steer}"; unit = %, "-" means reduction) is shown below:

$$FC_{corr}, CO2_{corr} = FC, CO2 \cdot \left(1 + \frac{bf_{lift}}{100}\right) \cdot \left(1 + \frac{bf_{steer}}{100}\right)$$

- In cases where there is more than one liftable or steered axle on a vehicle, special rules apply.

Bonus factors for liftable axles

Trailer Classification				Liftaxle bonus factor					
				Long Haul		Regional Delivery		Urban Delivery	
Bodywork type	Volume orientation	Trailer type	Number of axles	payload low	payload rep	payload low	payload rep	payload low	payload rep
all	No/Yes	DA	2	-0.8	-0.3	-2.3	-1.6	-3.2	-2.1
			3	-0.6	-0.2	-3.6	-2.4	-5.3	-3.5
		DC	2	-0.6	-0.2	-2.2	-1.5	-3.1	-2.0
		DB	3	-0.6	-0.2	-2.1	-1.4	-3.0	-2.0
		DC	3	-0.6	-0.2	-3.6	-2.4	-5.2	-3.5

Bonus factors for steered axles

Trailer Classification				Steered axle bonus factor					
				Long Haul		Regional Delivery		Urban Delivery	
Bodywork type	Volume orientation	Trailer type	Number of axles	payload low	payload rep	payload low	payload rep	payload low	payload rep
all	No/Yes	DA/DC	1	0.0	0.0	0.0	0.0	0.0	0.0
			2	0.0	0.0	-1.5	-1.5	-2.3	-2.3
		DA/DC	3	0.0	0.0	-3.0	-3.0	-4.5	-4.5
		DB	3	0.0	0.0	-1.5	-1.5	-2.3	-2.3

Bonus factors for liftable and steered axles – Special cases

- **Special case #1:** 1 liftable and 1 steered on different axles

$$\mathrm{FC_{corr}}, \mathrm{CO2_{corr}} = \mathrm{FC}, \mathrm{CO2} \cdot \left(1 + \frac{\mathrm{bf_{lift}}}{100}\right) \cdot \left(1 + 0.5 \cdot \frac{\mathrm{bf_{steer}}}{100}\right)$$

- **Special case #2:** 1 liftable and 1 steered on the same axle

$$\mathrm{FC_{corr}}, \mathrm{CO2_{corr}} = \mathrm{FC}, \mathrm{CO2} \cdot \left(1 + \frac{\max(\mathrm{bf_{lift}}, \mathrm{bf_{steer}})}{100}\right)$$

The generally valid formulas implemented in the code are documented here. For some cycles, some bonus factors are 0.

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Bonus factors for liftable and steered axles – Special cases

- **Special case #3:** 2 liftable axles

  Payload "low": $$FC_{corr}, CO2_{corr} = FC, CO2 \cdot \left(1 + 1.5 \cdot \frac{bf_{lift}}{100}\right)$$

  Payload "rep:": $$FC_{corr}, CO2_{corr} = FC, CO2 \cdot \left(1 + \frac{bf_{lift}}{100}\right)$$

- **Special case #4:** 2 steered axles

  $$FC_{corr}, CO2_{corr} = FC, CO2 \cdot \left(1 + 1.2 \cdot \frac{bf_{steer}}{100}\right)$$

- **Special case #5:** In case more than 2 features are present on the vehicle (could theoretically only be the case for a 3-axle trailer and comprising at least a single steered axle), the rules for special case #1 are applied.

The generally valid formulas implemented in the code are documented here. For some cycles, some bonus factors are 0.

Overview content of Masterexcel (1/4)

The VECTO Trailer Tool Masterexcel is an integral part of the tool documentation and fulfils the following functions:

- Documentation of the classification matrix used internally in the tool, which is more detailed than the classification according to Annex I.
- Documentation of all generic data stored in the tool, e.g.
  - mission profile and payload allocation
  - specifications of reference trailers
  - standard values for reduction rates of aerodynamic devices
  - bonus factors for liftable and steered axles
- Interactive documentation of the formulas for calculating the air drag for the various combinations of generic towing vehicles and trailers

The content of the individual sheets is described in overview on the next slides.

In the context of a normal application of the tool, it is not necessary to engage with the Masterexcel.

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Overview content of Masterexcel (2/4)

Excel sheet	Description
Classification	General information stored in the tool for each trailer configuration • Vehicle group acc. to Annex 1 • Information on the allocated generic towing vehicle • Mission allocation + weighting for aggregated results • Payload and axle weight shares per mission
Generic CAD vehicle	Main dimensions and air drag values of the generic CAD models used as a starting point to calculate the air drag of trailers with different dimensions (could be the reference- or the specific trailer)

Reference Trailer	Information on the reference trailers for each trailer configuration
	• Curb mass and cargo volume
	• Tyre specifications
	• Main external dimensions to calculate the air drag
	• Indication on which aero corrections are applied to which trailer configuration
	  • „1“ means aero correction is applied
	  • „0“ means aero correction is not applied

Overview content of Masterexcel (3/4)

Excel sheet	Description
...	...

Specific trailer	Information on technologies that may be present on a specific trailer
	• Bonus factors for liftable and steered axles depending on trailer configuration, mission and payload
	  • These factors are to be understood as reduction factors on overall fuel consumption / CO_2
	• Indication on which aero corrections are applied to which trailer configuration
	  • „1“ means aero correction is applied
	  • „0" means aero correction is not applied
	  The individual aero correction formulas can be viewed in the "Reference/Specific Trailer Aero" sheet and are documented in detail in Task 2 report section 2.4.5.
	• Aero reduction values for standard aerodynamic devices acc. to sheet „Combination Add-ons DX*“

Standard Trailer	Information on the standard trailers also used in Regulation EU 2017/2400 to calculate the reference factors

*DX... Placeholder depending on trailer type
DA... Semi Trailer
DB... Drawbar Trailer
DC... Centre axle Trailer

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Overview content of Masterexcel (4/4)

Excel sheet	Description
...	...
Reference (Specific) Trailer Aero	Main dimensions and air drag values of the generic CAD models used as a starting point to calulate the air drag of trailers with different dimensions (Reference/Specific trailer) Step by step calculation process on how to apply the individual aero corrections to get the final air drag values for a reference/specific trailer In the columns AN to AX, the aero-relevant data can be entered for the individual trailer groups. The results for CdxA(0) as well as the polynomial coefficients of the polar can then be found in the columns DT and EB to ED.
Standard aero device DX*	Air drag reduction in % for the specific combination of standard aerodynamic devices (the reduction values can also be found in the sheet „Specific Trailer“
Efficiency Ratios - DA	Example on how the individual and weighted efficiency ratios are calculated based on a DA trailer

*DX... Placeholder depending on trailer type
DA... Semi Trailer
DB... Drawbar Trailer
DC... Centre axle Traielr

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Annex B – Feedback Excel Testphase I (2021)

Table 4 contains the comments and feedback received from the 2021 stakeholder testing phase and the resulting action for the software. To do's that were open at that time were also included in the list. Table 4 thus represents a complete list of all the work carried out on the VECTO Trailer Tool between autumn 2021 and April 2022.

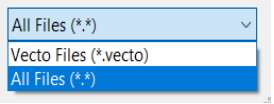
The columns with the contact person for feedback were removed for the report for data protection reasons.

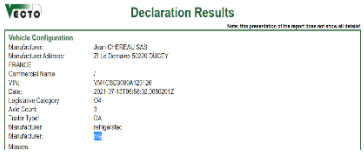
Table 4: Feedback Excel Testphase I (2021)

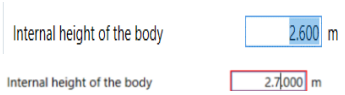
Item #	Kind of issue	Function of the tool	Detailed description	Action
1	Methods update coordinated with task force	Classification and reference trailers	Update of classification matrix and generic data in the tool according to the final version of Annex I and final reference vehicles agreed in the task force	Done
2	Methods update coordinated with task force	CdxA calculation	CdxA influence of trailer coupling point to be included (foreseen only for trailers of type DC)	Done
3	Methods update coordinated with task force	RRC of reference trailers and generic towing vehicles	New tyre dimensions introduced by CLCCR. To be discussed which generic RRC values should be allocated to the reference trailers and what to do with the allocated generic towing vehicles	Done
4a	Methods update coordinated with task force	Input data	Update input data based on final version of Annex III	Done
4b	Methods update coordinated with task force	Input data	Update input data based on final version of Annex V regarding XML for certified aero device	Done
5	Methods update coordinated	Outputs	Update output data based on final version of Annex IV	Done

Item #	Kind of issue	Function of the tool	Detailed description	Action
	with task force			
6	New feature	Calculation of "reference factors"	Reference factors shall be added to the customer information file to allow vehicle operators to assess the performance of a specific towing vehicle - for which results of the motor vehicle VECTO are available and a (semi-)trailer	Done. The actual calculation of the reference ratios (which are fixed values for each trailer group) takes place in a separate mode of the VECTO Trailer Tool, which can only be started from Visual Studio. These are then stored in the source code for each compilation of the tool and written to the CIF for each calculation.
7	Improvement / new feature	Outputs	It is suggested that a checkbox is added to the tool for providing formatted output w/o using a browser and the VectoReports.css stylesheet file (e.g. directly into a pdf)	Done
8	Calculation of Liftable axles	Liftable axles	efficiency ratios seems to be wrong for trailers with liftable axles independent from position	Fixed
9	Re-calculation of existing files	Repeat existing calculation	The re-calculation of an existing input file with unchanged variables leads sometimes to different results	Fixed
10	Volume oriented trailers	Calculation and allocation	There might be mistakes for the correct allocation of volume oriented trailers to the correct reference trailer	Fixed
11	Installation	Unzip and start in several companies not possible	Software/hardware configurations leads to problems to start the VectoTrailer.exe	Fixed

Item #	Kind of issue	Function of the tool	Detailed description	Action
12	Abort of calculation	Simulation	Software interrupts calculations immediately after start	Fixed
13	Input variables	Distance between trailers	Distance between lorry and trailer cannot be adapted - aerodynamic results questionable	Item identified to be of no relevance. No action.
14	Validation of input variables	Functionality does not really work	Mistakes will not detected (e.g. zero values, extra large numbers, point vs. comma …)	List of input data checks added.
15	Input variables	Input data	Some input data needs some better description in a kind of textbox to click (e.g. dimensions vs volume, distinction between normal and volume oriented)	Implemented solution: Part 1) The input parameter description in the GUI uses exactly the same terms than Annex III. Part 2) The XSD shall contain also contain a documentation of the parameters (parameter number, component, unit). No info/textboxes foreseen for the GUI.
16	Output files	xml Format and relation to CSS	xml Format is to be supplemented by pdf-file, function of CSS stylesheet should be explained, handling is a bit complex	not relevant anymore, pdf generation handled now differently (see item 7)
17	Output data	Aerodynamic results	Are the calculated aero-effect validated?	Part of the task 2 final report. No action for software.
18	Loading new input files	Input data	The file is a xml-file but the program askes for a vecto-file	Fixed
19	Parameter variation	Stability and Validity of results	It is recommended to perform a parameter study to detect mistakes, slight variations of some input data generate large effects in the output data	Handled by the validation exercise as documented in the task 4 report.
20	Steerable axles	Results	There seems to be mistakes in the calculation for regional	Not a bug. No action necessary.

Item #	Kind of issue	Function of the tool	Detailed description	Action
			delivery between modes low and max payload	
21	Manual missing	User Manual	Manual missing	User manual elaborated. User Manual can be opened also from the GUI of the tool.
22			In principle, I think xml is not bad as a result file. However, I agree with Mr Svensson's comments and have made the same experience that you quickly get into the situation that you have to edit in the xml.	Pdf option included (see item 7).
23			the influence of the lift axle is too great	Fixed
24			the influence of the steering axis is not present	Fixed
25			In the "Add Job" selection window, the selection filter is set to "Vecto Files". It is not obvious that XML files can also be selected.	Fixed
26			When the computer switches to the lock screen, the simulation pauses.	This is an issue beyond the tool. No action for software.
27	Improvement	ADD JOB	In the directory to find your job, you must specify "All file"s otherwise it cannot find our file 	Fixed

Item #	Kind of issue	Function of the tool	Detailed description	Action
28	Improvement	START SIMULATION	In the directory to find your job, you must specify "All file"s otherwise it cannot find our file 	Fixed
29	Improvement	REPORT VISUALIZATION	To start the simulation, you must be in the correct language under Windows: Control panel --> Region --> English (United States): Otherwise when we click on Start we get the following error message 	Formatting improved.
30	Improvement	Input data	Infotip would be useful in order to give correct definition of item required, or scheme/drawing showing the distances that are required	Action see item 15)
31	Improvement	Input data	Annex4 says 1,2,7 Length from trailer front END to centre of first axle, while the tool doesn't say END ("length from trailer front to first axle")	Fixed
32	Improvement	Input data	There are 2 "Manufacturer" lines, one is always n/a What means manufacturer, and why 2 lines 	Formatting improved.
33	Methods update coordinated with task force	Input data	Commercial Name, the field is mandatory, should it not be possible to leave it blank?	Comment forwarded to Commission. Would need to be specified in Annex III (e.g. "In case

Item #	Kind of issue	Function of the tool	Detailed description	Action
				no such information is available, 'N.A.' shall be provided."). Following this approach its not a software issue.
34	Improvement	Input data	Trailer coupling point Does LOW always relate to DC and high to DB trailers? Where does the High/Low configuration comes from?	Explanation given in updated Annex III. Not an issue for software.
35	Methods update coordinated with task force	Input data	Masses for drawbar trailers _ TPMLM total/axle assembly It is impossible to set the same mass? Are you considering axle assembly as axles with less than 1,8m distance? What if only solo axles are on the vehicle?	Checks for masses added after consultation with CLCCR.
36	Improvement	Input data	The Input Validation / Show validation errors seams to show nothing?	The "Input validation" as a separate item has been removed. All checks are now done automatically when "save" is pressed or calculation is started.
37	Improvement	Input data	Selecting a value with a digit after the comma doesn't work properly. After selecting the value (becomes blue), and typing something to replace, if only type before the comma. 	GUI feature improved
38	Methods update coordinated	Start Simulation	Start on an invalid job can crash VECTO, that closes	Error could not be reproduced. No action.

Item #	Kind of issue	Function of the tool	Detailed description	Action
	with task force			
39	Improvement	Output data	Results in MRF and CIF are not in the same sequence all the time	Fixed
40	Improvement	Output data	Units in the stylesheets missing	To be updated based on the final tool version for the final report version
41	Improvement	Output data	Unit in the output files missing	To be updated based on the final tool version for the final report version
42	Improvement / new feature	Outputs	VECTO-Trailer -> Options -> Output Directory: Button for the selection of the output folder is too small.	Fixed
43	Improvement / new feature	Outputs	VECTO-Trailer -> Options -> Output Directory: Selection of Output directory should be a selection for folders and not for data. Currently *.vecto files are suggested to select.	Fixed
44	Improvement / new feature	Input Data	Input XML-file: The namespaces in the Input XML-files are not very handy while filling the xml e.g. by MS-Access. Would it be possible to not use namespaces in the file to reduce the complexity? For EC-type approvals for example, the necessary IVI-files do not use namespaces and are much more simple build. We see problems for further versions, as our program needs to be updated each time. Attached: Example of IVI-XML-file.	Namespacing cleaned up.

Item #	Kind of issue	Function of the tool	Detailed description	Action
45	Improvement / new feature	Input Data	It would be great if a xsd-scheme is going to be provided in future to find errors more easily while creating the Input XML-file with other programs. At the moment the VECTO-Tool just hardly broke down without any information about the error. In the best case this is going to be distributed together with the manual already mentioned.	Providing xsd schemas is now part of the standardised VECTO trailer tool release process.
46	New feature	Outputs	To calculate every single vehicle is a very long termed job. It would be fantastic if the tool is working like a service in the background and pols a folder where input files can be putted into. The calculation runs automatically in the background and output data is set into a separate folder.	Background worker added.
47	Improvement	Classification and reference trailers	The classification of our test vehicles are not correctly according to Annex I. The master excel classification is correct but is not equal to the annex I. You can check any of our sample Outputs where all the classification is about refrigerated box body. In the case of DA trailer this is 133V (internal height of 3.000m) which is not defined. Attached: Test Files DA/DB/DC	Corrected (consistency with final version of Annex I)
48	Improvement	Input Data	In the provided test Input XML-file for the DB-trailer, the first axle wasn't defined as steered axle. Is this correct or how are steered axles defined?	This has been updated based on the definition of "steered axle" in Annex III. Now also the first axle of a DB needs to be declared accordingly. This is checked by the tool (however this steered function is

Item #	Kind of issue	Function of the tool	Detailed description	Action
				not related to the bonus factors). The tool and the example files have been updated accordingly.
49	Improvement	Outputs	For all our test vehicles the Output data value for Loading Long Haul, Regional Delivery and Urban Delivery are the same. Shouldn't they depend on the vehicle type DA,DB,DC and also depend on the payload of the trailer? For example the Loading value in the Output Data of the DB trailer is 19300kg and the payload of the trailer is only 13430kg and the TPMLM is also only 18000kg. Also the weighted Payload for the Trailers are all the same. The connection between standard trailer T2a and T2b is not correct for DC and DB 2 and 3 axle trailers - they are swapped. In our opinion it is furthermore not very clear why the standard trailer is taken for the masses on the customer information file and not the reference trailers (there are huge differences in the payload between 1,2, and 3 axle trailers).	Not a bug. No action necessary.
50	Improvement	Outputs	We do not know about the details of the calculation, but for us the value Summary->Fuel Consumption l/m³-km does not seem to be correct. We have a Cargo Volume of 51.3m³ and a Fuel Consumption of 23.7 l/100km. Doesn't it have to be (23.7l/51.3m³)/100 =	Not a bug. No action necessary.

Item #	Kind of issue	Function of the tool	Detailed description	Action
			0.0046l/m³-km (In discussion with Sascha Pfeifer, this is due to the cargo volume of the truck)	
51	Improvement	Input Data	In the 'Create Trailer Job'-tool you can select all four aerodynamic devices, but the long and short variants are mutually exclusive. By the way the window is opened to small and has to be extended manually.	The check whether the aerodynamic devices are compatible is performed together with all other checks once either the file is saved or the job is calculated.
52	To be discussed	Input Data	We are unsure, whether the different tyre profiles with summer and winter tyres (different rolling resistance) leads to a wrong direction, so that the manufacturers changes to summer tyres because of the lower CO2-value in contrast to the better security functions of the tyres. Maybe a factor is needed to get a fair balance.	Issue handled in the Regulation. No action for software.
53	Improvement	Input Data	In our opinion the semi-trailers with two different height are not well considered in the tool. The cargo volume is too high if you only multiply the internal length, width and height. Also the external height of the trailer is unclear how to define.	Approach reworked (updated and extended definitions in Annex III). Cargo volume now direct input parameter. Changes reflected in the updated tool version.

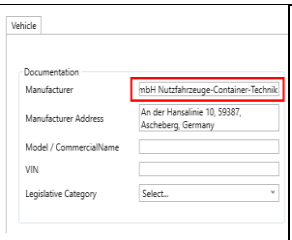
Item #	Kind of issue	Function of the tool	Detailed description	Action
54	Methods update coordinated with task force	Input Data	The definition of the external height of the body should be defined clearer, e.g. Top of the body to the lower side of the subframe.	Proposal forwarded to the Commission. Not a software issue.
55	Improvement	Input Data	Latest version of tyre XML not supported	Fixed
56	Improvement	Output data	Differentiation of the information given in the output files depending on which version of the Tyre XML (version 1.0 to 2.2 = old; version 2.3 and later = new). Old: Fuel efficiency class remains empty	Included
57	Improvement	Output data	Correct presentation of results for efficiency ratios (use term as in Annex IV; unit is dimensionless [-])	Fixed.

Annex C – Feedback Excel Testphase II

Table 5 contains the comments and feedback received from the 2022 stakeholder testing phase and the resulting action for the software. The columns with the contact person for feedback were removed for the report for data protection reasons.

Table 5: Feedback Excel Testphase II (2022)

Item #	Kind of issue	Description of bug or feature	Detailed description / further information	Action and reply from the development team
1	Bug	Wrong curb masses and cargo volume for some reference trailers	Item identified in pre-discussions with CLCCR / Pflug	Mastertable and code corrected accordingly
2	New feature	No simulation if component hashes for tyres or aero devices are not correct	- - -	Implemented, i.e. tool does not execute a simulation in case either of the component hashes is incorrect
3	Improvement	There is an extra effort needed to clarify the use of "Reference Factor" as presented in page 13. Perhaps some illustrations with reference vehicles and actual vehicles that have been used before can help.	Item identified in discussions before or in the May 2022 trailer tool workshop	User Manual updated with further principal explanation and example
4	Temporary solution	Application of reduction values for aerodynamic devices, which have not yet been determined by CFD.	The tool version as released in June 2022 applies placeholder dummy values instead. This is intentional so that testing of tool functions can be carried out already.	Placeholder values implemented
5	Bug	Opening window "Create trailer job" in full size. Currently you need to do this manually each time.		Implemented. Main window now opens the same way as it was closed. The Job Edit window matches the size of the content automatically.
6	Bug	Weighted Results in Customer and Manufacturer file do not match in the rounding position (maybe this is also in other sections - here it was the most obvious)		Fixed. Number of decimal places reduced that now in general three significant digits are given.

7	Bug	The field of manufacturer does not become bigger if there are more characters as it is in the field Manufacturer Address.		Fixed (also for Model / Commercial Name)
8	Improvement	If you enter a DB, it shouldn't be possible to select 1 axle. Maybe it would be the best way like with the steered axle: if you select DB, the number of axles is set to 2 if it is 1		Fixed, the GUI now indicated two axles as default in case DB is selected. Saving / simulating of DBs with a single axle is furthermore prevented by plausibility checks inside the tool.
9		Function of 'Commit vehicle Changes': I assume this button is to "save" the information as initial parameters for the 'Create Trailer Job' Window. Currently you have to enter the complete parameters for new even if you only want to change the VIN. If you click the save as button, the window is closed directly. So no chance to create two input data without entering all information twice. If this is the case, maybe it would be better to rename the button to 'save as standard'. Otherwise I don't know what this button is for.		The function "commit vehicle changes" has been removed from the GUI. Instead the "Save as" button was added. This allows to save a job under a different name before e.g. just modifying a single parameter. This function meets the requirement as was asked for.
10	Bug	Creating a job with tyre xml from Goodyear which has a valid hash wasn't possible with the 'create trailer job' function		Error in metadata writing fixed.
11	New feature	different tyre sizes should be allowed because 3-axle DBs are existing with twin tyres at the first axle and		Tyre dimension check removed, thus the feature as requested is now enabled.

		single tyres on the second axle of the boggie		
12	New feature	In the input field "length between centres of axles" the setting "0.000" has to be deleted		This field is now set to "empty" per default and an additional check that the value is > 0.000 mm is implemented
13	New feature	For some tyre sizes the input box "twin tyres" should be suppressed		For such checks it would be required to define "some", which is assumed to be a very exhaustive task. No action.
14		The vehicle types "conditioned" and "drop side tarpaulin body" shall be dated with their specific data in the slide "reference trailer" in the masterexcel		This is very intentional because the Commission has decided that for both types a different type of trailer shall be the reference (i.e. for conditioned = dry box and for drop side = curtain sider). And the intention of the masterexcel is to document what is done by the tool in the official application. No action.
15		For DB and DC trailers the calculated CdxA values for yaw angle >0° are lower than the CdxA for yaw = 0°. This is not reasonable		The issue has been identified (wrong formula applied to calculate the polar coefficients for DB and CD trailers). Issue fixed in documentation and in the tool
16	Bug	There are a few other concerns about the aero calculations		Issues have been clarified bilaterally with the reporter. No further action required.
17	Improvement	Change displayed digits after the comma in results to 1 for "Cargo Volume" and weighted result for "Fuel consumption in [g/km]²		Changed output (MRF and CIF) accordingly

18	Improvement	When creating a new trailer Job change pre-set trailer configuration with "Select..." for "Number of Axles", "Trailer Type", "Bodywork Type" (similar to "Legislative Category"		Implemented