The European Commission's science and knowledge service

Joint Research Centre

VECTO Simulation Tool

2018 VECTO Workshop

Ispra, November, 2018

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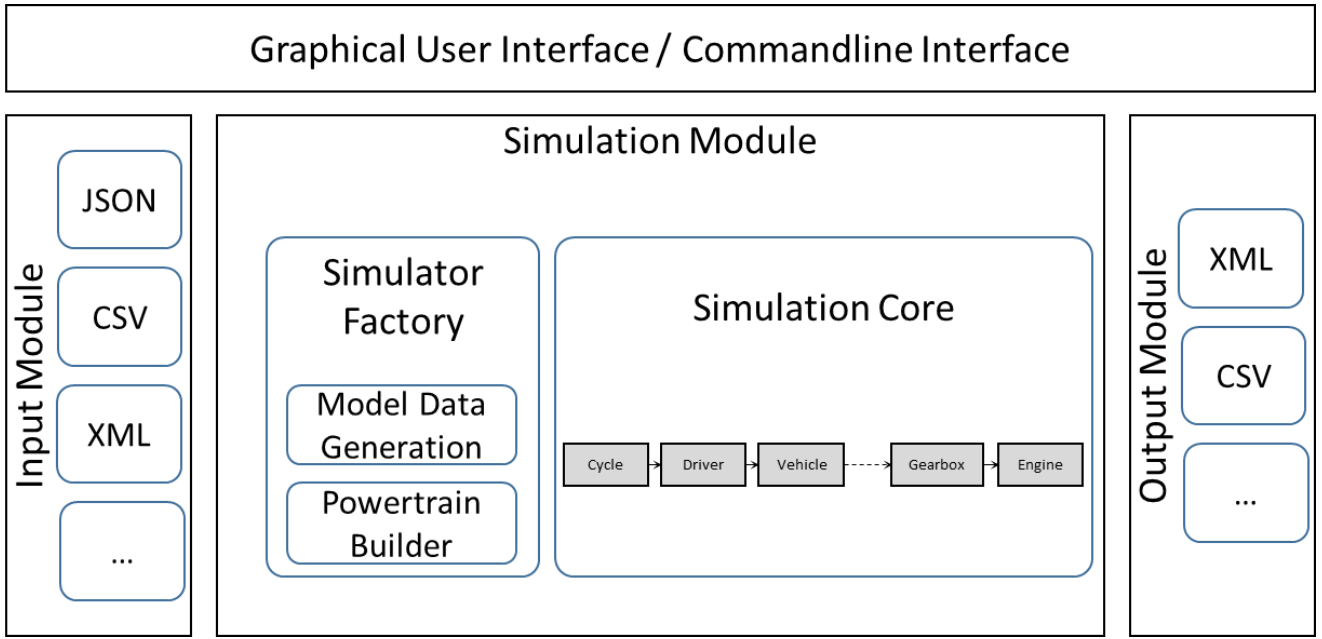
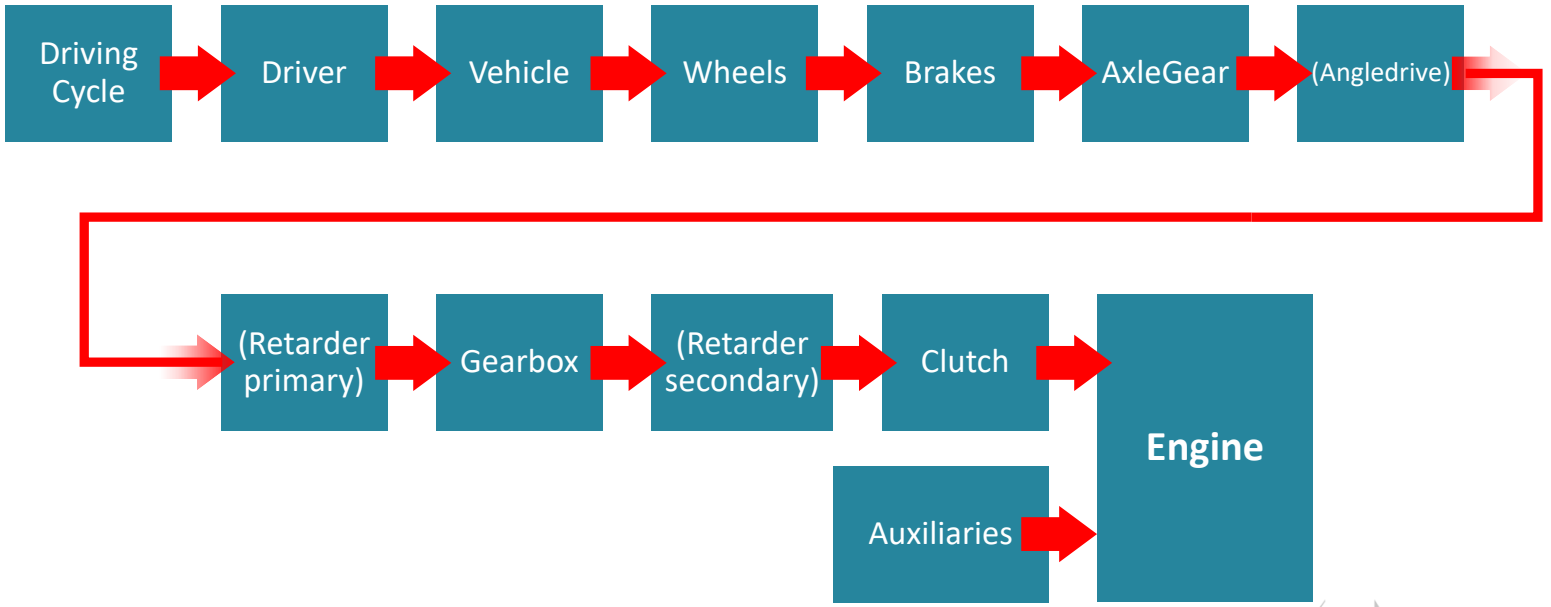
VECTO Software Architecture



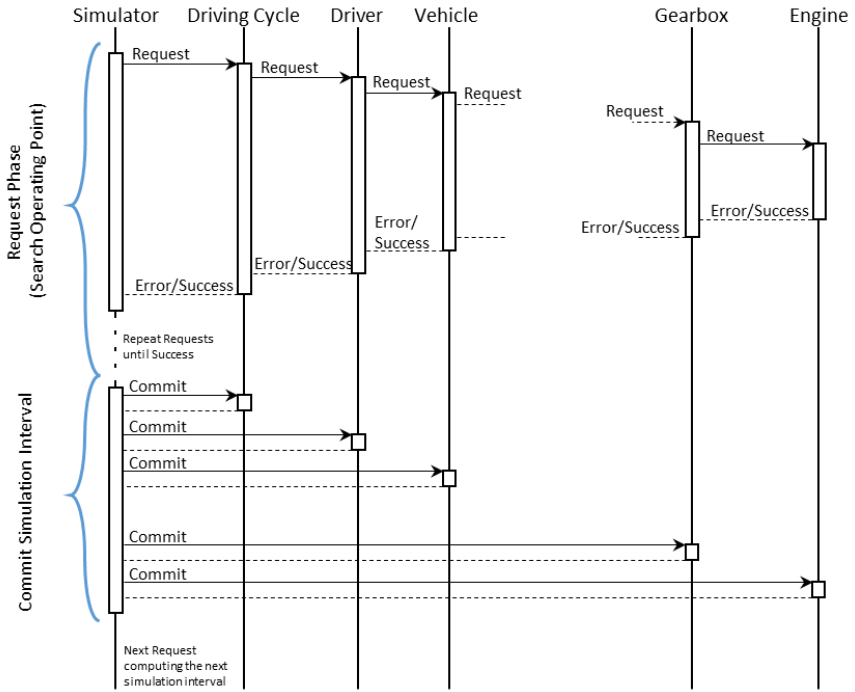
VECTO Component Model

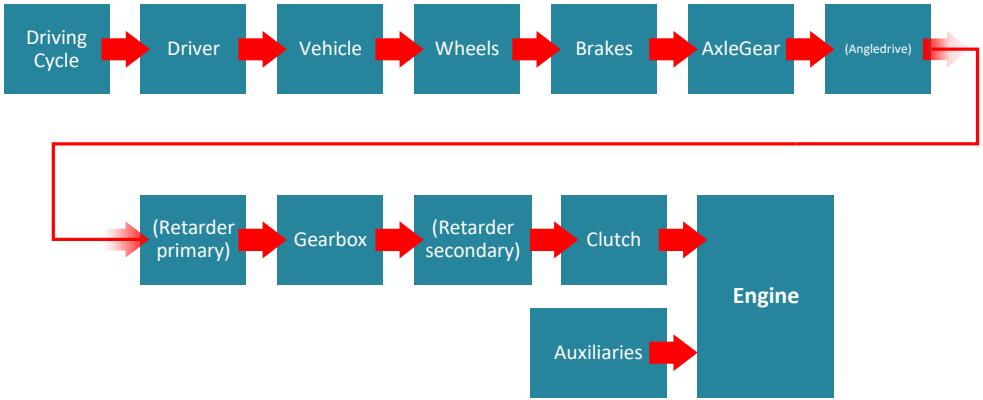


VECTO Simulation Loop

- Distance-based simulation
- Simulation with variable time steps
  - Target simulation time interval: 0.5 s
  - Certain events are calculated at finer granularity
    e.g., traction interruption, braking, …
- Two-step approach
  - Request phase: search valid operating point
  - Commit phase: write results for current simulation phase, advance to next simulation step

VECTO Simulation Cycle





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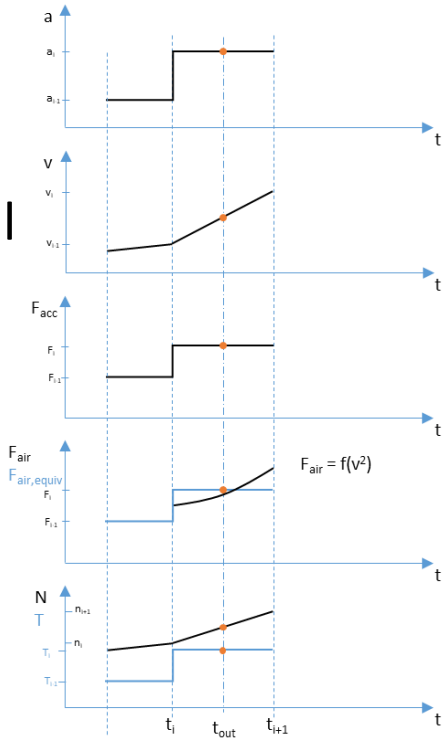
Request Phase

- Simulation interval: ≈ 0.5s
- Constant acceleration within a simulation interval
  - ⇒ Constant acceleration force
  - ⇒ Linear (angular) speed increase
  - ⇒ Constant torque
- Loss-map lookups are done with average angular speed within simulation interval
- If possible, exact physical behavior is calculated within simulation interval and average constant load is applied (e.g., air drag)



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VECTO Component Model Data (I)

- Driving Cycle
  - Target speed, stop times, and road gradient over distance
- Driver
  - *Max. acceleration and deceleration over vehicle speed (generic)*
- Vehicle
  - Total vehicle mass (curb mass + body mass + trailers + payload)
  - Rolling resistance coefficient
    Weighted sum of all wheels, including generic trailer if applicable
  - Air drag coefficient C_d * A

VECTO Component Model Data (II)

- Wheels
  - Dynamic tire radius (*VECTO models only one driven axle!)*
  - Inertia
- Brakes
  - None
- Axle gear, angle drive
  - Gear ratio
  - Loss-map: torque loss depending on torque and speed at input shaft

VECTO Component Model Data (III)

- Retarder
  - Step-up ratio
  - Idle loss-map: torque loss depending on retarder speed
- Transmission
  - Type of transmission
  - Gear ratio
  - Loss-map: torque loss depending on torque and speed at input shaft
- Torque converter
  - Characteristic curves of input torque and torque ratio depending on speed ratio

VECTO Component Model Data (IV)

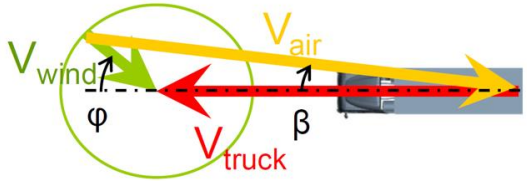
- Internal combustion engine
  - Full-load torque depending on engine speed
  - Drag torque depending on engine speed
  - Fuel consumption map
  - Fuel consumption correction factors (WHTC, cold/hot, NCV, …)
  - Fuel type
  - *Transient full-load torque ramp-up (generic)*
- Auxiliaries
  - Power demand

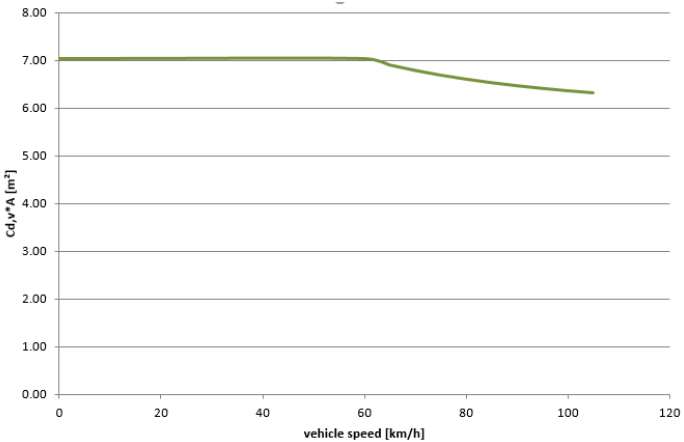
Driver Model

- Follow the target speed as good as possible
- Mimic real driver behavior
- Look ahead for target-speed decrease
  - Coast and brake, such that the vehicle's speed is not higher than the new target speed
- Overspeed
  - Vehicle accelerates downhill only due to potential energy

Crosswind Correction (Declaration Mode)

- Boundary conditions:
  - Wind of 3 m/s at a height of 4 m above ground level
  - Wind blows uniformly distributed from all directions
- Computation of speed-dependent correction factor (5km/h steps)
  - Compute average cross-wind influence for all wind directions (10° steps) from ground level to vehicle height





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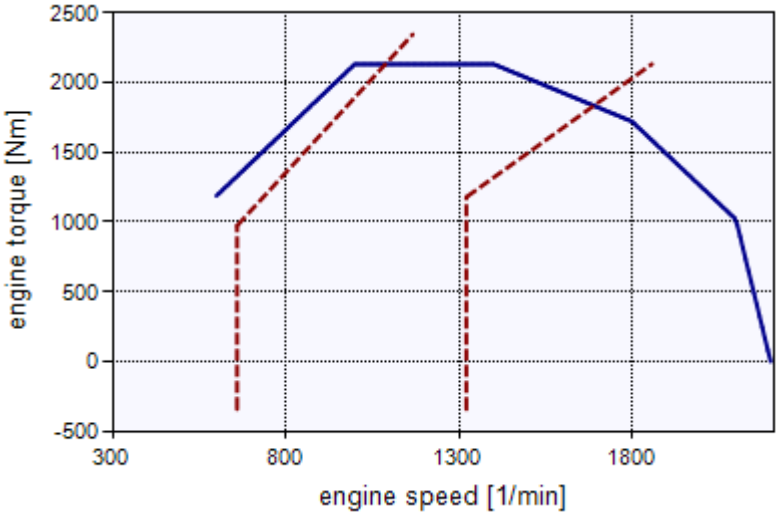
Advanced Driver Assistance Systems

- Implementation 2018
  - Considered technologies:
    - Engine stop-start during vehicle stops
    - Eco-roll without engine stop-start
    - Eco-roll with engine stop-start
    - Predictive Cruise control
  - Fixed CO2 reduction rates per vehicle group, mission profile & payload
  - Vehicle groups 4, 5, 9, 10
- Implementation 2019
  - In-the-loop simulation
  - Considered technologies still under discussion

Gearshift strategy

- Current implementation:
  - Based on shift polygons, derived from vehicle configuration and engine properties (all transmission types)
- Updated shift strategy
  - Gear selection based on optimization of overall drivetrain efficiency (AMT & AT)



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WHTC Correction

- Stationary fuel consumption map
- Consider transient behavior by comparing fuel consumption of measured WHTC with simulated WHTC
  - Part of VECTO Engine
  - Separate correction factors for rural, urban, and motorway part
- Weighting of WHTC factors for every mission cycle

	Urban	Rural	Motorway
Long Haul	11 %	0%	89 %
Regional Delivery	17 %	30 %	53 %
Urban Delivery	69 %	27 %	4 %

Declaration Mode vs. Engineering Mode

- Engineering mode
  - Almost all model parameters can be freely defined
    e.g. driving cycle, number of axles, gearshift parameters, payload, …
- Declaration mode
  - Only model parameters as set out in Commission Regulation (EU) 2017/2400 are allowed
  - Generic values for all other parameters, depending on vehicle group
- Declaration mode and engineering mode use the same software components, only the model data is filled differently
- *Certification mode*
  - Same as the Declaration mode
  - Input data has to be in XML format, using certified component data

VECTO XML File Format

VECTO Input Data Format

- Model parameters for every component are defined in the relevant Annexes of Commission Regulation (EU) 2017/2400 *(see also VectoParameters.html in VECTO archive)*
  - Parameter number, SI unit, name
  - Data type (incl. precision for floating point values)
- Data format not part of the legislation
- Agreed format for certified components, job data (vehicle) and reports is XML
- XML schema defines the structure of all input parameters

XML Schema

- Available on CITnet server:
  - Schema for job data:
    https://webgate.ec.europa.eu/CITnet/svn/VECTO/trunk/Share/XML/XSD/VectoInput.1.0.xsd
  - Schema for component data:
    https://webgate.ec.europa.eu/CITnet/svn/VECTO/trunk/Share/XML/XSD/VectoComponent.1.0.xsd

XML Terminology

- **Start tag** (often only tag): `<Model>`
- **End tag:** `</Model>`
- **Element:** `<Model></Model>`
- **Attribute:** `<Data id="some value">`
- **Namespace:** differentiate elements with the same name
  `<a:Model/>` VS. `<b:Model/>`
  Identified using a URI (e.g.: http://www.w3.org/2001/XMLSchema-instance)
  (Think of them as surnames for elements)
- **Namespace prefix:** define short name for long namespace identifier
  - Can be arbitrarily chosen, only URI of the namespace is relevant
  - `xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"`

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Basic Structure Component XML

XML declaration

Root element

Namespace definitions

Component element

Component model data

Data integrity

```
<?xml version="1.0" encoding="UTF-8"?>
<tns:VectoInputDeclaration
    xmlns="urn:tugraz:ivt:VectoAPI:DeclarationDefinitions:v1.0"
    xmlns:tns="urn:tugraz:ivt:VectoAPI:DeclarationComponent:v1.0"
    xmlns:di="http://www.w3.org/2000/09/xmldsig#" schemaVersion="1.0"
    xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
    xsi:schemaLocation="urn:tugraz:ivt:VectoAPI:DeclarationComponent:v1.0 https://

    <tns:Engine>
        <Data id="ENG-gooZah3D">

        </Data>
        <Signature>

        </Signature>
    </tns:Engine>

</tns:VectoInputDeclaration>
```

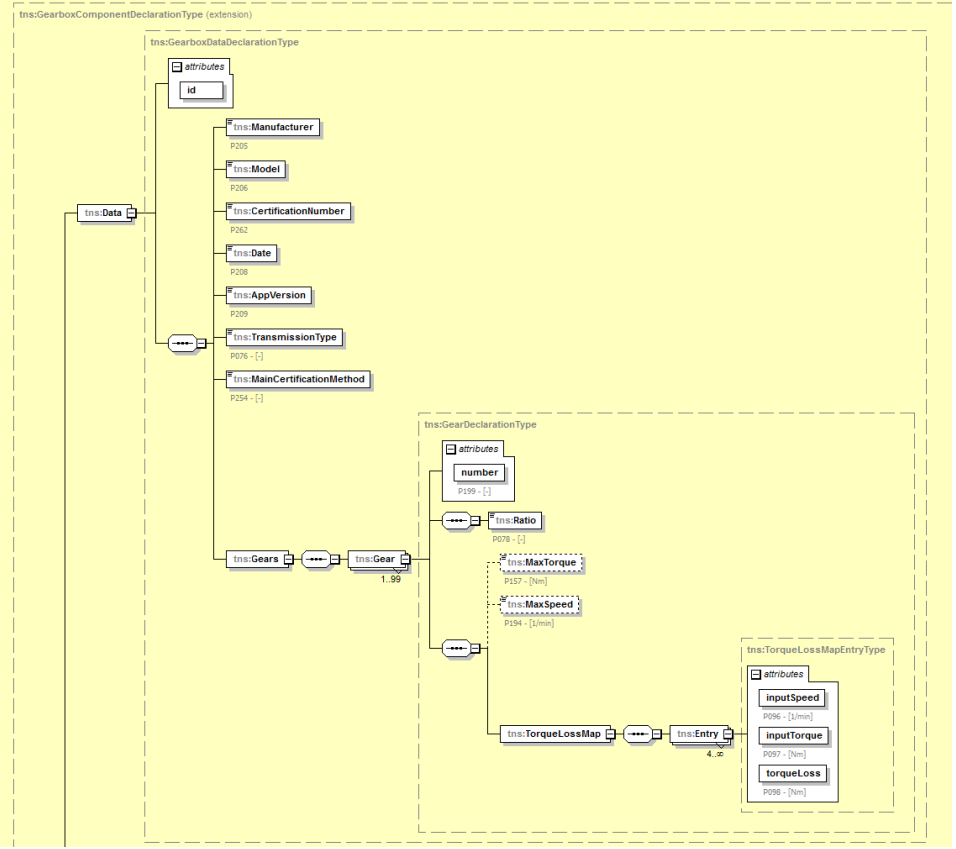
Basic Structure Component XML

Common component data

Component-specific model data

```
<tns:Engine>
    <Data id="ENG-gooZah3D">
        <Manufacturer>Generic Engine Manufacturer</Manufacturer>
        <Model>Generic 40t Long Haul Truck Engine</Model>
        <CertificationNumber>e12*0815/8051*2017/05E0000*00</CertificationNumber>
        <Date>2017-02-15T11:00:00Z</Date>
        <AppVersion>VectoEngine x.y</AppVersion>
        <Displacement>12730</Displacement>
        <IdlingSpeed>560</IdlingSpeed>
        <RatedSpeed>2200</RatedSpeed>
        <RatedPower>380000</RatedPower>
        <MaxEngineTorque>2300</MaxEngineTorque>
        <WHTCUrban>1.0097</WHTCUrban>
        <WHTCRural>1.0035</WHTCRural>
        <WHTCMotorway>1.0200</WHTCMotorway>
        <BFColdHot>1.0000</BFColdHot>
        <CFRegPer>1.0000</CFRegPer>
        <CFNCV>1.0000</CFNCV>
        <FuelType>Diesel CI</FuelType>
        <FuelConsumptionMap>[...]</FuelConsumptionMap>
        <FullLoadAndDragCurve>[...]</FullLoadAndDragCurve>
    </Data>
```

Documentation of XML Structure



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Basic Structure VECTO XML Job

- XML declaration
- Root element
- Namespace definitions
  - Vehicle element
    - Vehicle parameters
    - Powertrain components
      - Component model data

```
<?xml version="1.0" encoding="UTF-8"?>
<tns:VectoInputDeclaration
    xmlns="urn:tugraz:ivt:VectoAPI:DeclarationDefinitions:v1.0"
    xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" schemaVersion="1.0"
    xmlns:tns="urn:tugraz:ivt:VectoAPI:DeclarationInput:v1.0"
    xsi:schemaLocation="urn:tugraz:ivt:VectoAPI:DeclarationInput:v1.0 https://webgate.ec.
    xmlns:di="http://www.w3.org/2000/09/xmldsig#">
    <Vehicle id="VEH-1234567890">
        <Manufacturer>Generic Truck Manufacturer</Manufacturer>
        <ManufacturerAddress>Street, ZIP City</ManufacturerAddress>
        <Model>Generic Model</Model>
        <VIN>VEH-1234567890</VIN>
        <Date>2017-02-15T11:00:00Z</Date>
        [...]
        <Components>
            <Engine>
                <Data id="ENG-gooZah3D">[...]</Data>
                <Signature>[...]</Signature>
            </Engine>
            <Gearbox>[...]</Gearbox>
            <Axlegear>[...]</Axlegear>
            [...]
        </Components>
    </Vehicle>
</tns:VectoInputDeclaration>
```

XML Data & Standard Values

- VECTO does not contain the standard values for most components
- Standard values have to be provided in job data
  - Exception: Airdrag (only dependent on vehicle group)

VECTO Output

VECTO Result Files

- Declaration mode
  - Manufacturer's records file – XML
  - Customer information file – XML
    (XML schema definitions available for both reports)
- Engineering mode (optional in declaration mode)
  - Summary data file – CSV *(.vsum)*
    Single line per simulated job, vehicle summary & aggregate/average values
  - Modal results file – CSV *(.vmod)*
    Detailed results for every component in every simulation step

Declaration XML Reports

- According to Commission Regulation (EU) 2017/2400
- Description of vehicle
  - VIN, axle configuration, vehicle group, …
- List of components and their description *(only MRF!)*
- Simulation Results
  - Fuel consumption, CO_2 for every simulated cycle and payload combination
  - In various metrics: l/100km, l/100t-km, l/m^3-km, …

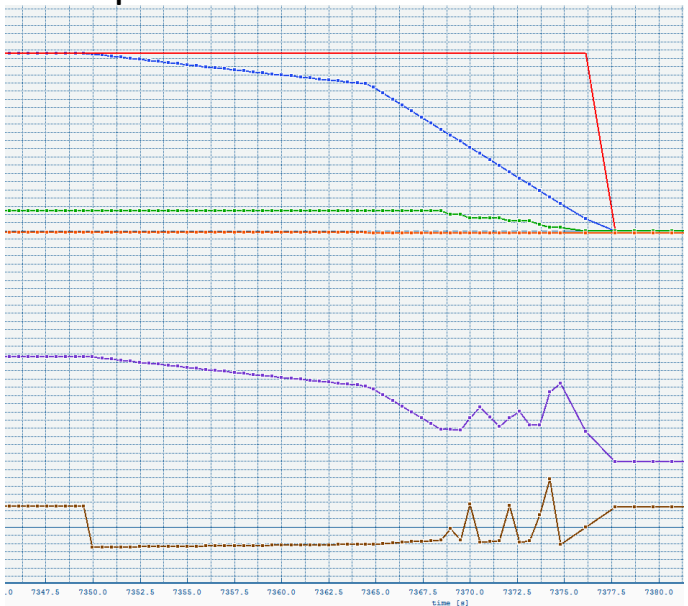
Example Manufacturer's Record File

```
<?xml version="1.0" encoding="utf-8"?>
<VectoOutput schemaVersion="0.4" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xmlns
  <Data id="RESULT-ea79e47e75e6487fa859">
    <Vehicle>
      <VIN>VEH-1234567890</VIN>
      <LegislativeClass>N3</LegislativeClass>
      <VehicleGroup>5</VehicleGroup>
      <AxleConfiguration>4x2</AxleConfiguration>
      <GrossVehicleMass>40000</GrossVehicleMass>
      <CurbMassChassis>7100</CurbMassChassis>
      <PTO>false</PTO>
      <Components>
        <Engine>
          <Model>Generic 40t Long Haul Truck Engine</Model>
          <CertificationNumber>e12*0815/8051*2017/05E0000*00</CertificationNumber>
          <DigestValue>W2q5ralzB4hZ+KaZEHIPQgDYgZZt5/AxakDP7Jaatfg=</DigestValue>
          <RatedPower>380000</RatedPower>
          <IdlingSpeed>600</IdlingSpeed>
          <RatedSpeed>2200</RatedSpeed>
          <Displacement>12730</Displacement>
          <FuelType>Diesel CI</FuelType>
        </Engine>
        <Gearbox>
          <Model>Generic 40t Long Haul Truck Gearbox</Model>
          <CertificationMethod>Standard values</CertificationMethod>
          <DigestValue>5BDnQpUdND4mtHCVVz7RsM3yuO+QfuHzlIjVNXYoeis=</DigestValue>
          <TransmissionType>AMT</TransmissionType>
          <GearsCount>12</GearsCount>
          <TransmissionRatioFinalGear>1.000</TransmissionRatioFinalGear>
        </Gearbox>
        <Retarder>
          <RetarderType>Transmission Output Retarder</RetarderType>
          <Model>Generic Retarder</Model>
          <CertificationMethod>Standard values</CertificationMethod>
          <DigestValue>SObnLSgCbODYSKUXgsxVV1+HeoypF1+2WMnZtBBwMbQ=</DigestValue>
        </Retarder>
        <Axlegear>
          <Model>Generic 40t Long Haul Truck AxleGear</Model>
          <CertificationMethod>Standard values</CertificationMethod>
          <DigestValue>4zNNxDHUsN32kPYIi5NuHkZIzYFgptEjv8Z9eFCDKrU=</DigestValue>
          <LineType>Single portal axle</LineType>
          <Ratio>2.590</Ratio>
        </Axlegear>
```

```
  <Results>
    <Status>success</Status>
    <Result status="success">
      <Mission>Long Haul</Mission>
      <Distance unit="km">100.185</Distance>
      <SimulationParameters>
        <TotalVehicleMass unit="kg">17200</TotalVehicleMass>
        <Payload unit="kg">2600</Payload>
        <FuelType>Diesel CI</FuelType>
      </SimulationParameters>
      <VehiclePerformance>
        <AverageSpeed unit="km/h">79.7</AverageSpeed>
        <MinSpeed unit="km/h">0.0</MinSpeed>
        <MaxSpeed unit="km/h">86.5</MaxSpeed>
        <MaxDeceleration unit="m/s²">1.00</MaxDeceleration>
        <MaxAcceleration unit="m/s²">1.00</MaxAcceleration>
        <FullLoadDrivingtimePercentage>2.31</FullLoadDrivingtimePercentage>
        <GearshiftCount>47</GearshiftCount>
      </VehiclePerformance>
      <FuelConsumption unit="g/km">227.1</FuelConsumption>
      <FuelConsumption unit="g/t-km">87.4</FuelConsumption>
      <FuelConsumption unit="g/m³-km">2.50</FuelConsumption>
      <FuelConsumption unit="MJ/km">9.70</FuelConsumption>
      <FuelConsumption unit="MJ/t-km">3.73</FuelConsumption>
      <FuelConsumption unit="MJ/m³-km">0.107</FuelConsumption>
      <FuelConsumption unit="l/100km">27.2</FuelConsumption>
      <FuelConsumption unit="l/t-km">0.104</FuelConsumption>
      <FuelConsumption unit="l/m³-km">0.00299</FuelConsumption>
      <CO2 unit="g/km">710.9</CO2>
      <CO2 unit="g/t-km">273.4</CO2>
      <CO2 unit="g/m³-km">7.81</CO2>
    </Result>
    <Result status="success">
      <Mission>Long Haul</Mission>
      <Distance unit="km">100.185</Distance>
      <SimulationParameters>
        <TotalVehicleMass unit="kg">33900</TotalVehicleMass>
        <Payload unit="kg">19300</Payload>
        <FuelType>Diesel CI</FuelType>
      </SimulationParameters>
      <VehiclePerformance>
```

Modal results

- Simulation details for every component in every simulation step
  - Available signals are documented in the VECTO user manual
  - Simple graphical representation of .vmod in VECTO GUI (over time or distance)



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Hands-On Demonstration

Future of VECTO

Main Open Issues and Future Challenges

- Generic gear shift strategies in VECTO for AMT and AT transmission vehicles
- Advanced Driver Assistance Systems (“ADAS”)
  Engine stop-start, eco-roll, predictive cruise control
- Advanced engine technologies
  e.g. dual fuel engines, waste heat recovery
- Methods for buses and coaches
- Hybrid electric vehicles (He-HDV)
- Incorporation of specific designs of bodies, trailers and semitrailers into the CO_2 certification
- N2 and M2 vehicles with a technically permissible maximum laden mass not exceeding 7.5 tons
- Incorporation of OEM specific control strategies