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The CO_2MPAS tool

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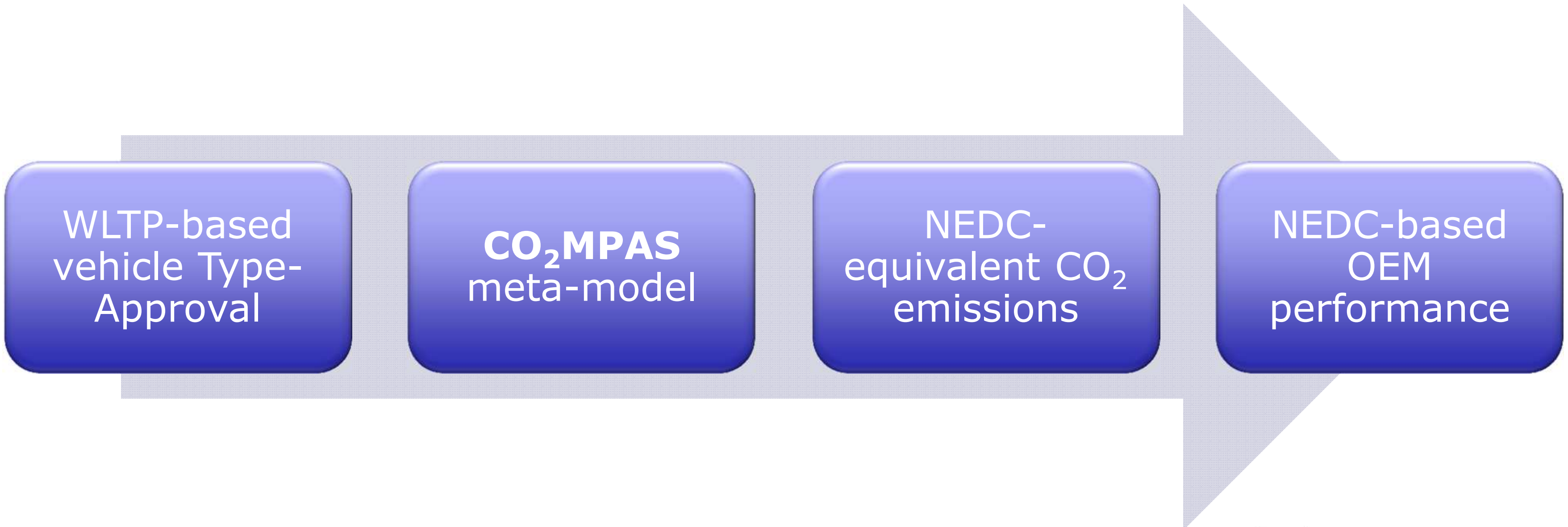
European Commission

Approach – WLTP Phasing-in

- During the **WLTP phasing-in**, WLTP measurements will be correlated into NEDC values using CO_2MPAS (CO_2 Model for PAssenger and commercial vehicles Simulation), developed by JRC.



What is CO_2MPAS

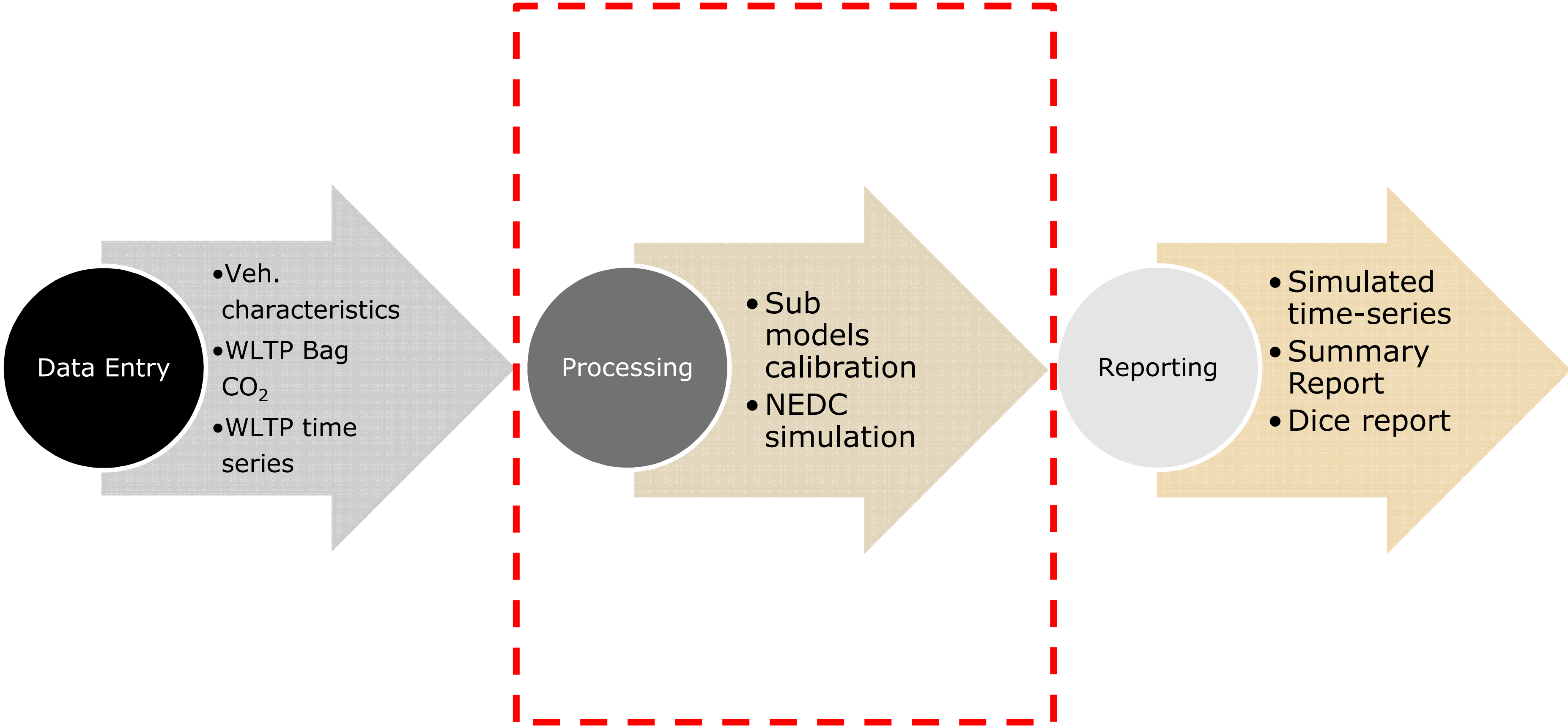
- CO_2MPAS is a vehicle simulator developed in order to facilitate the introduction of WLTP in the European TA approval scheme.

- CO_2MPAS is founded on established engineering approaches used in vehicle simulation. Eg. longitudinal vehicle dynamics, modular structure, extended-willans model for fuel consumption calculation etc

- CO_2MPAS is unique in the sense that it is a “self calibratable” model, calibration takes place based on WLTP data

- CO_2MPAS Type approval operates with the minimum input data. Specific assumptions and boundaries associated with the official tests are embeded

CO_2MPAS data flow overview



Key features

- Comprises of 2 main calculation modules

Power – RPM module

- Simple longitudinal dynamics (WLTP-GTR)
- Engine power and RPM calc'd @ 1hz
- Inclusion of Mech or Elec. loads where needed
- Generic start-stop logic
- A/T and CVT RPM prediction model
- Alternator logic calibrated over WLTP

FC module

- Calculation of FC
  Indicative instantaneous approach
- Based on an extended Willans model
- Semi-physical empirical cold start model
- Calibration - Optimization based on WLTP results
- Specific engine technologies included

+Parallel work for HEV control module and optimization

Accurate calculation of average / instantaneous power demand

Very good accuracy when compared with results obtained from the Cruise simulations by LAT and **Real test data from 40 vehicles**

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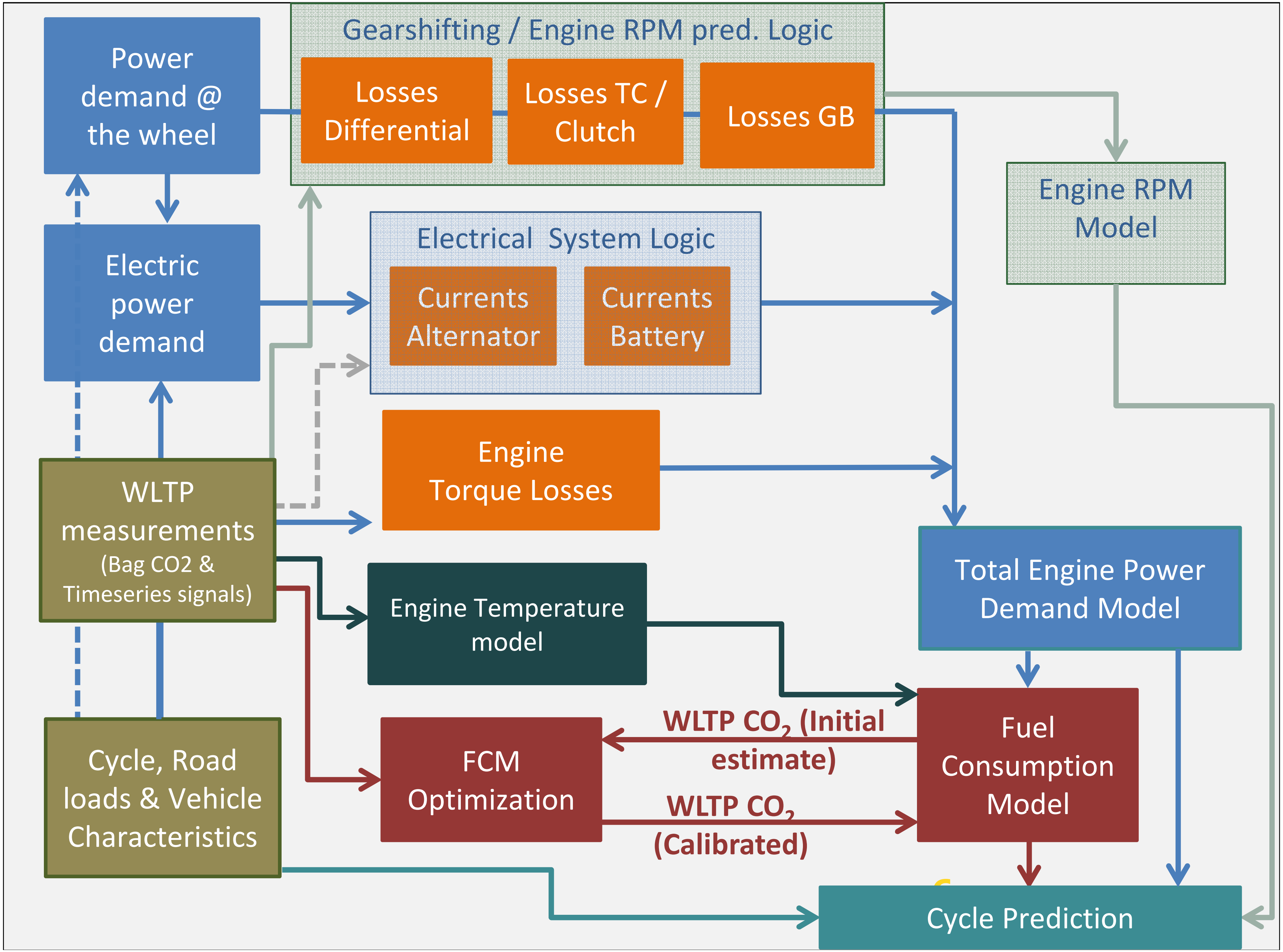


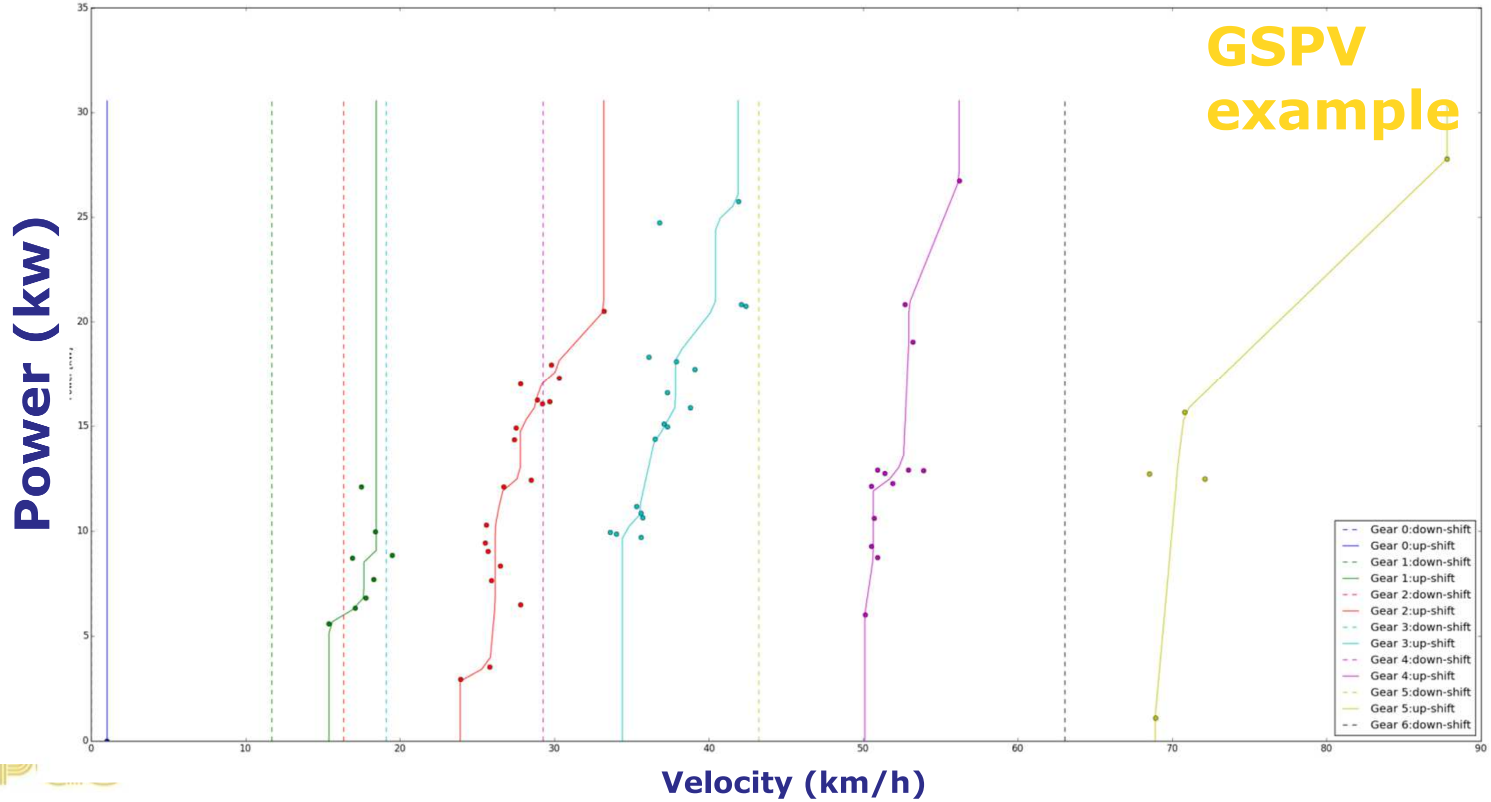
Power demand @ the wheel
Gearshifting / Engine RPM pred. Logic
Losses Differential
Losses TC / Clutch
Losses GB
Engine RPM Model
Electric power demand
Electrical System Logic
Currents Alternator
Currents Battery
Engine Torque Losses
WLTP measurements (Bag CO2 & Timeseries signals)
Engine Temperature model
Total Engine Power Demand Model
Cycle, Road loads & Vehicle Characteristics
FCM Optimization
WLTP CO2 (Initial estimate)
WLTP CO2 (Calibrated)
Fuel Consumption Model
Cycle Prediction

CO_2MPAS sub-models

- CO_2MPAS includes the following sub-models:
  - **Automatic Transmission model (gear shifting)**
  - **Clutch / Torque converter model score**
  - **Engine cold start speed model**
  - **Engine speed model**
  - **Start stop model**
  - **Alternator model**
  - **Engine coolant temperature model**
  - **Engine fuel consumption (CO_2) model**

Automatic Transmission model (gear-shifting 1/2)

- There are 2 **official** options enabled in the A/T model:
  - Corrected Mean Velocity (**CMV**) creates a "map" of gear upshifts and down-speeds as a function of vehicle speed.
  - GearShift Power-Velocity (**GSPV**) creates a map of gear upshifts as a function of vehicle speed & the power at the gearbox
- CO_2MPAS automatically selects the option that better reproduces gear shifting over WLTP
- In engineering mode the DT option can be also enabled



Automatic Transmission model (gear-shifting 2/2)

- Two sets of gear-shift maps are calculated, **hot** and **cold** conditions
- Final step: Matrix Velocity Limits (**MVL**) correction model corrects gear-shifting over quasi-steady state conditions (enables lower gears)
- For **CVT**s a gradient boost regressor is used to predict Engine RPM as a function of vehicle speed, acceleration and power at the gearbox

Clutch / Torque converter model

- CO_2MPAS by default calibrates a clutch model (generic or DTC) unless a TC is declared as present on the vehicle:
  - **In both cases an "RPM-slip" model as a function of acceleration is fitted based on experimental data**

- Efficiency model (predefined non calibrated):
  - **Clutch: linear TC efficiency as a function of RPM ratio**
  - **TC: a non-linear efficiency as a function of RPM ratio**

- For TCs a lock up velocity (48km/h) is used

Engine cold start speed model

- The ECSSM increases idling RPMs during the cold start phase
- An optimizer is used to calculate the unit less ΔRPM_{idle} [%] function during cold start
- ΔRPM is a linear function o f engine temperature capped at a certain value which is also estimated by the optimizer

Engine speed model

- The ESM calculates the exact RPM/Velocity ratios over the specific test
- Gear ratios (or default RPM/V ratios) and information on tyre dimensions provided by the user are used as starting values
- An optimizer calculates the optimal dynamic radius of the tire based on the dyno velocity and engine RPM data measured over the WLTP

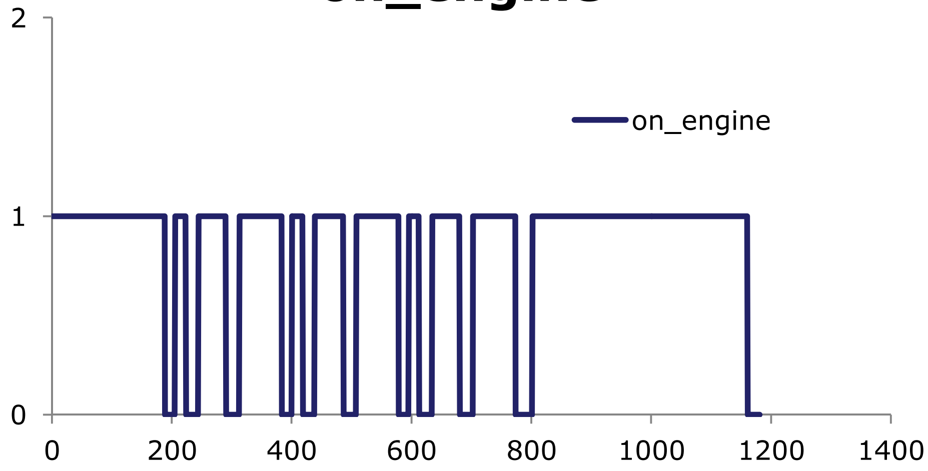
Start stop model

- The SS model defines where the engine should be switched off for SS equipped vehicles

- CO_2 MPAS uses a classifier in order to associate engine switch off events to vehicle deceleration and velocity.

- SS functionality is initiated based on the user provided input on engine SS initiation time

on_engine



Alternator model

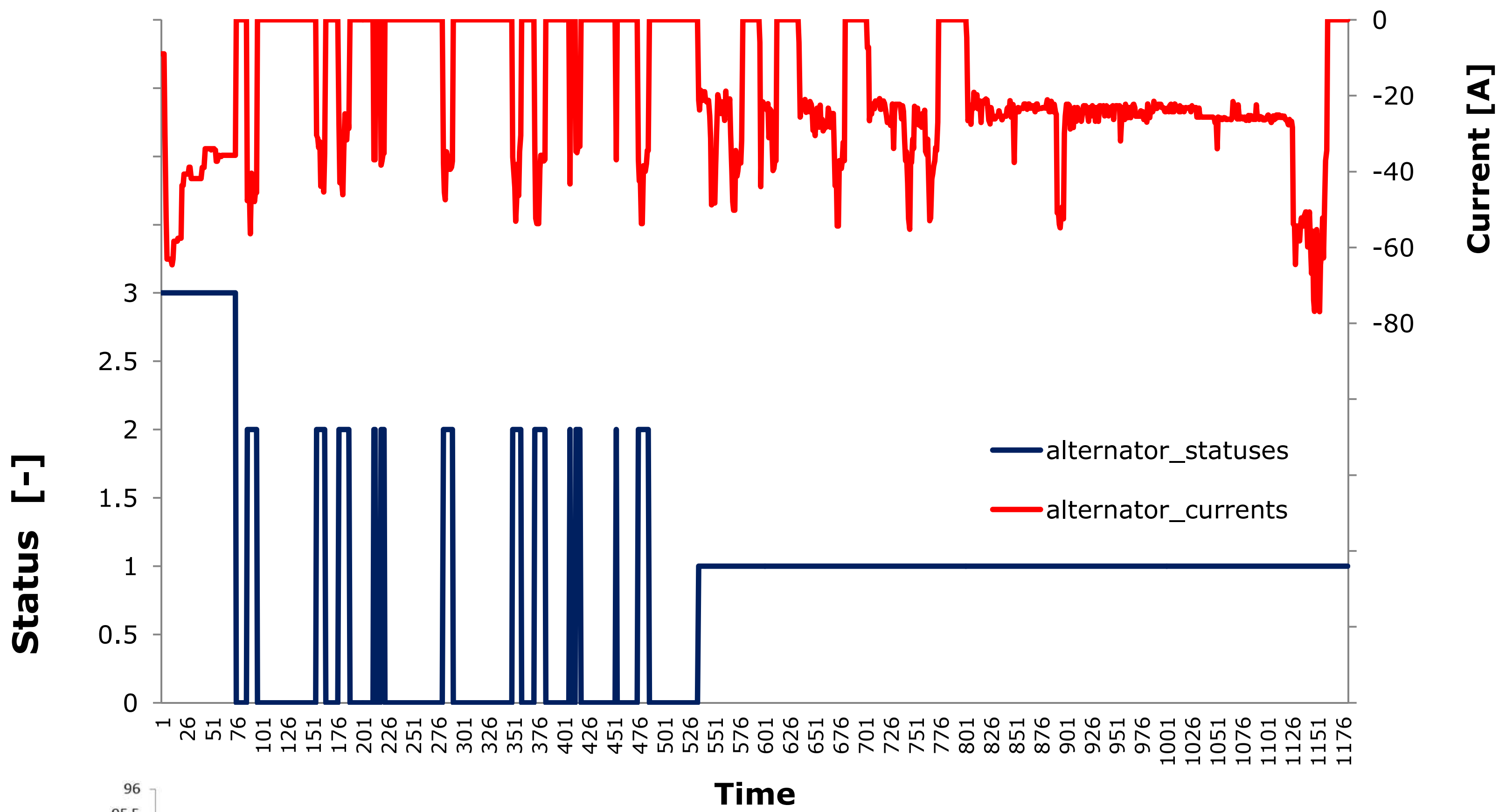
- Comprises of 2 parts:
  - **Logic part (when the alternator operates and how)**
  - **Electric part (what current is supplied by the alternator)**

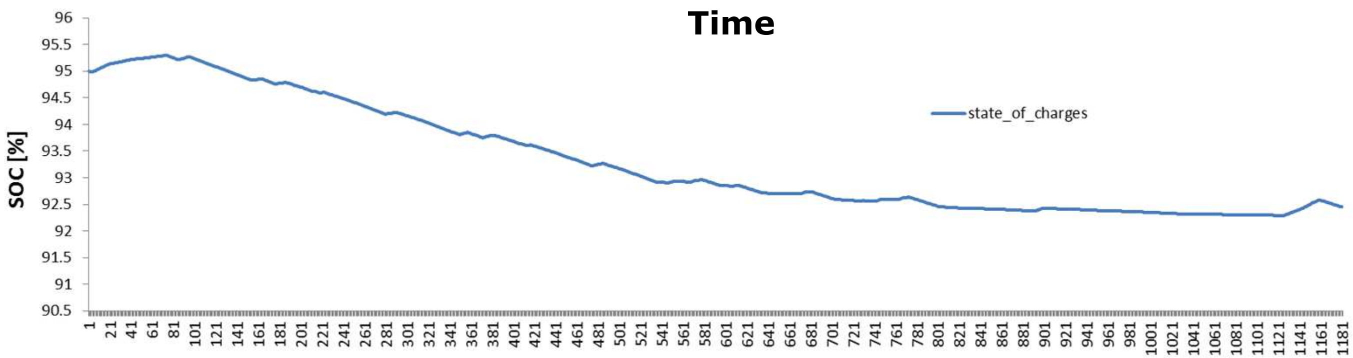
- **Logic part** identifies different phases (idling, regenerative braking, battery charging, battery depletion) and under what conditions those occur → result: alternator status

- **Electric part** identifies the current per each phase based on other parameters (eg RPM, Battery SOC, deceleration)

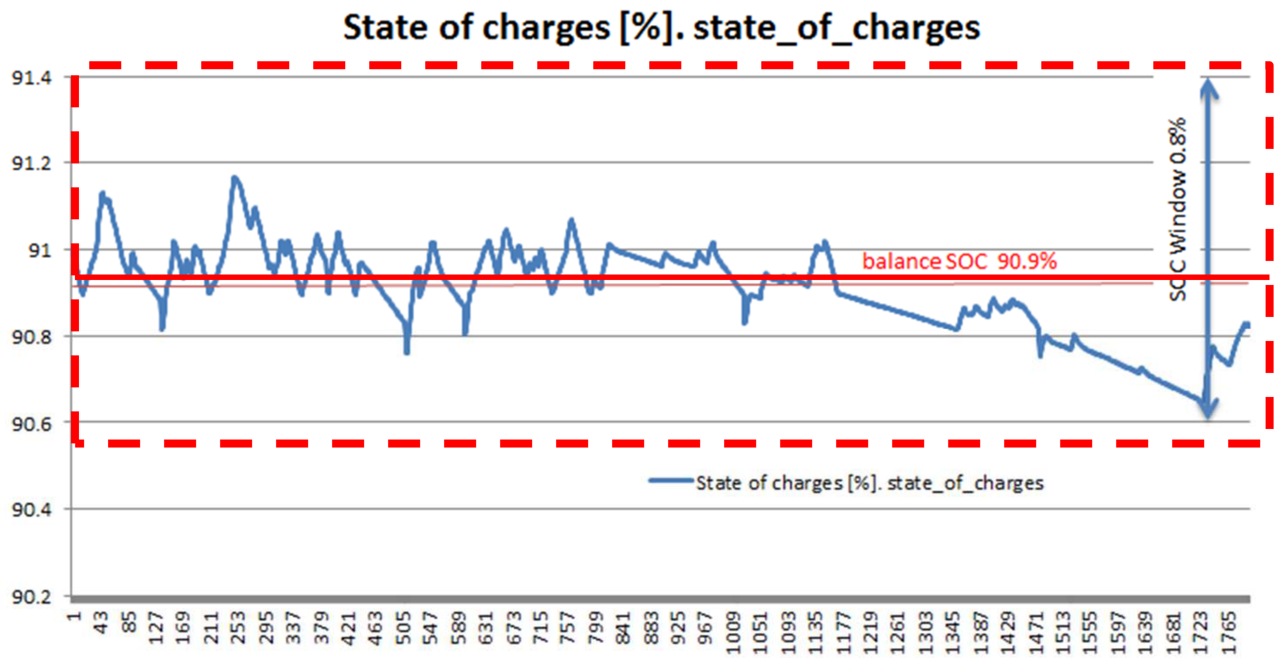
- A gradient boost regressor is used for predicting the currents based on alt. status, acceleration, power at g/box, SOC at t-1, and initialization time

Alternator logic and current prediction





Alternator logic and current prediction - windows



Engine coolant temperature model

- CO_2MPAS uses a regressor to predict engine temperature (T) evolution

- T_i is function of T_{i-1} , RPM, acceleration and the power at the gearbox

- The regressor is calibrated based on WLTP recorded time series using Gradient Boost algorithm (ransac algorithm used for inlier and outlier detection)

Engine fuel consumption (CO_2) model

- Extended Willans Model approach:
- Fitting of a specific non-linear Willans model

$$BMEP=(a+b\times cm+c\times c_m{}^2)\times FuMEP+(a2\times FuMEP^2)+l_0+l_2\times cm^2$$

- Where:
  - **BMEP: brake mean effective pressure**
  - **cm: mean piston speed**
  - **FuMEP: fuel mean effective pressure**
  - **a, b, c, a2, l0, l2 are the parameters that are being fitted**

Engine fuel consumption (CO_2) model

Fuel Consumption (Fc) Calculation Function

$$\int FMEP(t)\,dt = \int \frac{-(a + b * C_m(t) + c * C_m(t)^2) + \sqrt{(a + b * C_m(t) + c * C_m(t)^2)^2 - 4 * a_2 * \left(\left({T(t)}/{T_{target}}\right)^{-k} * (l + l_2 * C_m(t)^2) - BMEP(t)\right)}}{2 * a_2}\,dt$$

Cold start factor

, where:

- $C_m(t)[m/s] = 2 * {}^{Engine\ Speed\ [rpm]}/_{60} * Engine\ Stroke\ [m]$
- $BMEP(t)[Pa] = {}^{2 * Engine\ Power\ [W]}/_{\left(Engine\ Capacity\ [m^3] * {}^{Engine\ Speed\ [rpm]}/_{60}\right)}$
- $Fuel\ Consumption(t)[g/s] = {}^{FMEP(t)[Pa] * Engine\ Capacity\ [m^3] * {}^{Engine\ Speed\ [rpm]}/_{60}}/_{2 * Fuel\ Lower\ Heating\ Value\ [{}^{J}/_{g}]}$

The following are considered as knowns from the measurement / other COMPAS modules (*in order to understand issues and improve the stability of the FC module*):

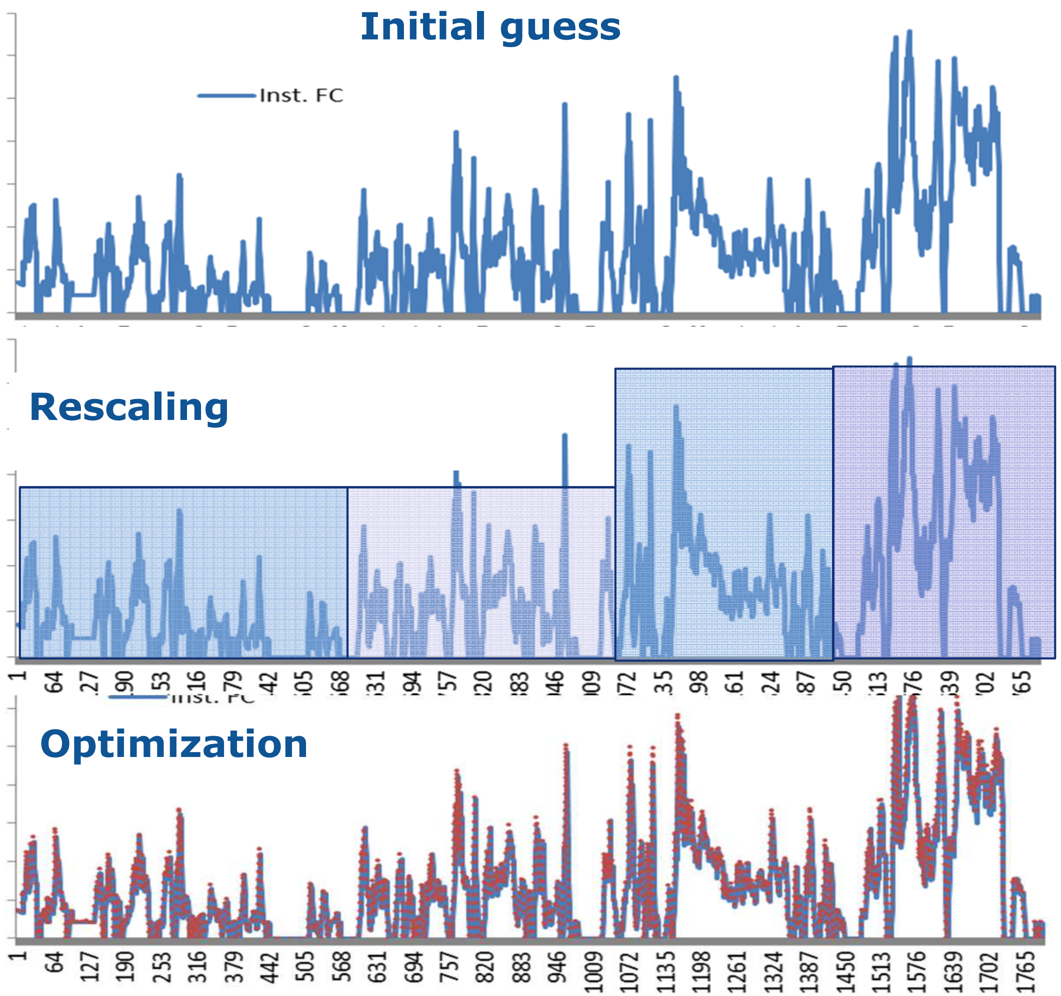
- Engine Speed, Temperature, Engine Power
- The constant parameters are calculated by optimization of the above equation against WLTP CO_2 measured data

Engine fuel consumption (CO_2) model

- Extended Willans Model is calibrated using WLTP CO_2 results
  - An initial estimate is made based on generic values (categorized per engine and aspiration type)
  - The model perturbates until the initial and final estimate of the CO_2 time series converge
  - A final optimization is done in order to reduce the error in the WLTP bag value prediction.

- Specific technologies are currently considered using the Extended Willans approach
  - For Petrol engines: Variable valve actuation, Lean combustion, Aspiration type, Cylinder deactivation (limited validation), External EGR (limited validation)
  - For Diesel engines: External EGR, Cylinder deactivation (limited validation), Selective catalytic reduction (limited validation)

Optimization path



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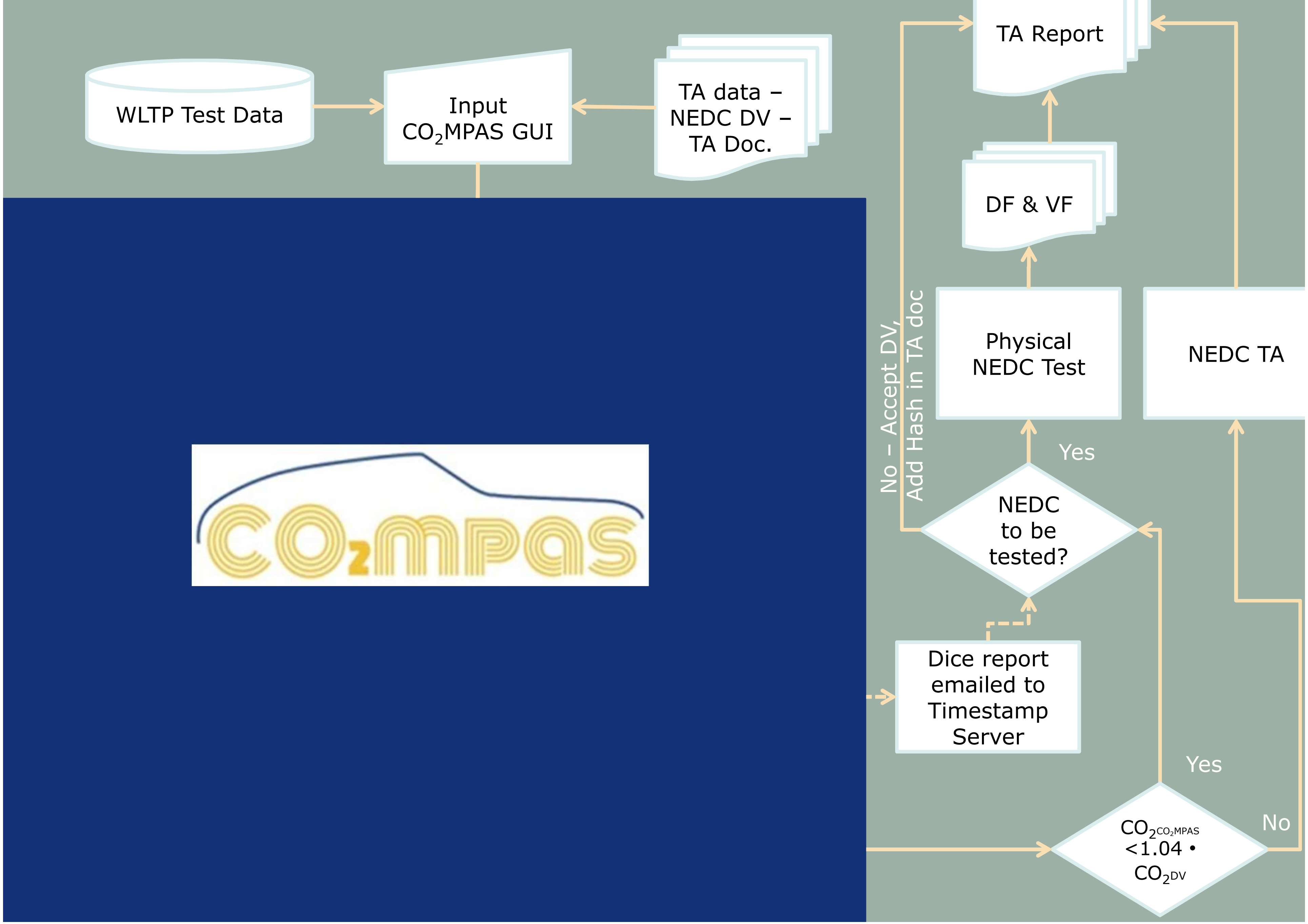
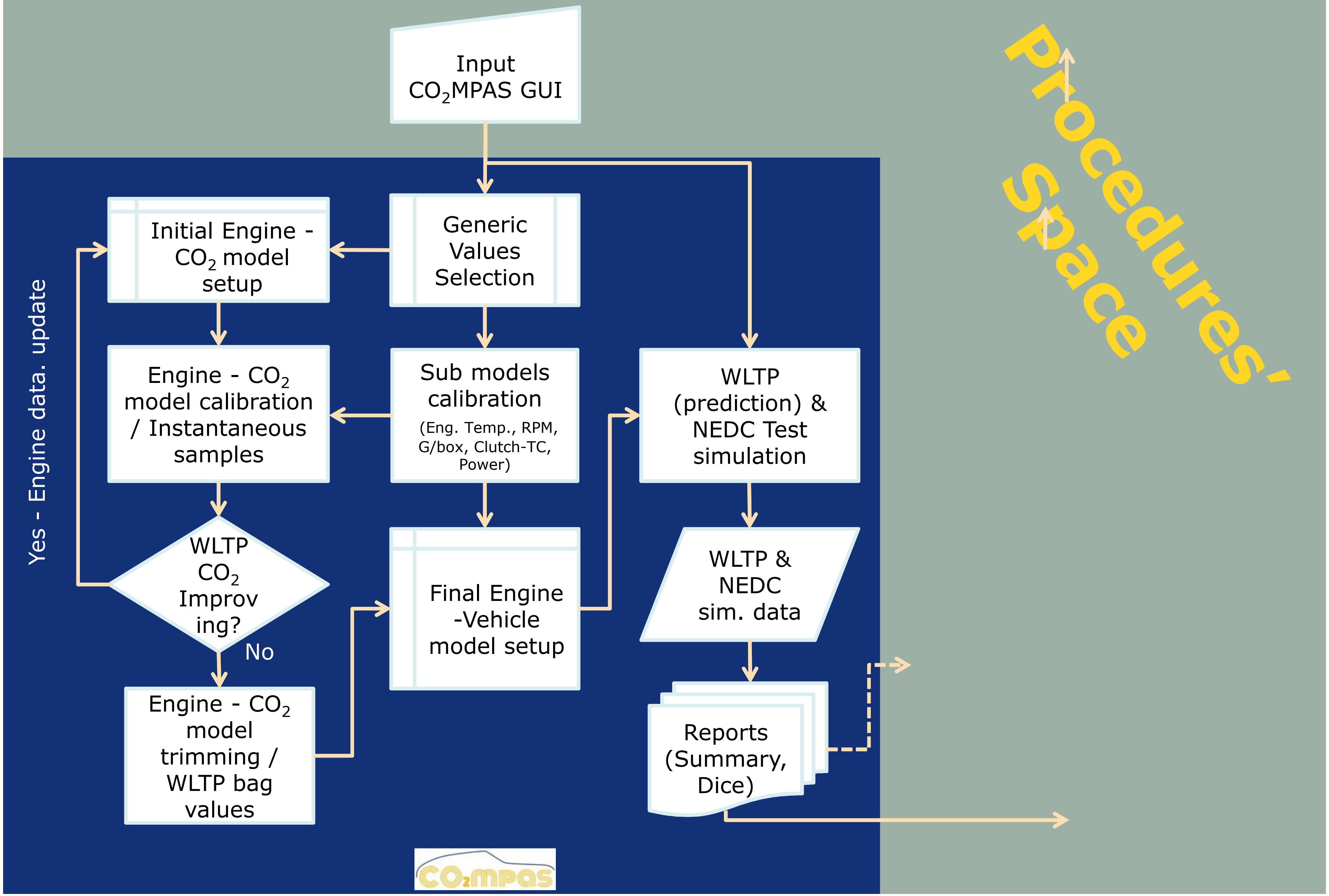
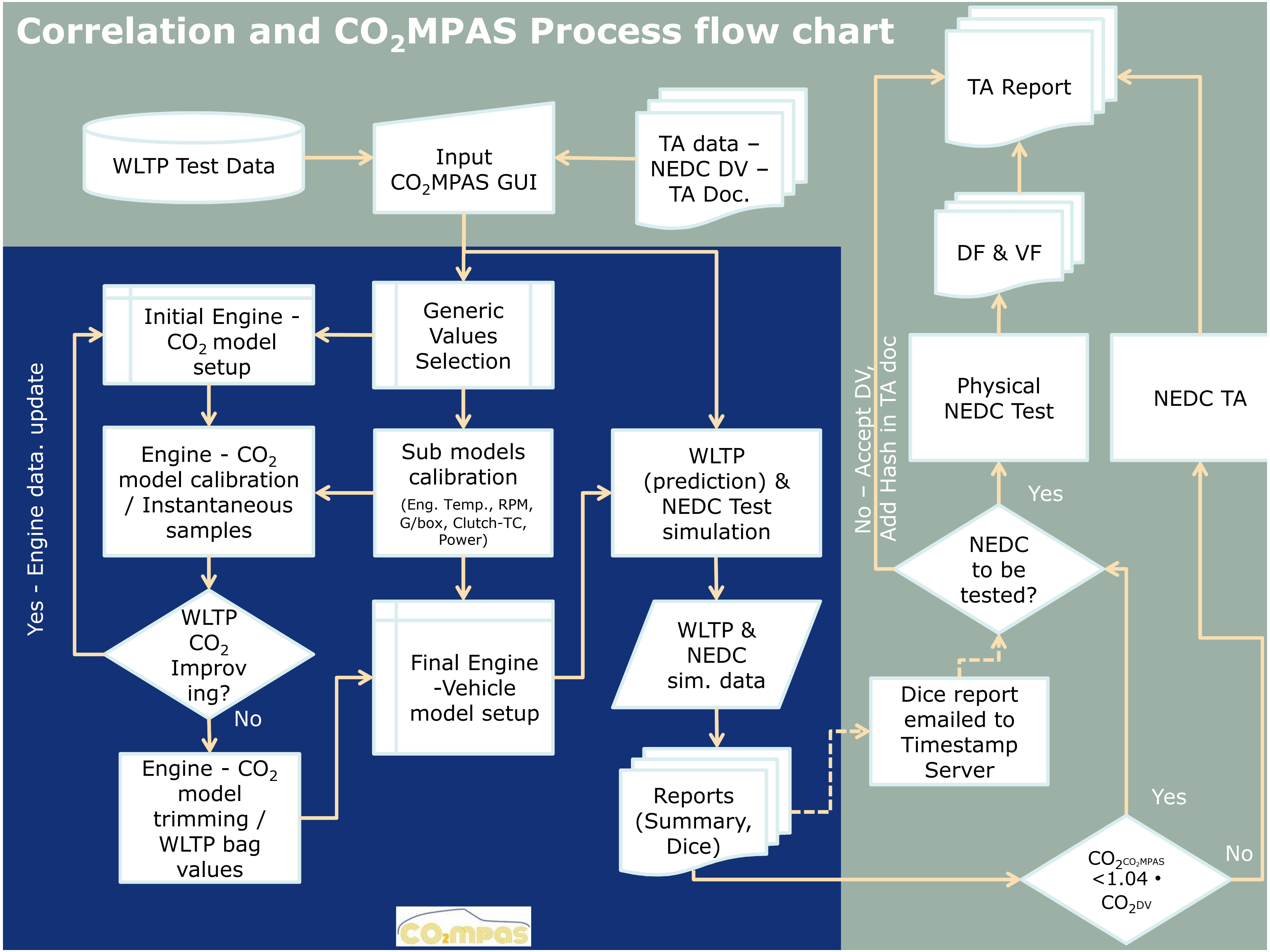
Summary

Correlation and CO_2MPAS Process flow chart



Correlation and CO_2MPAS Process flow chart




Correlation and CO_2MPAS Process flow chart
WLTP Test Data
Input CO_2MPAS GUI
TA data – NEDC DV – TA Doc.
TA Report
DF & VF
Generic Values Selection
Initial Engine - CO_2 model setup
Engine - CO_2 model calibration / Instantaneous samples
Sub models calibration
(Eng. Temp., RPM, G/box, Clutch-TC, Power)
WLTP (prediction) & NEDC Test simulation
Physical NEDC Test
NEDC TA
Yes - Engine data. update
WLTP CO_2 Improving?
No
Final Engine -Vehicle model setup
WLTP & NEDC sim. data
No – Accept DV, Add Hash in TA doc
Yes
NEDC to be tested?
Dice report emailed to Timestamp Server
Engine - CO_2 model trimming / WLTP bag values
Reports (Summary, Dice)
Yes
No
$CO_{2_{CO_2MPAS}} < 1.04 \cdot CO_{2_{DV}}$
CO₂MPAS

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