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The CO_2MPAS tool

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Ispra, 17/11/2016

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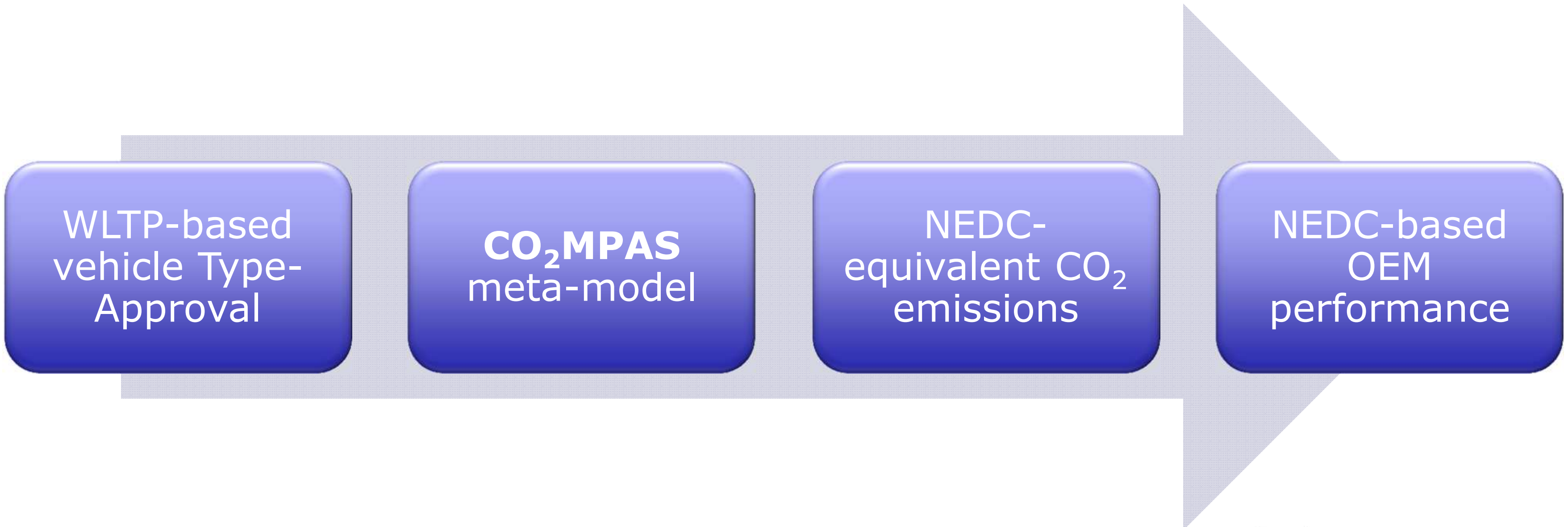
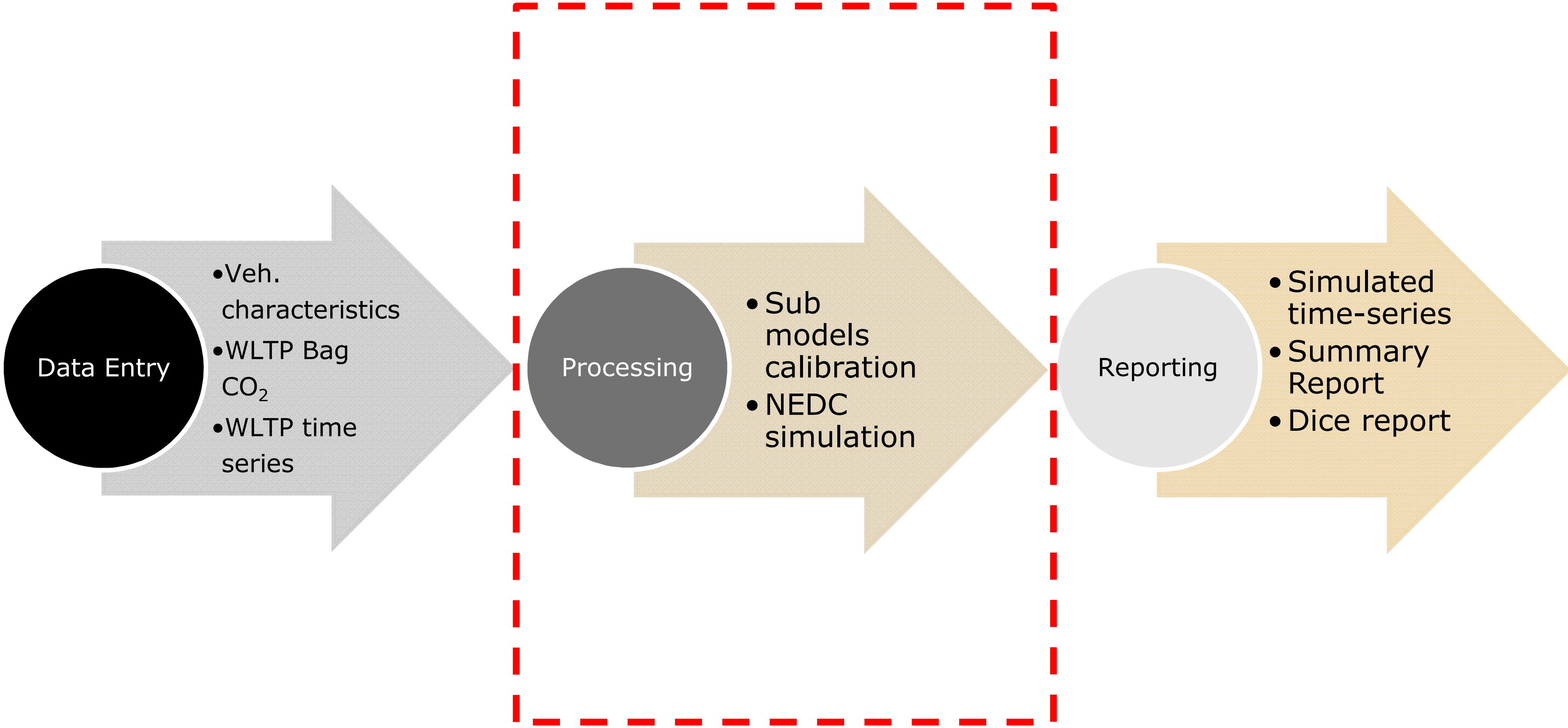
Approach – Phasing-in

- 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.



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

Accurate calculation of average / instantaneous power demand

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

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

+Parallel work for HEV control module and optimization

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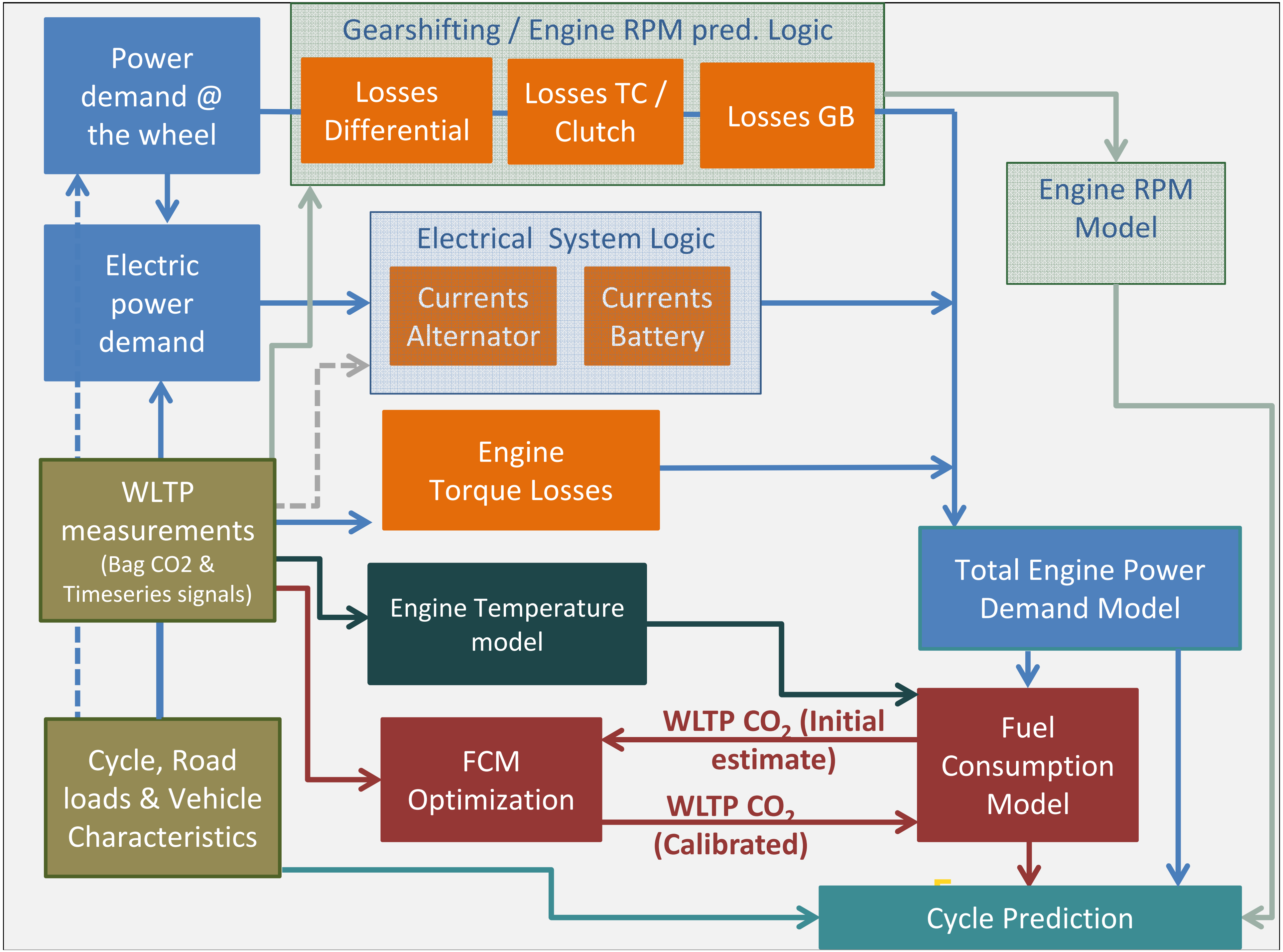

Power demand @ the wheel
Gearshifting / Engine RPM pred. Logic
Losses Differential
Losses TC / Clutch
Losses GB
Engine RPM Model
Electric power demand
Electrical System Logic
Currents Alternator
Currents Battery
Engine Torque Losses
WLTP measurements (Bag CO2 & Timeseries signals)
Total Engine Power Demand Model
Engine Temperature model
WLTP CO_2 (Initial estimate)
Fuel Consumption Model
Cycle, Road loads & Vehicle Characteristics
FCM Optimization
WLTP CO_2 (Calibrated)
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**

CO_2MPAS self assessment of internal models

CO2MPAS DICE REPORT

TA Certificate Number	
CO2MPAS version	1.4.1rc0
Date/Time	2016/11/16-18:24:31
Type approval mode	False

	Vehicle H	Vehicle L	units
Fuel Type	diesel	diesel	-
Engine Capacity	1596.00	1596.00	cc
Gearbox type	manual	manual	-
Turbo engine	TRUE	TRUE	-
sub_models_uuid	b'\x80\x03}q\x00(X\x1	b'\x80\x03}q\x00(X\x1	-
alternator_model score	11.48	10.51	A
at_model score			-
clutch_torque_converter_model score	43.74	43.74	RPM
co2_params score	0.01	0.02	CO2g/s
engine_cold_start_speed_model score	46.40	46.33	RPM
engine_coolant_temperature_model score	1.08	1.49	°C
engine_speed_model score	15.38	15.38	RPM
start_stop_model score	-0.99	-0.99	-
CO2MPAS deviation			%

CO2MPAS DICE REPORT

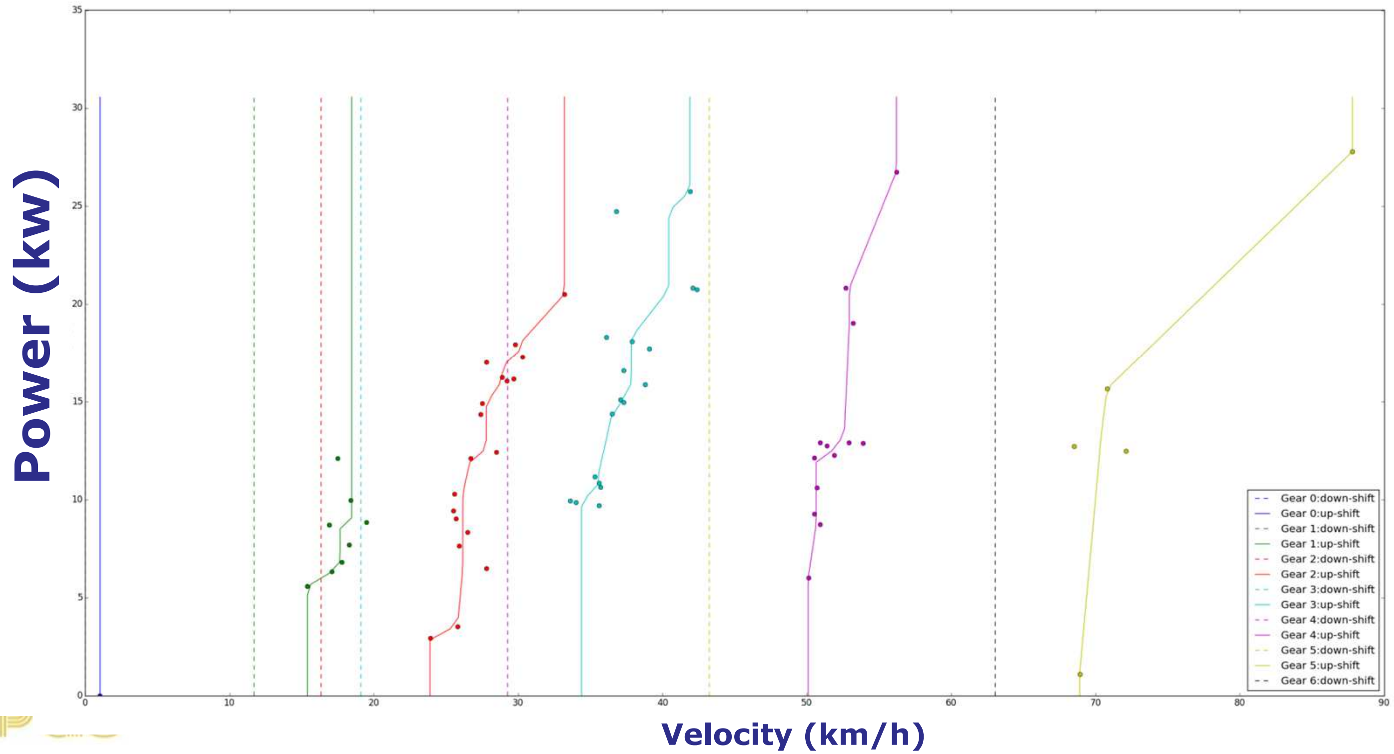
TA Certificate Number	
CO2MPAS version	1.4.1rc0
Date/Time	2016/11/16-18:36:07
Type approval mode	False

	Vehicle H	Vehicle L	units
Fuel Type	gasoline	gasoline	-
Engine Capacity	3498.00	3498.00	cc
Gearbox type	automatic	automatic	-
Turbo engine	FALSE	FALSE	-
sub_models_uuid	b'\x80\x03}q\x00(X\x1	b'\x80\x03}q\x00(X\x1	-
alternator_model score	10.05		A
at_model score	-0.79		-
clutch_torque_converter_model score	68.68		RPM
co2_params score	0.04		CO2g/s
engine_cold_start_speed_model score	89.14		RPM
engine_coolant_temperature_model score	1.28		°C
engine_speed_model score	20.49	42.10	RPM
start_stop_model score	-1.00		-
CO2MPAS deviation			%

- **Mean absolute error (quantities with units)**
- **Calibration coefficient for unit-less quantities**

Automatic Transmission model (gear-shifting 1/2)

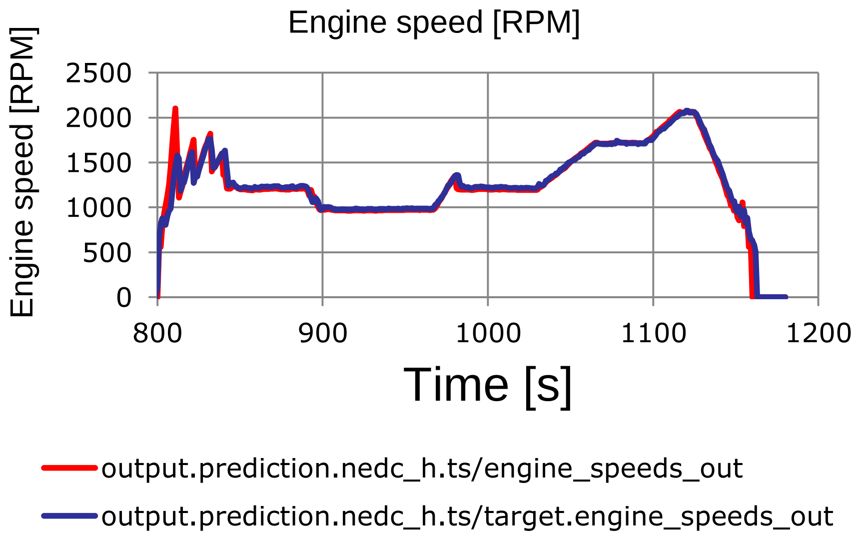
- There are 2 **official** options enabled in the A/T model:
  - Corrected Mean Velocity (**CMV**) creates a "map" of gear upshifts and down-speeds as a function of vehicle speed.
  - GearShift Power-Velocity (**GSPV**) creates a map of gear upshifts as a function of vehicle speed & the power at the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

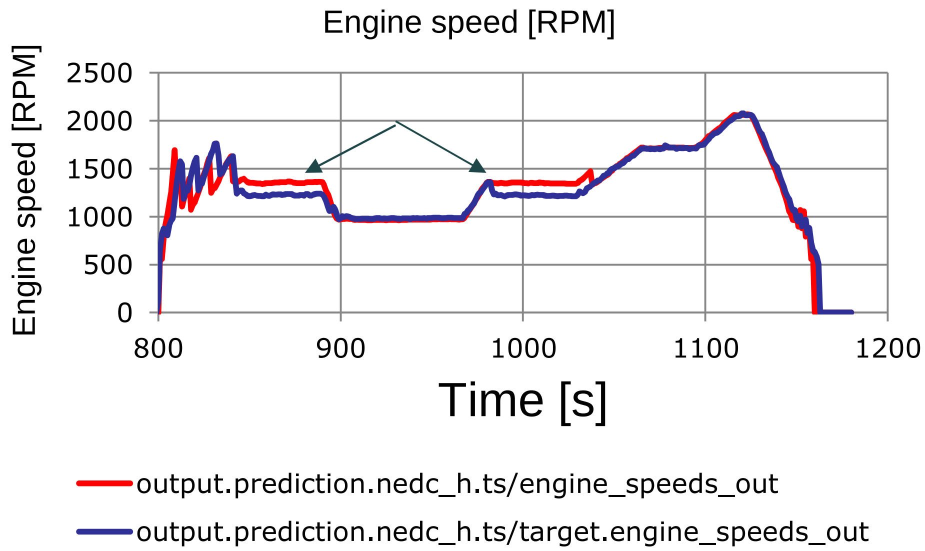


GSPV example

Automatic Transmission model (gear-shifting 2/2)

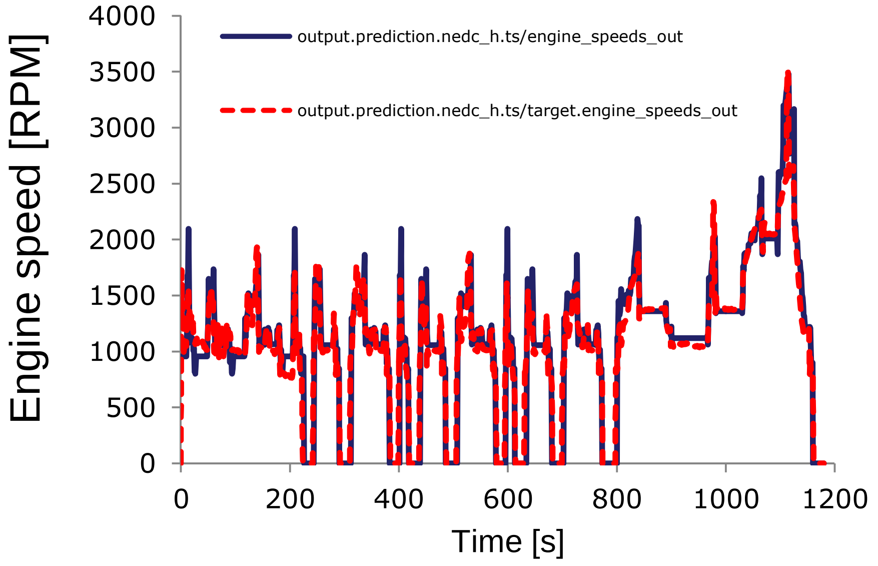
- Final step: Matrix Velocity Limits (**MVL**) correction model corrects gear-shifting over quasi-steady state conditions ()

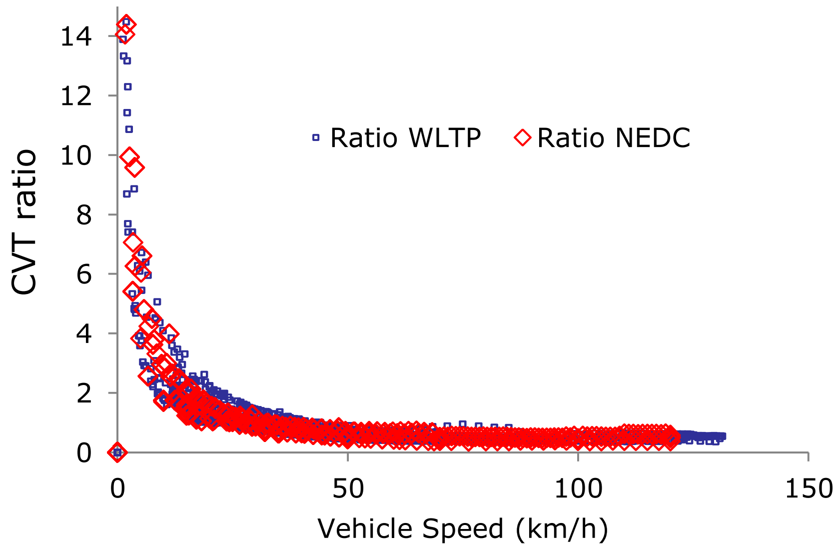




Automatic Transmission model (gear-shifting 2/2)

- 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





Gearbox Losses (1/2)

- A generic torque loss model is used in CO_2MPAS
  - T_{out} [Nm] = GB10 · RPM_{in} + GB01 · T_{in} + GB00
  - Where
    - GB00 = -0.0034 * T_{max} + $\begin{matrix} -0.3\ if\ warm\ conditions\ (80°C) \\ -0.7\ if\ cold\ conditions\ (40°C) \end{matrix}$
    - GB10 = -0.0034/2000 * T_{max} + $\begin{matrix} -0.1/2000 if\ warm\ conditions\ (80°C) \\ -0.25/2000\ if\ cold\ conditions\ (40°C) \end{matrix}$
    - GB01 = $\begin{matrix} 0.975\ if\ warm\ conditions\ (80°C) \\ 0.965\ if\ cold\ conditions\ (40°C) \end{matrix}$
  - All quantities refer to the input shaft (engine side) of the gearbox
- Linear interpolation between cold and hot T_{out} according to GB temperature calculated by CO_2MPAS

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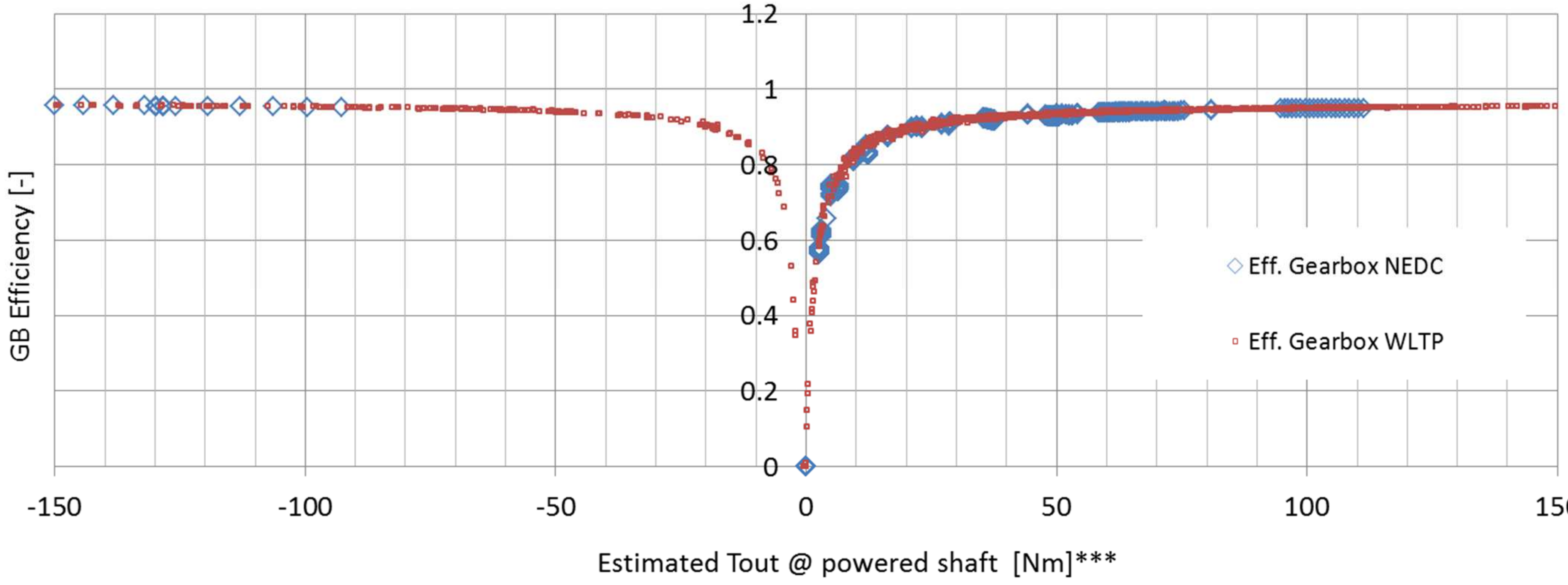
Gearbox Losses (2/2)



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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**

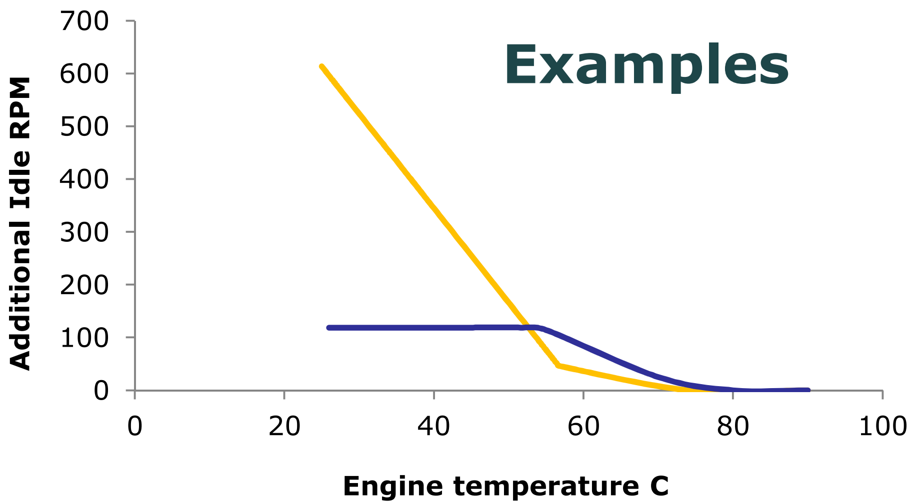
- For TCs a lock up velocity (48km/h) is used

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

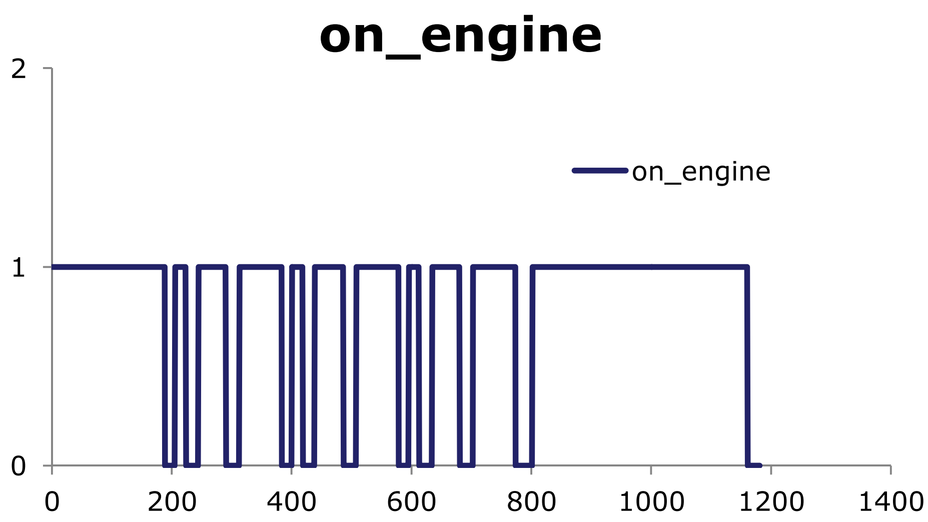


Engine speed model

- 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



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Alternator model

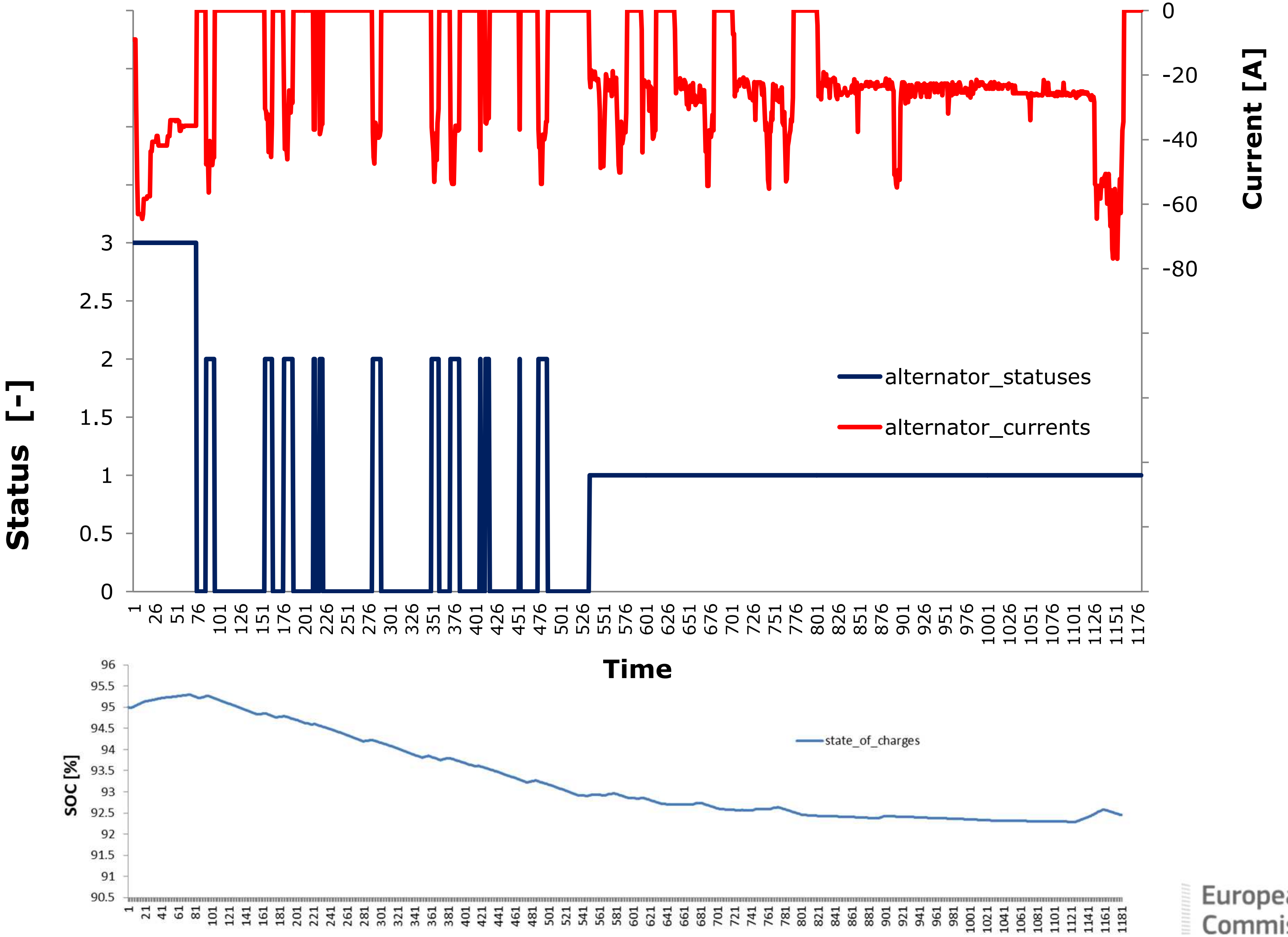
- Comprises of 2 parts:
  - **Logic part (when the alternator operates and how)**
  - **Electric part (what current is supplied by the alternator)**

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

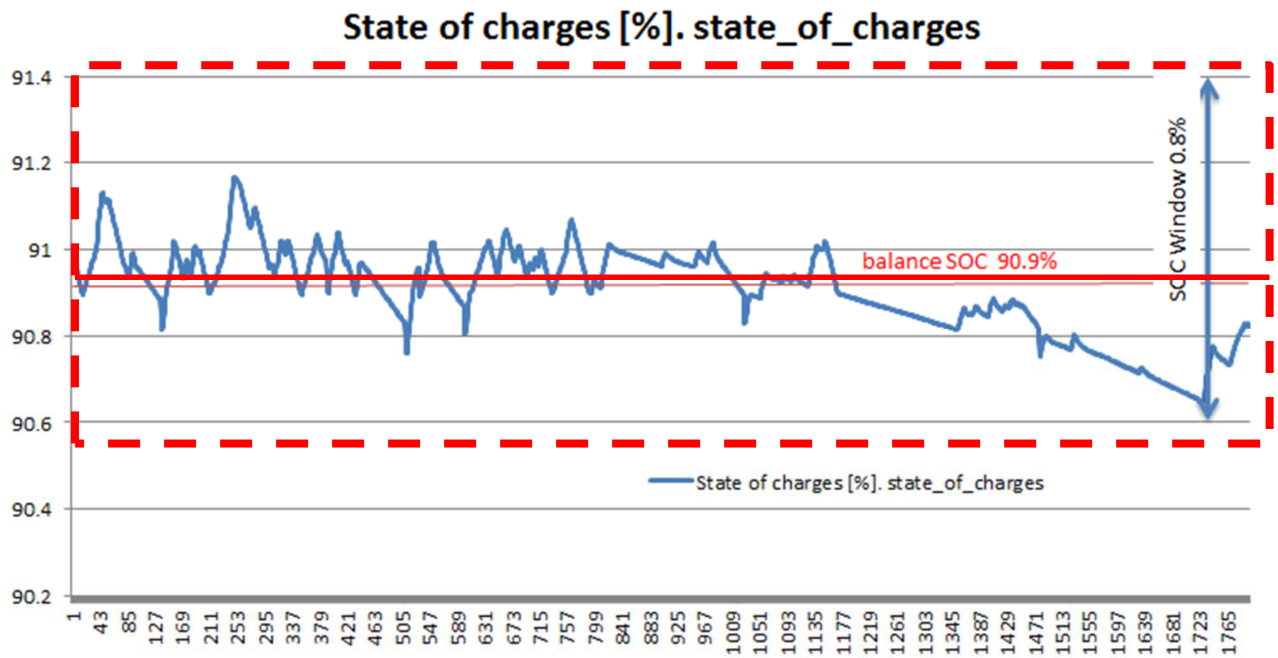
- **Electric part** identifies the current per each phase based on other parameters (eg RPM, Battery SOC, deceleration)

- 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



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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)

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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*):

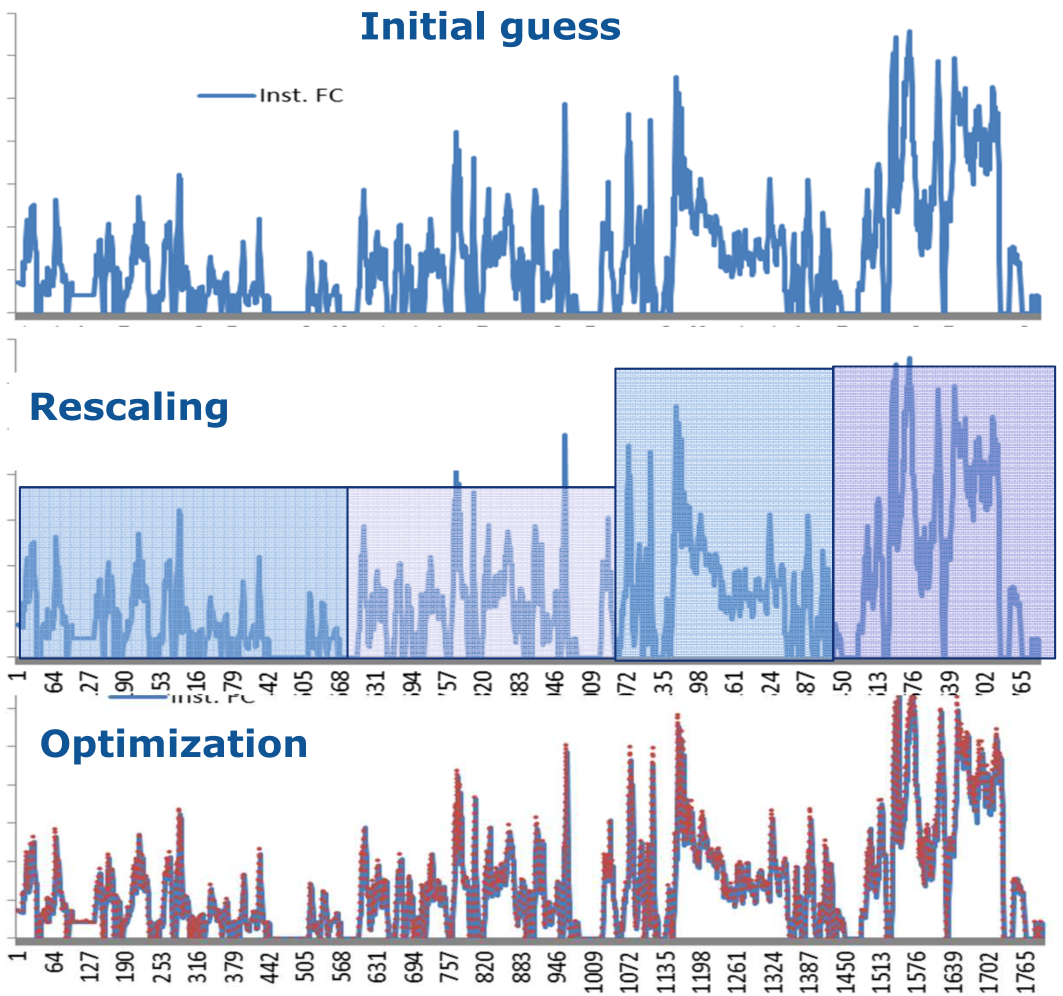
- Engine Speed, Temperature, Engine Power
- The constant parameters are calculated by optimization of the above equation against WLTP CO_2 measured data

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.

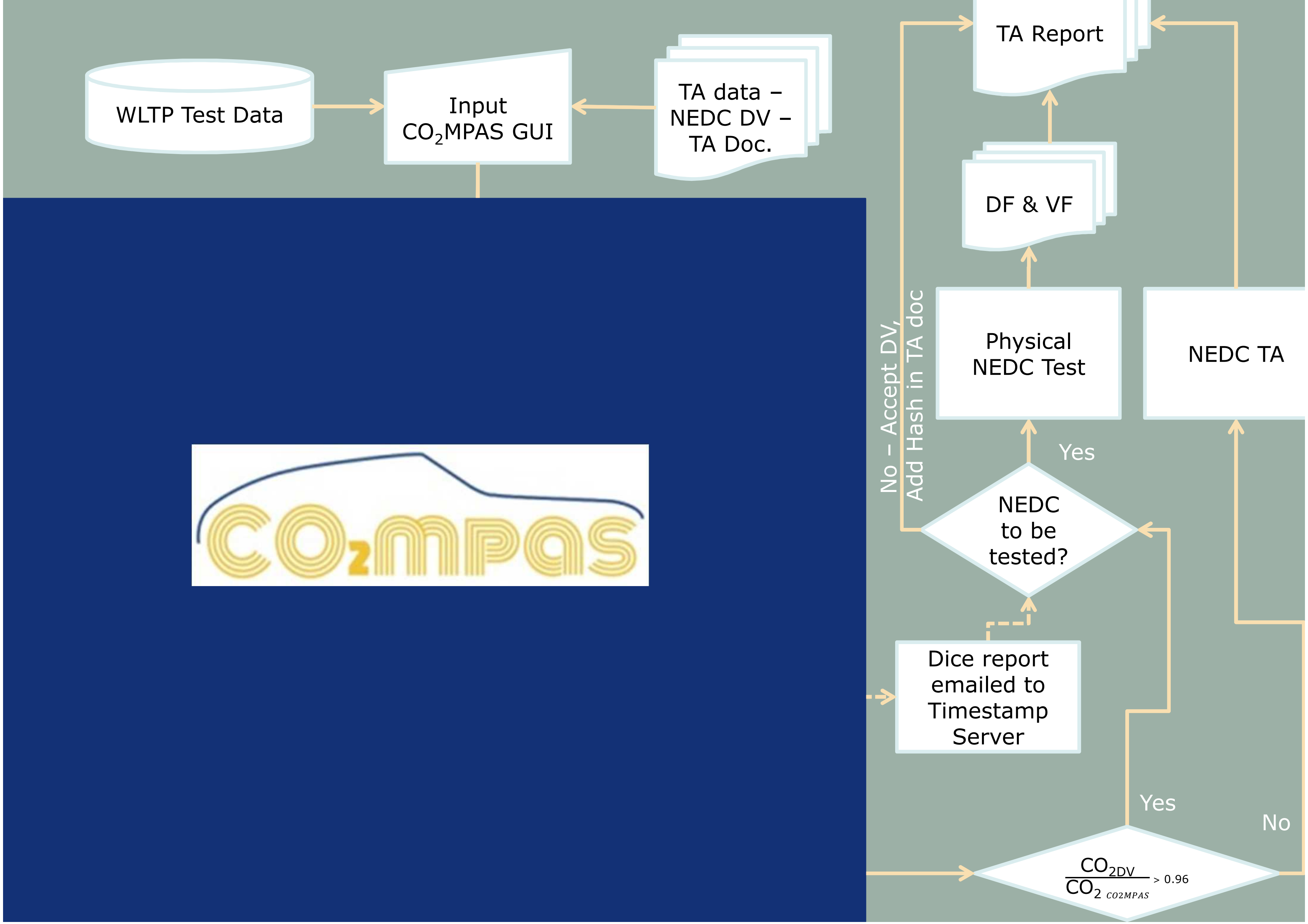
- Specific technologies are currently considered using the Extended Willans approach
  - For Petrol engines: Variable valve actuation, Lean combustion, Aspiration type, Cylinder deactivation (limited validation), External EGR (limited validation)
  - For Diesel engines: External EGR, Cylinder deactivation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

Optimization path

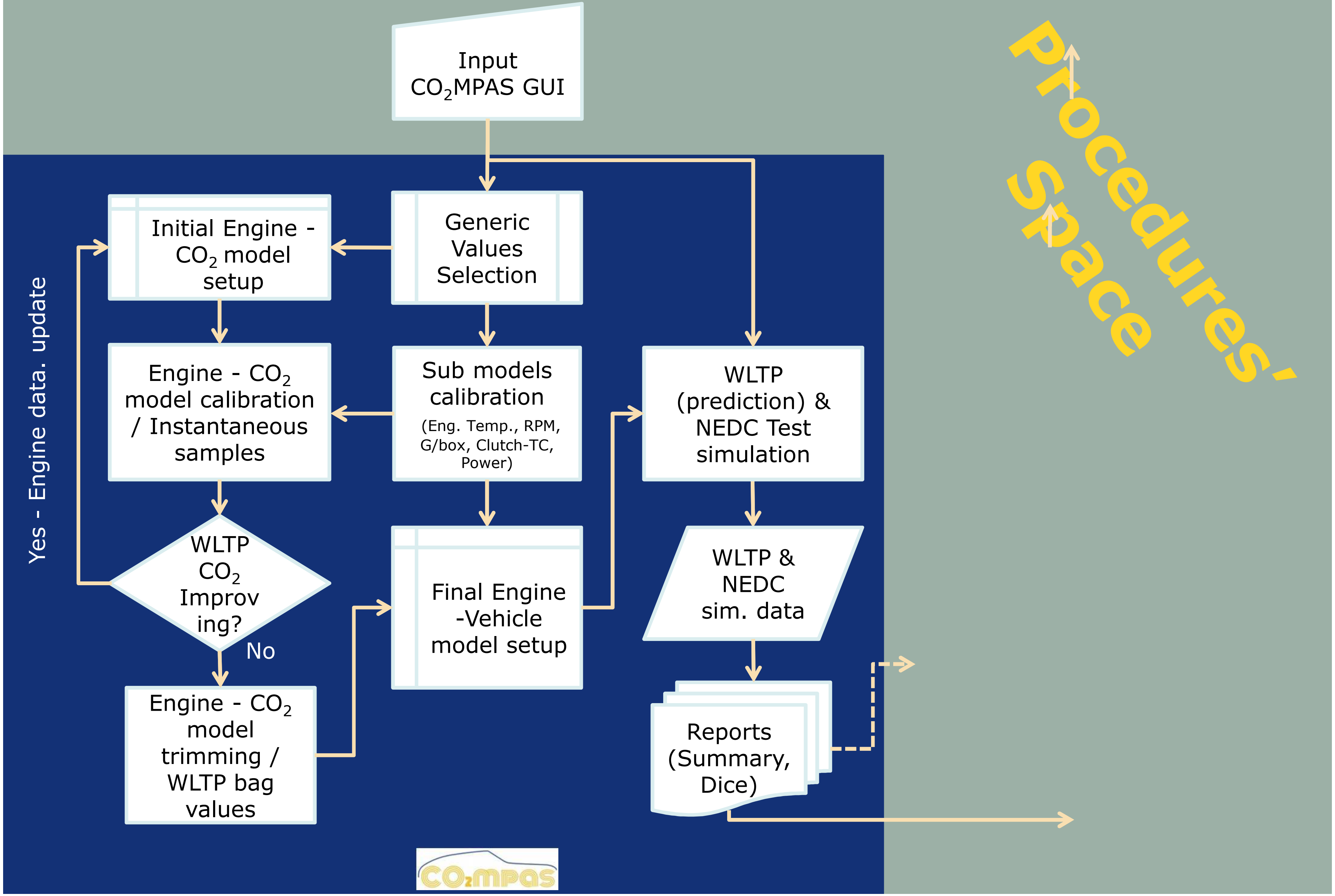


Summary

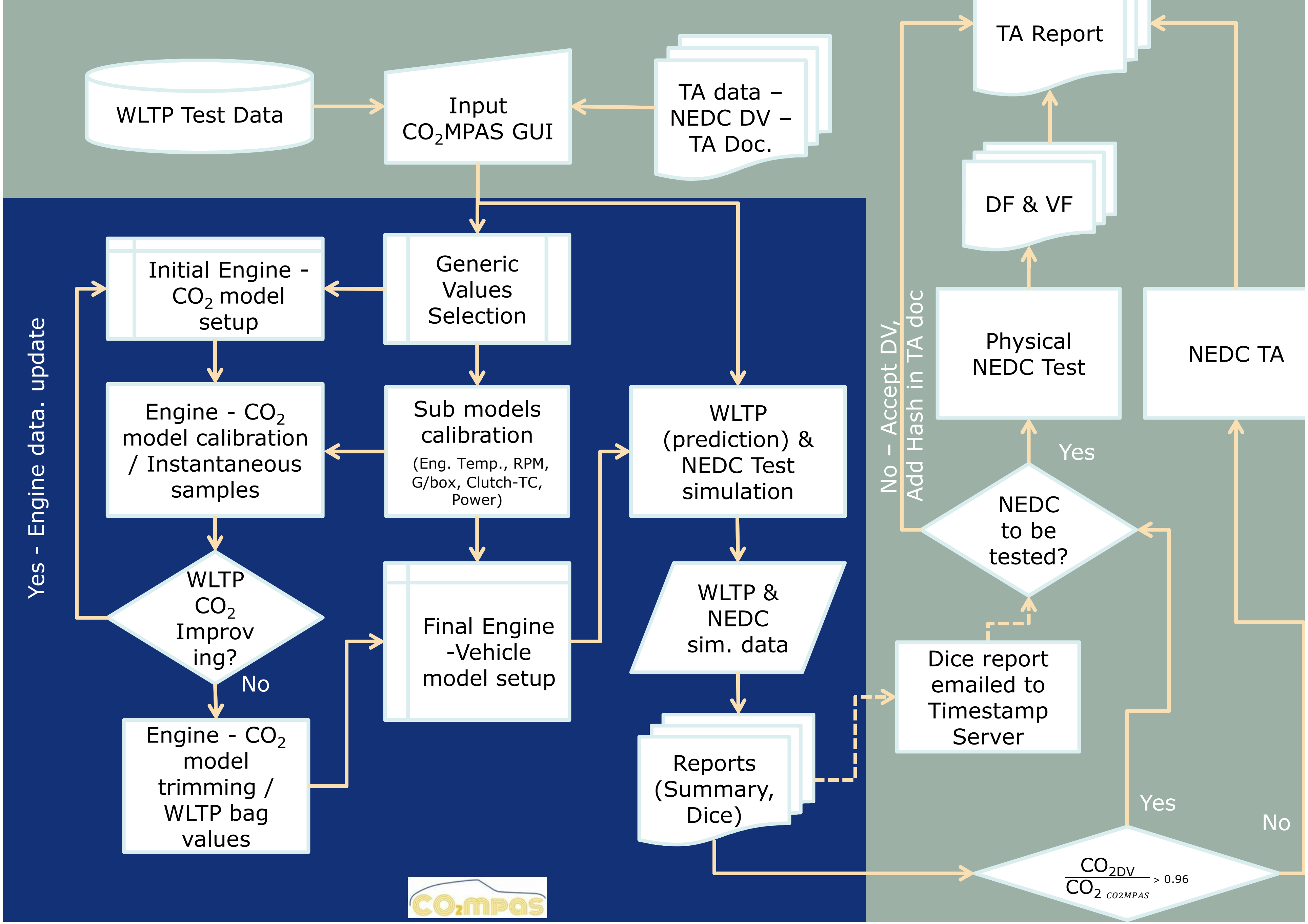
Correlation and CO_2MPAS Process flow chart



Correlation and CO_2MPAS Process flow chart



Correlation and CO_2MPAS Process flow chart



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