

# Parametric modeling of CVT-based hybrid drive trains

Theo Hofman,  
Control Systems Technology group

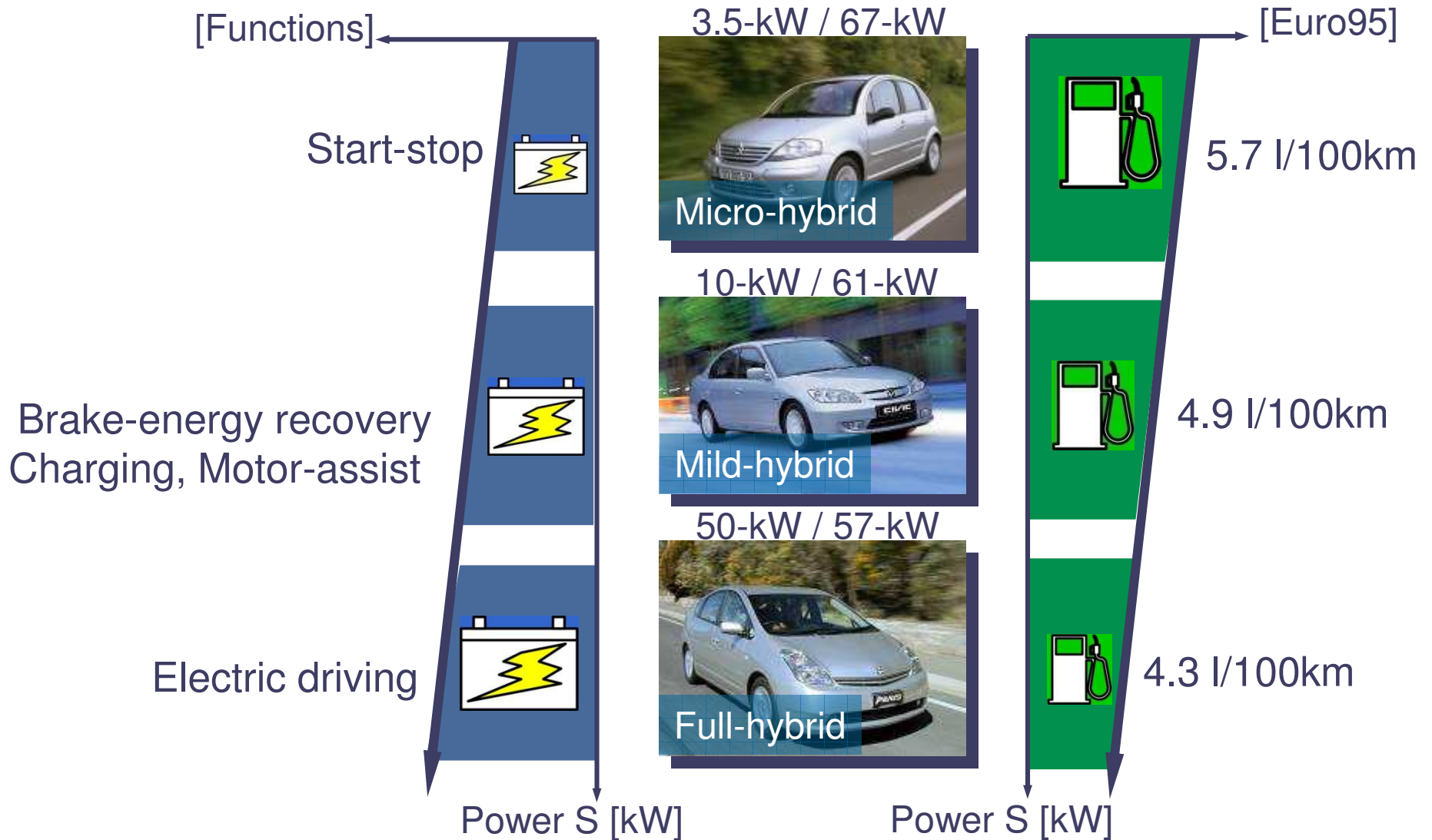


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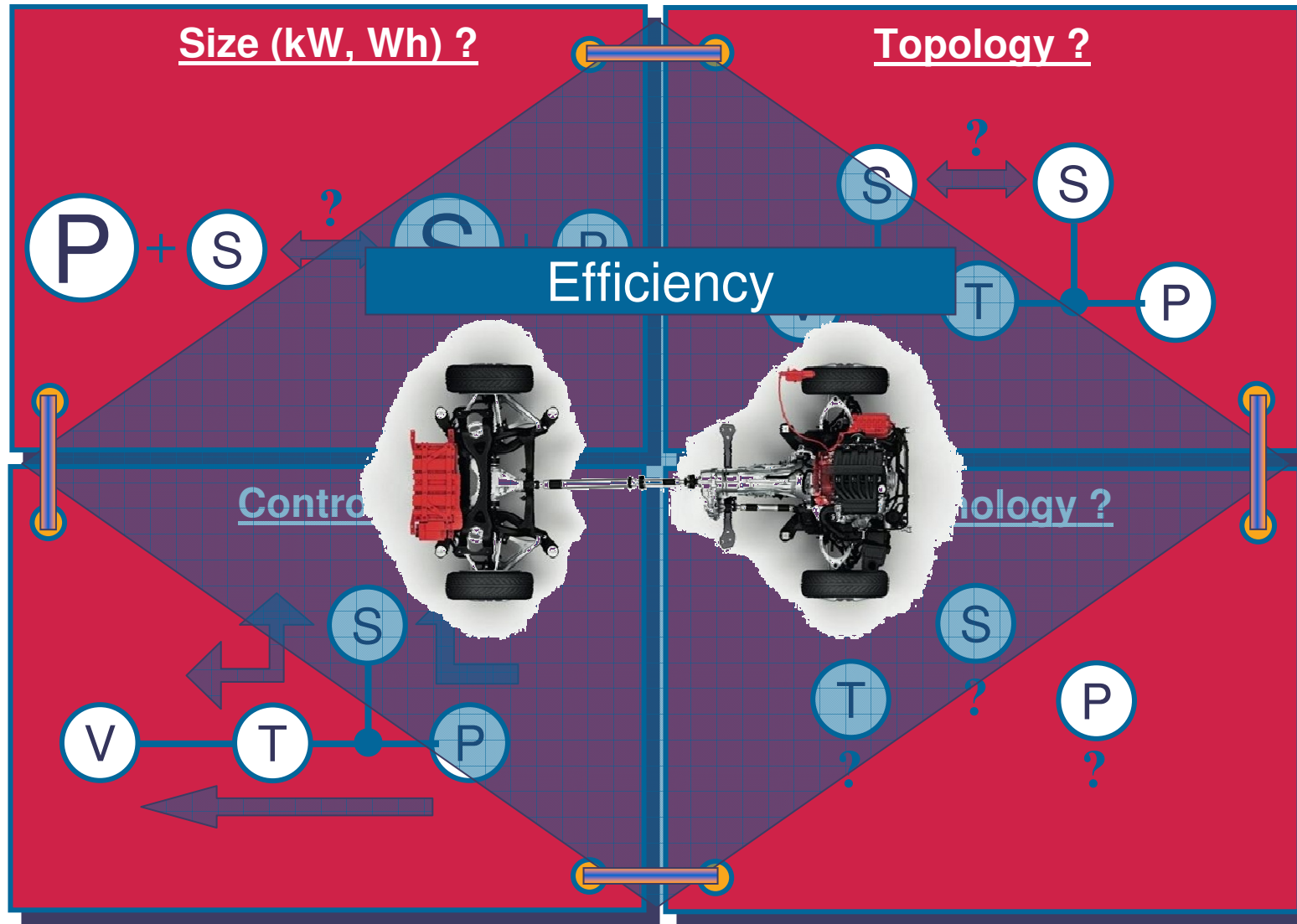
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Where innovation starts

# Hybrid Vehicles



# How to design a Hybrid Powertrain?



# Design issues

- Large design space:
  - battery technologies (Li-ion, LiPo, Ni-MH, Super Cap's, etc.),
  - transmission technologies (CVT, AMT, AT, MT, power-splits, etc.),
  - engine technologies (Diesel, Otto, HCCI, etc.),
  - electric machine technologies (DC brush, Asynchronous, etc.),
  - fuel cell technologies (SOFC, etc.),
  - topologies (RWD, FWD, AWD, etc.),
  - control strategies (ECMS, heuristic, etc.),
  - ....
- Multi-objective design problem, makes it difficult
- Interdependency of problem area's, makes it complex
- Large computation time to find solution

# Hybridization of CVT-equipped passenger car

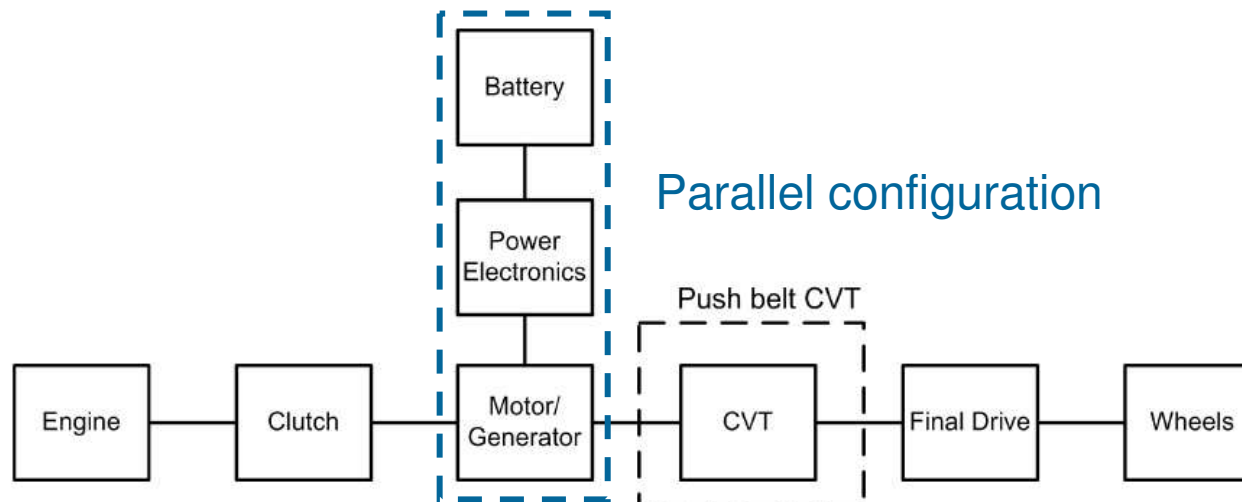


Toyota Yaris, 64 kW VVTi engine

Test	Fuel consumption on the JP10-15	
	l/100km	Relative values
Measured value (TC)	5.10	100.0%
Catalogue value (TC)	5.00	98.0%
Simulated value (TC)	5.00	98.0%
Simulated value (CL)	4.90	96.0%

TC = Torque Converter, CL = Wet-plate clutch

Fuel economy – Base line vehicle

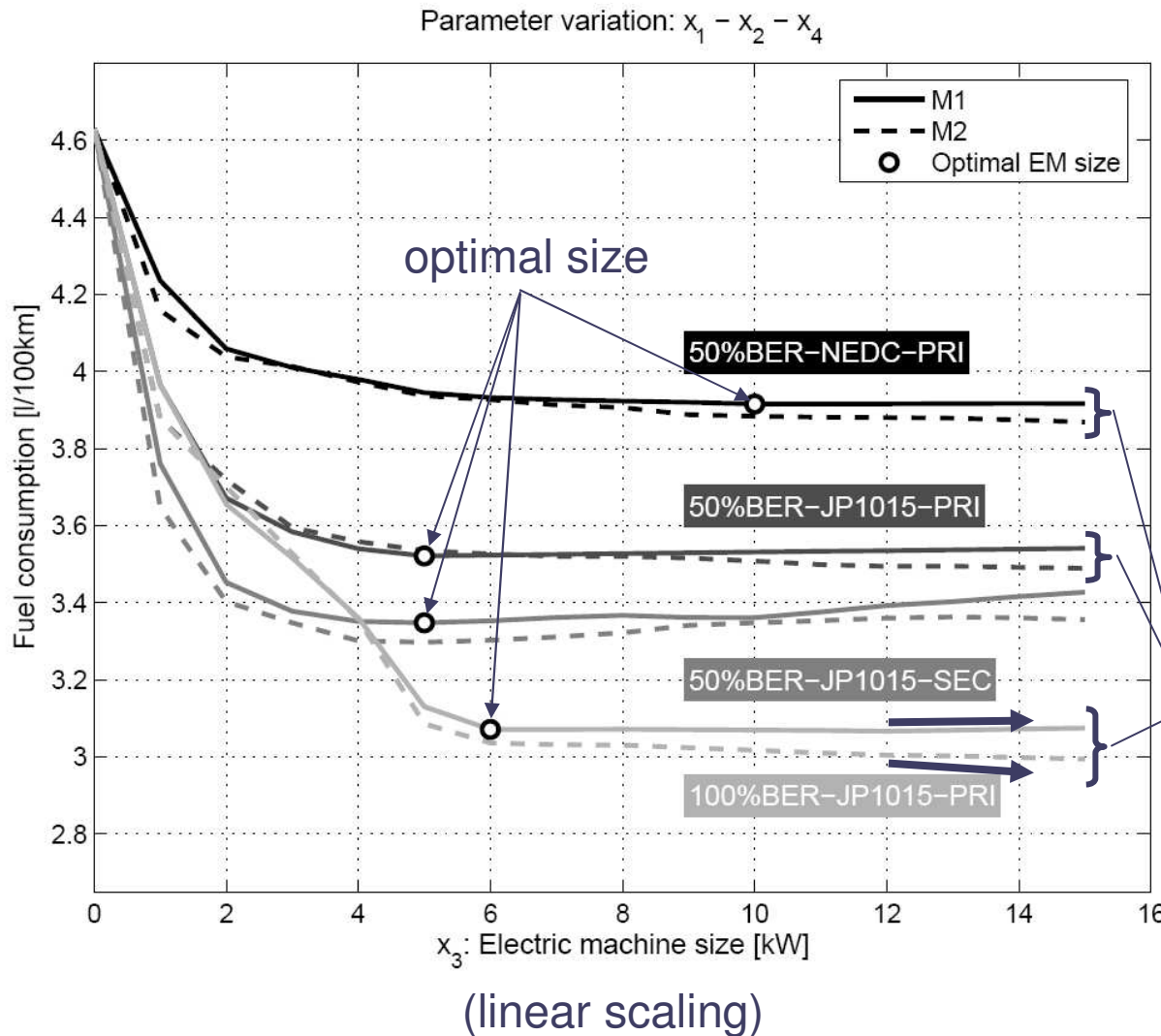


Hybrid drive train model

# Optimization Problem and Method

- Design Objective: Fuel economy
  - Design parameters: [Size, Regenerative brake fraction, Cycle, Topology]
  - Offline optimization; drive cycle known
- Control method: ECMS – Equivalent Consumption Minimization Strategy
- Comparison between two modeling approaches:
  - M1: component efficiencies are dependent on operation point and not determined by predefined operation preferences;
  - M2: component efficiencies using power-based fit functions are estimated in advance by using certain operation preferences:
    - electric-only and engine-only modes are used separately for S and T, P respectively, and
    - P, S (dependent on topology) operated at optimal operation points over whole drive cycle

# Results

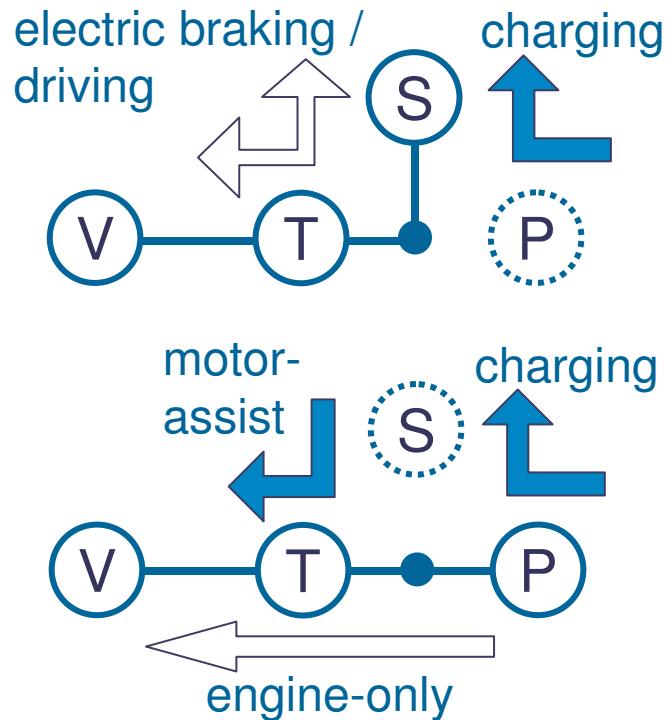


## Observations:

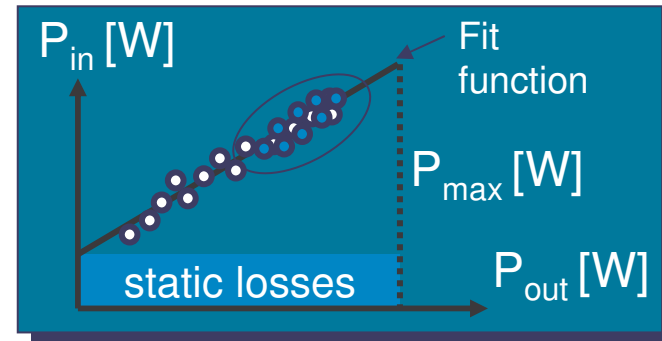
- Sensitivity order: size, brake fraction, cycle, topology
- Difference between M1 and M2:
  - is small (average 1.6%, maximum 3%)
  - increases with size S
- PRI: engine operated at OOL determines operation electric machine MA/CH modes -> efficiency decreases with increases with size S -> decrease fuel economy

# M2: estimation of component efficiencies

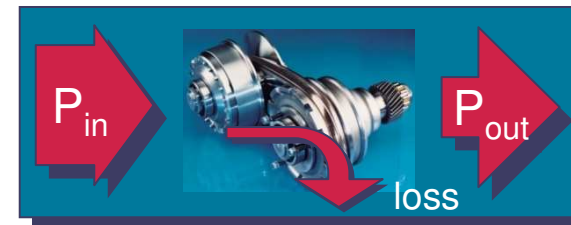
## M2



## P, S and T



Example:



Estimation of efficiencies can be done with sufficient accuracy. Since, effect motor-assisting, charging modes on S, P, T efficiency is small for NEDC/JP10-15.

# Conclusion

- The influence of power exchange between P and S during driving on the efficiency of T and S is small (2%-3%)

Example: Table 2: Transmission efficiency  $\eta_{CVT}$  (JP10-15)

CVT technology	Efficiency model parameters			
	Vehicle	$c_1$ [-]	$c_0$ [W]	$\bar{\eta}_{CVT}$ [%]
	Base	1.04	182	90.3
EMA-PRI	Hybrid <sup>†</sup>	1.04	161	92.6
5-kW EM size	Hybrid	0.85	2040	79.4

<sup>†</sup>  $\eta_{CVT}$  corrected with battery power.

- Influence of power exchange (motor-assist, charging) between P and S on the efficiency of S increases with increase of size S
- Employing the simplified component modeling approach, design parameter variation can be investigated very quickly and with sufficient accuracy (average error 1.6%)