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Proposal for VECTO’s new Transmission Control Unit

SCANIA

Basic ideas for VECTO's new TCU. Overview

- The proposed TCU performs a continuous optimisation of the gear selection with respect to a low energy consumption.
- During every timestep the engine operation point (OP, speed, torque) is predicted and rated for every gear:

Low level. If the predicted OP is below the max. engine torque, and in the range of permitted speed: Gears are rated with respect to energy consumption

Medium level. If the predicted OP is above the max. engine torque, and in the range of permitted speed: Gears are rated with repect to the missing cardan torque

High level. If the predicted OP is outside the range of permitted speed: Gears are rated with respect to the distance to the permitted engine speed

➔ If a gear gets a better (= lower) rating than the present one: Shift to the more beneficial gear

Basic ideas for VECTO's new TCU. Preprocessing.

- Input of complete vehicle data as for VECTO

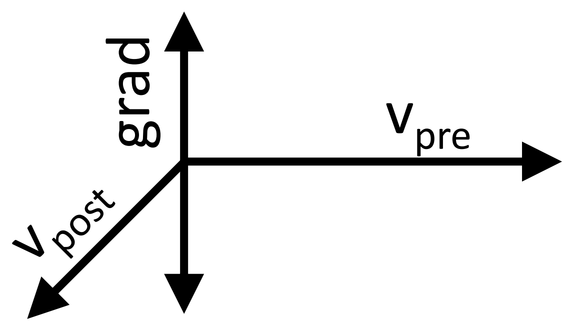
- Calculate in preprocessing before main simulation starts:

  Vehicle velocity after gearshift (after free rolling for 1 to 2 s).

  Matrix: x) Velocity pre-shift (v_{pre}, 10 to 160 km/h)

  y) Road gradient (grad, -24 to +24 %). Assumed to stay constant.

  z) Velocity post-shift (v_{post}, below or above v_{pre})



Basic ideas for VECTO's new TCU. Each timestep.

- Interpolate the vehicle velocity after a hypothetical gearshift (v_{post})

- Determine the predicted velocity somewhere in the 2nd half of the gearshift interval (higher velocity drop → closer to end of interval)
  - To compensate for the change of velocity during the gearshift.

- Calculate the predicted rotational speed at the cardan shaft (ω_{card})

- Determine <u>two</u> different values for the vehicle acceleration

  The driver demand (a_{driver}), e. g. +0.4 m/s², <u>from driver model</u>

  The acceleration reserve (a_{reserv}), e. g. +0.2 m/s², from TCU data

Note 1, note 2, note 3; see annex

Basic ideas for VECTO's new TCU. Each timestep.

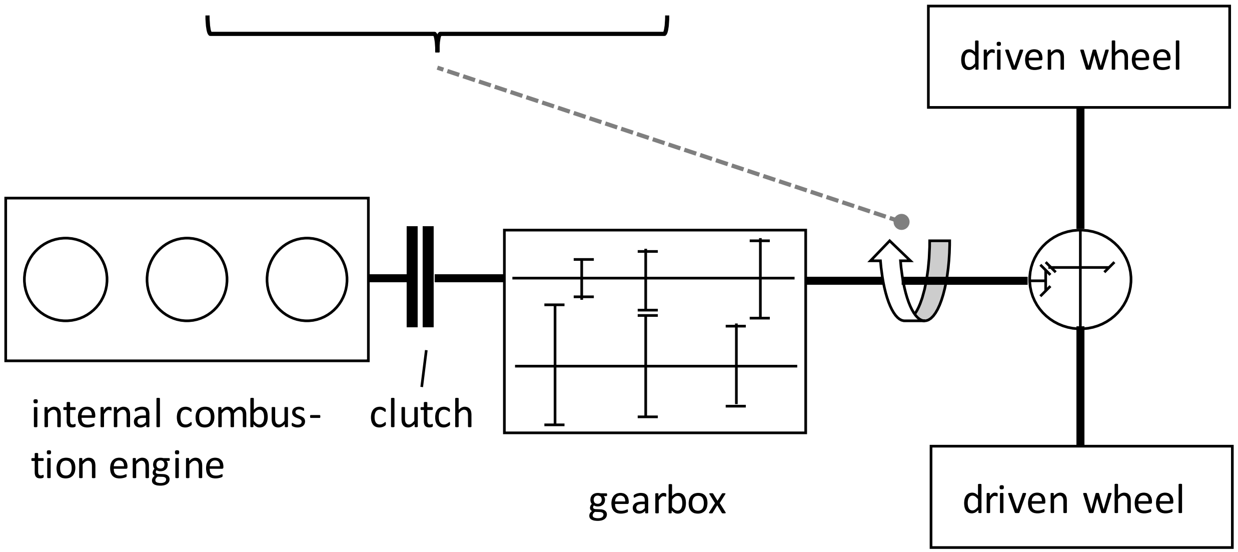
- Calculate backward two different torques at the cardan shaft

  To overcome:

  (air drag) + (rolling resistance) + (road gradient) +...

  [(inertia force from a_{driver}) OR (inertia force from a_{reserv})]

  => $Tq_{card,driver}$ and $Tq_{card,reserv}$



Basic ideas for VECTO's new TCU. Each timestep.

- Calculate backward for every gear the engine operation point for both cardan torques.

$$\omega_{eng,gear} = \omega_{card} \quad * \quad ratio_{gear}$$

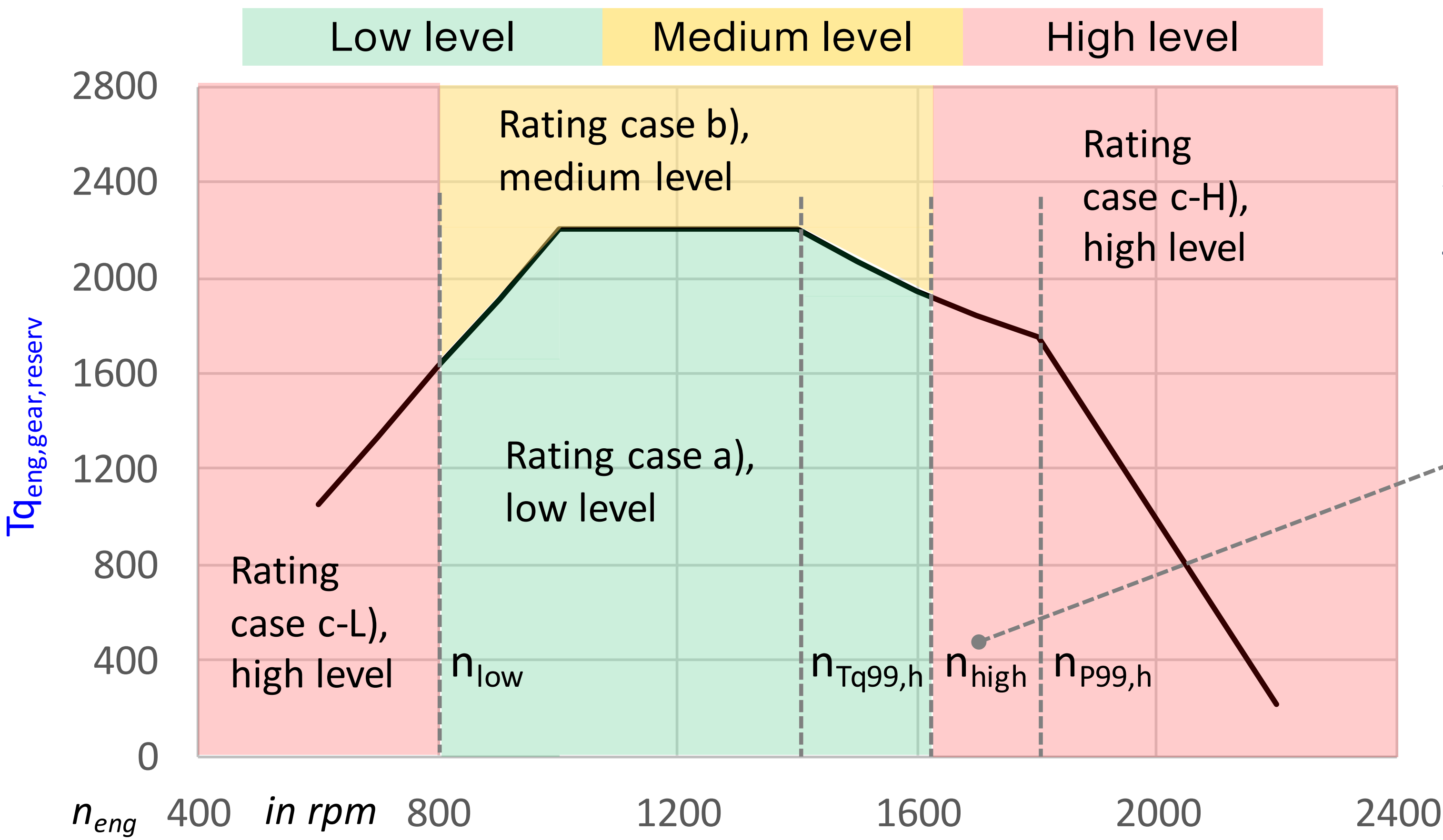
$$Tq_{eng,gear,driver/reserv} = \ldots$$

$$Tq_{card,driver/reserv} \,/\, ratio_{gear} \quad + \quad Tq_{loss,gear,driver/reserv} + \ldots$$

$$P_{aux} \,/\, \omega_{eng,gear} + \quad J_{eng} * \dot{\omega}_{eng,gear,driver/reserv}$$

Basic ideas for VECTO's new TCU. Each timestep.

- Allocate the engine operation point, calculated from $\omega_{eng,gear}$ and $Tq_{eng,gear,reserv}$, into one of three cases for the later rating



$n_{Tq99,h}$ or $n_{P99,h}$: Highest speed, where 99 % of max. torque or power are reached

Variable, to avoid over-revving during acceleration, but to enable high speed at uphill.

Basic ideas for VECTO's new TCU. Each timestep.

- The allocation into the cases for the later rating is done with the engine torque from the acceleration reserve.

  → $Tq_{eng,gear,reserv}$ during acceleration phases usually below $Tq_{eng,gear,driver}$

  → Enable early upshifts into higher gears.

- n_{high} varies between $n_{Tq99,h}$ and $n_{P99,h}$:

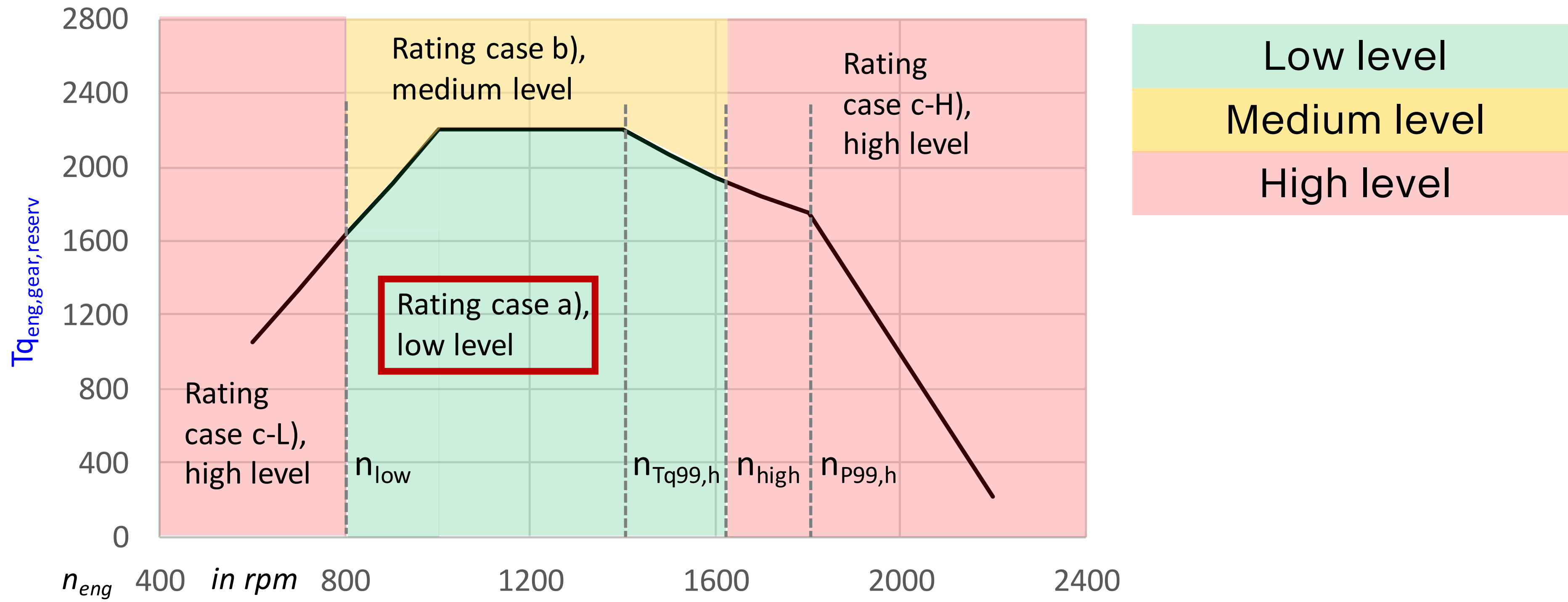
  If the share of the inertia force at the overall wheel force (F_{inert} / F_{wheel}, <u>from vehicle model</u>) is high in the current timestep, AND the vehicle velocity is low, decrease n_{high} to $n_{Tq99,h}$.

  → Enable early upshifts during fast accelerations.

  If the share is low, OR the velocity is high, increase n_{high} to $n_{P99,h}$.

  → Enable late upshifts during slow accelerations uphill.

Basic ideas for VECTO's new TCU. Each timestep.

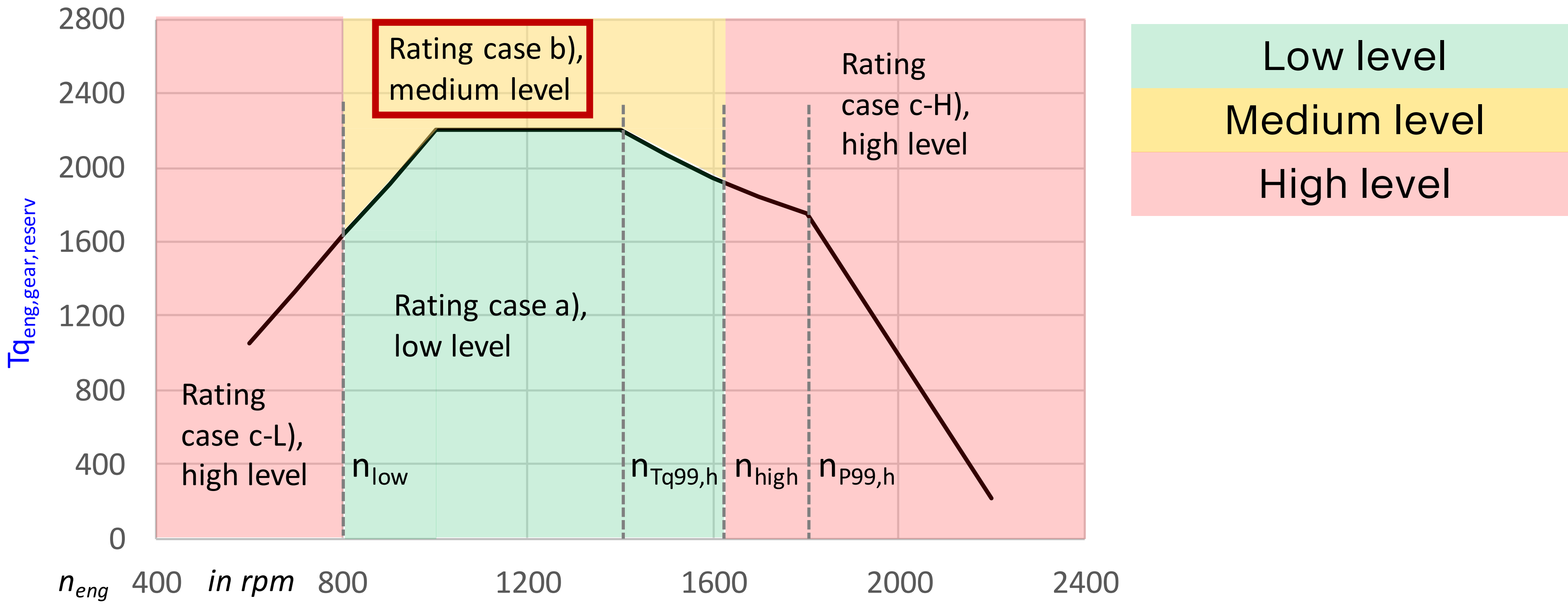


- **Case a)**: Choose engine operation point from driver demand ($Tq_{eng,gear,driver}$)
- Calculate rating via specific fuel consumption referred to cardan shaft.

➔ Rating_a = $FC_{gear}(\omega_{eng,gear}, Tq_{eng,gear,driver}) / (Tq_{card,driver} * \omega_{card})$

Note 4; see annex

Basic ideas for VECTO's new TCU. Each timestep.

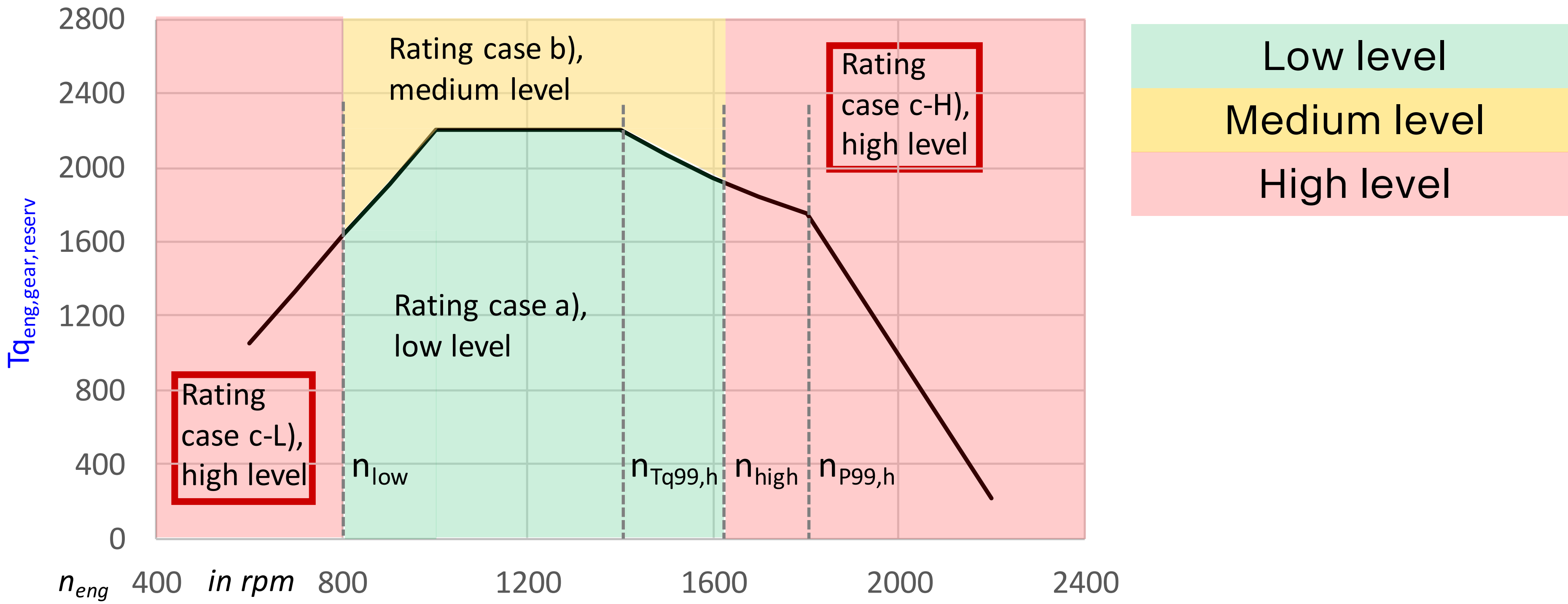


- **Case b)**: Calculate rating via distance to demanded torque at cardan shaft.

$$Tq_{card,gear,max} = [\, Tq_{eng,gear,max}(\omega_{eng,gear}) - J_{eng} * \dot{\omega}_{eng,gear,reserv} - \ldots$$
$$P_{aux} / \omega_{eng,gear} - Tq_{loss,gear} \,] * ratio_{gear}$$

➔ Rating_b = $(Tq_{card,reserv} - Tq_{card,gear,max}) + penalty_{medium}$

Basic ideas for VECTO's new TCU. Each timestep.



- **Case c-L) / c-H)**: Calculate rating via <u>distance to range of permitted speed</u>

➔ Rating_c-L = ($n_{low} - n_{eng,gear}$) + $penalty_{high}$

➔ Rating_c-H = ($n_{eng,gear} - n_{high}$) + $penalty_{high}$

Basic ideas for VECTO’s new TCU. Each timestep.

- Every gear gets in every timestep its rating factor: A small number (case a), a medium number (case b), or a big number (case c-L or c-H).
  - Low level: Energy consumption
  - Medium level: Missing cardan torque
  - High level: Distance of engine speed to permitted speed
- Application of multiple rules against oscillating gearshifts, and for exceptional gearshifts, e. g. if speed threshold crossed.
- If a gear other than the current gear gets a lower rating factor, and shifting is permitted (or necessary):

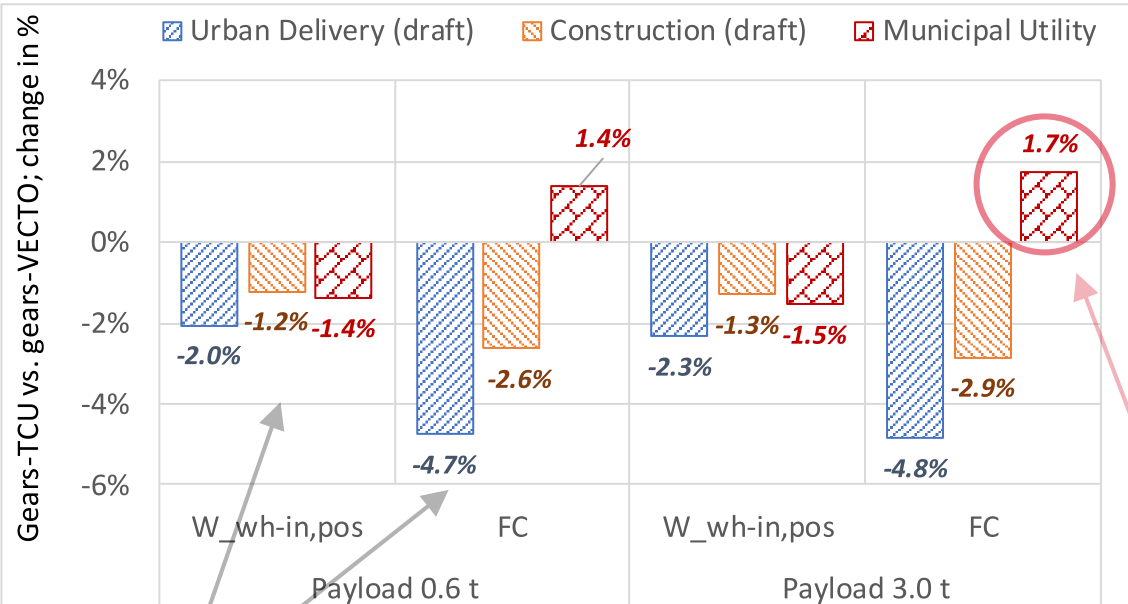
➔ Shift to the gear with the lowest rating factor.

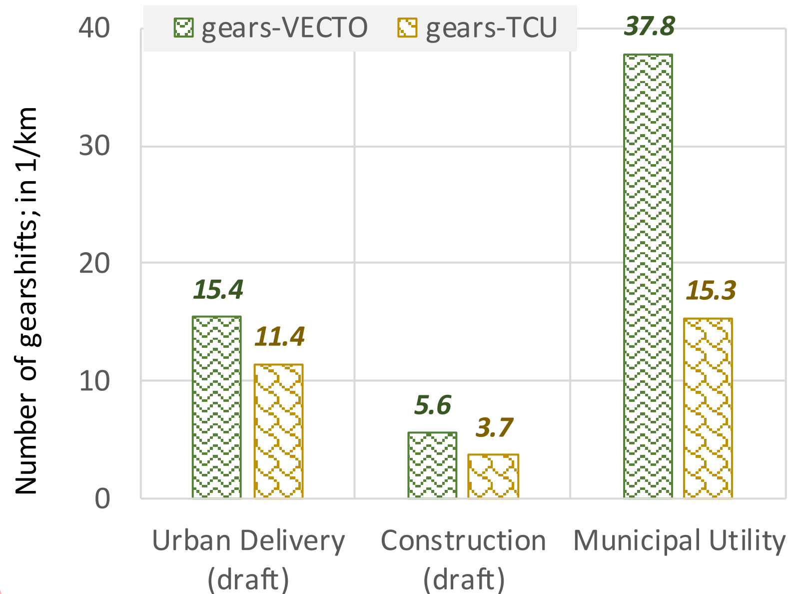
Basic ideas for VECTO's new TCU. Each timestep.

- Case negative predicted cardan torque: Simple speed-dependent rules.
- Separate mode for selection of start-gear after stops.
  - Rating like before, but for fix velocity & acceleration (≥ 10 km/h , 0.5 m/s^2)
  - Choose gear with lowest rating factor → 1) FC; 2) cardan torque; 3) engine speed

Basic ideas for VECTO's new TCU. 1st results. Comparison with old gearshift, target velocity

- Model of rigid truck 4x2, gr. 4, payload 0.6 and 3.0 t.





(Reduction of FC) higher than (reduction of tractive work input at driven wheels from differences in driving cycles).

⇒ Effect of gearshift.

Ca. 9 drive-off/km => Clutch losses significant

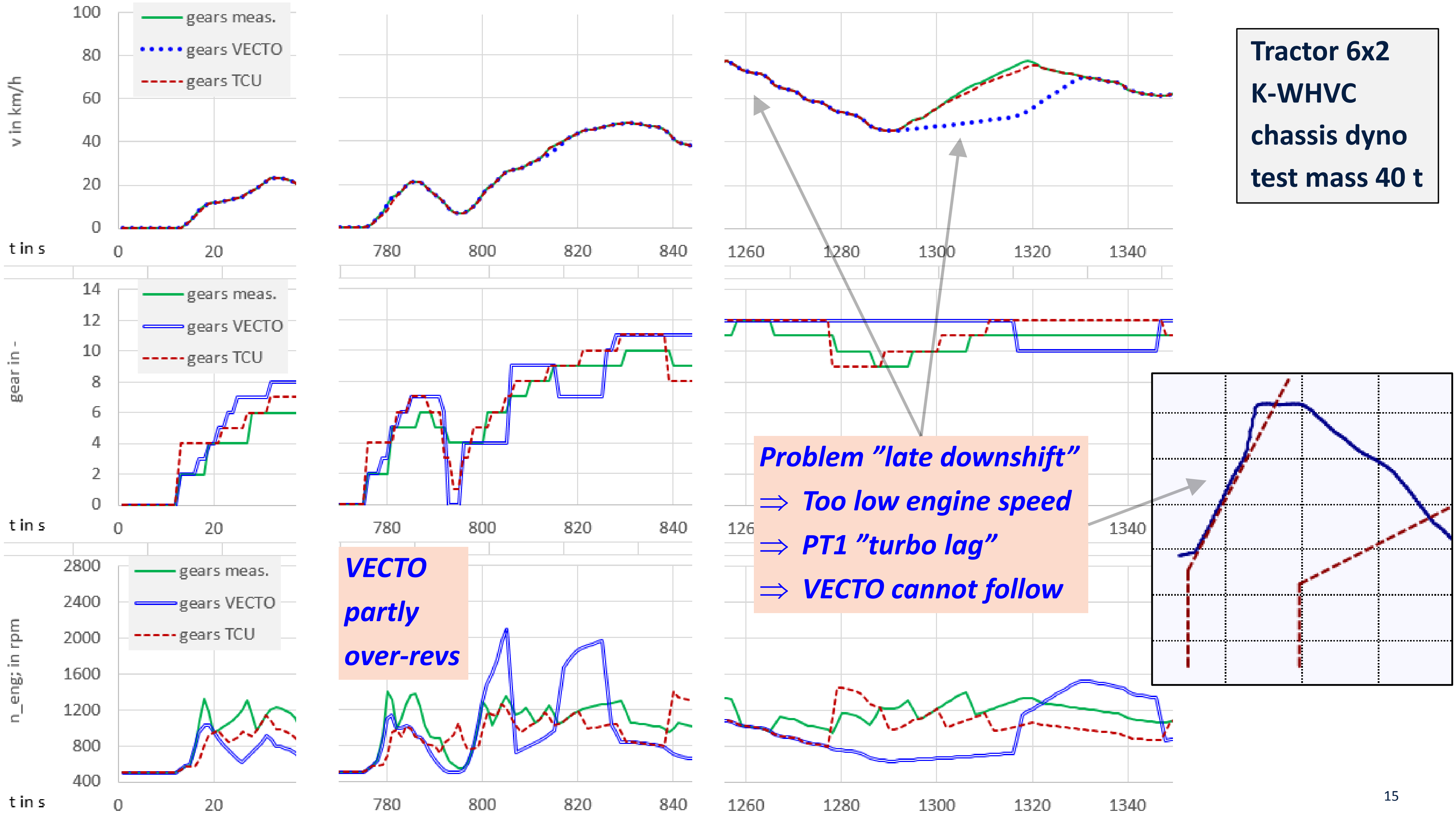
TCU starts in 3rd gear, VECTO in 1st gear (what is not realistic).

=> Longer sliding & 4x higher clutch losses with TCU-gears

BUT: Clutch models Simulink & VECTO not aligned!

Source: https://webgate.ec.europa.eu/CITnet/jira/browse/VECTO-578 , 2018-05-16_Check-proposed-TCU-VECTO.zip\Scania_2018-05-16_Check-proposed-TCU-VECTO.pdf, p. 6

Basic ideas for VECTO's new TCU. 1st results. Comparison with old gearshift, measured velocity



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Annex: Note 1

- In the Simulink model the operation points calculated from the driver acceleration (a_{driver}) are labelled *__FC_rat, because they are only used for the fuel consumption rating.
- In the Simulink model the operation points calculated from the accele-ration reserve (a_{reserv}) are labelled *__Tq_rat, because they are used for the torque rating of the gears.

Annex: Note 2

- The driver demand (a_{driver}) is usually an output from the driver model.
- In VECTO is no driver model implemented yet, but a_{driver} can be determined e. g.
  - 1) from the simulated acceleration in the current timestep
  - 2) from the required acceleration to reach the demanded velocity in the next timestep.

Annex: Note 3

- In case of the VECTO target velocity cycles the acceleration reserve (a_{reserv}) is dependent on the distance between the current and the target velocity.
- If the distance is big, i. e. the HDV model is below the target velocity, e. g. 10 km/h below, the acceleration reserve is positive, e. g. +0.2 m/s².
- If the distance is zero, i. e. the HDV model is at the target velocity, the acceleration reserve is slightly negative, e. g. -0.1 m/s².
- In between the acceleration reserve is interpolated linearly.
- With the slightly negative acceleration reserve <u>at</u> target velocity aggressive downshifting is avoided at small positive road gradients. So the simulated velocity can drop for a few km/h without an immediate downshift.

Annex: Note 4

- In case a) the *allocation into this case* is done with the calculated engine torque from the acceleration reserve ($Tq_{eng,gear,reserv}$).
- But the *rating factor* is calculated with the FC interpolated for the engine torque from the driver demand ($Tq_{eng,gear,driver}$).
  => This torque would be *really* demanded after a hypothetical gearshift.
- $Tq_{eng,gear,driver}$ can get above the possible max. engine torque at the predicted speed ($\omega_{eng,gear}$).
- In that case the engine torque is limited to the max. possible engine torque, and subsequently the resulting max. possible cardan torque is calculated. Calculation like for case b).
- In that case the specific FC referred to the cardan shaft is calculated with the FC at the max. possible engine torque, and the resulting cardan power from the max. possible cardan torque.