Assessment methods of High Capacity Transports

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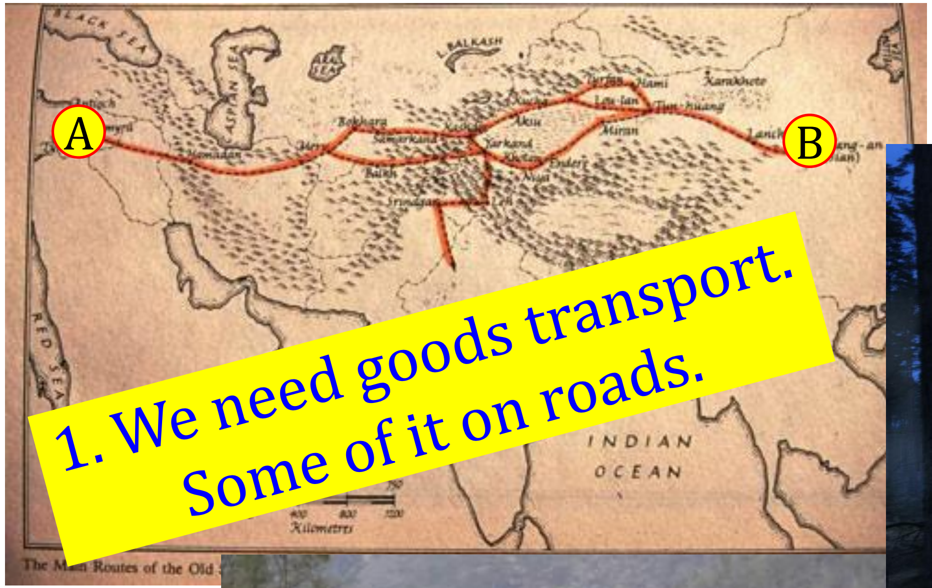
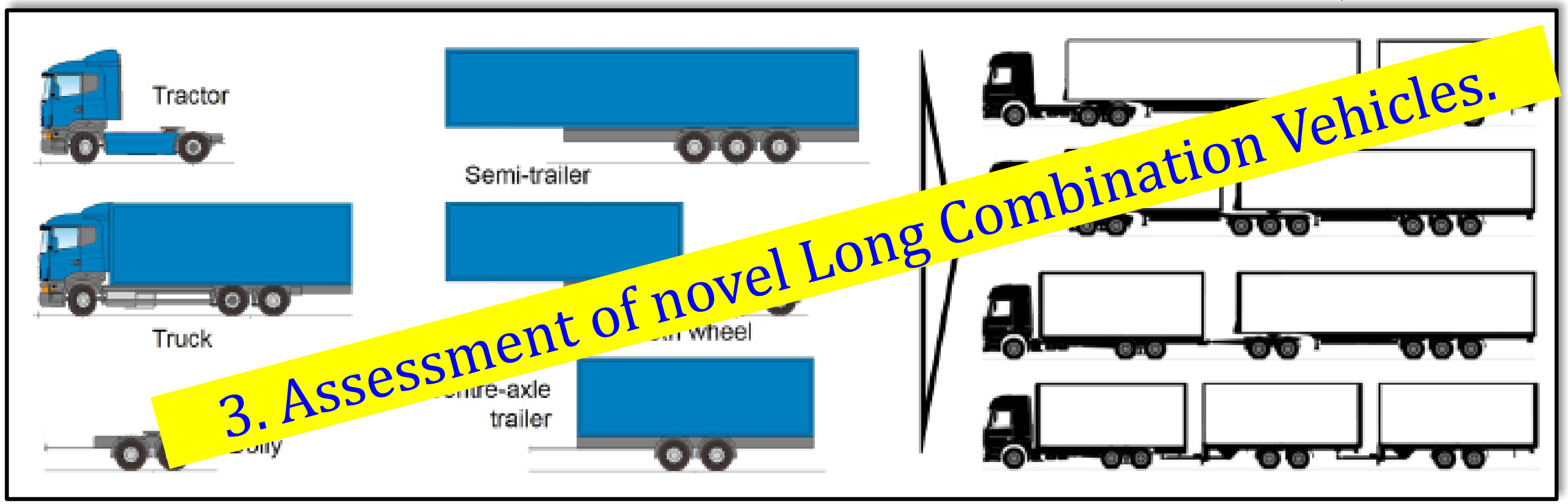
Why & How High Capacity Transports



1. We need goods transport. Some of it on roads.

2. HCTs is a "low-hanging fruit" for CO_2 savings.

from Karel Kural, PhD thesis:

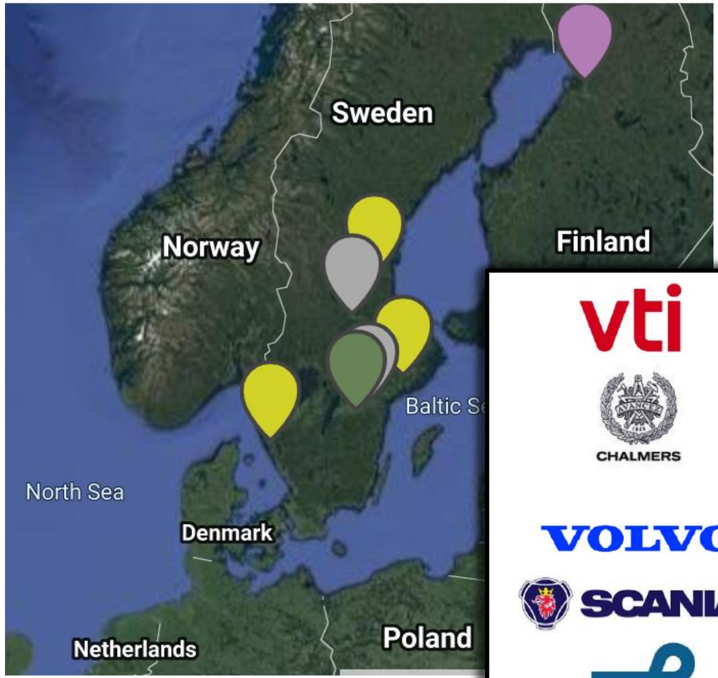


3. Assessment of novel Long Combination Vehicles.

My present involvement in Assessment of HCT

https://research.chalmers.se/en/project/8350

project: **Performance Based Standards 2, PBS2**, 2018-2020



- **Chalmers University of Technology**, Gothenburg, Sweden
- **Nokian Tyres**, Finland
- **Parator Industri,** Bollnäs, Sweden
- **Scania,** Södertälje, Sweden
- **Swedish Transport Administration,** Borlänge, Sweden
- **Swedish Transport Agency,** Norrköping, Sweden
- **Swedish National Road and Transport Research Institute (VTI),** Linköping, Sweden
- **University of Oulu,** Oulu, Finland
- **Volvo Group,** Gothenburg, Sweden

WP1 –Tire Modelling..

WP2 –Heavy vehicle experiments..

WP3 – Road network categorization..

WP4 – Simulations..

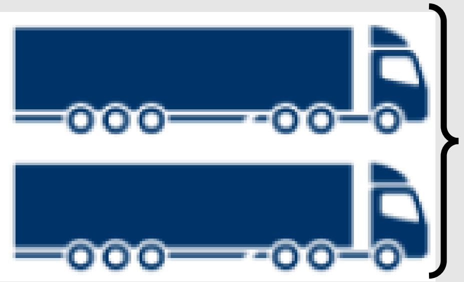
WP5 – PBS Assessment..

WP6 – International cooperation and knowledge spreading....

WP7 – Project management..

How can HCT save CO_2?

$$m \cdot \dot{v} = F_{prop} + F_{brk} - m \cdot g \cdot RRC + m \cdot g \cdot \varphi_{grade} - \frac{\rho \cdot A \cdot c_d}{2} \cdot v^2; \quad where\ m = m_{kerb} + m_{load};$$



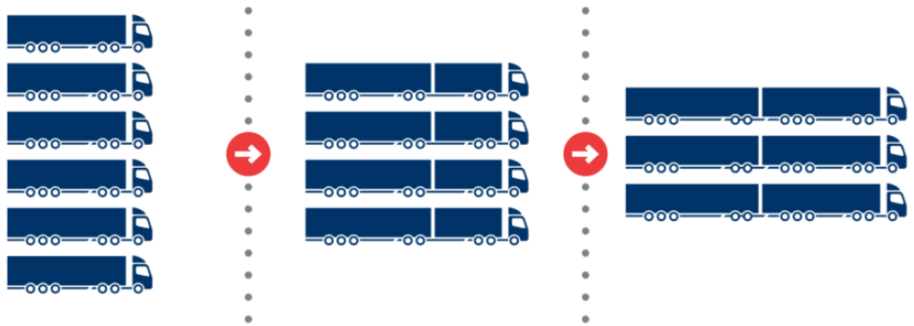
fewer kerb weights → less grade and rolling resistance

fewer front areas → less air resistance

typically 20% less CO2 per $ton \cdot km$

...and even more reduction of CO2 per $\mathrm{m}^3 \cdot km$:

TRANSPORTATION OF 600 M3 OF VOLUME LIMITED GOODS WITH THE SAME DENSITY (150KG/M³)



Vehicles (and drivers)	6	4	3
Vehicle length	16.5 m	25.25 m	32 m
Load per vehicle	100 m³	150 m³	200 m³
Fuel consumption	3.5 ml/m³km	3 ml/m³km	2.5 ml/m³km
CO2 emissions	100%	85% = -15%	73% = -27%
Road use	499 m	368 m	296 m

Source: Cider L, Larsson L, HCT DUO2-project Gothenburg-Malmö in Sweden, 2019

Special HCT assessment? What “(Traffic) Risks” do we see?

Today: Each vehicle **unit separately** approved. Automatically OK to couple some, e.g. one Tractor + one SemiTrailer.

So, what can be “risks” when combining more of approved units?

Traffic Flow

- *Stuck in uphill* ⇒ Startability
- *Slow in uphill* ⇒ Gradeability
- *Slow on entry/exit roads* ⇒ Acceleration Capability)
- *...*⇒ Low Speed Swept Path
- ...⇒ Frontal Swing
- ...⇒ Tail Swing
- ...⇒ Friction demand on Drive Tyres
- ...⇒ Friction demand on Steering Tyres
- ...⇒ Tracking Ability on a Straight Path

Traffic Safety

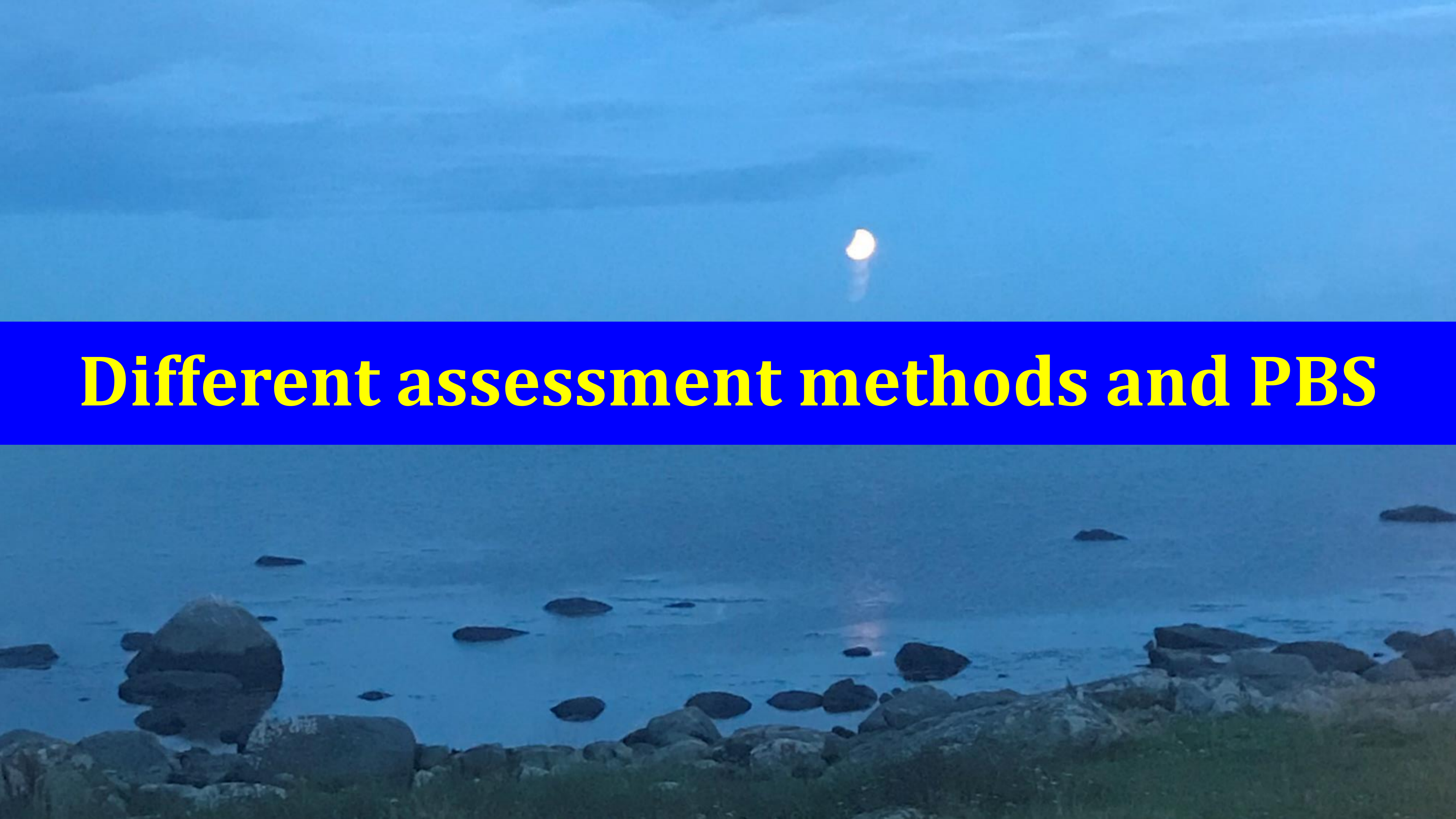
- ...⇒ High Speed Steady State Off Tracking
- ...⇒ Steady State Rollover Threshold
- ...⇒ Load Transfer Ratio
- ...⇒ High Speed Transient Off Tracking
- ...⇒ Yaw Damping
- ...⇒ Rearward Amplification
- ...⇒ Braking Stability in a Turn
- ...⇒ Coupling Forces

Each bullet is “*Traffic Risk* ⇒ PBS”.

Each **PBS** is motivated by one **Traffic Risk**, which we think is **not** handled by approval of the single units.

We strictly define one (PBS) **measure** for each risk and set a numerical min/max **requirement**.

Different assessment methods and PBS



How can we assess HCT?

PBS (for all PBSes:
$Measures_i > Requirement_i$):

- Strict agreements on measures
- Real vehicle test
  - Expensive, poor repeatability, difficult to vary operation parameters, such as road friction
- or Virtual test (computation, simulation)
  - Authorized "assessors" with their own models
    - or Anyone compute with agreed open models
  - How to get parameter values?

Prescriptive:

- "Blue prints"
- Envelops in table format

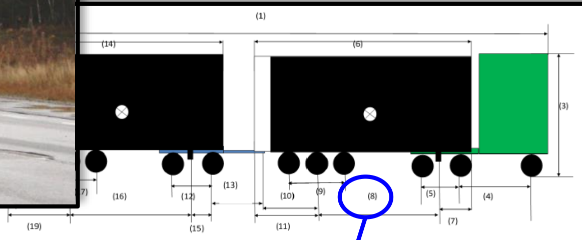


Figure 6.22: A-Double : Description and Dimensions

Table 6.6: Dimensional limit chart for A-double

Vehicle	Ref	Feature	Dimensions(Sweden)	Dimensions(Canada)
Overall	(1)	Length of the combination	Max 34m	Max 40 m
	(2)	Width of Vehicle	Max 2.6m	Max 2.6 m
	(3)	Height of the Vehicle	-	Max 4.15 m
Tractor	(4)	Wheelbase	3.0 - 3.8 m	Min 3.5 m
	(5)	Tandem axle spread	1.37 m	1.2 - 1.85 m
Lead Semi-trailer	(6)	Length	13.6 m	14.5 - 16.2 m
	(7)	Front Over-hang	1.6 m	Max 2 m
	(8)	Wheelbase	7.7 - 8.5 m	10.9 - 12.5 m
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	(11)	Rear Over-hang	3.5 - 4.3 m	Max 3.4 m
Converter Dolly	(12)	Wheelbase	1.3 m	1.2 - 1.85 m
	(13)	Drawbar length	3.0 - 5.0 m	Max 3m
[illegible]d Semi-trailer	(14)	Length	13.6 m	14.5 - 16.2 m
	(15)	Front Over-hang	1.6 m	Max 2 m
	(16)	Wheelbase	7.7 - 8.5 m	10.2 - 12.5 m
	(17)	Tridem axle spread	2.6 m	2.4 - 3.7 m
	(18)	Distance to hinge point	2.4 - 3.6 m	-
	(19)	Rear Over-hang	3.5 - 4.3 m	35% of wheelbase

Lead-Semi-trailer: Wheelbase: 7.7-8.5 m

Statistics from real use:

- Assess each Individual vehicle
- Assess each Transport operator

Warning: An assessment method can reduce incentive for technology developments!

Finland

January 2019, Finland allows: **34,5 m 76 ton**, on whole road network, except some bridges and intersection.
Assessed by test and simulation. Using regression ⇒ “PBS-based envelope-table”.

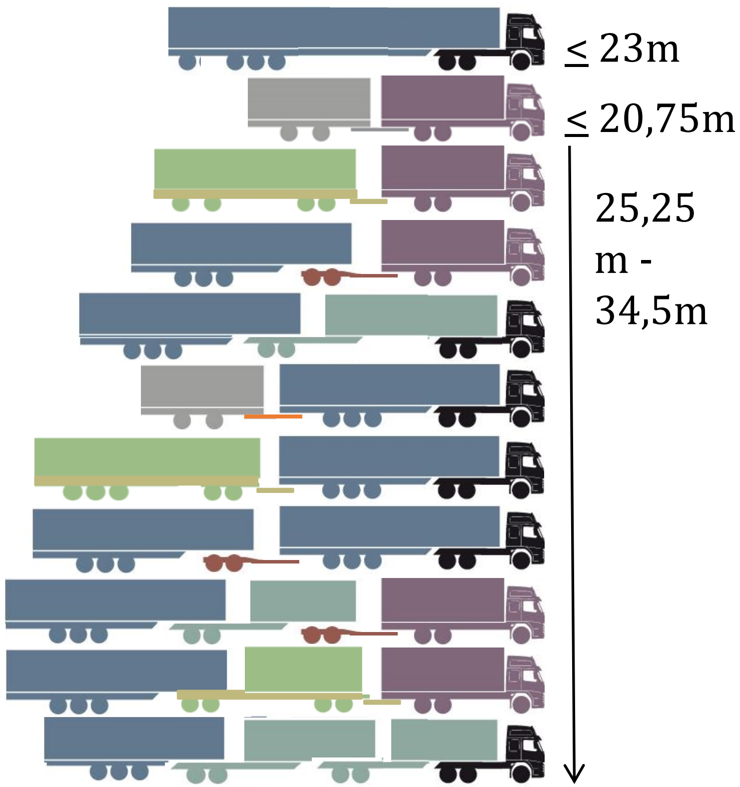
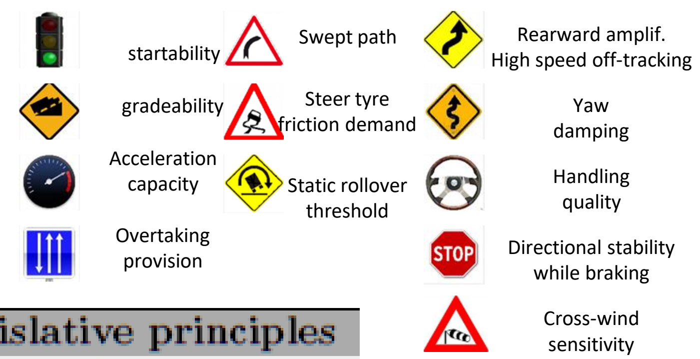


Table 6. Example of the parameter study results, measures in mm.

Semi-trailer wheel-base	Full trailer wheel-base	Coupling under hang	Coupling from the bogie	Yaw rate rearward amplification [RA] Drawbar length				
				3500	3750	4000	4250	4500
8108	8108	200	2592	2.36	2.35	2.33	2.31	2.29
		400	2392	2.33	2.32	2.30	2.28	2.26
		600	2192	2.29	2.28	2.26	2.25	2.22
		800	1992	2.26	2.25	2.23	2.21	2.19
	8282	200	2592	2.30	2.29	2.27	2.25	2.23
		400	2392	2.27	2.25	2.24	2.22	2.20
		600	2192	2.23	2.22	2.20	2.19	2.16
		800	1992	2.20	2.19	2.17	2.15	2.13
	8457	200	2592	2.24	2.23	2.21	2.19	2.17
		400	2392	2.21	2.20	2.18	2.16	2.14
		600	2192	2.18	2.16	2.15	2.13	2.11
		800	1992	2.14	2.13	2.12	2.10	2.08
	8631	200	2592	2.19	2.17	2.16	2.14	2.12
		400	2392	2.15	2.14	2.13	2.11	2.09
		600	2192	2.12	2.11	2.10	2.08	2.06
		800	1992	2.09	2.08	2.06	2.05	2.03
	8805	200	2592	2.13	2.12	2.11	2.09	2.07
		400	2392	2.10	2.09	2.08	2.06	2.04
		600	2192	2.07	2.06	2.05	2.03	2.01
		800	1992	2.04	2.03	2.02	2.00	1.98
	8980	200	2592	2.08	2.07	2.06	2.04	2.02
		400	2392	2.06	2.04	2.03	2.01	1.99
		600	2192	2.03	2.01	2.00	1.98	1.96
		800	1992	2.00	1.99	1.97	1.95	1.93
	9154	200	2592	2.04	2.02	2.01	1.99	1.97
		400	2392	2.01	2.00	1.98	1.97	1.95
		600	2192	1.98	1.97	1.96	1.94	1.92
		800	1992	1.95	1.94	1.93	1.91	1.89
(pink)	High rearward amplification, RA > 2							
Open-loop lane change test according to ISO 14791 f = 0.40 Hz ja v = 80 km/h								

EU



picture from HAN (Joop Pauwelussen)

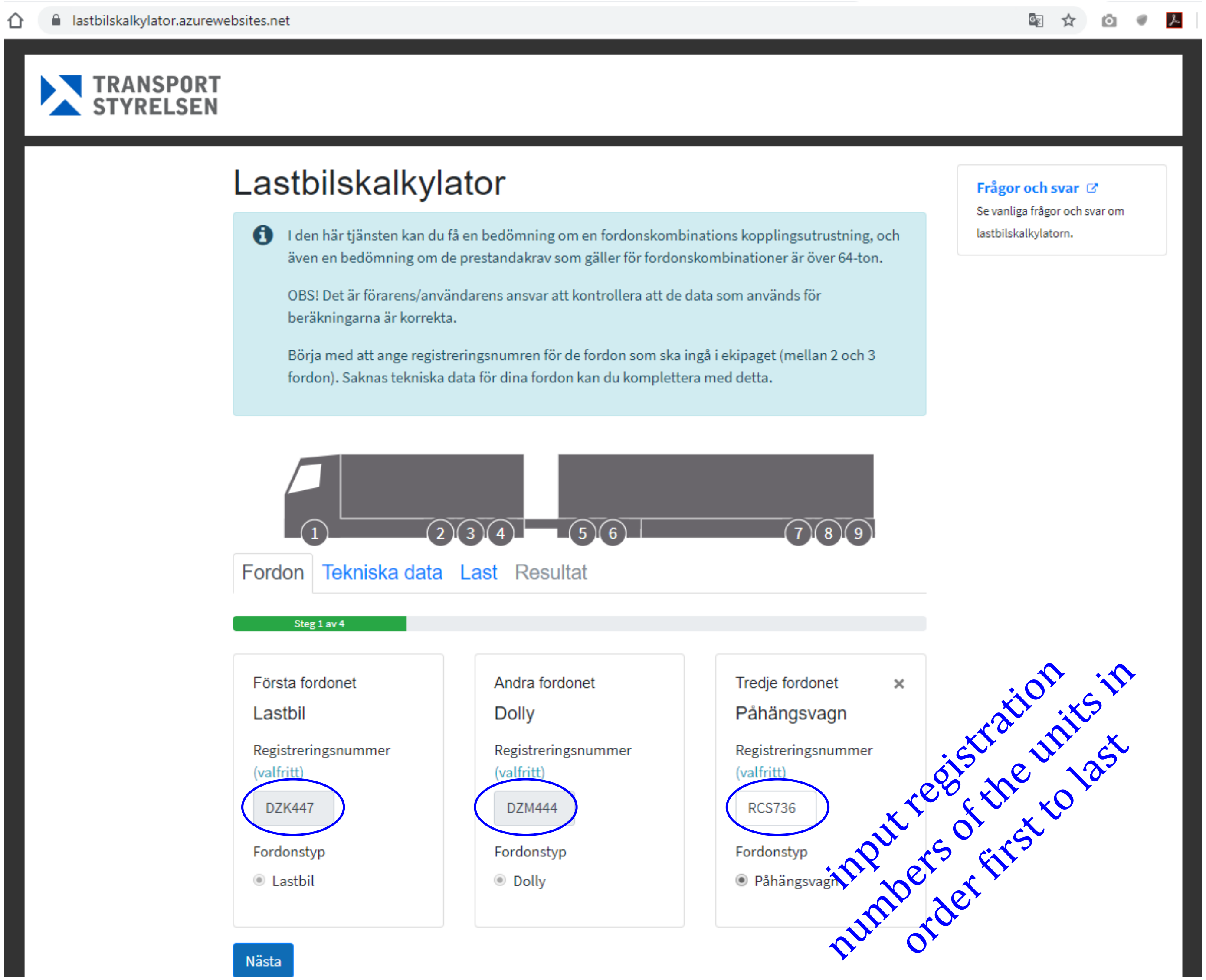
from Karel Kural, PhD thesis:

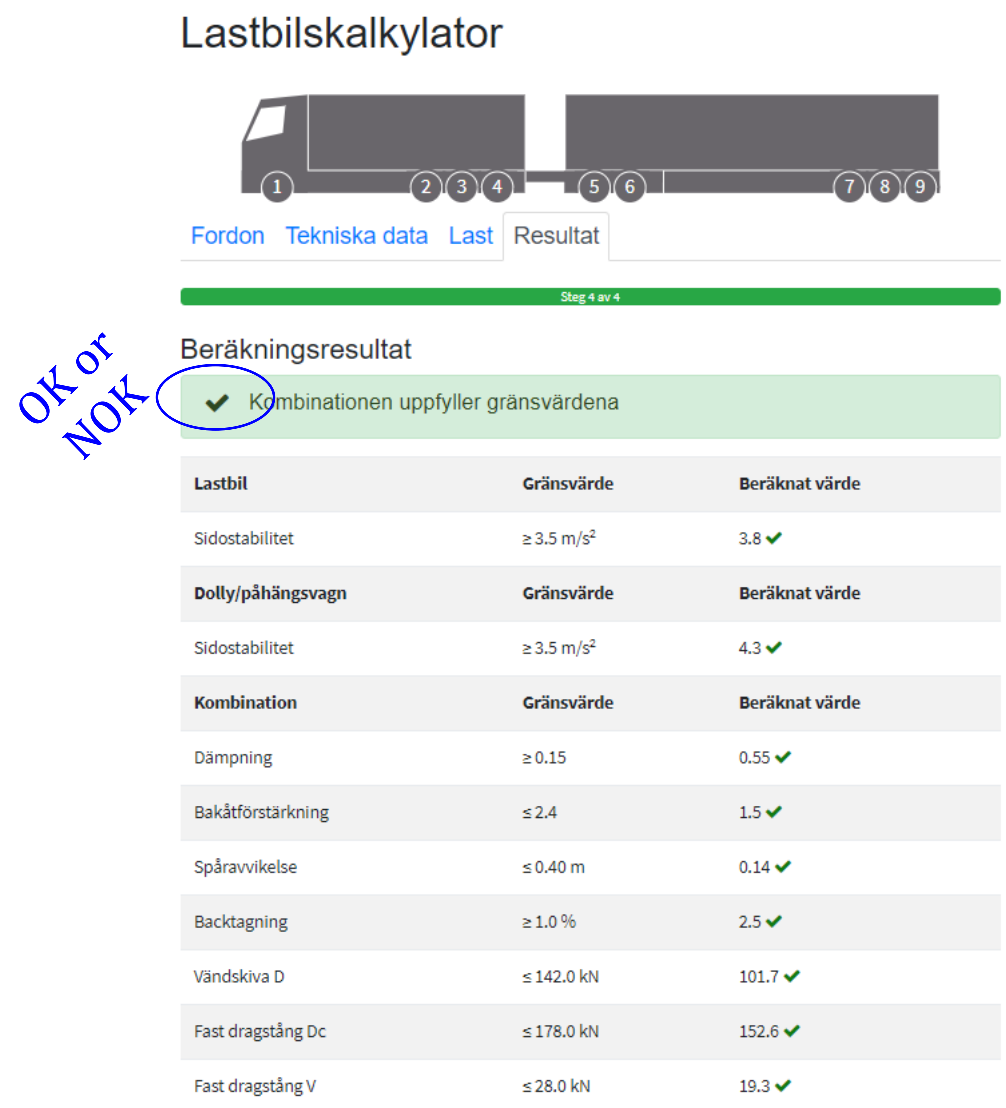
No.	Australian PBS Measure	Current EU-Legislation	Proposed EU legislative principles
1	Startability	R No 1230/2012 - Min. slope	R No 1230/2012 - Min. slope
2	Gradeability	R No 1230/2012 - Min. engine power	R No 1230/2012 - Min. engine power
3	Acceleration capability	R No 1230/2012 - Min. engine power	R No 1230/2012 - Min. engine power
4	Tracking ability	N/A	N/A
5	Directional braking stability	R No 661/2009 - Braking stability	R No 661/2009 - Braking stability
6	Overtaking provision	N/A	N/A
7	Low-speed swept path width	D 97/27 EC - Max. swept area	D 97/27 EC - Max. swept area
8	Steer tyre friction demand	R No 1230/2012 - Min. steer axle load	R No 1230/2012 - Min. steer axle load
9	Frontal swing	N/A	Use Australian definition
10	Tail swing	D 97/27 EC - Tail swing	D 97/27 EC - Max. tail swing
11	Static rollover threshold	N/A	Use Australian definition
12	Rearward amplification	N/A	Use Australian definition
13	Yaw damping	N/A	Use Australian definition
14	Load transfer ratio	N/A	Use New Zealand definition
15	High-speed transient offtracking	N/A	Use Australian definition
16	Handling quality	N/A	N/A
17	Pavement vertical loading	D 96/53/EC - Max. axle load	D 96/53/EC - Max. axle load
18	Pavement horizontal loading	D 96/53/EC - Axle spacing vs. load	D 96/53/EC - Axle spacing vs. load
19	Tyre contact pressure distribution	D 96/53/EC - Air suspension required	D 96/53/EC - Air suspension required
20	Bridge formulae	N/A	N/A

Table 2.11: Comparison of EU legislation with Australian legislation and proposal for future legislative principles.

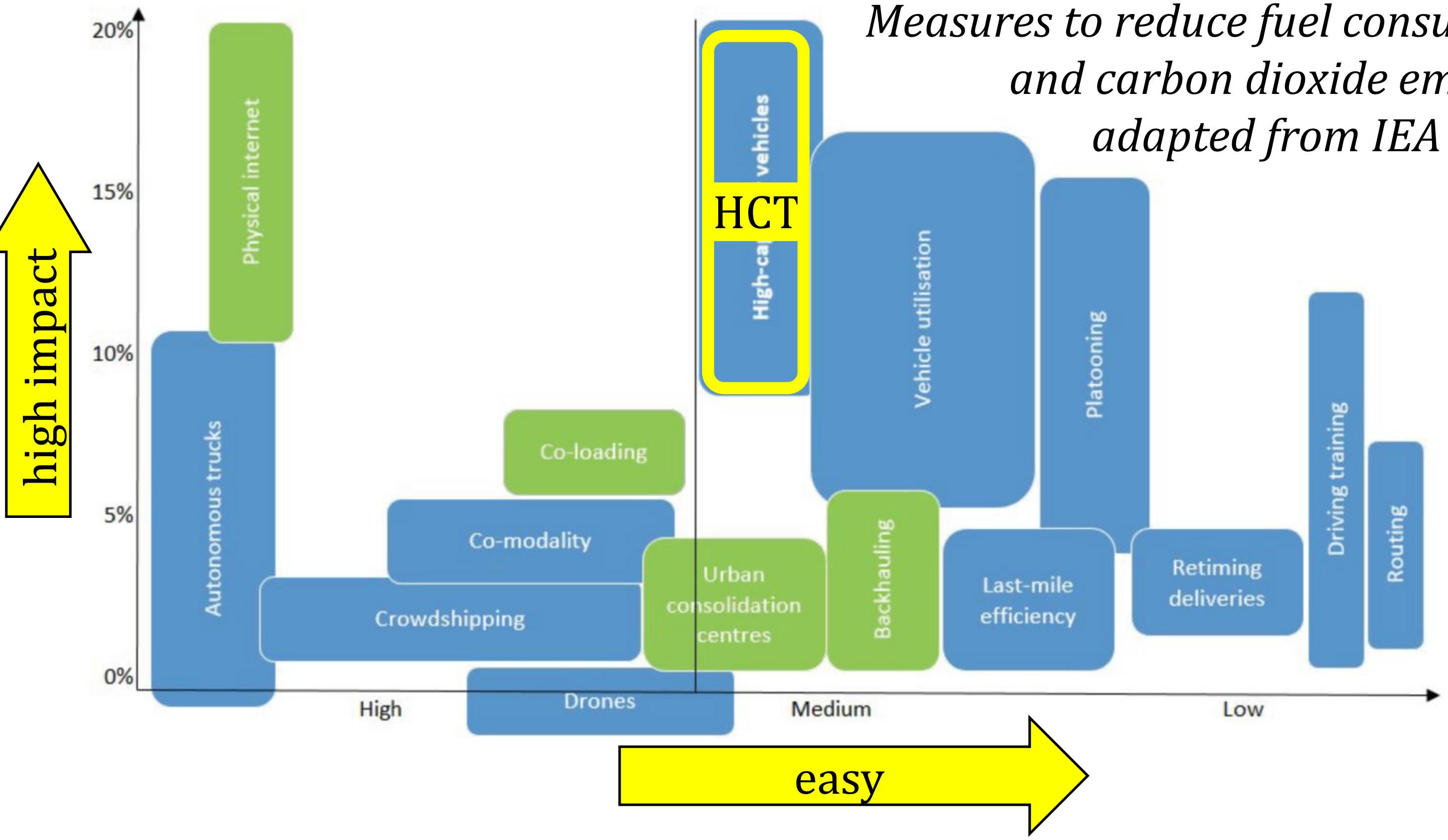
LastBilsKalkylatorn **LBK** https://lastbilskalkylator.azurewebsites.net

Sweden introduced a web service (LBK) to assess individual **combination vehicles** when for 64 ton was allowed 2018. (Actually assesses individual “transport **operations**”, since F_z per axle is input.)





CLOSER https://closer.lindholmen.se/en



Measures to reduce fuel consumption and carbon dioxide emissions, adapted from IEA (2017).

The overall goal for **2030** is to provide the conditions so that **80%** of the freight transport work on the road is carried out by HCT vehicles (the targets for **2020** are **5%** and for 2025 45%) and that this means that energy consumption will be 10% lower per tonne meter than 2018

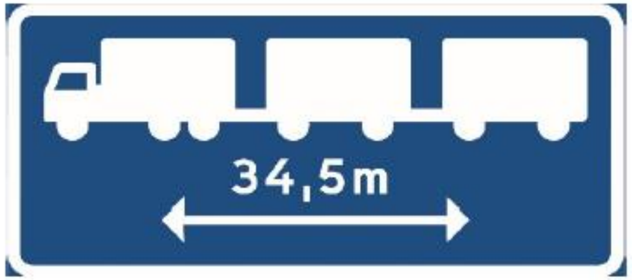
Innovationsdomän	Tidshorisont	Delmål	Ansvarig aktör	Barriärer
PBS	2025	Lastbilskalkylatorn har kompletterats med PBS-baserat krav för längre HCT-fordon.	Transportstyrelsen, forskningsinstitut	
PBS	2030	Ett europeiskt system för SIAP "Smart Infrastructure Access Policy" finns vilket innebär optimering av matchningen fordon ó infrastruktur	Transportstyrelsen, forskningsaktörer	Brist inom finansiering samt samarbete mellan involverade intressenter.
Regelverk	2030	Ett globalt regelverk finns på plats för att certifiera hårdvara, mjukvara och processer för uppkopplade fordon och alla tillhörande back-end och molnsystem.	Regeringar	Särintressen

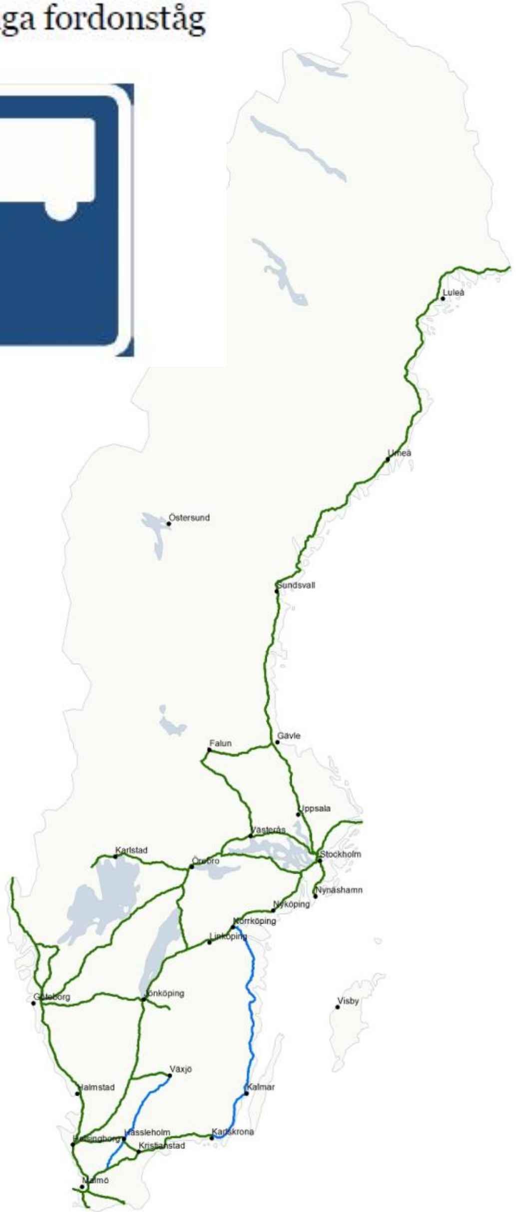
LBK+

Presently on remittance in Sweden

https://www.trafikverket.se/contentassets/1160ae4fe6504bba8e3629eee4b60d7c/langre_lastbilar_pa_det_svenska_vagnatet_for_mer_hallbara_transporter.pdf

Vägmärke: F31.a Färdväg för långa fordonståg





Tabell 1. Resultat från förenklad samhällsekonomisk beräkning.

Effektkategori	Samhälls-ekonomisk effekt	Effekt tidigare studie	Resultat, mkr	Känslighets-analys högt marknads-upptag, mkr	Känslighets-analys lågt marknads-upptag, mkr
Producent-/ konsumenteffekter	Fordons-ägare eller godstransport-köpare	177 963	12 916	15 499	10 333
Budgeteffekter	Dieselskatt	-30 733	-2 231	-2 677	-1 784
Externa effekter	Road wear	2 910	211	253	169
	Air pollution	538	39	47	31
	CO2	8 382	608	730	487
	Accidents	3 040	221	265	177
	Transport time	835	61	73	48
	Totalt	**162 935**	**11 825**	**14 190**	**9 460**

$\approx 10^9€$

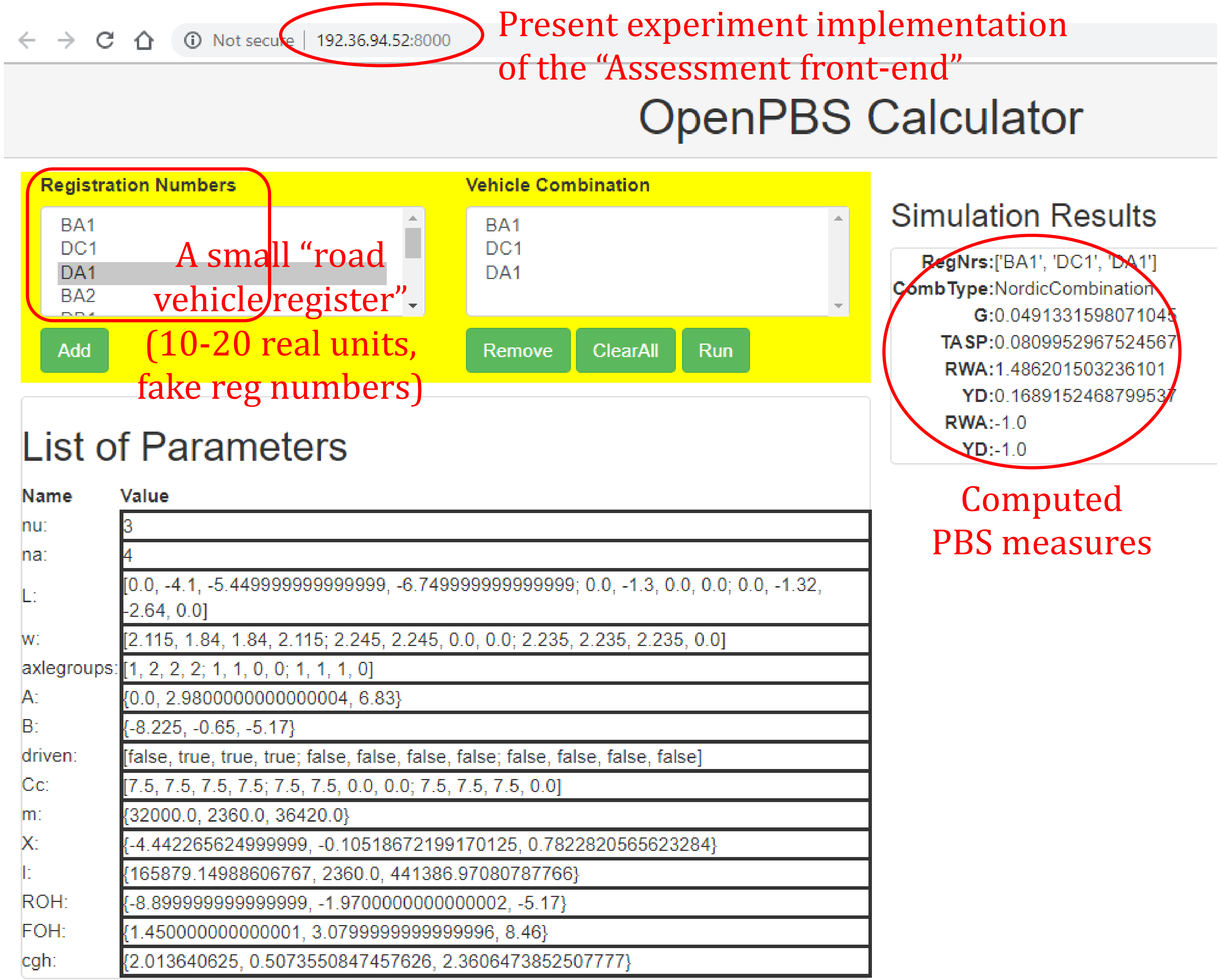
LBK^{+} ≈ OpenPBS http://192.36.94.52:8000/

PBS2 project extends the LBK to longer than 24.5 m.

The initiative is called OpenPBS and has 2 front-ends:

- An "**assessment front-end**" with a simple user interface as in present LBK
- An "**R&D front-end**", enabling download and editing of models (change any parameters, add equations and parameters to try e.g. extra propelled and steered axles).

Both front-ends are using the same dynamic models on the open format Modelica (https://modelica.org/)



So, whats the problem???

Definition of PBSes:

- ISO gives several selections and can be interpreted differently.
- Who agree and How?
- What more than PBSes is needed

e.g.
- Rearward amplification RA ratio of ω_z or a_y?
- and $RA = \frac{max_t(|\omega_{iz}|)}{max_t(|\omega_{1z}|)}$ or $max_f\left(\frac{|H_{\delta sw \to \omega iz}(f)|}{|H_{\delta sw \to \omega 1z}(f)|}\right)$?
- and is manoeuvre single sine (what Δx? what Δy?) or single lane change (what Δx? what Δy?)
- and what speed v_x? and what road friction μ?

Proposal: First agree on which “risks”

e.g. clash between unit bodies

Model (equations):

- How detailed is necessary? How simple is possible?

e.g. is roll important? is xy-planar motion enough?
See: Santahuhta, thesis from University of Oulu, Finland, 2019.

Parameters (numeric values) :

- The vehicle registry does not include all parameters.

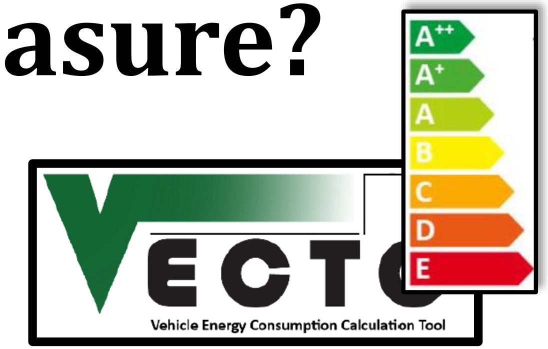
- e.g. suspension data, engine map, gear ratios, …
- e.g. cornering coefficient=7.5 [N/N]?, …
- e.g. should operator/driver input F_z per axle or compute from max allowed gross weight and assumed CoG location

Consider: An assessment method can remove incentive for technology developments

- *e.g. steered axle on towed units*
- *e.g. control algorithm (IP!), …*

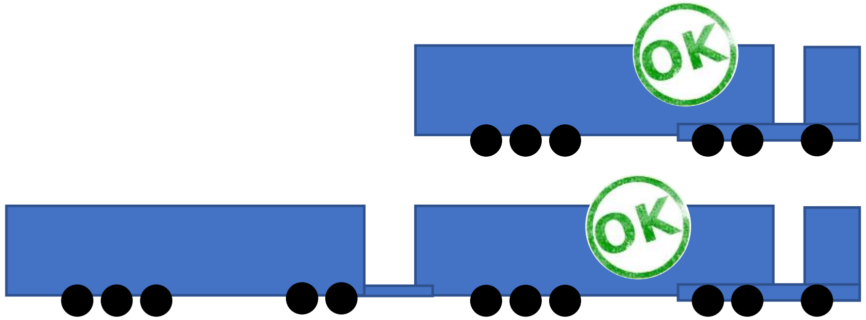
Could CO_2 be a PBS measure?

Euro1, Euro2, …
Legal assessment
of **engines**



Vecto
Rating of
towing
vehicles

Vecto can also become tool
for next legal assessment
of **towing vehicles**



CO2 a future "PBS measure"?
I.e., per **vehicle** (not per unit)?

…or per
operation?

from Karel Kural, PhD thesis:

No.	Societal Benefit Measure	Units
1	Carbon dioxide pollution - load-wise	CO_2/ton.km
2	Carbon dioxide pollution - volume-wise	CO_2/m^3.km
3	Fuel consumption - Load-wise	l/ton.km
4	Fuel consumption - Volume-wise	l/m^3.km
5	Transport costs - Load-wise	€ /ton.km
6	Transport costs - Volume-wise	€ $/m^3$.km

Table 2.12: Proposed societal benefit measures for future regulations

Design principles of “Open PBS”

Envisioned solution and top level Requirements on it

An Open PBS Tool

(Open means: Free and Readable and Understandable)

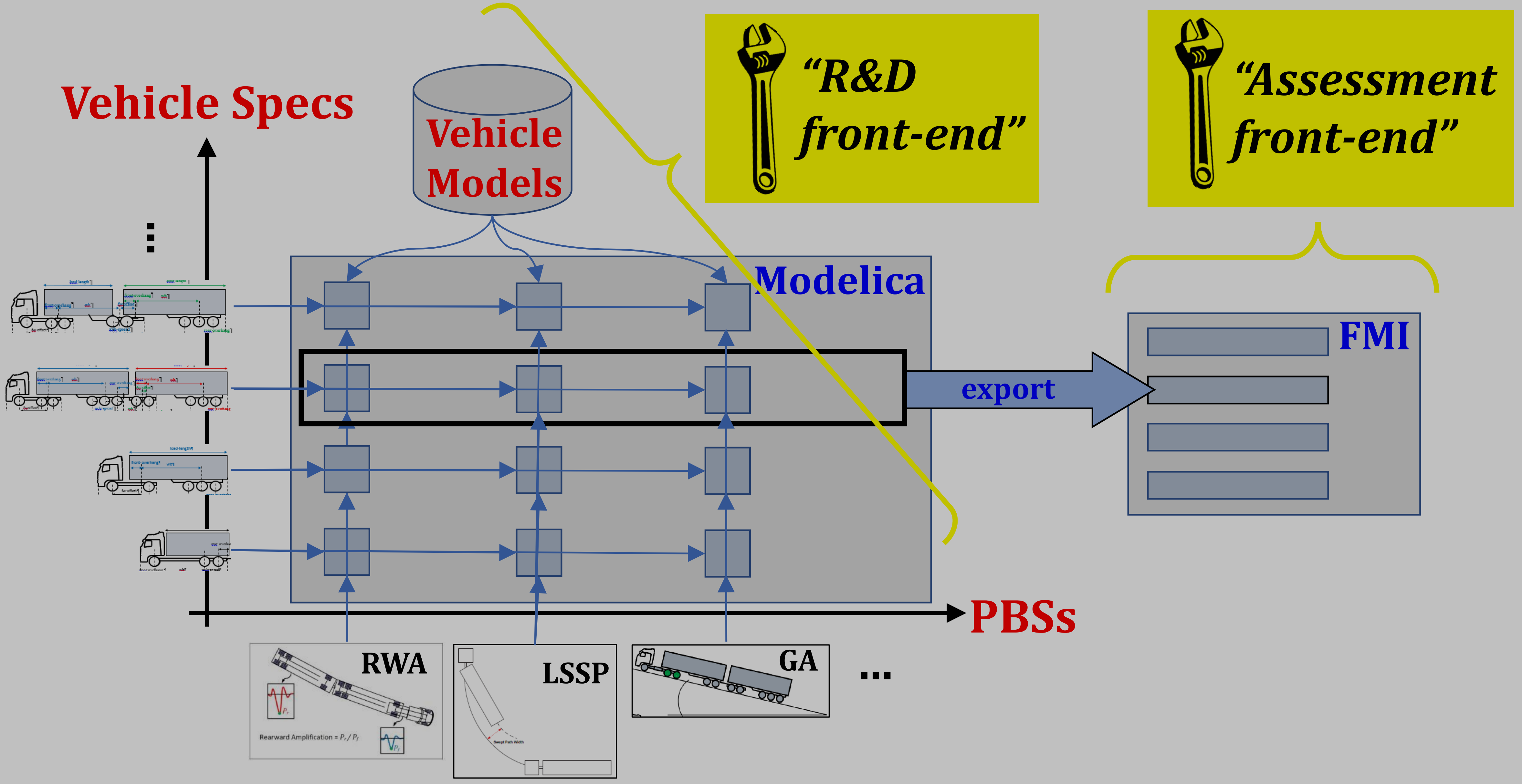
Requirements:

- PBSs independent of Vehicles
- Vehicles specifications (“parameters”) independent of Vehicle models (“equations”)
- Standardized format for dynamic models

Requirements on ⇒ Concepts for an “Open PBS Tool”

Requirements	**Conceptual solutions**
Define these 3 independently from each other: • PBSs (Manoeuvres & Measures) (“equations & parameters”) • Vehicle Specs (“parameters”) • Vehicle Models (“equations”)	Object oriented modelling
Physical and **strict** models (for adding novelties)	DAE
Understandable and **editable** for engineers	Modelica => *R&D front-end*
Runnable for non-experts. **Scriptable** for experts.	FMI => *Assessment front-end*
Limited parameter editable for non-experts. (In extreme: Only registration number on each of the units.)	Modelica concepts `Registry` and `Function`

Two tools in one...

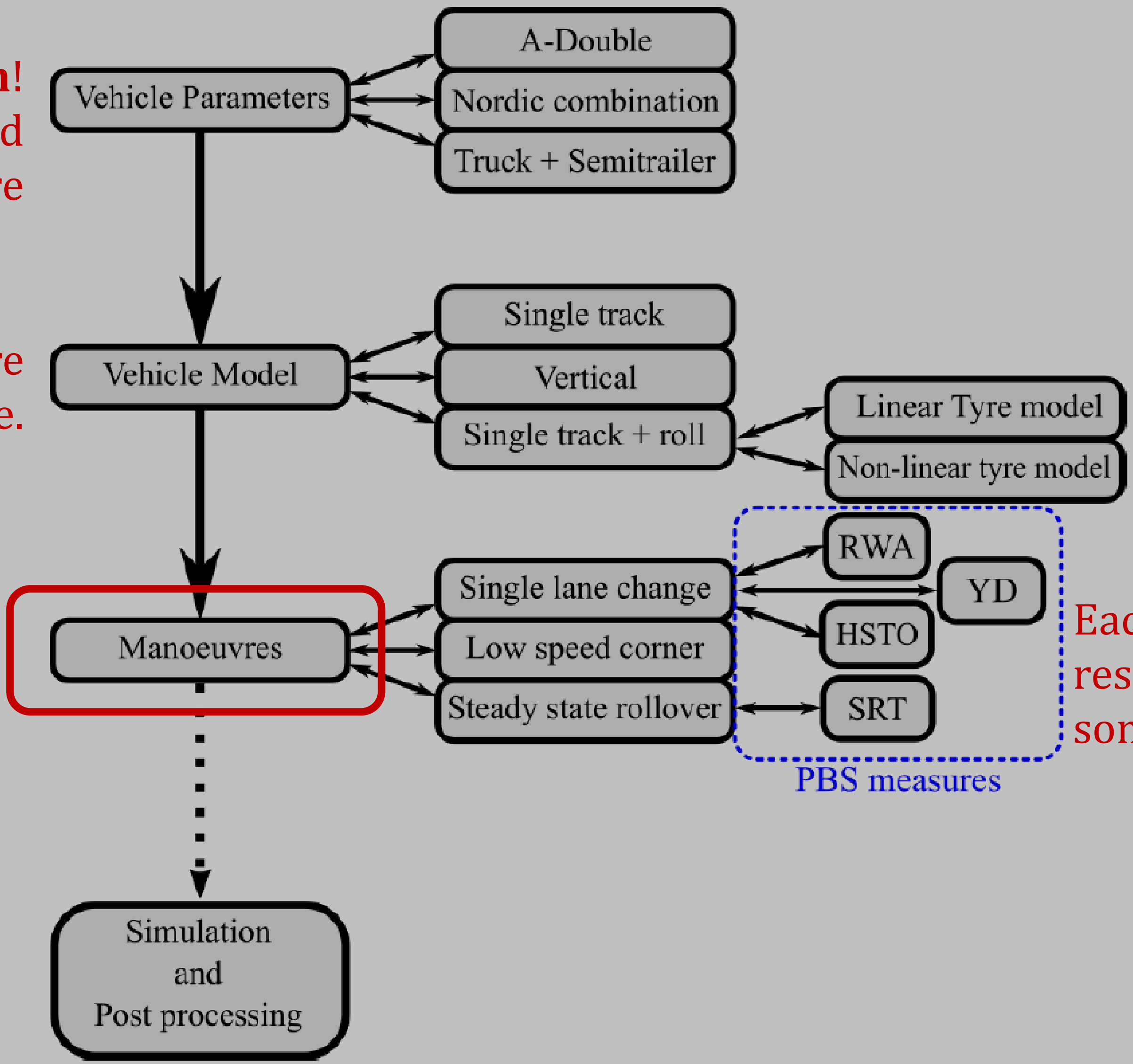


Concepts selected

Here is the **parameterisation**! Independent from model and manouvre

Vectorized models are used as far as possible.

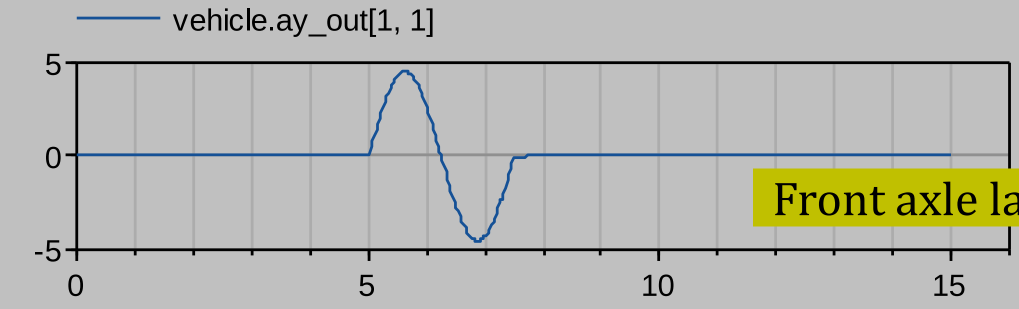
Manouvres are the “simulatable models”.



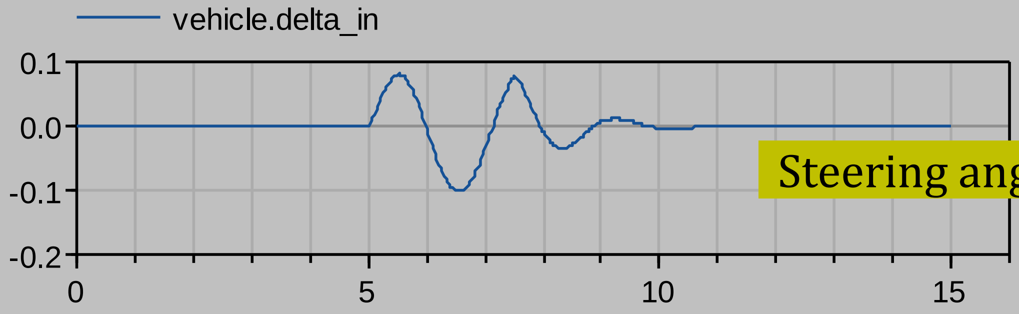
Each manoeuvre is responsible to compute some of the **PBSes**.

Figure 2. Overview of how OpenPBS is structured.

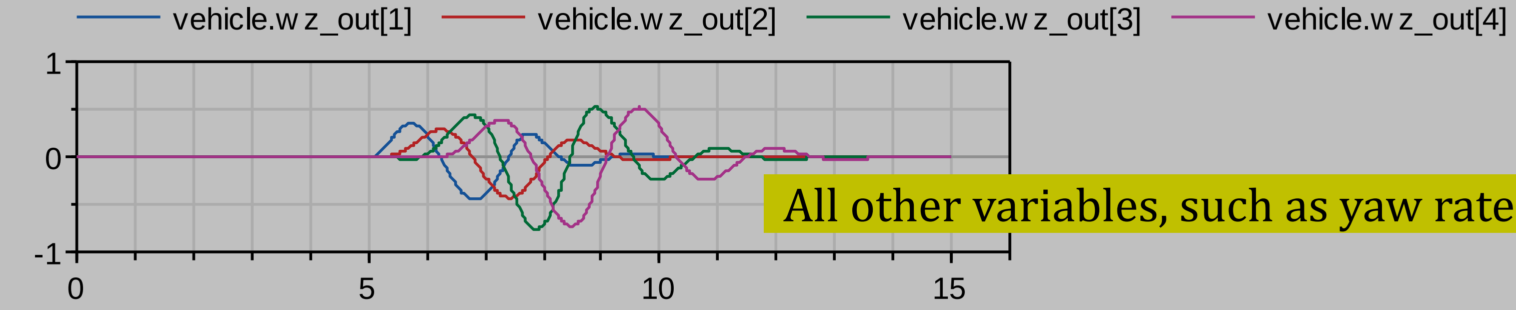
Example: Manoeuvre “High Speed Lane Change”



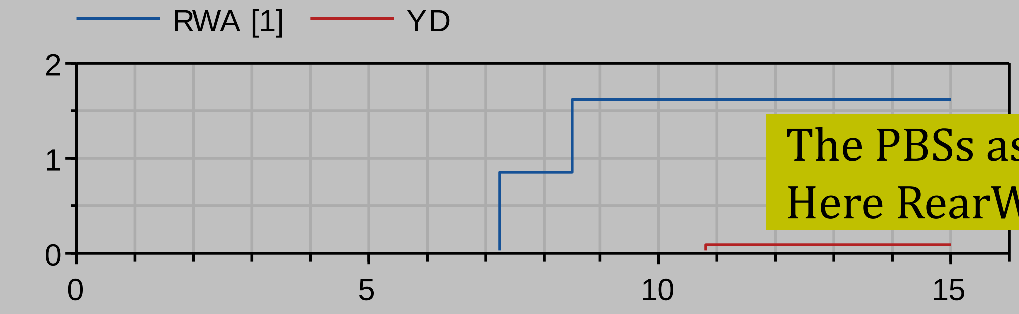
Front axle lateral acceleration is prescribed to exact sinus path



Steering angle is computed (but not of primary interest)



All other variables, such as yaw rates are, of course, also computed

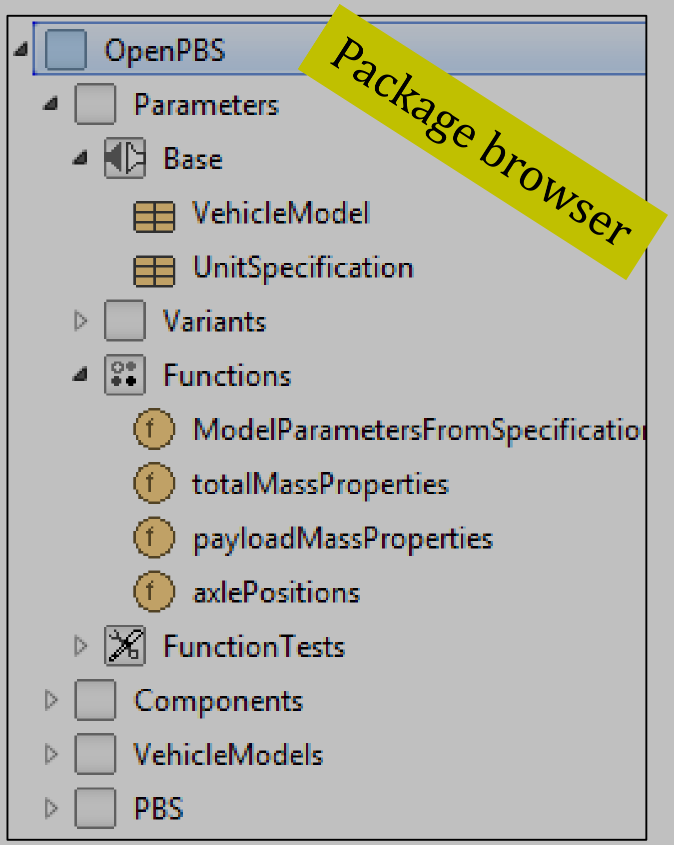


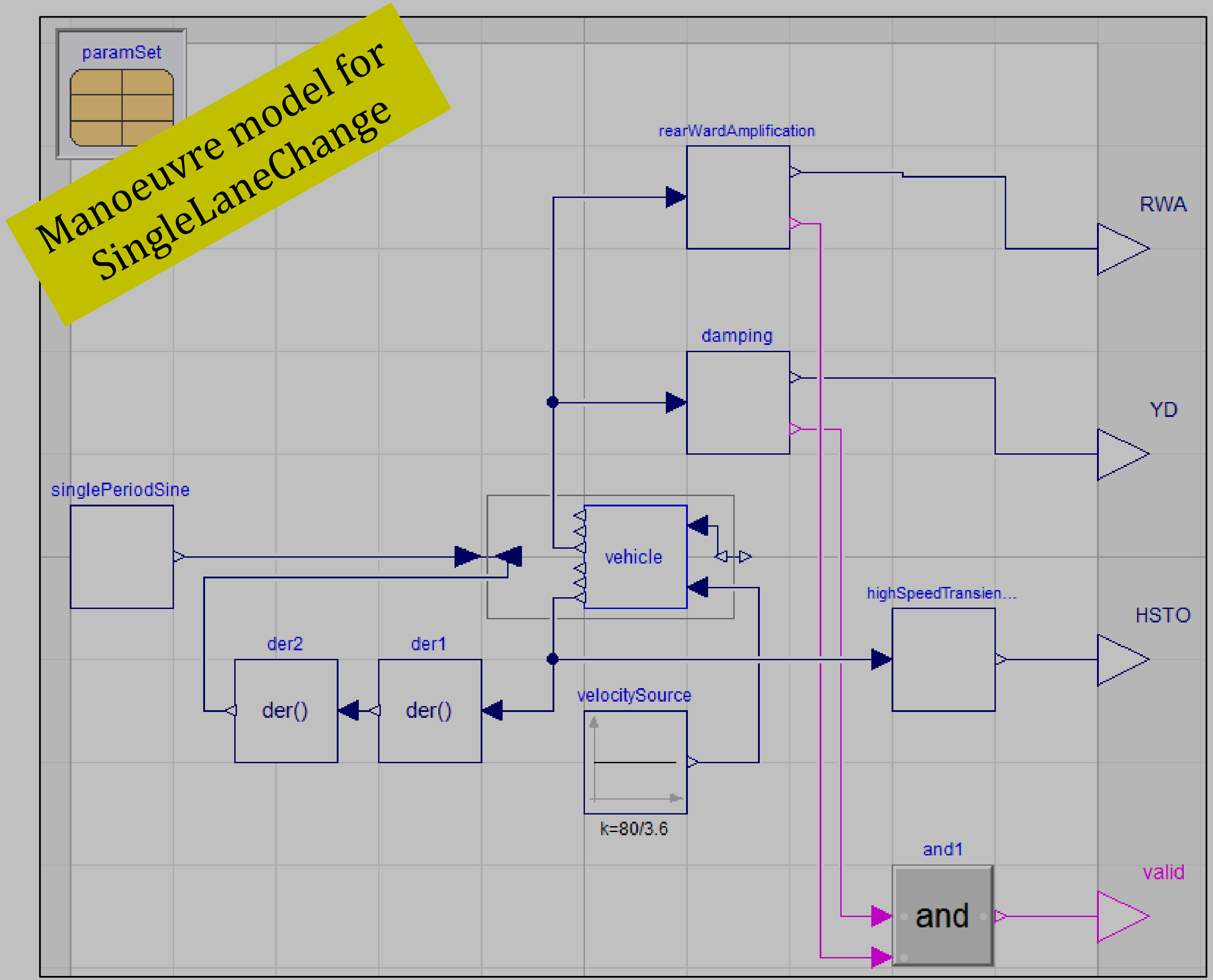
The PBSs associated with this manoeuvre is calculated.
Here RearWardAmplification (RWA) and YawDamping (YD)

How does "R&D tool" look?

The "R&D tool" is a Modelica "package" (`*.mo`).

Here opened in the Modelica tool "Dymola":



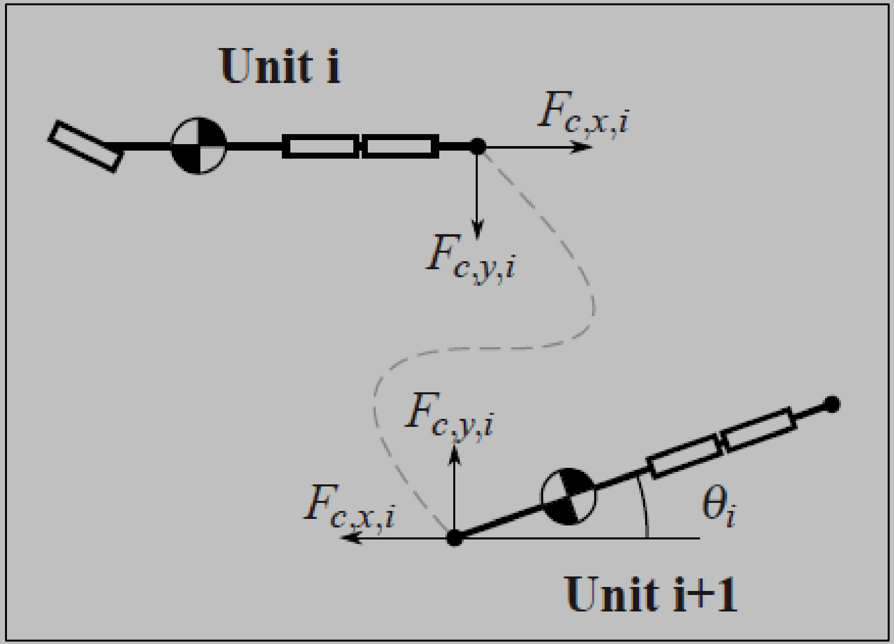


How does a "Vectorised VehicleModel" look?

Here, Vectorised Lateral Dynamics VehicleModel:

≈1 page declarations

≈1 page equations



(Dynamic) Equilibria:

```
ay=der(vy)+vx.*wz;
m.*ay=Fy*ones(na,1)-[Fcy;0]
+[0;Fcx].*sin([0;theta])
+[0;Fcy].*cos([0;theta]);
```

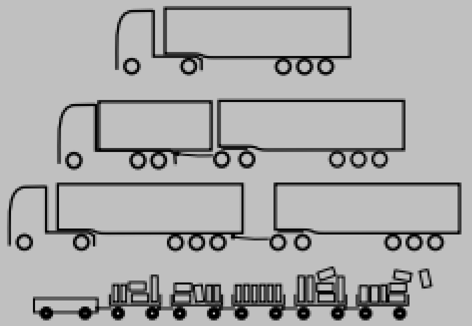
Constitution:

```
Fyw = -C.*alpha;
```

Compatibility:

```
for i in 1:nu-1 loop
vx[i+1] = vx[i]*cos(theta[i])
   -(vy[i]+Bcog[i]*wz[i])*sin(theta[i]);
vy[i+1]+Acog[i+1]*wz[i+1]=
   (vy[i]+Bcog[i]*wz[i])*cos(thet
   +vx[i]*sin(theta[i]);
end for;
```

...




Conclusions

Conclusions & Future work

- HCT seems to come on to the roads in EU soon. Already today in Finland!
- Assessment can be arranged based on PBS.
    - Two cooperating assessment tools in Sweden (Finland involved in same project.):
        - LBK (launched)
        - Open PBS, "experiment version" launched:
            - "Assessment front-end": at web
            - "R&D fronte-end": at github at web
            - "Open" means anyone is welcome to try it and contribute
- For sure, other similar tools are developed.
    - E.g. the "framework≈tool" within Karel Kural's PhD thesis work presented later today.

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Thanks for your attention.
Questions?