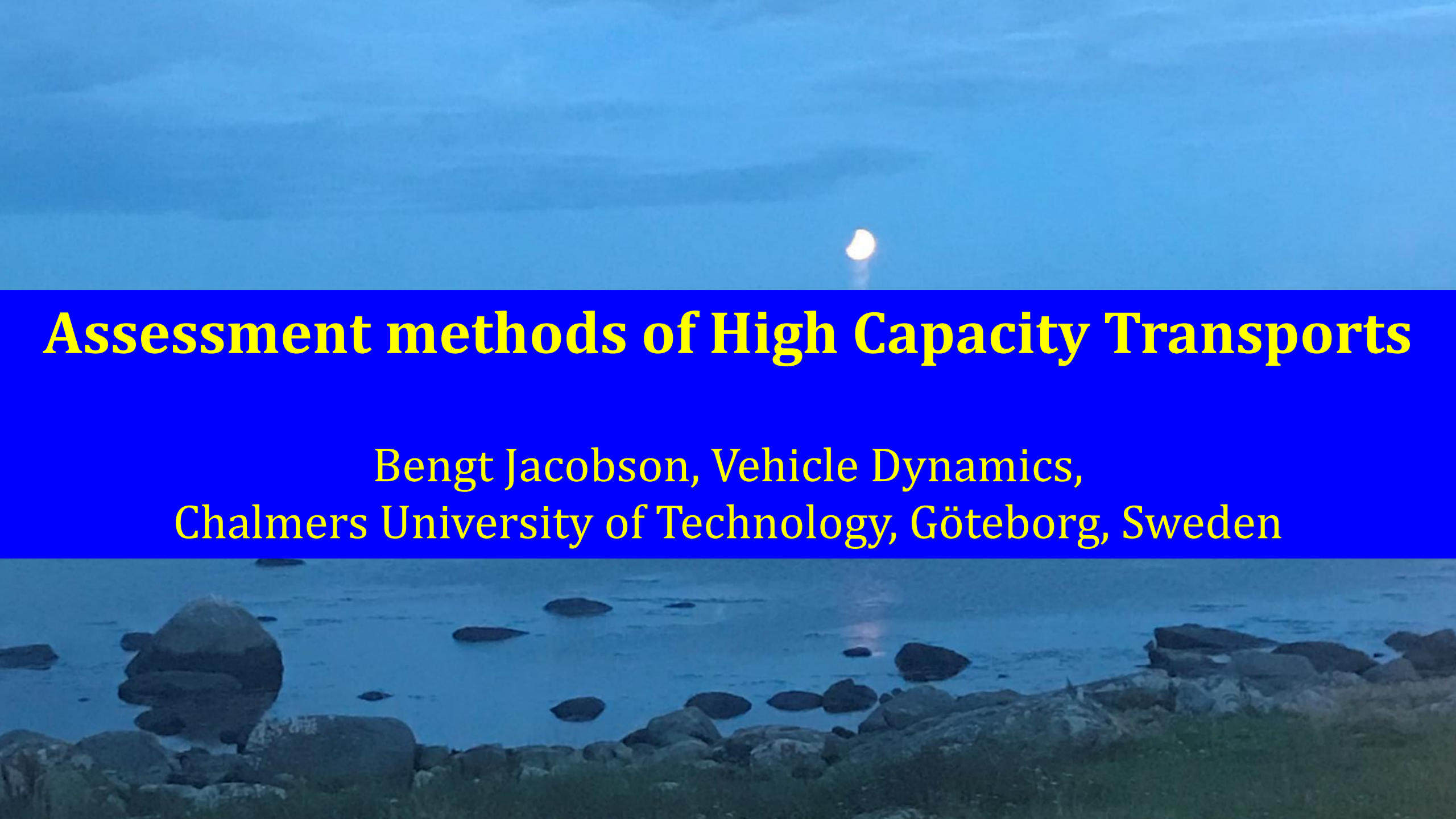
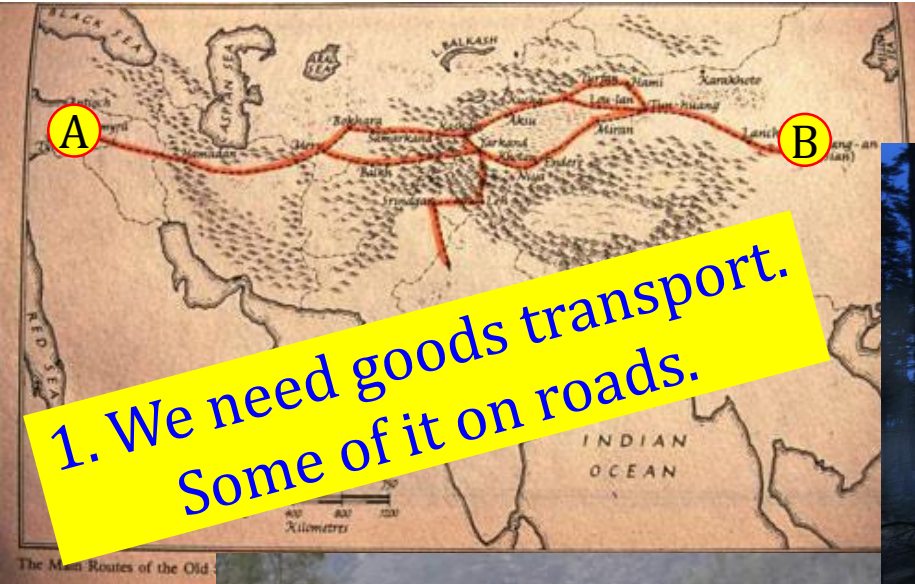




Assessment methods of High Capacity Transports

**Bengt Jacobson, Vehicle Dynamics,
Chalmers University of Technology, Göteborg, Sweden**

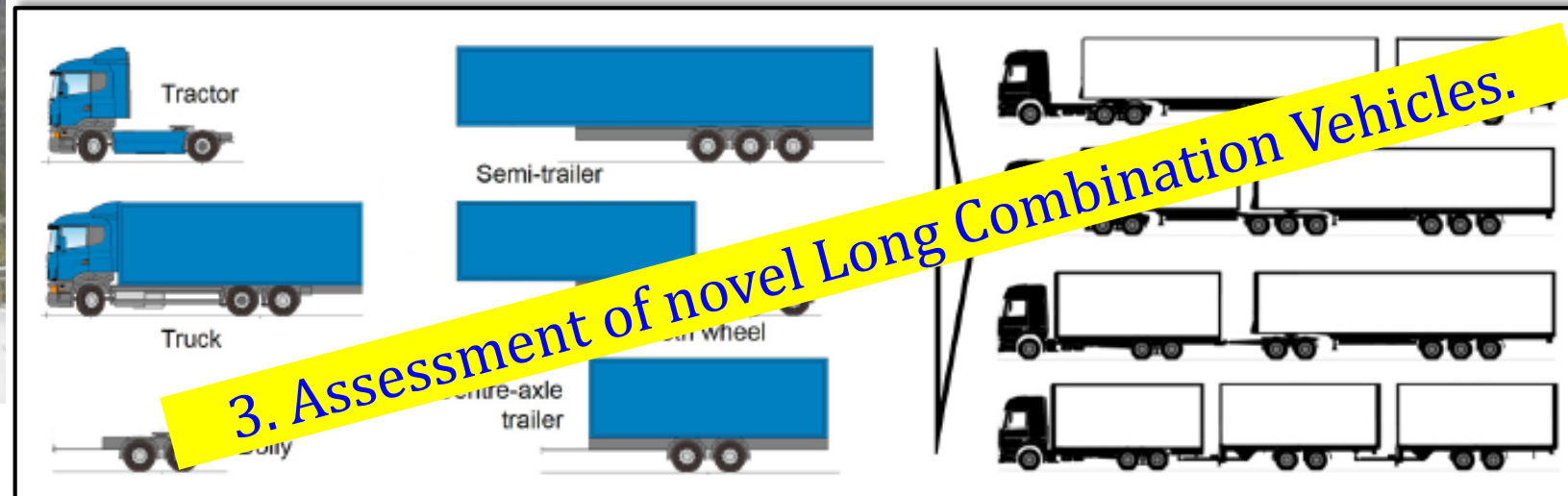
Why & How High Capacity Transports



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



2. HCTs is a “low-hanging fruit” for CO₂ savings.



3. Assessment of novel Long Combination Vehicles.

from Karel Kural, PhD thesis:

My present involvement in Assessment of HCT

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

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



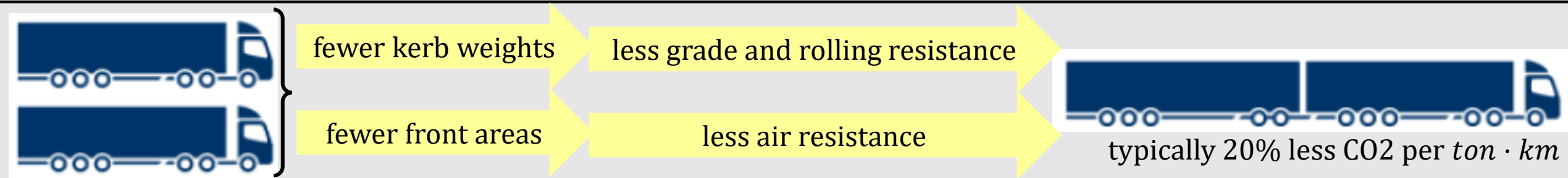
- **Chalmers University of Technology**, Gothenburg, Sweden
- **Nokian Tyres**, Finland
- **Parator Industri**, Bollnäs, Sweden
- **Scania**, Södertälje, Sweden
- **Swedish Transport Administration**, Borlänge, Sweden
- **Swedish Transport Agency**, Norrköping, Sweden
- **Swedish National Road and Transport 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 |

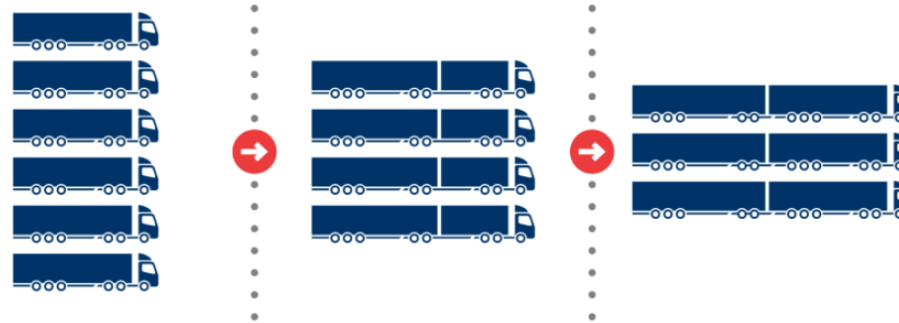
How can HCT save CO₂?

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



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

...and even more reduction of CO₂ per m³ · km:



Vehicles (and drivers)	6	4	3
Vehicle length	16.5 m	25.25 m	32 m
Load per vehicle	100 m ³	150 m ³	200 m ³
Fuel consumption	3.5 ml/m ³ km	3 ml/m ³ km	2.5 ml/m ³ km
CO ₂ 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* $\Rightarrow$ Startability
- *Slow in uphill* $\Rightarrow$ Gradeability
- *Slow on entry/exit roads* $\Rightarrow$ Acceleration Capability)
- ... $\Rightarrow$ Low Speed Swept Path
- ... $\Rightarrow$ Frontal Swing
- ... $\Rightarrow$ Tail Swing
- ... $\Rightarrow$ Friction demand on Drive Tyres
- ... $\Rightarrow$ Friction demand on Steering Tyres
- ... $\Rightarrow$ Tracking Ability on a Straight Path

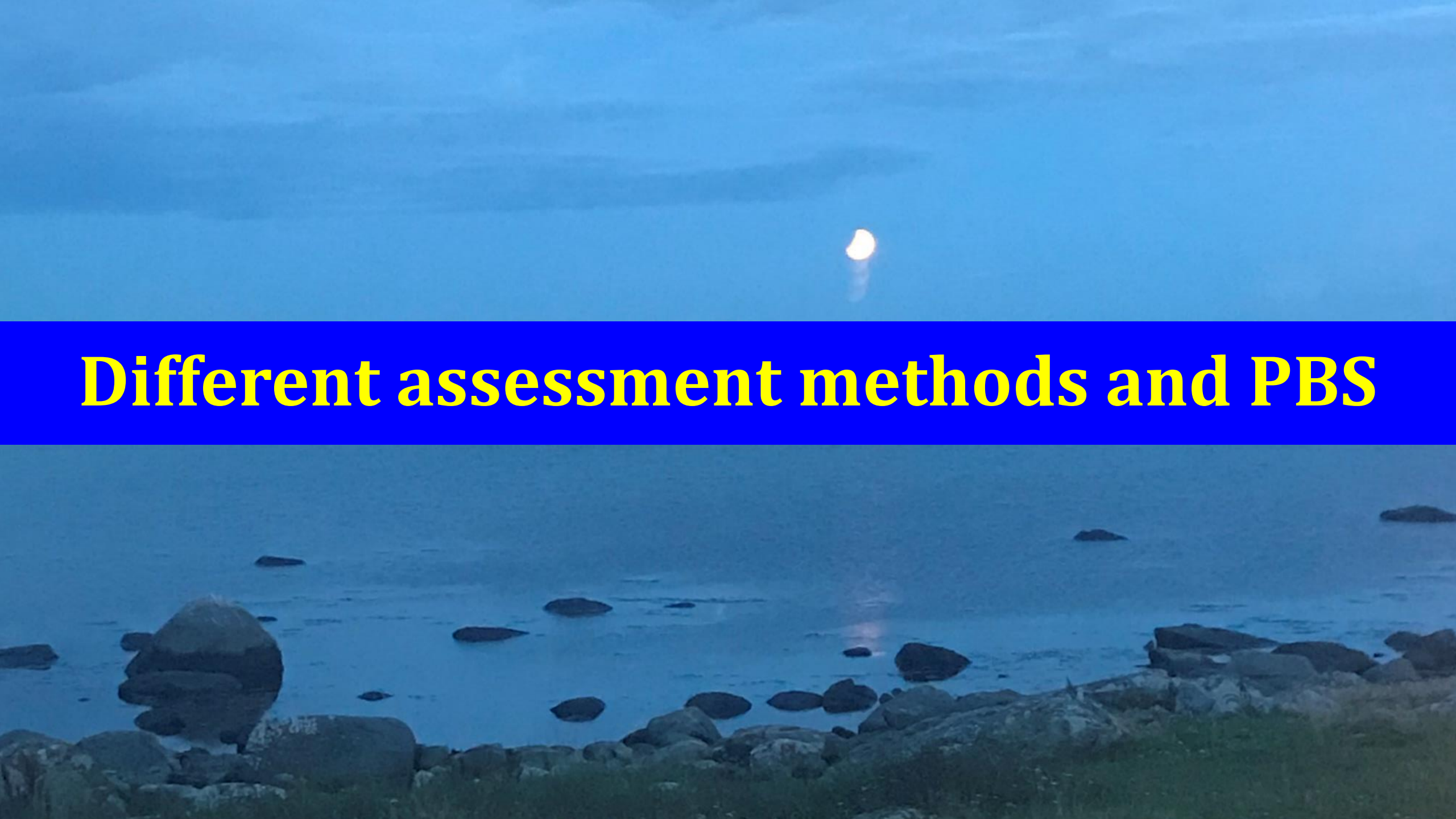
Traffic Safety

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

Each bullet is “*Traffic Risk* $\Rightarrow$ 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?

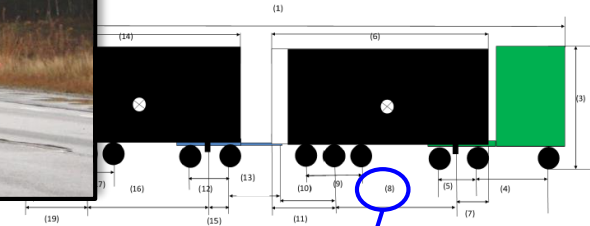


Figure 6.22: A-Double : Description and Dimensions

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
	(9)	Tridem axle spread	2.6 m	2.4 - 3.7 m
	(10)	Distance to hinge point	2.4 - 3.6 m	-
	(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
1 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

Prescriptive:

- “Blue prints”
- Envelops in table format

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!

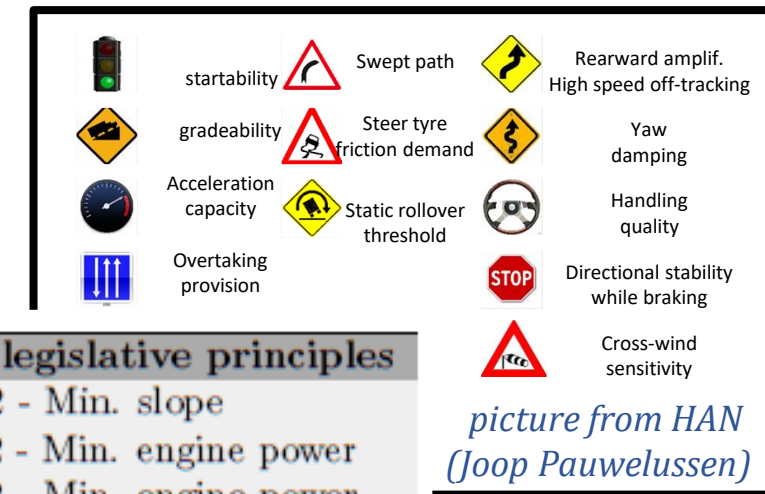
January 2019, Finland allows: **34,5 m 76 ton**, on whole road network, except some bridges and intersection.
Assessed by test and simulation. Using regression $\Rightarrow$ "PBS-based envelope-table".



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
High rearward amplification, RA > 2								
Open-loop lane change test according to ISO 14791 f = 0.40 Hz ja v = 80 km/h								

EU

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://lastbils kalkylator.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.)

lastbils kalkylator.azurewebsites.net

TRANSPORT STYRELSEN

Lastbils kalkylator

Frågor och svar
Se vanliga frågor och svar om lastbils kalkylatorn.

I den här tjänsten kan du få en bedömning om en fordonskombinations kopplingsutrustning, och även en bedömning om de prestandakrav som gäller för fordonskombinationer är över 64-ton.

OBS! Det är förarens/användarens ansvar att kontrollera att de data som används för beräkningarna är korrekta.

Börja med att ange registreringsnumren för de fordon som ska ingå i ekipaget (mellan 2 och 3 fordon). Saknas tekniska data för dina fordon kan du komplettera med detta.



Fordon Tekniska data Last Resultat

Steg 1 av 4

Första fordonet
Lastbil
Registreringsnummer (valfritt)
DZK447
Fordonstyp
☒ Lastbil

Andra fordonet
Dolly
Registreringsnummer (valfritt)
DZM444
Fordonstyp
☒ Dolly

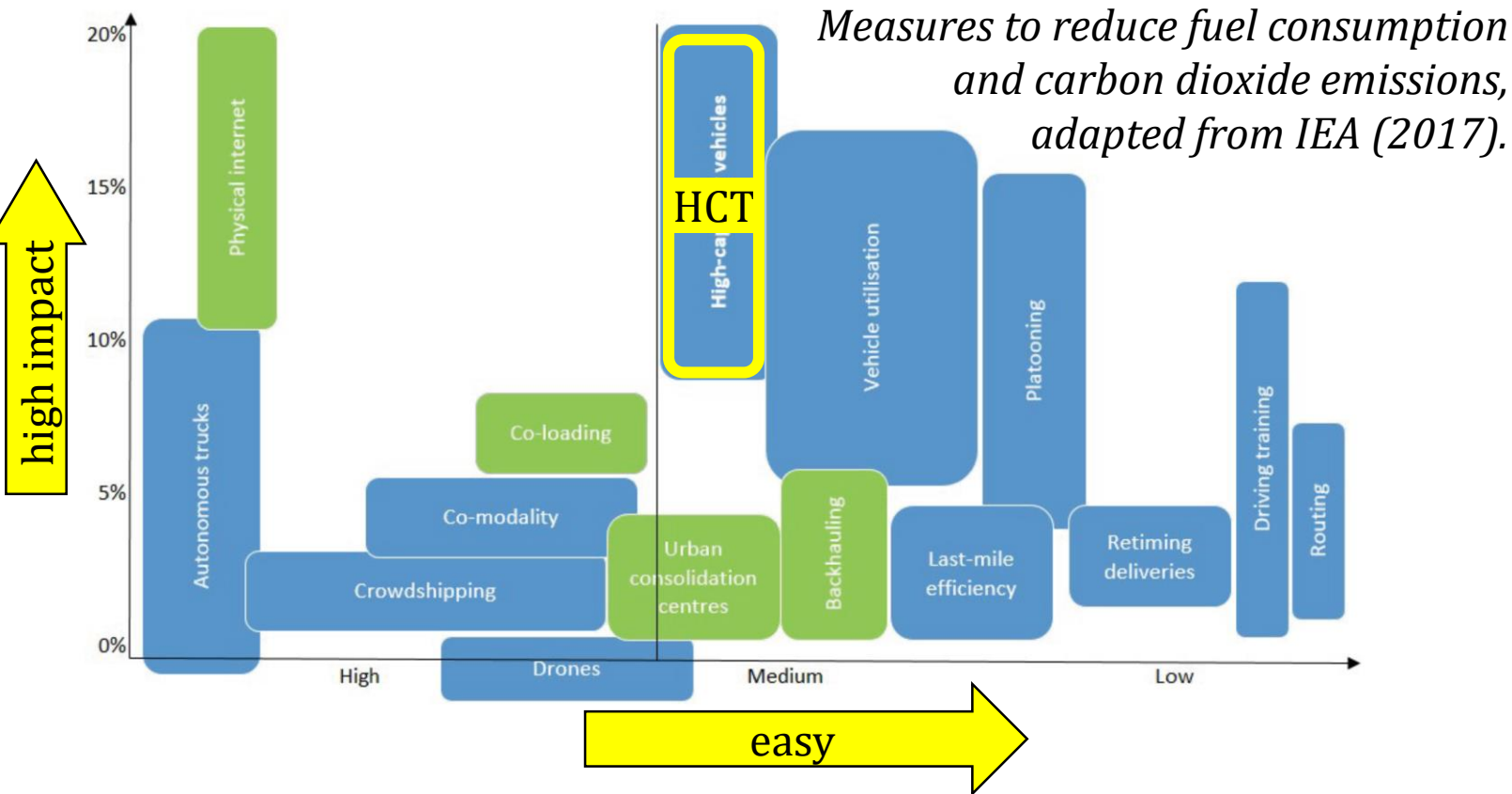
Tredje fordonet
Påhängsvagn
Registreringsnummer (valfritt)
RCS736
Fordonstyp
☒ Påhängsvagn

Nästa

input registration numbers of the units in order first to last

Lastbils kalkylator

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



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

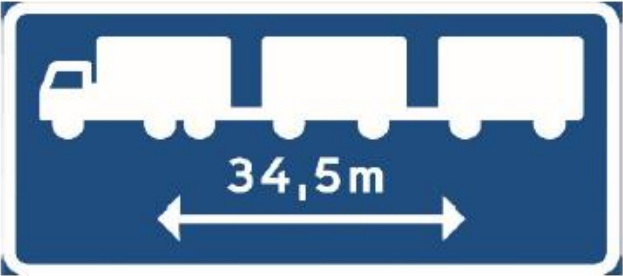
Innovationsdomän	Tidshorisont	Delmål	Ansvarig aktör	Barriärer
PBS	2025	Lastbils kalkylatorn har kompletterats med PBS-baserat krav för längre HCT-fordon.	Transportstyrelsen, forskningsinstitut	
PBS	2030	Ett europeiskt system för SIAP "Smart Infrastructure Access Policy" finns vilket innebär optimering av matchningen fordon & 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

≈ 10⁹€

LBK⁺ $\approx$ 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/>)

Present experiment implementation of the “Assessment front-end”

OpenPBS Calculator

Registration Numbers
BA1
DC1
DA1
BA2
DA1
Add

Vehicle Combination
BA1
DC1
DA1
Remove **ClearAll** **Run**

A small “road vehicle register” (10-20 real units, fake reg numbers)

Simulation Results

RegNrs:['BA1', 'DC1', 'DA1']
CombType:NordicCombination
G:0.0491331598071045
TASP:0.0809952967524567
RWA:1.486201503236101
YD:0.1689152468799537
RWA:-1.0
YD:-1.0

Computed PBS measures

List of Parameters

Name	Value
nu:	3
na:	4
L:	[0.0, -4.1, -5.449999999999999, -6.749999999999999; 0.0, -1.3, 0.0, 0.0; 0.0, -1.32, -2.64, 0.0]
w:	[2.115, 1.84, 1.84, 2.115; 2.245, 2.245, 0.0, 0.0; 2.235, 2.235, 2.235, 0.0]
axlegroups:	[1, 2, 2, 2; 1, 1, 0, 0; 1, 1, 1, 0]
A:	{0.0, 2.9800000000000004, 6.83}
B:	{-8.225, -0.65, -5.17}
driven:	[false, true, true, true; false, false, false, false; false, false, false, false]
Cc:	[7.5, 7.5, 7.5, 7.5; 7.5, 7.5, 0.0, 0.0; 7.5, 7.5, 7.5, 0.0]
m:	{32000.0, 2360.0, 36420.0}
X:	{-4.442265624999999, -0.10518672199170125, 0.7822820565623284}
I:	{165879.14988606767, 2360.0, 441386.97080787766}
ROH:	{-8.899999999999999, -1.9700000000000002, -5.17}
FOH:	{1.4500000000000001, 3.0799999999999996, 8.46}
cgh:	{2.013640625, 0.5073550847457626, 2.3606473852507777}

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 $\max_f \left(\frac{|H_{\delta_{SW} \rightarrow \omega_{iz}}(f)|}{|H_{\delta_{SW} \rightarrow \omega_{1z}}(f)|} \right)$?
- 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

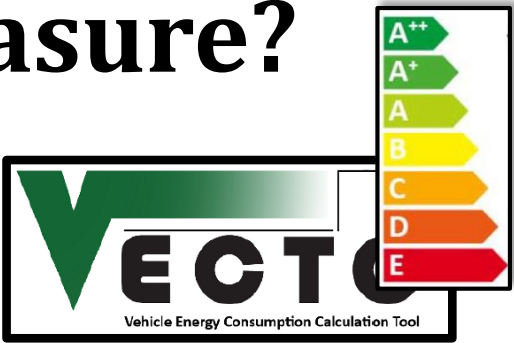
Consider: An assessment method can remove incentive for technology developments

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

Could CO₂ be a PBS measure?



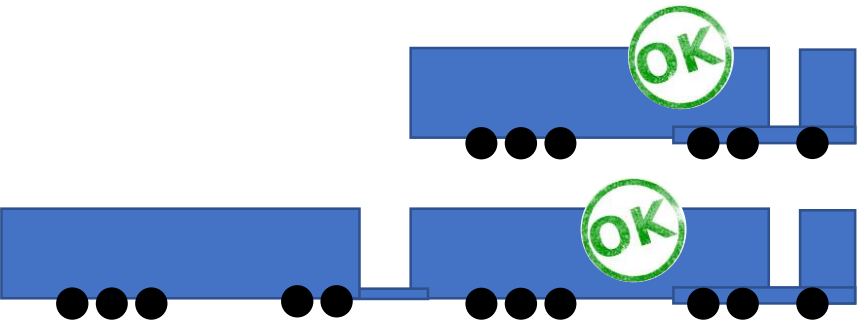
Euro1, Euro2, ...
Legal assessment
of **engines**



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)

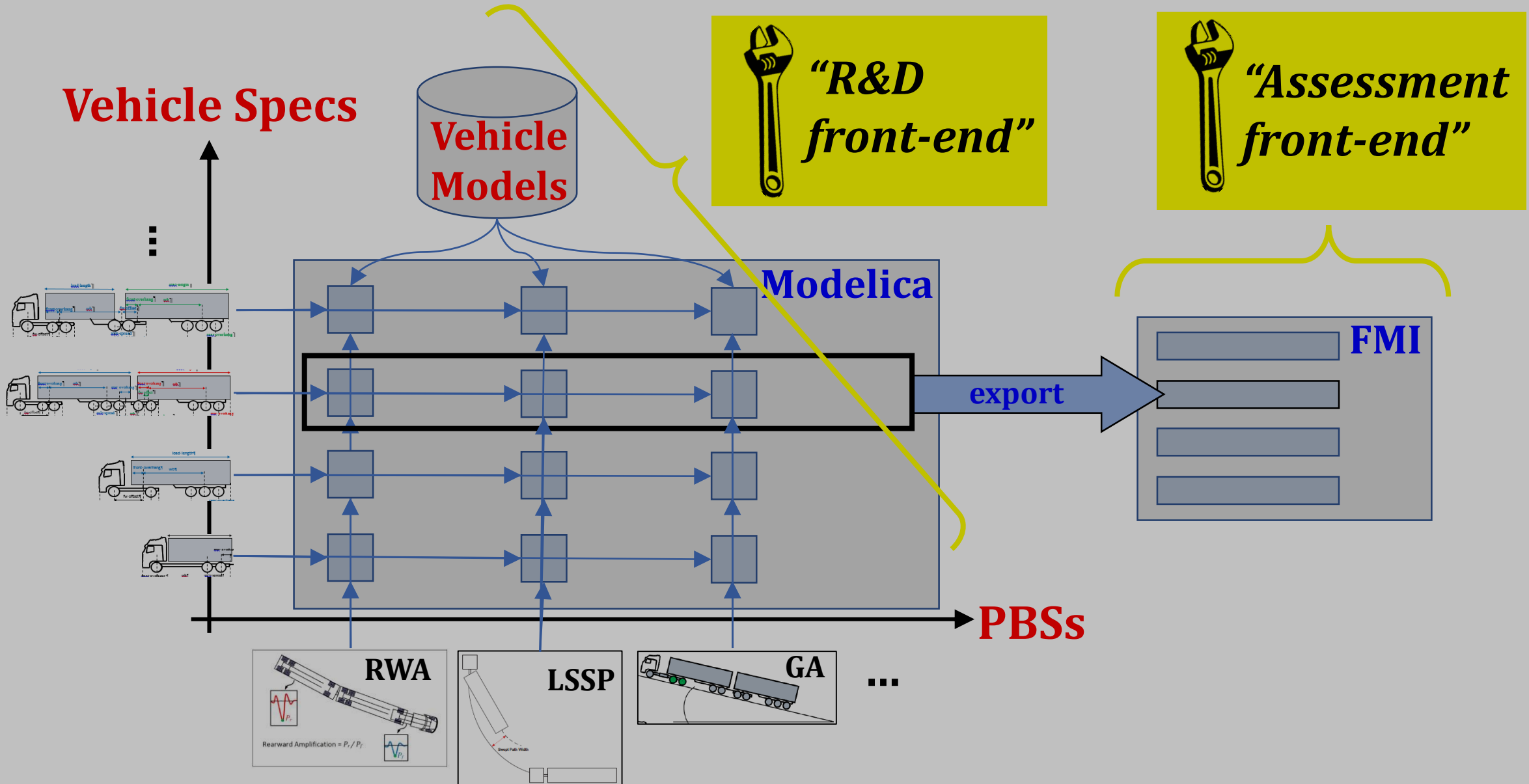
Requirements:

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

Requirements on $\Rightarrow$ 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 $\Rightarrow$ <i>R&D front-end</i>
Runnable for non-experts. Scriptable for experts.	FMI $\Rightarrow$ <i>Assessment front-end</i>
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...

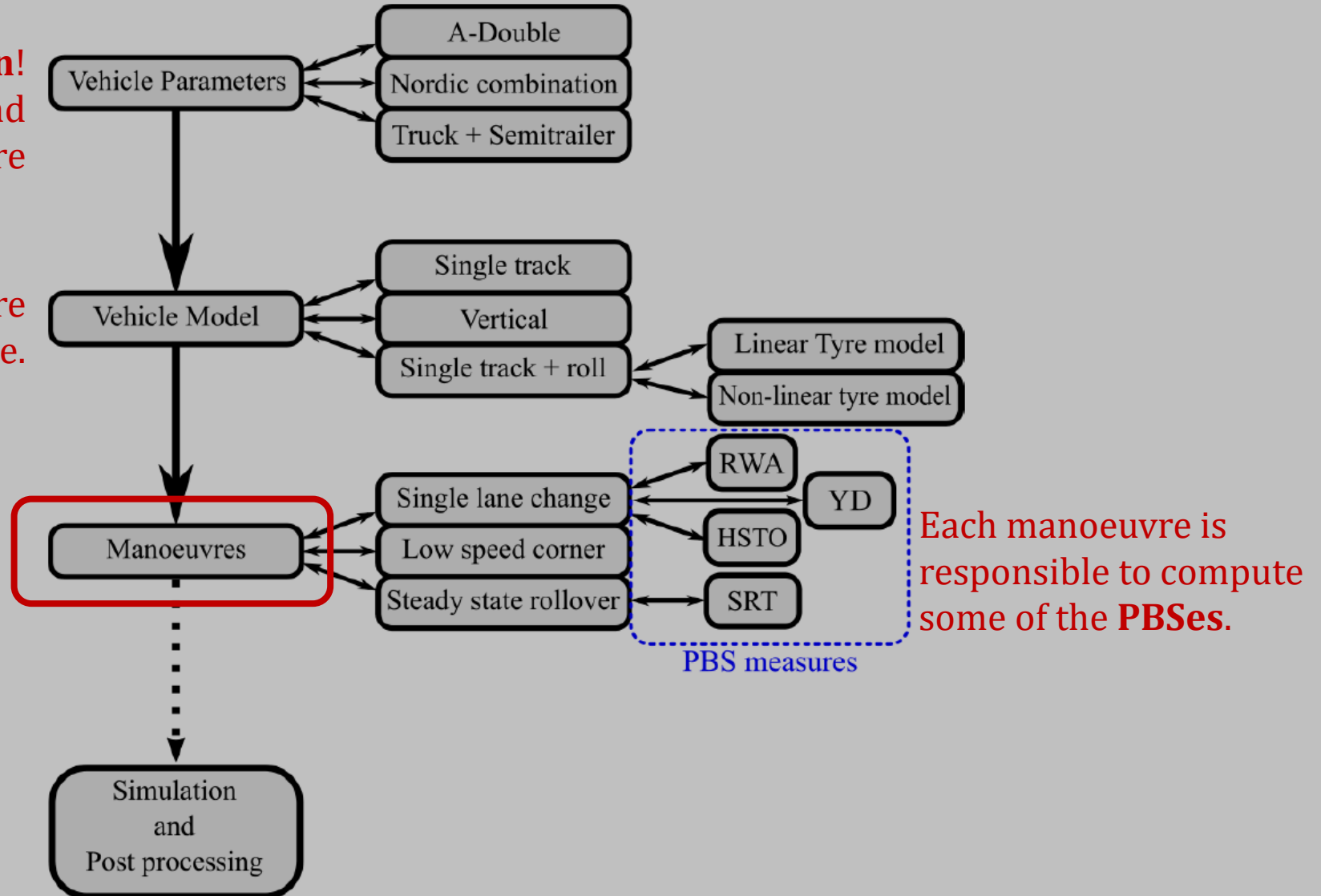


Concepts selected

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

Vectorized models are
used as far as possible.

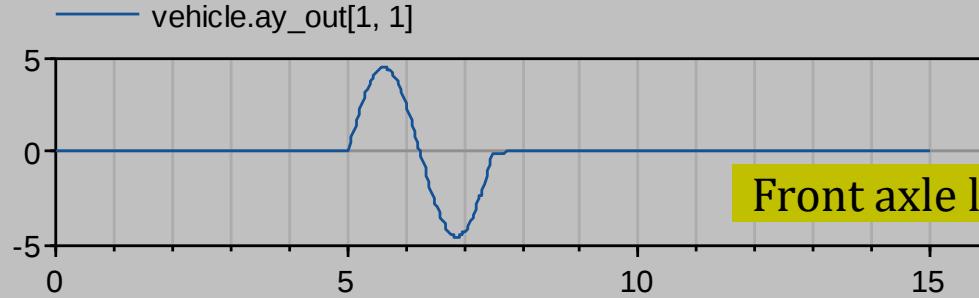
Manoeuvres are the
“simulatable models”.



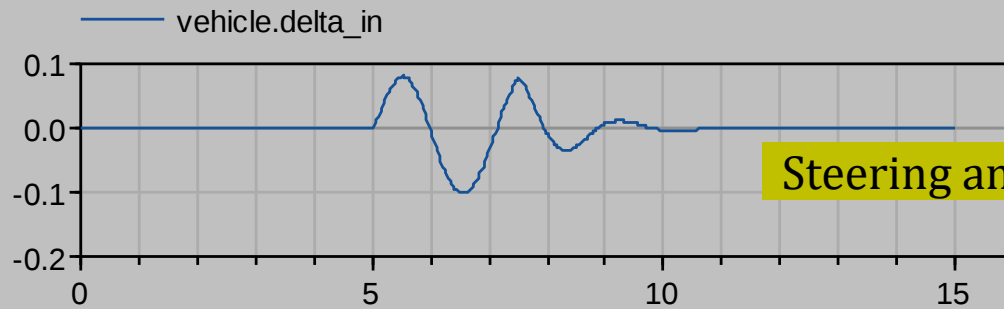
Each manoeuvre is
responsible to compute
some of the **PBSes**.

Figure 2. Overview of how OpenPBS is structured.

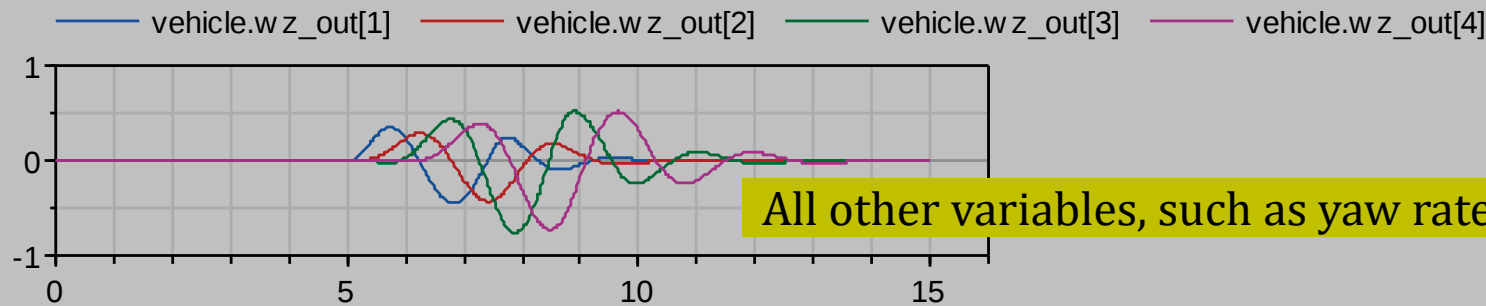
Example: Manoeuvre “High Speed Lane Change”



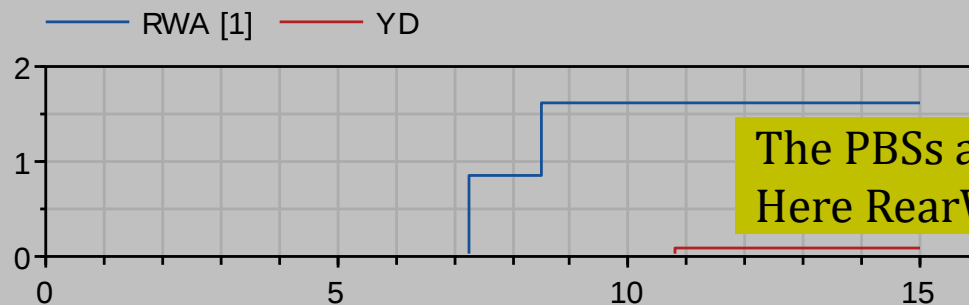
Front axle lateral acceleration is prescribed to exact sinus path



Steering angle is computed (but not of primary interest)



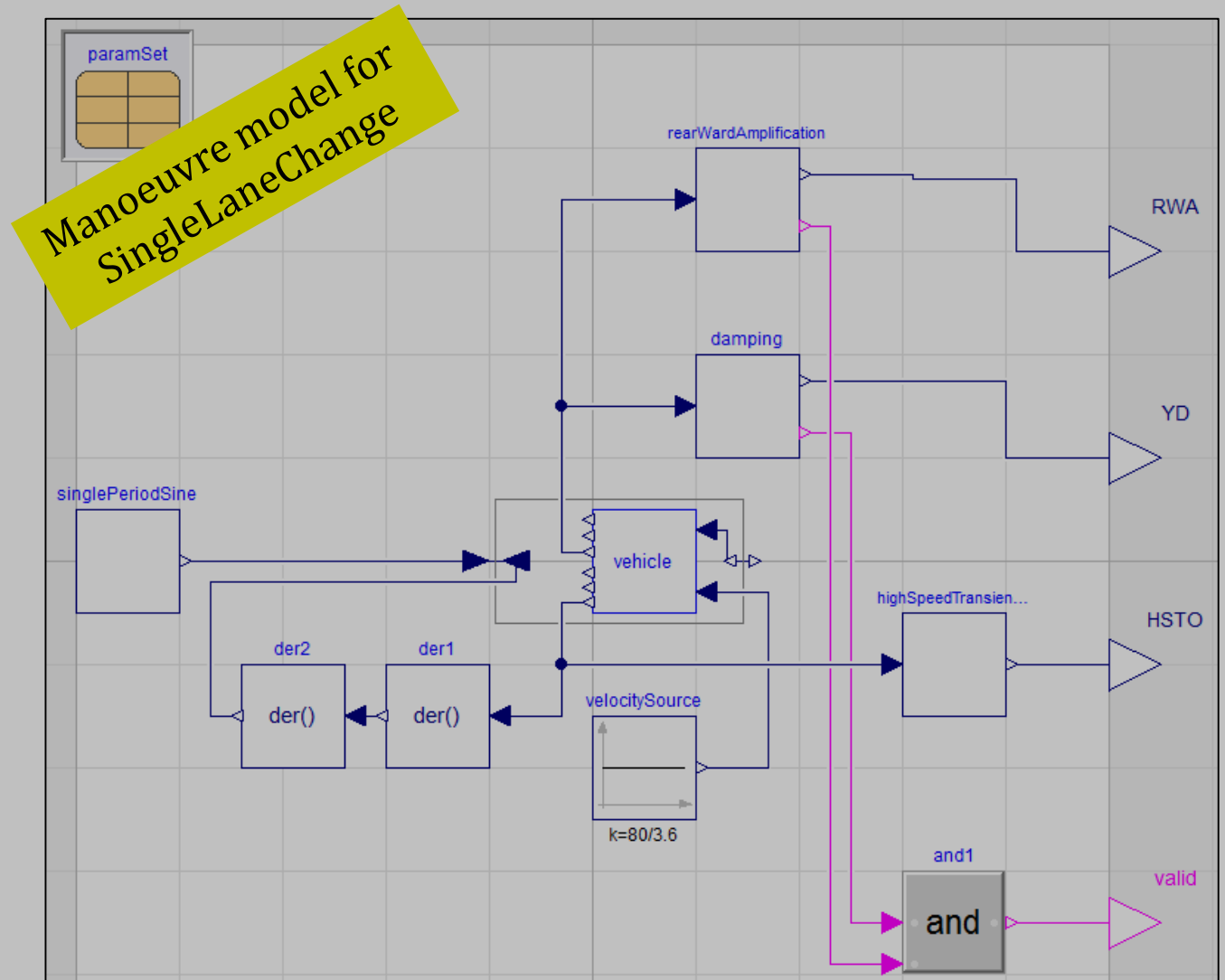
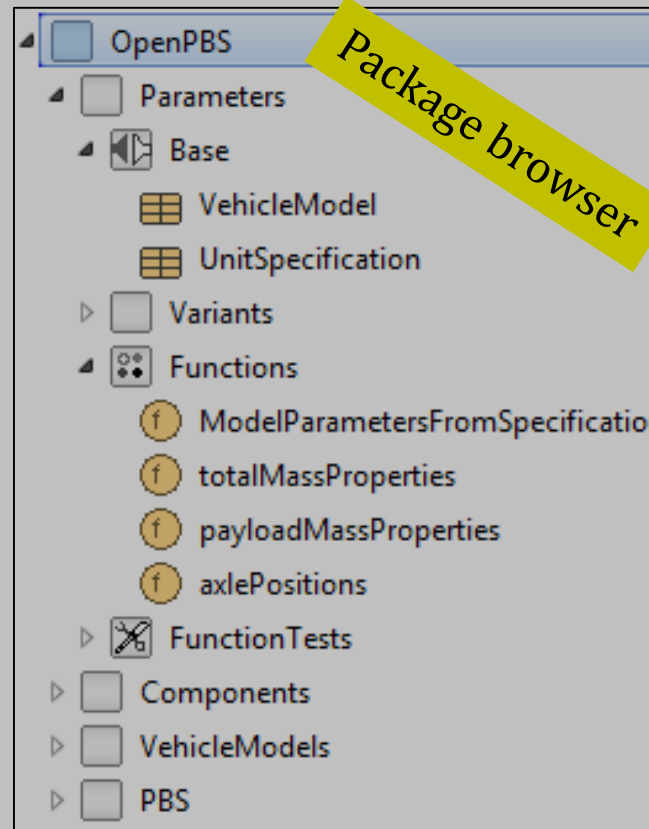
All other variables, such as yaw rates are, of course, also computed



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":

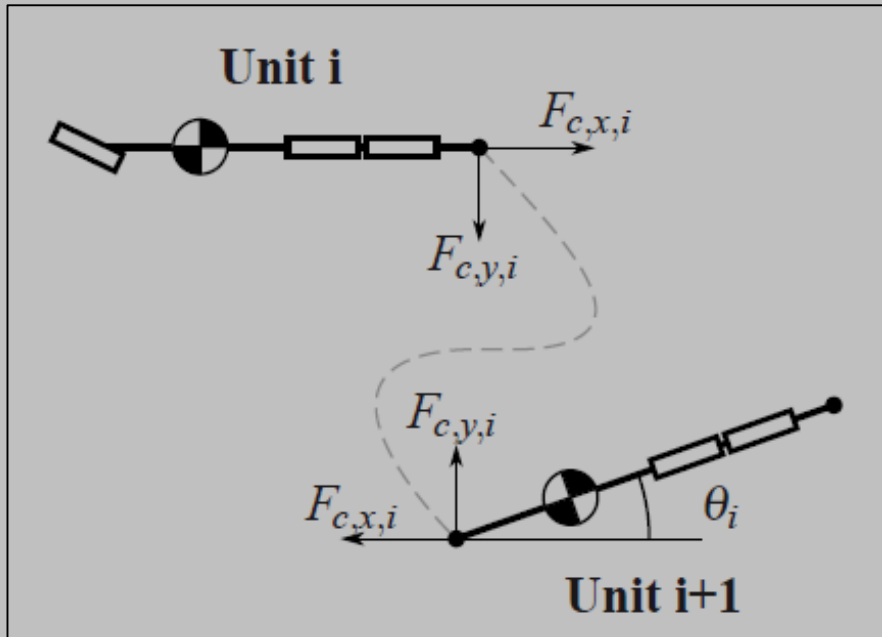


How does a “Vectorised VehicleModel” look?

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]);
```

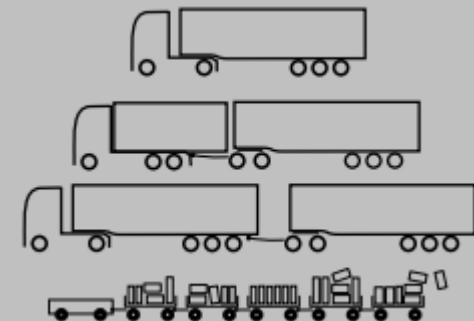
Constitution:

```
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?**