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New exterior design options for improving the efficiency of fully autonomous heavy duty vehicles

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Introduction

Current situation on vehicle emissions

- Despite improvements in engine and exhaust technology absolute carbon dioxide emissions increased by 22% over the past 23 years due to the rising numbers of commercial vehicles in Germany¹
- fully autonomous driving can also further reduce vehicle emissions and has potentials for increasing road safety and fighting the driver shortage

27,1%

Heavy duty vehicles share on CO₂ emissions in the transport sector in the EU

[CO₂-Emissionen von Pkw: Zahlen und Fakten \(Infografik\) | Aktuelles | Europäisches Parlament \(europa.eu\)](#)

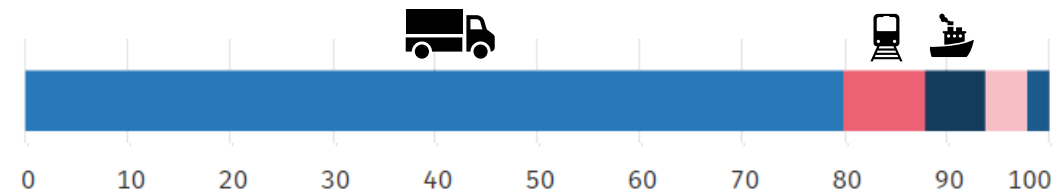
3.1 billion t

Inland road conveyance volume in Germany 2020

[Güterverkehr - Statistisches Bundesamt \(destatis.de\)](#)

80%

share of road traffic in transport volume (Germany 2020)



transport volume (Germany 2020)

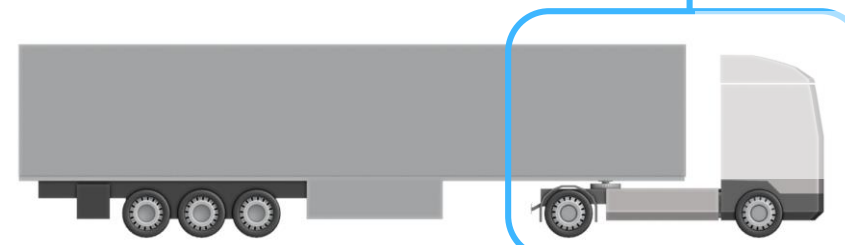
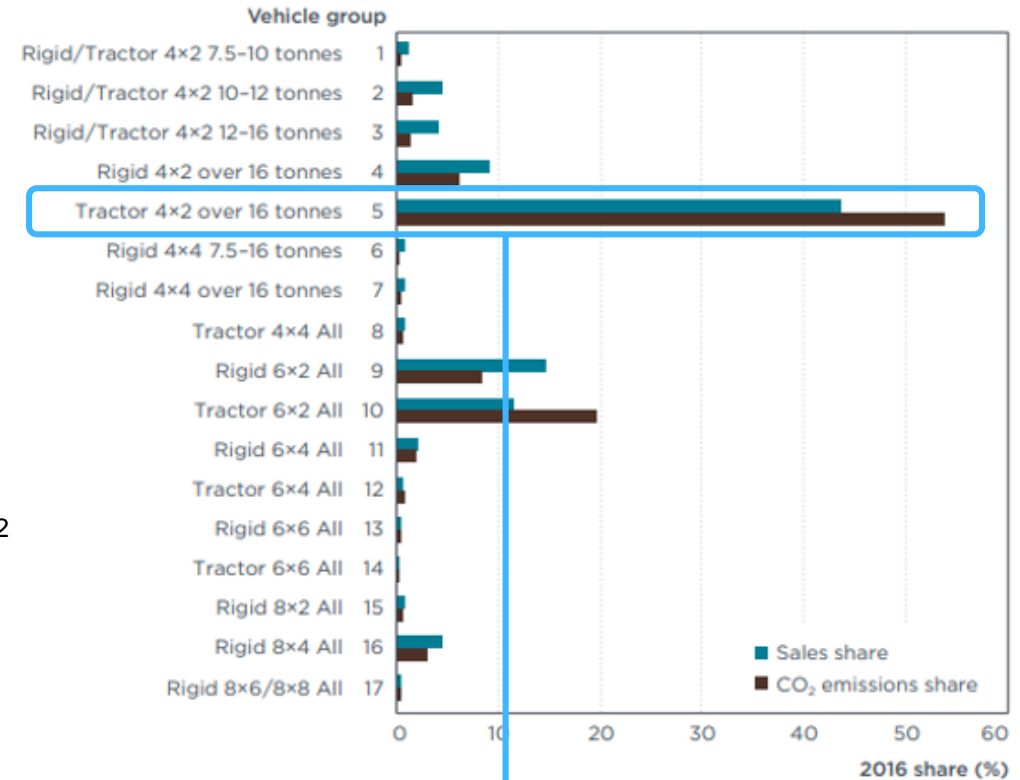
https://www.destatis.de/DE/Themen/Branchen-Unternehmen/Transport-Verkehr/Gueterverkehr/_inhalt.html#235066

¹ Statistisches Bundesamt, Güterverkehr -Beförderungsmenge und Beförderungsleistung nach Verkehrsträgern. [Online]. Available: <https://www.destatis.de/DE/Themen/Branchen-Unternehmen/Transport-Verkehr/Gueterverkehr/Tabellen/gueterbefoerderung-1r.html> (accessed: Oct. 11 2022).

Methodological approach

Vehicle selection

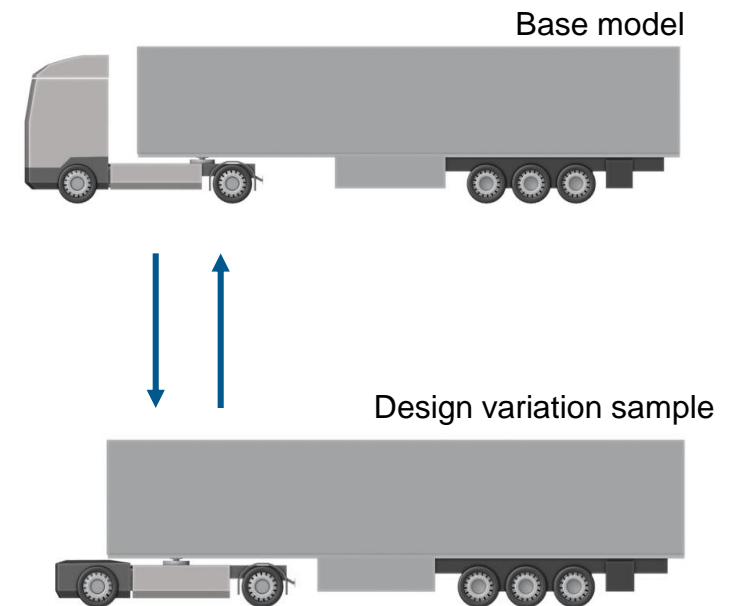
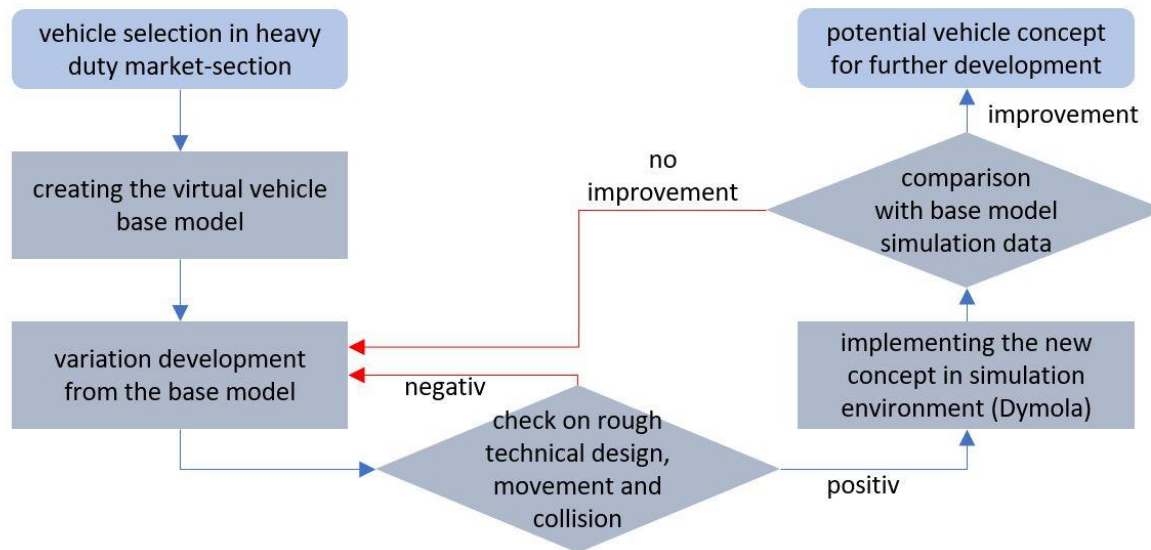
- Based on the grouping of the Commission Regulation (EU) 2017/2400 the vehicle selection was narrowed down to a smaller group of tractor units
- Mostly used shape in Europe is the cab-over box form, in which the driver's cab is located above the engine
- Group of 4x2 tractor units is responsible for the largest share of CO₂ emissions and sold vehicles in the heavy duty segment
- The most frequently recorded combination on the german highway was the 3-axle semitrailer¹ together with the tractor unit – so it was chosen as the reference model for the investigations
- The vehicle reference model will be assumed to be fully autonomous – therefore the drivers cab can be eliminated



International Council on Clean Transportation Europe. Fuel Efficiency Technology in European Heavy-Duty Vehicles: Baseline and Potential for the 2020–2030 Time Frame. 2017.

Methodological approach Design development

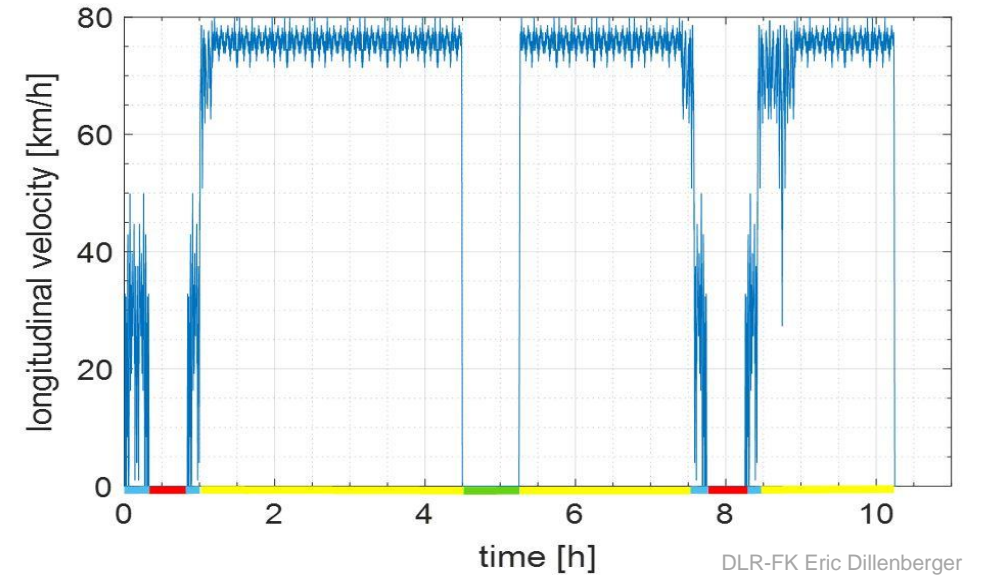
- reference long haul truck (5-LH, Long Haul; 4x2) was modeled as a virtual package shell vehicle model
- New design iterations are developed on top of the base model and could directly be checked for movement and collision control



Methodological approach

Vehicle powertrain simulation

- For the simulation a battery-electric-vehicle (BEV) powertrain is created with a daycycle generated from the FIGE cycle
- FIGE-daycycle information:
 - persists of 3 sections with regional, rural and interregional travel profiles
 - represents a typical journey of an HDV during a whole day with a distance of 581 km
 - Runs over a period of 10:15 h with a driving time of 9 hours
 - a share of 2:20 h is performed as empty trips (share of 25.8%)
- Only the vehicle longitudinal dynamics are considered in the simulation - rolling resistance, air resistance and acceleration resistance were included



Results

General concepts

- General concepts for optimization are based on the assumption that the driver's cab is eliminated by the assumed SAE Lvl. 5 full automation of the tractor unit

1. Concept - use of the cabin space

- coupling (Kingpin) for the semitrailer is moved further forward on the tractor unit
- tractor unit can theoretically be positioned up to 100% below the semitrailer
- cab space could be used as extended cargo space

2. Reducing the height of the semitrailer design of the tarpaulin body

- growing share of empty runs, which in 2016 was 58.5% or 23% of the distance traveled in freight transport

Stefan Dörfelt, Leerkilometer und Leerfahrten - Wie man sie reduziert und vermeidet.
[Online]. Available: <https://www.mm-logistik.vogel.de/leerkilometer-und-leerfahrten--wie-man-sie-reduziert-und-vermeidet-a-673353>

Results

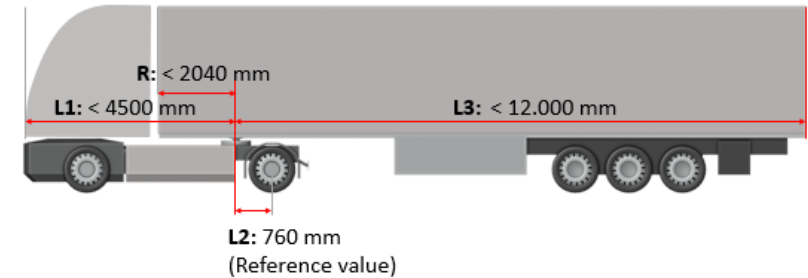
Concept 1

Option 1:

- Extending the cargo area to the front of the tractor unit
 - Existing restrictions from EU directives (Directive [96/53/EC]; [EU 2015/719])
 - maximum of 2040 mm swivel radius over the tractor unit
- Application of aerodynamic guiding surfaces in place of the drivers cabin
- Space under the aerodynamic structure is usable as packaging space for autonomous control systems or powertrain components

abbreviation	description
R	trailer swivel radius
VL	vehicle length
L1	measure vehicle front to fifth wheel
L2	measure fifth wheel to tractor unit rear axle
L3	measure fifth wheel to trailer rear end

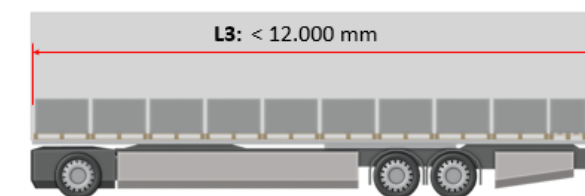
SAE5-vehicle base with aerodynamic cover: dimensional restrictions according to StVZO (Directive 96/53EG) and EU Directive



SAE5-vehicle with extended trailer



Autonomous rigid lorry version (29 pallet spaces)



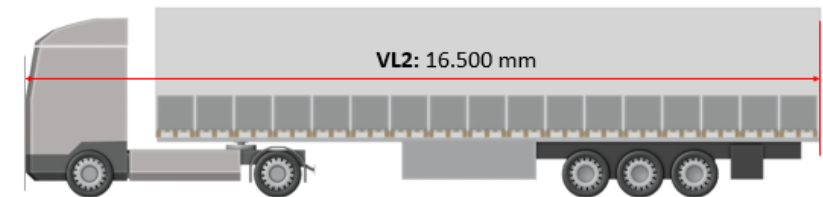
Results

Concept 1

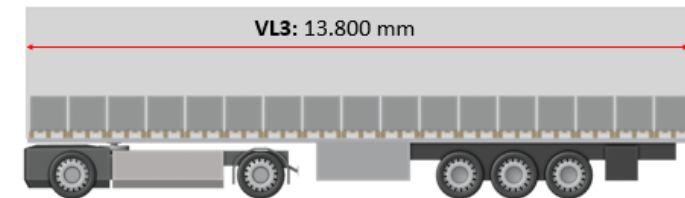
Option 2:

- inserting the tractor under the trailer and shortening the vehicle of up to 2460mm
 - Retracting the position of the tractor unit can reduce the turning circle of the semitrailer truck
 - A central positioning of the coupling point on the x-axis of the tractor unit would allow for versatile driving maneuvers
 - this has a significant negative impact on the stability and driving dynamics of the vehicle due to a shifted weight distribution and axle loads
 - aerodynamic guiding surfaces would have to be provided directly at the front of the trailer, especially for long haul transport

SAE5-vehicle base: dimensional restrictions according to StVZO (Directive 96/53EG) and EU Directive (34 pallet spaces)



SAE5-vehicle shorter version with retracted tractor unit (34 pallet spaces)

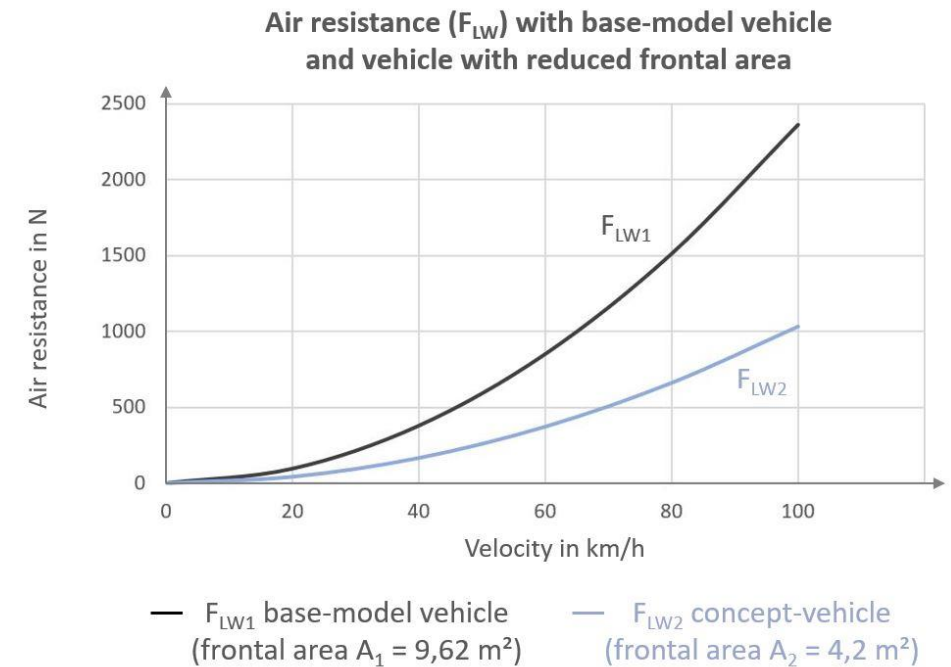
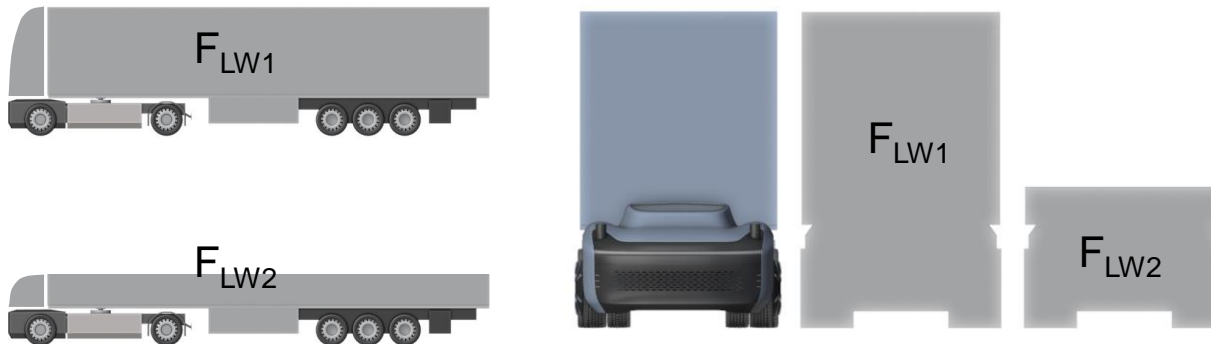


abbreviation	description
VL2	Semitrailer maximum length (EU-Richtlinie 96/53/EG)
VL3	Length SAE5-vehicle shorter version and correct swivel radius

Results

Concept 2

- reducing the height of the semitrailer design of the tarpaulin body to minimize energy losses through air resistance during an empty run
- by eliminating the driver's cab, the frontal area of a fully automated semitrailer tractor, for example, could be more than halved from 9.8m² to 4.2m²
- this would allow a theoretical reduction in aerodynamic drag of more than 50% to 660,6 N (at 80 km/h)

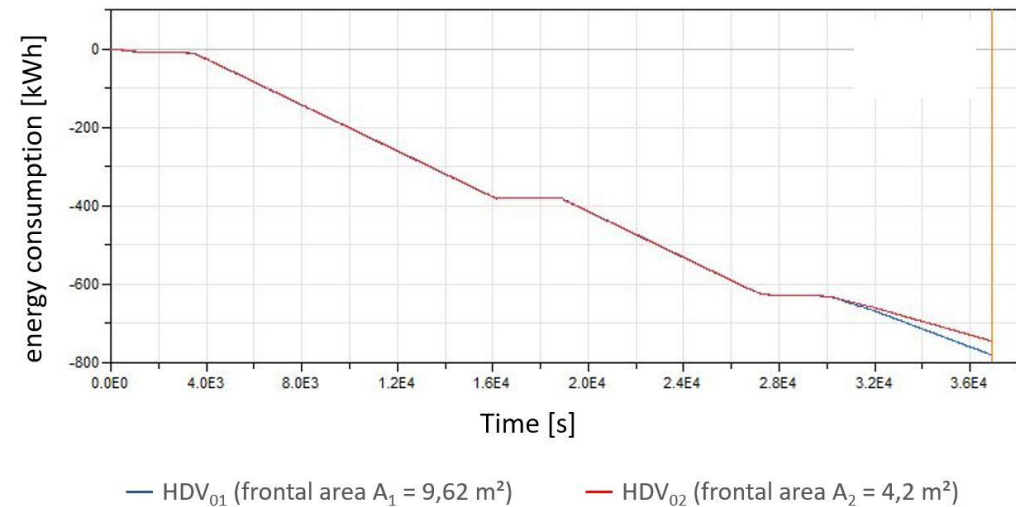


Results

Concept 2

- The reference semitrailer (frontal area: $A_1=9.8 \text{ m}^2$; $c_w=0.52$) is compared with the optimized variation via the created FIGE cycle
- Over the route sections without loading (2,33 h from 9 h total daily driving time), this results in an overall saving of 35.6 kWh (4.57 %)
- The value is strongly dependent on the driving profile and the loading condition

Attribute	Base model HDRT	Optimized HDRT
Frontal area	9.8m ²	4.2m ²
Cw	0.52	0.42
Total Energy consumption (FIGE)	778 kWh	743 kWh



Conclusion

HDRT exterior design options

- Due to existing regulations, only a minor increasing of the loading area over the tractor unit can be realized
 - more effectively with rigid lorry trucks (no trailer-swivel radius)
- Possible reduction in energy consumption of up to 4.6% on autonomous trucks with no driver cabin through lowering the tarpaulin body during empty runs
 - measures are highly dependent on the associated route shares in urban, regional or interregional traffic areas
 - on long-distance trips at a higher speed range it could be an additional option to improve the aerodynamics of the semitrailer trucks with appropriate covers in place of the driver's cab
- Detailed aerodynamic design of aerodynamic covers and their cost-benefit ratio would need to be investigated in further studies



Thank you for your attention!

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