Automotive and
Traffic Systems Technology

VDI-Berichte 2350

15th International Conference

Commercial Vehicles 2019

– Truck, Bus, Van, Trailer –

June 4 – 5, 2019, Baden-Baden, Germany

Source: © Milano Medien GmbH

VDI-BERICHTE

Editor:

VDI Wissensforum GmbH

Bibliographic information published by the Deutsche Nationalbibliothek (German National Library)
The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliographie (German National Bibliography); detailed bibliographic data is available via Internet at www.dnb.de.

The VDI report, which contains the presentations of the conference, appears as unedited manuscript print.
The individual contributions give the views and experiences of the respective participants based on personal insights lecturers or authors again. Printed in Germany.

ISSN 0083-5560
ISBN 978-3-18-092350-5

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Electric buses in Cologne
Present state and perspective of KVB's electric buses

Our plan for the complete transition of the bus fleet

Dipl.-Ing. **Jörn Schwarze,** Kölner Verkehrs-Betriebe AG, Cologne

Abstract

Kölner Verkehrs-Betriebe AG (KVB) was among the first public transport companies in Germany to operate electric buses. The present small fleet of electric buses serves line 133 between “Breslauer Platz” at the Cologne Main Station and “Zollstock Südfriedhof” in the periphery of the inner city (altogether about 14 kilometres). The drive and the auxiliary consumers of these electric buses are supplied with power by the batteries, which are charged by green electricity. Thanks to this design the amount of emitted carbon dioxide (CO_2) is reduced by 520 tons per year. Right from the beginning, the operation of the electric buses was based on the real traffic in big cities, inclusive of all disturbances and the necessity of frequent recharging of the batteries. Meanwhile the project has been significantly further developed.

Development until now

KVB's electric bus project has developed dynamically. On 11 July 2014 the contract for purchase of eight electric buses for line 133 with the bus manufacturer VDL Bus & Coach bv was signed. On 12 August 2014 Michael Groschek, then Minister of Building, Housing, Urban Planning and Transport of the Federal State of North Rhine-Westphalia (NRW), signed the allocation decision of 1.92 million euros, which was the official subsidy for the investment in the eight battery-electric buses. One articulated battery-electric bus cost 696,000 euros, i.e. more than twice as much as one articulated diesel-powered bus, which only cost about 300 000 – 330 000 euros. To improve the operation of electric buses on line 133 a ninth electric bus was purchased later.

At the Global Public Transport Summit of the UITP, the International Association of Public Transport, in Milan from 8 – 10 June 2015 VDL Bus & Coach presented the first fully electric articulated bus. A little later, on 26 October 2015, the first vehicle of the electric bus fleet was officially handed over to the KVB by VDL.

On 27 January 2016 the first electric bus was recharged along its route with charging infrastructure provided by RheinEnergie AG. The batteries of the buses are boost-charged with 140 kW during the daily operation each time the buses reach the terminal stops of the line and are fully charged in the North depot overnight with 50 kW so that the buses take up service with full battery capacity in the morning.

Exchange of experience: On 29 January 2016 Dr Barbara Hendricks, then Federal Minister for the Environment, visited the KVB. At this event, in which about 120 representatives from policy, economy, media and public transport companies participated, the minister emphasized the importance of innovative projects for the protection of the climate and the environment.

Since 5 September 2016 the first electric buses have performed line service on bus line 133. By then, the multistage test programme was so successful that it was possible to go ahead with the last phase of the programme. On 3 December 2016 the KVB shifted from diesel-powered buses to electric buses on line 133. Since then, up to eight electric buses are operated daily on this line.

Fig. 1: Linie 133 [Source: Stephan Anemüller / KVB]

The successful transition of line 133 spurred the KVB on to further develop the operation of electric buses. Already on 15 February 2017 the KVB announced that the company intends to expand its operation of electric buses. By 2021 another six bus lines in Cologne are to be served by electric buses. Meanwhile, the company has also decided that the six lines will be the lines 141, 145, 149, 150, 153 and 159.

On 4 December 2017 Hendrik Wüst, Minister of Transport of NRW, handed over the allocation decision of 13.28 million euros for the purchase of 53 electric buses. Thus, the Federal State of NRW pays 60 % of the additional costs that arise in comparison with the purchase of diesel-powered buses. The call for tenders concerning the purchase of these 53 additional (standard or articulated) electric buses was published at the beginning of December 2018.

Benefit from the exchange of experiences

Without the financial support of the State of North Rhine-Westphalia the KVB would neither have been able to electrify line 133 nor would the company be able to electrify another six lines with 53 electric buses by 2021. The Ministry of Transport of NRW has already allocated as much as 15 million euros to the projects. The KVB regards this allocation as an obligation to share its experiences with other public transport companies so that they can also profit from KVB's experiences in their projects.

Thus, groups from many regions of Germany as well as from abroad have already visited the KVB to inform themselves about KVB's electric bus project. The visitors wanted to hear about the reliability of the buses, the charging infrastructure concept, the experiences with the batteries, the handling of the general operating conditions, the requirements for the workshop staff etc.

The KVB also profits from the experiences of other public transport companies. The Association of German Transport Companies (VDV) has set up a group of experts, in which the challenges, possible solutions and the experiences are openly discussed. The KVB has been a member of this group from the start.

KVB offers a functioning solution

Each day the KVB shows that it is possible to operate battery-electric buses and to realise “double charging” of their batteries, i.e. overnight charging in the depot and boost charging during the day at the terminal stops of the line. The eight electric buses that are operated on KVB’s line 133 between “Breslauer Platz” and “Zollstock” are very reliable. At present, KVB’s electric bus fleet is the biggest within German public transport. The KVB was also the first company in Europe that operated electric articulated buses. The call for tenders concerning the purchase of the 53 electric buses that are needed for the next development stage was published at the beginning of December 2018. It is the intention that all KVB’s bus lines are served by electric buses by 2030.

Reasons for the success

The success is a result of the following three important principles: start early, work out the details thoroughly and rethink the network.

The KVB has dealt with the subject of electric bus operation for more than six years. Thus, the KVB began thinking about and planning its far-reaching modified bus operation before the politicians and the urban society took up the problems of the ambient air quality plan. The transition of line 133 to electric operation in December 2016 also mainly followed at the initiative of the KVB, but this step was honoured by many representatives from policy, economy and media and by the residents.

Nowadays many people call for the end of the operation of internal combustion engines due to the threatening ban on driving diesel-powered vehicles, which makes it clear how important and meaningful it was to start the electric bus project early. The KVB would probably be in big trouble today due to the public pressure if it had not started this project early as it is impossible to introduce such technology in the workshop and bring it onto the road at a “push of a button”. To aggravate the situation, it is also impossible to buy electric buses “off-the peg”.

The KVB has also learned that it takes time to introduce, establish and then expand electric mobility. Each step took a long time and demanded much attention – which will also be the case in the planned expansion phases. Thus, it is the intention to e.g. visit the manufacturer's plant and to see each electric bus through the test phase.

The decisive factor is always that the passengers are transported reliably, safely and comfortably from A to B, which means that the operated vehicles always have to function. Nobody will understand that it is necessary to change buses because e.g. the technology is not reliable. The passengers and the media closely observe the development.

Fig. 2: The requirements for the workshop changes: Requirements for "soft engineering with software" are added to the requirements for "hard engineering with big tools" [Source: Stephan Anemüller / KVB]

The high quality that is a must in such comprehensive projects can only be realised if all details are considered, well planned and intensively dealt with in the implementation phase. It is often the little things that cause the problems and bring the bus to an – unnecessary – halt. That is the big challenge that the experts have to cope with (often in addition to their usual daily tasks). The challenges of the electric bus are its technology, its charging infrastructure and its operation under city conditions. If one these three factors are neglected, the overall success is at risk.

And: To successfully change the vehicle technology and the technical equipment needed for the operation of electric buses, it is important to free oneself from the usual approaches. Many aspects require creativity. And many very different professional groups have to co-operate to ensure the success. Thus, neither electric power supply nor charging infrastructure along the route were relevant by the operation of conventional buses.

The success is only possible if the vehicle manufacturer, the suppliers of technical equipment, the power supply utility, the schedulers, the operating controllers and scientists co-operate closely. It is advisable to set up new networks because electric mobility differs somewhat from the mobility by way of conventional diesel-powered buses. The workshop staff, the drivers and the operating controllers have also had to learn this.

Future call for tenders

Above all, the KVB has learned that the transition to operation of electric buses is a system change. This fact was not sufficiently considered as the first electric buses were put into service, which became apparent in small details. An example is the higher number of components on the roof of the bus and thus the higher number of feedthroughs through the roof structure. If this detail is not considered by the manufacture of the bus, water might penetrate into it. Another example is the technical concept of the bus system. If it is considerably modified within the scope of the manufacture, the complete software has to be adapted, i.e. from the internal bus control system to the communication of the bus with the charging infrastructure. In Cologne many of the problems that the KVB had as the electric buses were put into service arose because the real state and the state mapped in the software differed, e.g. in respect of time.

Most of these problems were solved without affecting the passengers. The co-operation with a manufacturer who was able to quickly present and realise a solution to a technical problem proved its worth.

The KVB is convinced that the on-going operation of electric buses on line 133 is a great success, but nevertheless the company intends to more intensively supervise the manufacture of next electric buses to be ordered. Particular focus will also be on the quality of the software to be developed.

Charging infrastructure along the route

As the present call for tenders is for 53 electric buses to be operated on other lines, additional charging infrastructure also has to be set up. Therefore, the parties involved, i.e. the KVB, RheinEnergie AG and the City of Cologne, are preparing a standardised procedure for economic and fast set-up of the charging infrastructure. As soon as it is known who is going to provide the charging infrastructure, a final test, which will consider the specific conditions on the spot, will be made. Thereafter, the planning will be completed and released. The project partners hope that this procedure makes it possible to realise relatively short implementation times for the charging infrastructure along the lines.

Depots

The KVB wants to increase its bus transport offer this year. Therefore, the bus fleet will grow by 30 buses. The charging infrastructure in the bus depots also has to be developed, which reduces the number of parking spaces for buses in the depots. Thus, the capacity of the North depot will be reduced by about 20 buses.

Fig. 3: The charging infrastructure for the eight electric buses has been set up at one side of the depot, but a bus fleet with more than 50 electric buses requires much more space in the depot. [Source: KVB]

Consequently, the KVB has decided to build a new depot, which will be strategically situated to the southeast of Cologne and have a capacity for about 110 electric buses. This area is so big that it is also easily possible to build a workshop for the maintenance of the buses and a building yard for the rail infrastructure. Moreover, a substation for RheinEnergie AG can be integrated, if necessary.

All in all, the KVB is well prepared for the complete transition of its bus fleet to electric buses by about 2030.

The Mercedes-Benz eCitaro

A modular concept for sustainable electro mobility in city bus operations

Dipl.-Ing. (BA) **Daniel Vorgerd**, EvoBus GmbH, Mannheim

Abstract

The transition of public transit to emission free city buses needs a new evaluation of vehicle concept requirements. Based on the analysis of select customer operations it is obvious that boundary conditions differ a lot. This concerns infrastructure, operation and required range. As a consequence different technical approaches, as well as new key technologies are needed to deliver suitable solutions for customer relevant operations.

The Mercedes-Benz eCitaro [Fig.1] is an innovative fully electric bus that fulfils this wide range of customer requirements. The intelligent modular concept allows for a high degree of flexibility in terms of charging technology, battery technology and a fuel cell application. The charging options consist of plug charging and high power opportunity charging. The battery strategy contains two technological options with NMC or innovative solid-state technology.

Besides a high energy capacity, an optimized energy consumption is necessary to ensure the achievement of high range demands. Furthermore, the especially critical energy requirements in winter and summer need to be considered. Thus, the development of an efficient thermal management concept has played a major role. This contains a number of innovative measures such as a CO2-operated heat pump as well as a sophisticated pre-conditioning functionality. With all its technological innovations the Mercedes-Benz is a future-proofed fully electric bus that fulfills the requirements associated with emission free public transit.

Fig. 1: Mercedes-Benz eCitaro

Vehicle concept

When starting the concept design of the new fully electric city bus from Mercedes-Benz one major requirement was to develop a series product. The new product needed not only to be locally emission-free. It also had to cover all major customer requirements and needed to be as a reliable as a conventional city bus.

As a result the Mercedes-Benz eCitaro is closely linked to the proven city bus platform Citaro. The frame structure is almost identical. Minor modifications were necessary considering the higher load of the battery mass. The battery packs and relevant technological components are situated on the roof and in the rear allowing for optimum weight distribution. [Fig. 2] The integration is accomplished via pre-assembled technology modules thus making it possible to fully integrate the eCitaro in to the conventional production line. In order to ensure passenger capacity demands an 8 ton front axle has been developed. It allows for full use of the legal limit of 19.5 tons gross vehicle weight rating.

Fig. 2: Integration of key technology

The basis of the eCitaro's drive system is provided by an electric portal axle with electric motors at the wheel hubs. The peak output of the motors is 2 x 125 kW, while torque is 2 x 485 Nm. It is an inherent feature of such motors that this power is fully available right from the start. Thus, dynamic performance is ensured even with a full complement of passengers.

Besides good driving performance another major target for the electric drivetrain has been the optimisation of energy consumption. For example the electronic drive control and corresponding brake management functionality have been completely new designed in order to achieve the maximum possible electric recuperation energy during deceleration phases.

Thermal management

For electric buses the ambient conditions have far more relevance for the operational range compared to a conventional diesel bus. As operators need to rely on the bus all-year round the huge impact of electric heating in winter and air conditioning in summer on energy consumption needs to be considered [fig. 3]. These latter conditions are crucial in order for buses to operate efficiently. That is why when developing the eCitaro, special emphasis was placed on reducing energy consumption in “borderline operation” scenarios. Only on this basis can the available battery capacity be partitioned in a way that ensures critical functional demands are met.

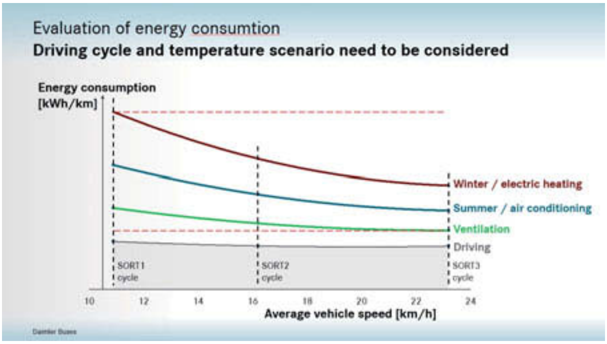


Fig. 3: Energy consumption

At high exterior temperatures, energy consumption increases considerably with air conditioning of the interior. At below-zero temperatures, the result is even more challenging less efficient: at an exterior temperature of -10 °C, the energy consumption of a city bus can more than double. In general, a battery-electric bus is estimated to consume approximately 1 kWh/km of energy for the vehicle drive and auxiliary units. In harsh winters, the consumption can rise to about 2 kWh/km, thus halving the range.

When considering the full range of operational demands; thermal management is one of the key technological features of the battery-driven eCitaro. Therefore, mastering this represented one of the core development tasks. After all, it is not enough to piece together components supplied by different sources. For maximum function and energy efficiency, a perfect combination of all parts is required. The basis is new components for heating and air conditioning, which became ready for series production with the eCitaro, plus a system of connecting and controlling them. [Fig.4]

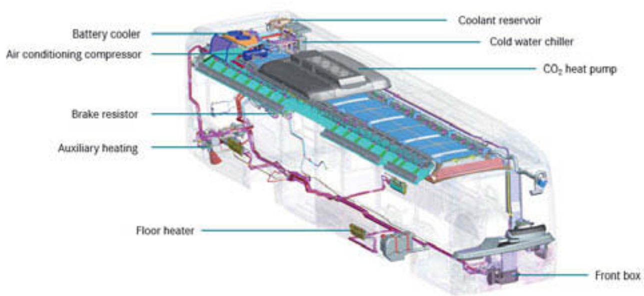


Fig. 4: Components of the thermal management system

Battery cooling is one essential feature. The ideal temperature of approximately 25 °C for the lithium-ion battery is maintained by actively cooling the vicinity of the battery. The result is maximum chargeability, performance and durability of the battery. Cooling is achieved by a separate battery cooling unit on the roof of the bus. If the vehicle's own battery cooling is not adequate at extremely hot outside temperatures, the standard passenger compartment air conditioning contributes to battery cooling.

The basis of air conditioning in the vehicle interior is the standard EvoThermatik Plus roof-mounted air conditioning system, a CO2 air conditioning system with a heat pump. The heat pumps is a source for energy-efficient heating and cooling of the passenger compartment. It uses the physical effect of the transition of a fluid from gas to liquid form and back again. The refrigerant, CO_2 or R-744, enables a particularly efficient use of the heat pump with a high heat exchange, even at very low temperatures down to -10°C

Another heat source is the brake resistor. Its excess heat is used to heat both the passenger compartment and the separately heated driver's cockpit. In addition, if desired, in extreme winter weather, a fuel-driven auxiliary heater can be used at specific times in addition to the eCitaro's HVAC system in order to extend the range.

The thermal management system of the eCitaro also takes into account the number of passengers on board. A seated passenger with an average weight of approximately 75 kg at an ambient temperature of approximately 20 °C gives off about 120 W of surplus heat. In a bus which is half full, this can add up to about 4 to 5 kW. This means that if a bus is occupied, the heating can be reduced somewhat in good time. In addition, the setting of the air conditioning system also varies depending on the number of passengers on board: the proportion of fresh air is adjusted so it is ideal for the current number of passengers. The utilisation rate of the bus is calculated via the axle load sensors.

An important determining factor of the eCitaro thermal management is preconditioning. While the batteries are being charged in the depot, the vehicle interior can be pre- and even over-conditioned to the desired temperature. This preconditioning considerably reduces the energy consumption required for adjusting the temperature in the first kilometers, thus extending the overall range accordingly. Apart from the passenger compartment and driver's cockpit, the batteries of the eCitaro are also preconditioned. This leads to maximum chargeability and efficiency before starting and during operation; for example in recuperation phases.

In addition a revised specification for the passenger compartment temperature reduces energy consumption significantly. The previous constant temperature of 24 °C all year round was replaced by an eco-control. At extreme ambient temperatures, the limits to the level of comfort are slightly lowered in the interests of energy consumption and range. The modification is oriented to the comfort of the passengers, adapted according to the situation. As they generally only spend a short time in the vehicle and they are dressed to suit the season, on summer days the interior temperature is kept slightly higher and on cold days lower.

There is a different strategy when it comes to the driver's workplace: As the bus driver has to spend the entire working time in the bus, the demands on the driver's air conditioning are more exacting. Also, the driver's maximum fitness must be guaranteed at all times. For this reason, the desired temperature is a constant 24 °C regardless of the exterior temperature.

Operational requirements and modularity

In an early stage of the development the requirements for an electric bus in terms of operation were analysed. The target was to define the specification and the optimum degree of modularity that is needed. Other than a conventional diesel bus, an electric bus faces a few specific challenges that require extra attention:

- Range is a limiting factor due to available battery capacity
- Battery technology is evolving quickly
- Charging requirements need to be considered in terms of time and infrastructure

One key finding out of the analysis was that an optimised approach for electric buses needs to consider the whole system including both buses and infrastructure. The boundary conditions have to be considered for each city bus operator individually. Relevant aspects are operating area, line topography, infrastructure and operational processes [Fig. 5].

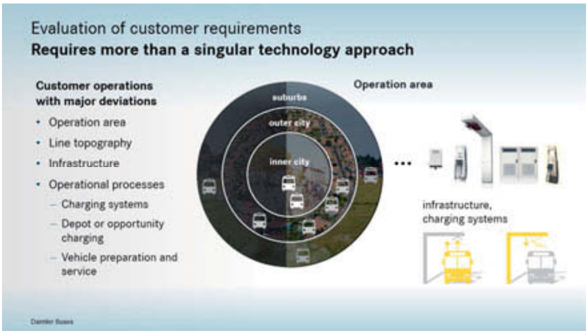


Fig. 5: Operational requirements

It became obvious that there is not one single specification that can cover all the different requirements. As a consequence the eCitaro design is modular and flexible in terms of battery technology and capacity as well as charging technology and power. In addition, the integration of a fuel cell range extender was considered for future deployment.

The rollout of these technologies will be taking place in a stepwise approach [Fig 6]. The main reasons for this approach is on one hand, the availability of the relevant technologies, and on the other hand, time requirements for purposeful testing.

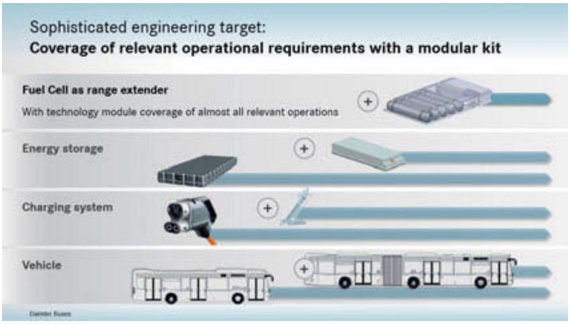


Fig. 6: Rollout plan for technology steps

At the specific vehicle type level the series starts with the 12m Solobus, which is already in operation at several customers. The production of the more complex 18m articulated bus will start in 2020. Both vehicles rely on the same technology and are closely linked by the eCitaro's modular platform.

The eCitaro's charging technology allows it to adjust to the individual wishes and requirements of the transport operators. For the start of series production, only plug-in charging is implemented. To this end, the city bus has a connection for a standardized Combo 2 plug for DC charging. The communication is done based on the ISO 15118 protocol standard. The corresponding DC-charging power is limited to approximately 150 kW.

If, in order to extend the range of the vehicle, there is a requirement for opportunity charging, the full-electric Citaro can also be charged via a pantograph on the roof connecting to a corresponding infrastructure. This option will be available by end of 2019. A second variant will be available later consisting of charging rails on the bus with charging via a fixed-installation pantograph at the charging station. In both cases the equipment will be mounted in a standard space above the front axle on the roof enabling a maxing charging power of approximately 300 kW.

Battery and fuel cell strategy

The core component of the eCitaro is doubtlessly the traction battery. The characteristics of the battery technologies available in general show that there is no single technology fully covering all relevant requirements. Therefore, for the eCitaro a two-technology strategy has been defined. [Fig 7]

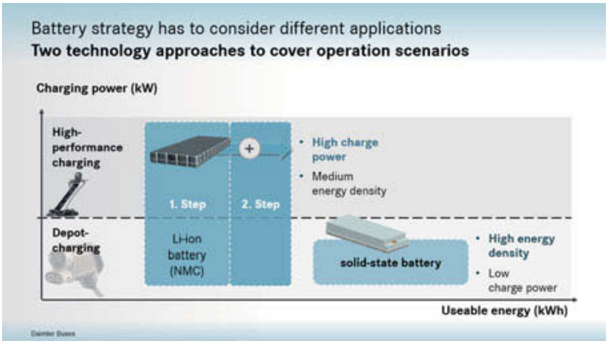


Fig. 7: Battery strategy

From the series start the first generation Lithium-ion batteries based on NMC-technology will be available. A maximum of twelve battery modules can be installed with a total of 292 kWh of battery capacity. Four of them are installed in the rear compartment and eight on the roof. This results in a long range, even in difficult conditions at the height of summer, amounting to around 170 kilometres in accordance with SORT2, without recharging along the route. In ideal conditions, the range can even be as much as about 280 kilometres.

The NMC-technology is able to meet the requirements of both a high energy depot charging operation as well as opportunity charging operations with high charging power. Furthermore, this technology is already in its second generation phase of development. It will supply higher energy and be compatible to the first generation regarding installation space and interfaces.

For even more energy and range the use of lithium-polymer batteries, also referred to as solid-state batteries is one part of the rollout plan. In this case, seven battery packs are sufficient in order to provide a battery capacity of 441 kWh. The maximum charging power is of this configuration is however limited. One positive aspect is that high energy density solid-state batteries have a good lifetime perspective. Thus making it an optimized solution for depot charging [Fig 8]. It will be available in 2020.

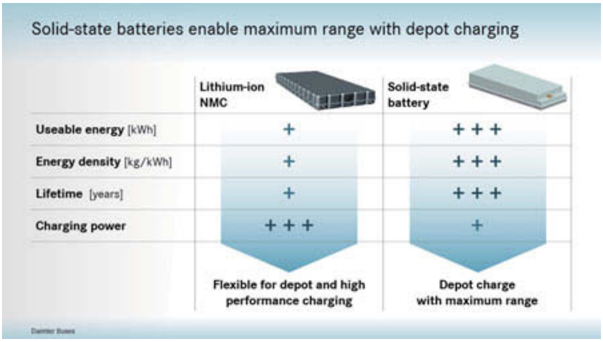


Fig. 8: Comparison of battery technologies

Additionally, with respect to the target of covering 100 percent of all relevant city bus operational requirements with the eCitaro, a fuel-cell range extender is also in development. It is sized to close gap that cannot be covered even with the solid-state batteries. This technology eliminates the need for opportunity charging and the complex infrastructure required for it. [Fig. 9]

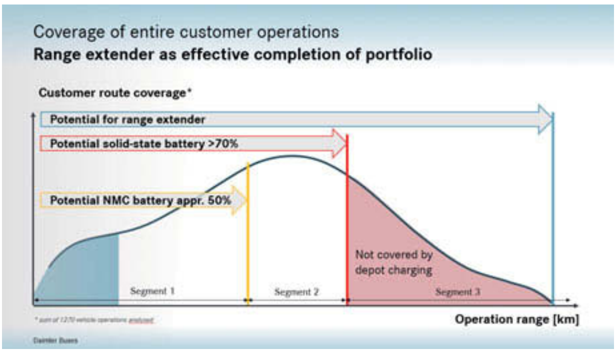


Fig. 9: Coverage of customer operation

Conclusion

The Mercedes-Benz eCitaro is not only emission-free in local use and almost noiseless. It combines the tried and tested platform of the Mercedes-Benz city bus with wide spectrum of new technological solutions. The fully electric bus pushes electro-mobility for city buses to a whole new level. The new eCitaro uses innovative components available just now for the first time ever. The eCitaro will continue to achieve even higher levels of energy efficiency in both comfort and range. The performance of the eCitaro already meets the majority of the public transport companies even at launch.

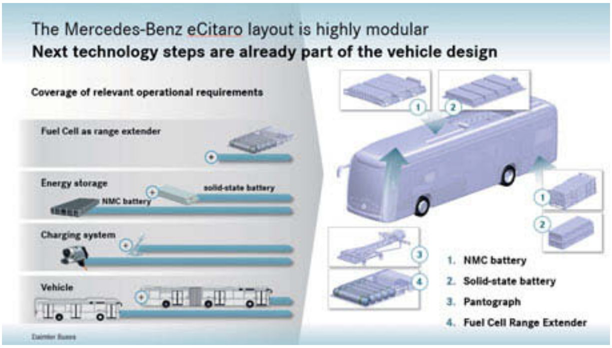


Fig. 10: Modular layout

It is also already prepared for the battery technology of the future and a fuel-cell range-extender. All relevant technologies are an integral part of the eCitaro's design. The intelligent modular concept allows an efficient integration of developing technologies long into the future. [Fig. 10]

The new MAN Lion's City – path-breaking vehicle design concept for more attractive public transport for tomorrow

Carefully structured design as an important element in linking together the complex demands of drivers, passengers and various user groups, operators and bus service experts: the appealing and extremely functional design constitutes a strong basis for the modular construction system of the new MAN city bus

Graduate Designer **Stephan Schönherr**,
MAN Truck & Bus SE, Munich

Abstract

This is what a highly innovative and design prize-winning city bus can look like! The new Lion's City is the variable and flexible base vehicle of MAN' new city bus family with a freely selectable drive concept. As there are diesel, gas, hybrid and electric drivelines, the bus can be powered just as the customer requires. With its modern, high-quality appearance it sets standards in its class. Its dynamic, timeless lines give it a formal independence while expressing its outstanding modular features. New assembly technologies, lightweight construction and new materials save over 800 kg in weight. The exterior is revolutionary in that it is entirely segmented, making it easy to service and paint off-line. The high proportion of glass is both ecological and attractive. Thanks to the Colour & Trim and the innovative lighting concept, including indirect lighting and optional ambience lighting, the disabled-friendly and barrier-free interior appears spacious, inviting and bright. The entire passenger area has an aura of flexible spaciousness and is designed as an integrated whole. Partitions and handrails are attached to the walls, which makes cleaning easier and greatly improves service-friendliness. The ergonomically designed, user-friendly and clearly structured driver's workplace features a convincingly high level of functionality and aesthetics for the driver's wellbeing.

View 1: The Lion’s City family with diesel, gas and electric vehicles

MAN Lion’s City: setting standards for scheduled services

With the new generation of the MAN Lion’s City a completely newly developed city bus is rolling on to the streets of our cities. The new city bus has already gained the admiration of the “iF design award” and “Red Dot Award” juries: the Lion’s City has won the renowned “Red Dot Award: Product Design 2019” and the “iF DESIGN AWARD 2019”. The innovative design concept and its timeless elegance are constantly being given special mention. Numerous technical innovations unite with and support the new MAN bus design language. MAN’s new generation of city buses is characterised by a clear focus on efficiency, economy, comfort, technology and ergonomics in conjunction with a design that is all of a piece.

In setting this focus the Engineering and Design departments were aiming to set new standards for all components. Examples of this are the completely new driveline with the MAN EfficientHybrid, the independent-wheel suspension on the front axle, the LED lighting functions or the new modular interior. The latest MAN Lion’s City thus marks the beginning of a new era and therefore already meets all present and foreseeable legal standards.

The new Lion’s City is even more economical than its predecessor, and with the EfficientHybrid a stop-start function is now possible. Innovative materials and production processes used not

only make the bus look good, but also make it above all lighter and more robust. In addition they improve the ease of operation, for example at the service, maintenance and engine compartment flaps. Another example: the 12-metre version of the new MAN Lion's City has lost 800 kg in weight compared with its predecessor with the old engine generation, changes in equipment thereby being taken into account. This was achieved by, among other things, a newly designed engine compartment flap without a steel frame, thinner glass and a weight-optimised side-wall concept including i.a. visually high-quality side-wall panelling made of polypropylene reinforced with natural fibres.
The new and lighter 9-litre engine, which already meets the future Euro 6d exhaust-gas standard, can as an option be combined with the MAN EfficientHybrid, which makes for a considerable reduction in fuel consumption and emissions.

View 2: The Lion's City G (articulated bus)

Exterior design: an attractive appearance that meets all requirements

From the outside the new city bus undeniably speaks the new MAN bus design language: a modern yet timeless and dynamic design for any urban environment. Its prominent feature is – beside the striking headlights with LED band as daytime driving lights and the typical black

MAN mask with chrome bar and the high-grade MAN insignia – the deep-reaching glass on the sides. Not only does this give the vehicle a dynamic appearance but, as part of the segmented bodywork, it also helps to lower the life-cycle costs (LCC).

View 3: The Lion's City LED daytime running lights and the typical MAN front

The reduced share of coloured panelling parts gives the vehicle a lighter and more restrained appearance. Of course, fewer parts have to be painted as well. The rear too, with its smartphone visuals in the new MAN Lion's City, as already in the new MAN Lion's Coach, is now a distinguishing feature. It also permits simple and generous access to the various driveline components.

A new idea in bus design is the set of panelling modules containing all the variable roof components. In the conventional diesel bus a slim horizontal roof fin section extending from front to rear has been installed. It covers the air-conditioning equipment and its inelegant junction with the bus roof and shields additional roof components from view. For the gas bus configuration there are additional gas tank hoods; these are combined with the roof fins. If a diesel or gas bus is used as a hybrid bus, the roof landscape is supplemented by the very elegant and attractive hybrid hood. With the Lion's City E, the brand-new electric bus, the roof curves are replaced by a higher and modified front roof dome and a set of higher roof fins. Whichever drive concept is used, the bus always retains its dynamic elegance and its unified and stylish appearance.

View 4: The Lion's City with hybrid cover at the rear top

The bus has been given a completely new set of dynamically shaped lightweight external mirror modules designed to optimise the view for the driver. The main and wide-angle mirrors can be configured with an arm extending forwards with integrated view of the front or as short suspended units mounted on the A-post on the right-hand side. On the driver's side short mirrors that are close to the vehicle body are available, either suspended or upright. In this way all wishes of drivers are met in a simple way. For public or private operators with a penchant for aesthetics the outer shells of the mirrors can also be painted in the same colour as the bus body. A designed-in groove on the front mirror cover can, if the customer so requests, be filled with a coloured warning stripe.

View 5: The Lion's City with right wing mirror

A further example of the designers' aim to set standards with the new MAN Lion's City is provided by the headlights and rear lights. MAN is going for LED, and not only for the daytime driving lights. The main headlights are available in full LED for the first time and, together with the LED rear lights, are part of the series fittings. In all lighting functions the LED lamps underline the characteristic design of the new MAN Lion's City and also help to improve safety and cut running costs. This type of lighting is convincing not only in its high energy efficiency with a service life of up to 10,000 hours of operation, but also in its high reliability, which means fewer lamp changes. At the same time the view is improved: with LED lamps the low-beam and high-beam headlights are about 50 % brighter than with halogen bulbs. Beside this the LED light is distributed more broadly and has a significantly longer reach.

View 6: The Lion's City full LED rearlights and function-oriented rear design

With the elegant, smooth doors too MAN has made further improvements to the design and engineering of the new city-bus generation. The doors are now 10 cm wider and feature a harmonious, faster and direct movement. Not only the door panels themselves with grips, actuating functions, fully clad doorposts and covered door function components, but also the stylish rubber door seals slot the doors elegantly into the vehicle's overall design.
All bodywork parts are fitted edge to edge with only small gaps; no projecting part disrupts the impression of smoothness. Cover strips and projecting hinge bands have been dispensed with. The glazing is frameless and flush-bonded. Folding windows of the flash window type are installed only with discreet gaps. All this makes the exterior easier to clean, simplifies attachment of adhesive advertising film and also optimises the streamlining, which issues in an improved cW value.

View 7: The Lion's City sidewall - Smooth surface and cW-optimised sidewalls

Interior design: the best ergonomics , comfort, convenience and safety for bus drivers and passengers alike

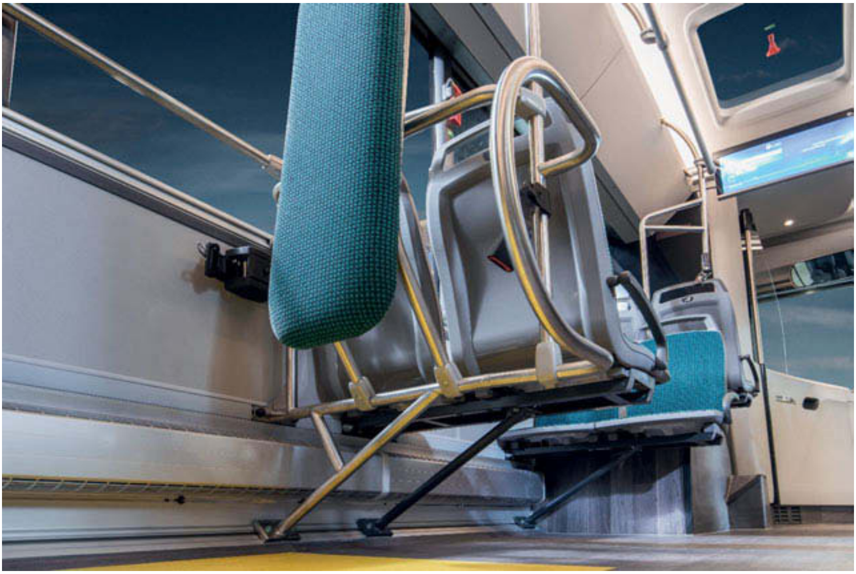
The bus's appealing inside design leaves a lasting impression. With its spacious and light-flooded interior and its modern colour concept the MAN Lion's City ensures a feel-good atmosphere throughout.

Inside the new MAN Lion's City the driver will find a completely revised and optimised workplace which, with the elegant curves of the driver's door and the rear wall, blends perfectly into the vehicle's overall design concept. The focus on ergonomics, convenience and safety has resulted, among other things, in an improvement in user-friendliness through re-arrangement of the switches and instruments. The controls are now divided into three zones according to the frequency of their use, while an optional additional instrument panel on the right caters for installation of further DIN equipment or monitors. The cup holder and the USB slot are in the lateral control panel; additional storage facilities are available too, e.g. in the form of a locker for the driver's bag or a magazine net.

View 8: The Lion's City driver's workplace - safe, versatile and very ergonomic

To improve the ergonomics by way of an optimum sitting position the driver's seat now has a longer horizontal adjustment range. The instrument panel moves synchronously with the movement of the steering wheel. The high-resolution 4" colour display, a series feature, ensures excellent readability. Safety is further improved by the higher seating position for the driver and by the forward-opening driver's door. A modular pane on the driver's door that can be extended up to the windscreen can provide additional protection against attacks. The dashboard, the door with integrated cash-desk function and all panelling around the driver are intended to offer him a professional and attractive workplace.

The new passenger seat concept with optimised spacing and stylish seats mounted on unobtrusive rails at the side both creates more space and makes cleaning of the interior an easier matter. With the help of adapters any other shell seats can be fitted simply and flexibly.



View 9: The Lion's City Seat and Handle Bar Mount on the Wall

Even standing passengers do not have to go without comfort and safety: the design-integrated overhead handrails with oval cross-section and a set of handrail modules are both attractive and provide a more ergonomic grip. Full-glass partitions do not disturb the feeling of space, let light into all corners, split up the interior into functional areas and provide protection from draughts etc.

View 10: The Lion's City handrail concept - A modular system for every application

Modern LED lighting technology with the emphasis on design is used in the interior too. The warm white LED lighting, on request available from front to rear, is indirect and elegantly unobtrusive and falls from above like sunlight. This, together with the optional ambience lighting available in many colours, conveys an evenly distributed, modern, dynamic light design in different accents and shades of colour. Particular attention was paid in the design to eliminating reflections in order to reduce glare for passengers and the driver to a minimum.

View 11: Lion's City LED Indoor Lighting - Indirect and with ambience option

Colour & Trim design concept: feel-good atmosphere for passengers of all sizes and ages

Both the passengers and the driver should feel at ease in the Lion's City and like using the bus. To this end a new Colour & Trim significantly enhances the interior, underlining its bright, friendly and visually spacious character. The new colour concept serves to achieve an impression of lavish spaciousness. A smaller selection of colours clearly allocated to particular areas is employed; it consists of a light and a dark shade of neutral grey, silver for various sections and black for functional components at the driver's station, windows and rubber door seals. The light and dark grey tones have been selected to emphasise the different functional areas of the vehicle but still complement the many and varied colours that customers like to order. Areas susceptible to dirt, in the floor and foot area, for example, are darker. At medium height on the side walls there are components made of easy-to-clean, high-value anodised

aluminium and wipe-down sandwich-construction side-wall panelling in freely selectable colours. Further up, the passenger area opens up into bright, friendly, light grey shades that do not conflict with the coloured handrails and attachments such as monitors.
The dark grey window post cladding is not really noticed; in fact, the impression is given that the window area is completely without posts.
In the ceiling and engine tower areas another colour trick is used: all connections to the side wall are in dark grey. The remaining lighter area that meets the eye thus appears to be slimmer, and the visible proportions have the effect of making the passenger compartment look higher than it actually is. The ceiling too seems to be less solid and heavy.
The dark attachment faces have another functional advantage as well, since with dark components dark gaps are practically not visible. Constructional tolerances and abutments thus become invisible to the beholder.

View 12: The Lion's City Color & Trim Color Concept

View 13: The Lion's City Color & Trim Color Concept

Innovative platform concept for commercial vehicle cabins

Optimized approaches in respect of modularity, assembly, light- weight and aerodynamics, flexible applicable for commercial vehicles of tomorrow

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Abstract

New and specific vehicle requirements like future regulations for aerodynamics and direct visibility, safety, various propulsion systems as well as customer needs further increase the complexity of vehicles. So for the commercial vehicle cabins, modularity is a significant topic to realize the customer demands and the production aspects.

Driven by that, MAGNA created the idea of a new cabin platform concept in order to fulfill the requirements, reduction of engineering and manufacturing costs under the aspects of weight optimization and increased comfort for the driver and his working environment.

The already IP protected concept idea is based on a new platform module, usable for several applications, enclosed by different cap, door and exterior modules.

The new light weight cabin platform module as a structural base for individual configurations will be equipped with the modular usable components like the dashboard system, carpet, seats, etc. In combination with different pre-assembled caps consisting of roof, rear wall and side wall the cabin will be completed and can be used for the selected applications.

Due to the universal cabin platform, and with this usability for different vehicle manufacturers, a big "scale of production factor" can be generated.

The OEM specific cap modules can be manufactured individually depending on the number of units, shapes and dimensions as well as material and manufacturing processes. Lightweight design is represented by the appropriate material selection and functional integration.

In the case of a new variant or a facelift only exterior modules has to be redesigned and a new type can be realized in a quick and cost efficient way.

By combining the different modules, the variant spectrum according application can be displayed in different cap variants for short and long cabs.

These cabs can be applied for future commercial vehicles with conventional and alternative propulsion systems, also with extended front end for further safety and comfort optimization.

1. Introduction

Conventional commercial vehicle cabins are traditionally developed and build of welded steel pressed parts. After painting all the interior parts will be installed in a sequence assembly way. Improved comfort and safety requirements as well as driver assistance systems are increasing the number of components and therefore the weight will counteracting the payload requirements.

Due to the different vehicle requirements driven by the application (long haul, distribution, traction, and city) as well as propulsion system (internal combustion engine, hybrid, electrical, fuel cell…), different commercial vehicle cabin types in individual configurations in low and high end class are necessary and with the modular attempt configurable.

In the concept finding phase major aspects have been analyzed:

- Line up, cabin versions and applications under consideration of market development
- Cabin requirements & performance targets
- BIW design principles
- Painting / coating
- Assembly
- Commonality / common areas
- Materials & weights
- Components / amount of parts
- Complexity reduction by modularity
- Future legal changes

The investigation showed that a flexibility is still important to follow the market requests. Individual configurations are needed to cover the whole line up range.

Light weight design has to be developed to compensate the weight increase to improve comfort and safety requirements as well as driver assistance systems.

Currently the production period of a body in white will be much longer than a decade. Refer to passenger cars, new versions / facelift´s will come to the market in a shorter time schedule, therefore this trend should be considered in the commercial vehicle truck segment too.

Assembly could be further simplified by usage of modules and subassemblies. Increasing number of components should be preassembled beside the line in order to reduce the installation time at the final assembly line.

2. New cabin platform concept

The new cabin platform concept is characterized by combinations of different pre-assembled modules (building block system).

Based on the modularity requirements, the cabin was spited into defined modules in order to reach highest flexibility by using a platform.

A new cabin platform module as a “non visible” structural base will be applied for different cabin versions. As this unit can be the same for several brands and applications, the production volume increases and therefore it leads to a cost reduction. The platform will be further equipped with all possible interior parts related to floor and dashboard in ergonomically assembly stations.

One of the different pre-assembled cap modules consisting of roof, rear wall and side wall will be further unified together with the pre-assembled platform.

For finalization the door modules and exterior modules will be installed.

The structural platform module is not related to the outer appearance. The OEM specific branding will be presented in the exterior module as well as in the cap and door modules.

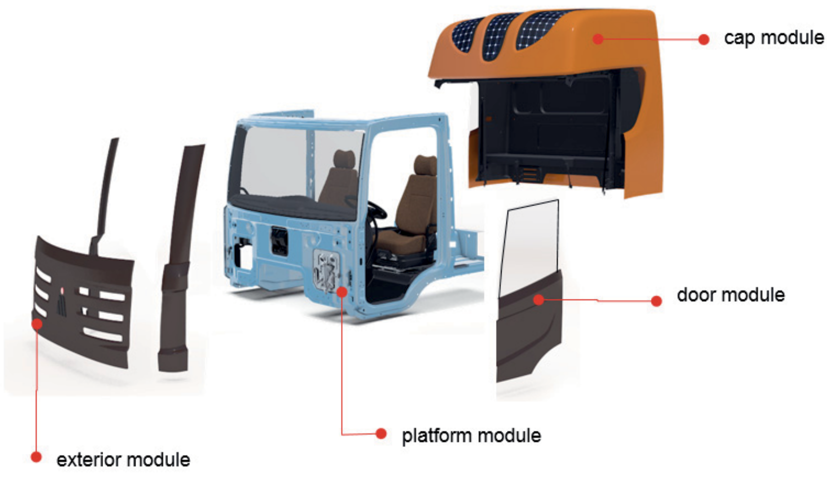

Fig. 1: Modules of new modular cabin platform

3. Pre-assembled modules

Pre-assembled modules have several advantages in the product variant realization by a combination of standardized modules (platform) and variable modules. A new product / version can be easy generated by combination with a standardized module.

Assembly can be simplified, once in the sub assembly by good and direct assembly access and second in the final assembly line due to reduction of assembly sequences.

Due to defined interfaces a module design is further predestined to control the tolerance quality. The module supplier will be responsible for the whole module / system in respect of quality, tolerance, completeness….)

<u>Platform module:</u>

The platform module will be the standardized module for several brands and applications.

On the base of the strict structural requirements for crash ECE R29.03 and durability, the platform structure is designed as a metal mix of conventional deep draw steel parts, high strength tailored blank parts as well as aluminum components for performance and light weight optimization.

High strength technology is implemented in the longitudinal members as well as on the A-pillar / door frame in high strength tailored blank technology.

As the platform could need also a variability in the front wall for different applications (e.g. with extra front window in the lower co-driver area for direct visibility improvement), a function integrated aluminum part manufactured as an internal high-pressure process gives the variability for different application scenarios. The connection between the aluminum front panel and the sheet metal platform structure will be realized by a structural glue in combination with bolts after painting.

Fig. 2: Design & material concept of cabin platform

Even as the platform structure is not visible when the complete cabin is assembled, it is not necessary to apply a premium color painting on this component.
On the platform structure all parts / systems related to the platform like front screen, HVAC, instrument panel, pedals, steering, floor covers, seats will be installed in an ergonomic assembly process to a final pre-equipped platform module.

Fig. 3: Pre-assembled cabin platform module

For the length variation the design includes an intelligent defined interface split which means the short (day) cabin will be a derivate of the long (sleeper) cabin with additional cutting operation – same stamping tool. Also the concept with adapters in length extension would be a possibility. Finally the overall line up and production volume will define the cost efficient working direction.

Fig. 4: Platform length variation

Cap module:

The pre-assembled caps consisting of roof, rear wall and side wall are the variant variable modules and presents the OEM specific appearance.

The design principle is very flexible, so it can be oriented to market and customer requirements. Height and length dimensions as well as the definition of package and equipment are easy to handle and control.

The material / light weight material concept will be established based on production volumes and available technology's in order to realize the most efficient solution.

Structural, weight and relative cost evaluations have been performed for different material concepts like steel, aluminum, RTM (Resin Transfer Molding) in sandwich design with PUR foam core, LFI (Long Fiber Injection Molding), etc.

With a sandwich design construction light weight can be realized through function integration like insulation, inner trims or spoiler function. An improved cabin insulation allows a downgrade of the HVAC system, which has advantages in packaging and energy needs, especially for electrical vehicles.

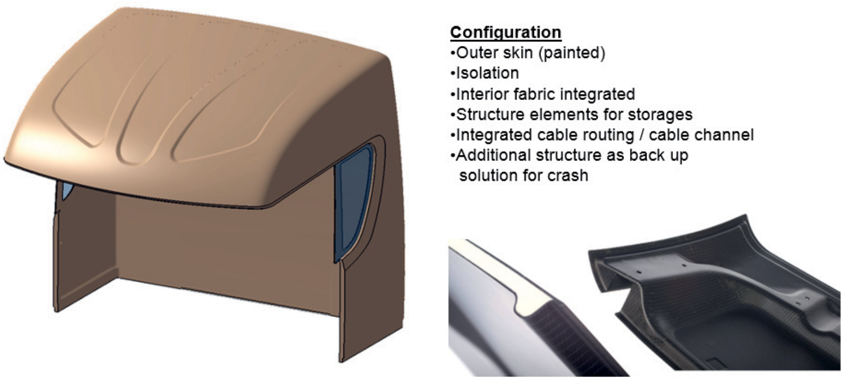

Fig. 5: Function integrated roof module (e.g. RTM sandwich)

Due to the excellent access all relevant interior parts e.g. roof hatch, lights, storages…can be assembled in ergonomic pre-assembly stations too.
With this concept an "overhead installation" of system related parts like inner trims, roof hatch or roof lights @ the final assembly line is not mandatory for the worker anymore.
The whole pre-assembled module can be delivered directly from the module supplier to the final assembly line.

Fig. 6: Ergonomic pre-assembly of cap module

A geometrical cabin styling upgrade / facelift or new version can be easy handled.

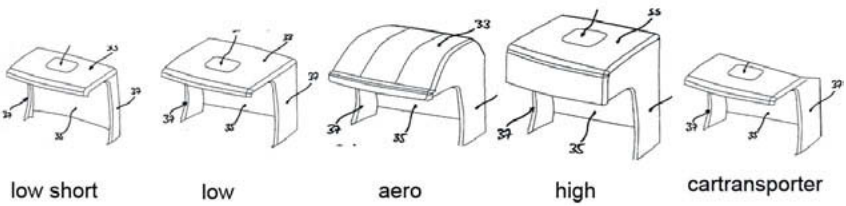

Fig. 7: Roof module / cap versions

Door module:

Standardized door frames and components like hinges, locks, latches, lift able window system, handles… will be the basics for the door. The styling appearance will be realized individual in the door outer panel. Due to different requirements also different door modules (e.g. with fixed window on lower side, cost / light weigh optimized door @ co. driver side…) would be advantageous and can be selected at vehicle order process based on application request.

	standard	standard with window	only window
optimized lower direct view	-	+	++
glass drop down	+	+	-
weight	+/-	-	+
costs	+/-	-	+

Fig. 8: Door line up overview

Exterior front modules:

The exterior front module will be individually designed, based on the OEM applications, system and styling requirements as pre-assembled modules.

Following flexible exterior systems are necessary:

- Front lid / hood including A-pillar covers
- Bumper unit including headlamp, front steps and integrated adjustable shutters for cooling and aerodynamics improvement
- Cab steps & step cover / fender including cover

Fig. 9: Exterior front module variants

4. Assembly

The pre-assembled modules will be delivered by the system supplier to the final cabin assembly line and the individual cap module will be united with the standardized platform.

A glue robot, similar process as a front screen installation, will apply the structural glue to the platform frame structure. After that the roof module will be guided (almost 45° assembly direction) with a device to the platform structure and connected. To guarantee a constant gluing gap, spacers are integrated in the platform and screws will clamp the cap module in position.

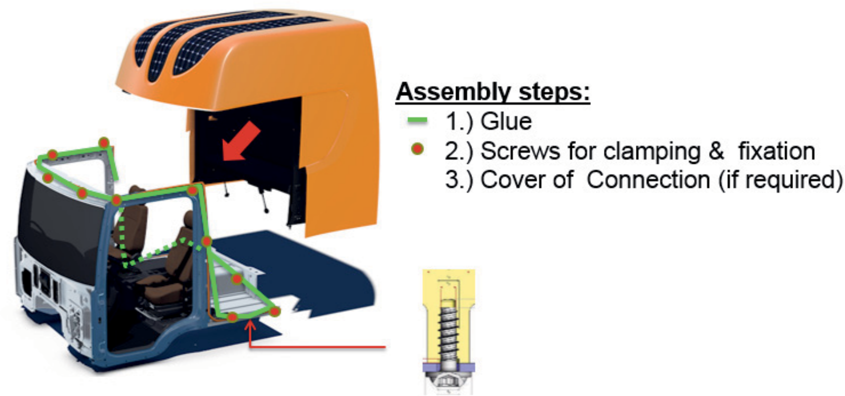

Fig. 10: Assembly of preassembled roof module / cap to platform

Finally the door and exterior front modules will be assembled in a traditional way.

5. Cabin versions & applications

Due to the module building block system a lot of combinations based on platform are possible. The cabin line up starts from a single cab with flat roof up to medium, sleeper and elongated cabs with aerodynamic or extra high roof. Also special versions like a car transporter can be easily developed.

The platform cabin can be used for different vehicle applications and chassis concepts.

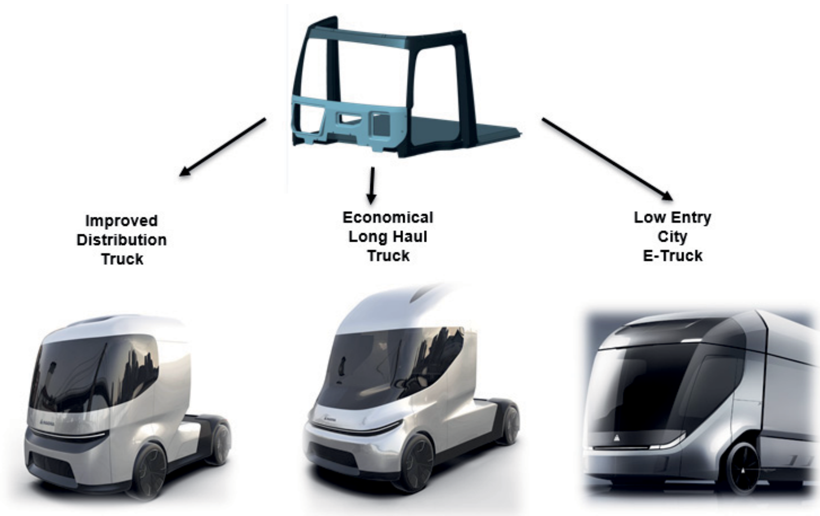

Fig. 11: New cabin platform for different vehicle applications

6. Special benefits for future regulations

Future regulation will be new challenges for the whole vehicle. Directive 96/53/EC allows elongated cabs for safety and aerodynamic improvements which means

- drag coefficient (cd-value) improvement for fuel saving
- visibility field / direct visibility improvement; reduction of blind spot
- safety and comfort for driver
- reduction of damages / injury for opposite road users

Aerodynamic:

From cabin front until B-pillar an aerodynamic shape with angled doors and angled roof shapes have been integrated. The package of the driver´s place from a 2,3m wide cab was unified with the sleeping area of a 2,5m wide cabin. As the trailer / body width dimension is almost 2,5m a variation for the cabin with is not necessarily and will reduce the cabin variance.
Within a typical cabin family lineup consisting of 2 widths a reduction from 8 to 5 versions could be possible. A common cabin width at the front area (dashboard, screen, wipers…) would simplify the development, production & assembly as well as spare parts management.
The exterior front module is flexible, also for elongation to improve the aerodynamics as well as pedestrian protection. “Improved Distribution Truck” shows an elongation <200mm and the “Economical Long Haul Truck” an extension of 500mm.

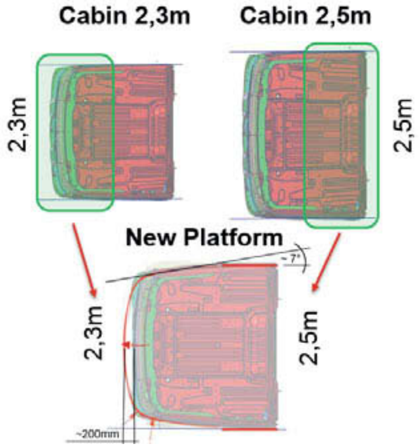

Fig. 12: Cabin unification of 2,3m & 2,5m cabs for better aerodynamic volume

Direct visibility:

For the visibility improvement the co-driver area should be changed in order to have a better direct view to the pedestrians and cyclist. An integrated window in lower area of co-driver door in combination with a foldable co-driver seat as well as an integrated window in front wall area will enable this request. Due to the modular front wall concept different solutions would be possible. In respect of platform thinking the front screen including wiper system should be common for all versions and the lower direct visibility function will be realized with an additional window.
Also the interior dashboard must be restyled to the minimum request for driving comfort.

Fig. 13: Improved direct visibility

7. Summary

In this concept study MAGNA showed that high flexibility in vehicle cabins based on a new cabin platform added with individual cap, exterior and door modules can be realized in order to fulfill new and specific vehicle requirements and reduce the engineering and the manufacturing costs.

The cabin concept includes approaches for aerodynamics, direct visibility and safety improvements as well as light weight aspects for future commercials vehicles with conventional and alternative propulsion systems.

The universal cabin platform can be used for several applications and different vehicle manufacturers. This will generate, a high benefit in terms of "scale of production factor".

OEM specific cap modules can be manufactured individually depending on the number of units, dimensions, styling under consideration of available material and manufacturing process for new versions as well as product upgrade / facelift.

Module building blocks will allow an ergonomic pre-assembly and shorten the assembly time at the final assembly line.

A unification of 2,3m & 2,5m wide cabins can reduce the whole cabin line up, optimize the weight and improve the aerodynamics.

Some ideas of the new cabin platform concept, especially special features can be also used for upgrading existing cabins / vehicles.

Development of a disruptive semitrailer tractor in light-weight construction

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1. Motivation

The most widely used supporting structure in truck design today is the ladder-type frame. This principle offers many advantages and meets requirements outstandingly, particularly at the beginning of truck development. Aside from the big payload, the concept is simple and robust while enabling a high degree of variability, usually in combination with a modular system. The relatively low torsional rigidity around the vehicle's longitudinal axis (by comparison with a body) is an advantage in what was previously a frequent type of deployment, namely operation on uneven, unpaved surfaces.

Over the course of well over a century of development, however, design engineers have had to rise to the challenge of a great many changes in their market. To name just the most important changes, these include more drive power, more stringent emission standards with simultaneous prevention of CO_2, more complex and highly variable vehicle systems for a variety of transport tasks, more volume and comfort in the driver's cab and specialisation in long-haul transport on predominantly smooth roads.

In consequence, different boundary conditions for the further development of the vehicle have defined themselves. Just for example, continually increased mileage and enhanced equipment with simultaneously reduced energy demands and improved environmental balance. The potential for optimisation here is mainly in the areas of energy management, driving strategy, driving resistances and lightweight construction. The lightweight construction area is under extreme cost pressure, especially in the commercial vehicles sector where the relatively low volumes are problematic. As a result, developments in this direction require significant resources because cost-effective lightweight construction is difficult to achieve by implementing isolated measures.

A further reason is directly related to ladder frames:

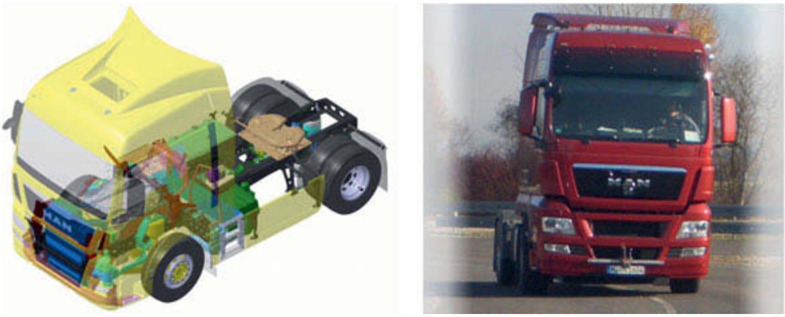
an additional consequence of the changes in the market is that the installation space available for the ladder frame has become severely restricted in all spatial directions. Given the inflexible ladder-frame concept, it was not possible to adapt the vehicle architecture to any significant extent. A consequence of the current frame concept for modern trucks is that developers are

forced to make considerable compromises in defining installation space and in the subsequently achievable mechanical properties of the ladder frames.
These compromises have an impact on the potential of existing components to be constructed in lightweight design and on the consequent costs.
Similar constraints led to passenger cars being produced with self-supporting bodies from around 1930 and buses and coaches from around 1954. However, significantly higher requirements with respect to product variability and to the associated logistics and production have until now hindered any similar development from taking place in trucks. However, thanks to the growing CO_2 debate, alternative drive concepts for trucks are again being more sharply focused on. This development has brought to the fore an advantage of the body concept that until now has not been given much attention in the sector: the gain of previously unusable installation space. The assignment of the research vehicle presented here is to demonstrate the magnitude of existing potential in lightweight construction and the gain in installation space on a semitrailer tractor with a short wheelbase.

2.0 Reference vehicle and target characteristics

2.1 Reference vehicle

Preliminary studies regarding the potential of lightweight construction of ladder frames indicated to MAN Research that we would have to abandon the current installation space of the frame in order to achieve the necessary improvement in dead weight. Seen together with the general changes in market conditions outlined in the introduction, the time had come for the structuring of a vehicle with a new vehicle architecture. The Research Department decided on a semitrailer tractor with equipment that is typical in long-haul transport as a reference vehicle. Additional air suspension on the front axle makes for better comparison of later measurements with the new vehicle architecture.

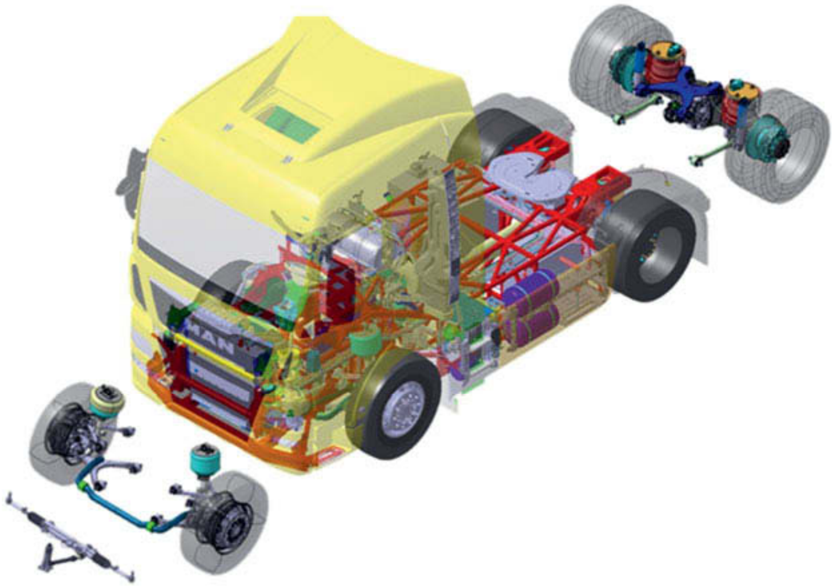


Reference vehicle: 18-tonne semitrailer tractor for long-haul transport

The cab, in its original location with mount, and the diesel driveline with engine and automatic gearbox were adopted from series production. Although the supporting structure is predestined mainly for future vehicle concepts with alternative drive systems, fundamental feasibility can also be demonstrated with the classic configuration. Because of the current situation with regard to entering the cab, the location of the front axle was also not changed. In principle, however, our vehicle concept makes it possible to relocate the front axle approximately 600 mm further forward. To improve the axle-load distribution, the driveline was moved backwards and downwards so that the cooling air-flow can also be optimised, which will in turn make smaller cooling surfaces possible. Although the vehicle's dimensions remain unchanged with a wheelbase of 3,600 mm, the supporting structure ends approximately 250 mm behind the two-bellows air suspension on the rear axle that enables this construction.

The aim of building a research vehicle that has a considerably more rigid supporting structure was to study and evaluate additional potential in handling and comfort as well as conceptual lightweight construction with a simultaneous gain in installation space. The first installation-space concepts already made it clear that independent wheel suspension and rack-and-pinion steering on the front axle exhibited advantages in terms of installation space, with additional potential as positive influences on handling. Prototypes are fitted with rack-and-pinion steering and independent wheel suspension.

The freed-up installation space is to be used to demonstrate possible improvements to the front of the vehicle in the area of active and passive safety.



Complete vehicle concept with highlighted running-gear components

2.2 Characteristics of the reference vehicle

Standard evaluations are undertaken of the rigidity, characteristics and damage (operational stability) of the primary supporting structure, the ladder frame, for commercial trucks of between 8 and 40 t gross weight. Various design-relevant parameters are thereby derived and stored in a database together with the field experience for the respective vehicles. These data are updated over the term of the vehicle series and used as the basis for new designs. Such data include rigidity values such as deformations under standardised load conditions. These are derived from the natural modes of the ladder frame. The ladder frame consists of two longitudinal U-beams connected by cross members.

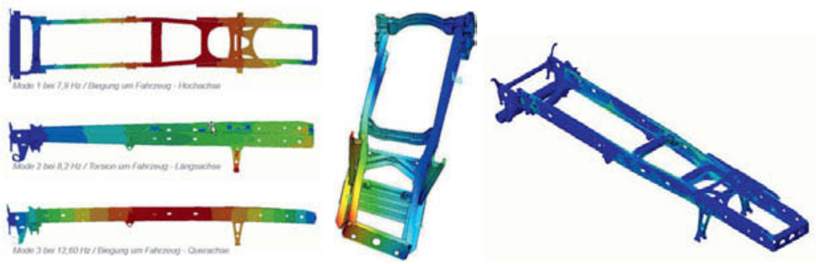
Reference vehicle ladder-type frame (photos from the vehicle dismantling)

In addition to the form of the side members with their offsets due to the installation space, various main dimensions of the U-beam and wall thickness are used. The side members are designed for the nominal stresses for the prevailing bending moment distribution of the frame, and are therefore predominantly oriented to the load and axle load distribution of the vehicle The side members are connected by various cross members to form the ladder frame. The vibration behaviour of the frame can be described fairly easily. Depending on the vehicle model, between 2 and max. 8 global natural modes of the ladder frame are relevant, in the case of the reference vehicle 3. These are the following, from top to bottom (with increasing frequency); the physical equivalent is shown in () in each case:

Mode 1: Bending about the vertical axis (longitudinal impact on a single wheel)
Mode 2: Torsion about the longitudinal axis (road unevenness)
Mode 3: Bending about the transverse axis (load)

In order to better illustrate the approach, let us consider the middle mode, the 1st order frame torsion, in more detail.

The simplified consideration of the ladder frame using modal analysis (FEA) shows a frequency for the frame torsion of below 10 Hz, i.e. in a critical excitation range and hence very important with respect to the damage to the supporting structure. In the real complete vehicle and the virtual complete vehicle model, the frequencies are slightly lower. For a qualitative comparison at an early stage of the concepts, however, the consideration of the basic structure is sufficient. A defined excitation from the road (uneven road surface / diagonal torsion) results in an amplitude for the twist angle at the frame about the vehicle longitudinal axis, between the front axle and rear axle. Together with the wheel load difference at the four wheels, this gives us a rigidity value as a moment per twist angle (normally expressed in kNm/rad). For the further consideration, not only the absolute value but also the gradient of the twist angle over the vehicle longitudinal axis is of interest. The value also depends on the vehicle variant and the suspension, as primary suspension and torsion rate of the frame interact.

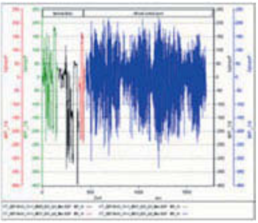


natural modes Equivalent load case Damage calculation

For a clearer representation, attachments and cross members or brackets have been hidden in the area of the front axle.

By means of measurements at the vehicle with different operating conditions and transport applications, collectives for the respective load type are derived and validated experimentally. This is necessary in order to avert damage to the primary structure of the frame over the vehicle service life. Due to the simple relationships with the ladder frame, tests on 4-posters, normally used in the passenger car sector, are generally not necessary.

Due to the extreme variation in the operating spectra for commercial vehicles, however, a fatigue-proof design of the primary structure of the frame is economically expedient only for the majority of the vehicles (approx. 95%). The other vehicle applications are designed for specific periods of operation, and thus result in a reduced operating life.



Measurement → Collectives Test stand Example of Damage

The figures show measurement data for determining the collectives for the frame torsion, the corresponding quasi-static test stand and examples of damage to the components.

In the case of passenger cars, the chassis is generally designed on the basis of criteria of rigidity and comfort (vibration behaviour in admissible frequency ranges). Additional measures to ensure operational stability are necessary only at a small number of points (e.g. shock absorber domes on front and rear axles or load transmission at the interface between chassis and car body, etc.). Crash scenarios primarily dictate the dimensioning of the strength of the body main structure. This applies essentially to the closed design of passenger cars.

2.3 Target characteristics of the research vehicle

The main goal in the development of the present frame concept is to significantly modify the mechanical characteristics and to make optimum use of the available installation space. Modifications to the vehicle architecture are necessary for this. As with the vehicle body concept for passenger cars and buses/coaches, lightweight construction is also systematically created as a side-effect. As with passenger cars and buses, however, this is not the driving force behind the change of technology. In the present case, installation space is to be generated. This wish, in conjunction with alternative drive systems, particularly with the current voluminous energy storage systems for e-mobility, is the main motivation for the project.

A further positive side-effect is that the vehicle can be more specifically configured, while the handling and comfort of the vehicle can be significantly improved.

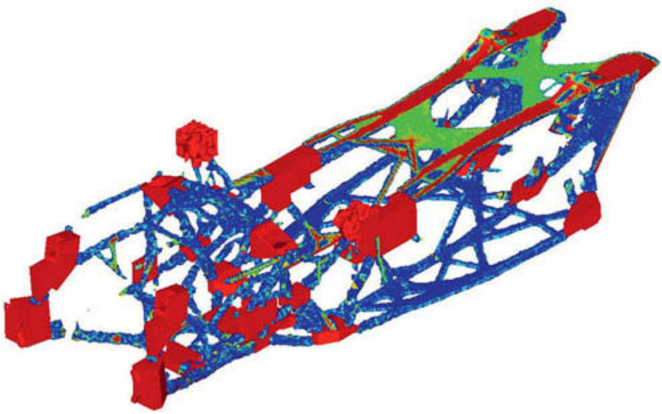
In concrete terms this means for our research vehicle a gain in installation space of > 1 m^3. In order to increase the operational stability of the frame structure in the direction of the passenger car at the same time, the frequency for the torsional vibration should be increased from below 10 Hz (currently 8.2 Hz) to roughly 25 Hz. In the first step, the bending about the transverse axis is not to be actively changed, as this is not expected to cause any damage. The preliminary considerations indicate that subordinate importance is also to be expected for the vibration pattern "bending about the transverse axis". This assessment must, however, be constantly reviewed. In addition, new and additional vibration patterns must be evaluated from the outset with respect to their hazard potential.

3.0 Development of a vehicle concept to achieve the objectives

3.1 Simulation process and design

Experience in designing trucks with ladder frames cannot be applied to body concepts. With the help of some preliminary tests and multibody simulations, it was possible to estimate the effect of a substantially stiffer frame system on running-gear forces beforehand, both experimentally and mathematically. For this purpose a series-production frame was globally stiffened using a bearer system. The loads for deployment in long-haul and distribution transport increase only minimally, which allows the use of corresponding near-series running-gear components in the initial approach. For the FE analyses of the concepts, a simplified method of static and dynamic stresses was used, the same as in the early concept phase of coach design. Moreover, in this vehicle segment, the running gear and the rigidities exhibited in the floor structure are comparable.

Installation-space models for topology optimisation are derived from the adequately detailed package models for vehicle architecture. The method is then applied - with varying boundary conditions - to manufacturing restrictions. The geometry is defined by calculation in several steps with manual control taking place between steps. Processing in this phase requires skills in the disciplines of design and simulation, preferably combined in individual persons.

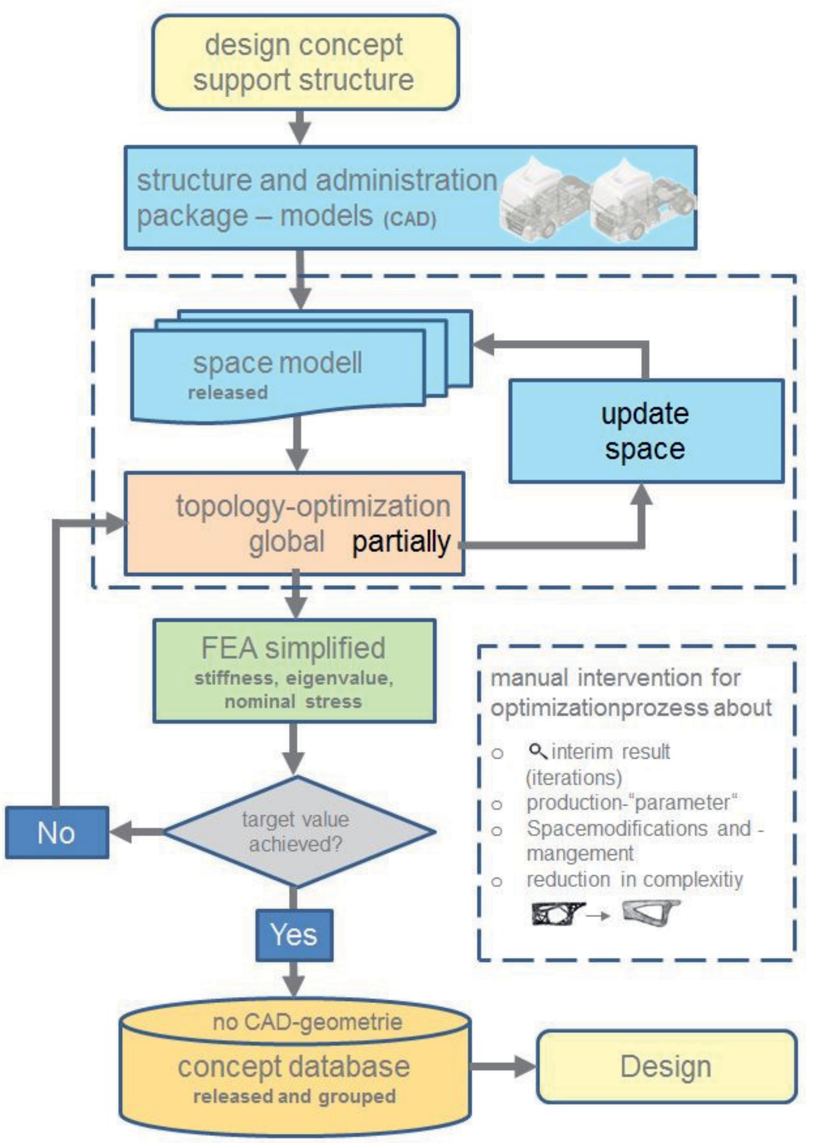


Interim results of topology optimisation of the complete supporting structure

Of central importance in conceptualisation is the earliest possible use of simulation methods: in our case, they were already applied to the structures from topology optimisation. The mechanical properties of the smoothed geometry are checked using FEA directly and without complex reduction into CAD. Besides static rigidities and eigenvalues, only nominal stresses are checked. In this way, fewer resources are invested in the detailing of designs that hold little promise of success.

The concepts or designs for supporting structures generated here are given corresponding version numbers depending on the package status within the different virtual concept vehicles. In our case these represent different drive concepts.

This means that it is possible to find many concepts that are equally worth following and with which the target values being aimed at are achievable. This modus operandi gives rise to a database with many and various solution approaches to manufacturing and production – an ideal pool of pre-development projects.



Flow chart of simulation process

3.2 Concept selection, degree of detail and verification by calculation

For the prioritised tasks of building a research vehicle and clarifying feasibility, the solution approaches selected were primarily those that are linked with sound manufacturing know-how. The approach finally chosen was one that combined locally reinforced tubular segments and sandwich structures with insert components. In this context, extensive development parameters are available to us, especially with regard to our own prototype construction.

Further processing and detailing of the design were carried out using CAD as the master system. This also makes it easier to apply a standardised process in verification by calculation. Besides the local verification of structural strength, a simplified examination of fatigue strength also takes place here. Target values for rigidity and eigenvalues continue to be checked here, as does the weight balance.

The project was completely processed in an agile manner by a small team possessing all the requisite skills. We were able to use this to our advantage to detail the entire supporting structure from individual cells and then complete it seamlessly.

In concrete terms this means that individual areas for which the environmental geometry had already been set down were initially detailed and parallel to this were also constructed as segments, while other areas were kept less structured and thus variable. The consequence of this method is that one achieves one's goal very quickly but that the big picture only crystallises little by little. Put another way: it emerges only during processing.

With respect to achieving the target values and the ongoing FEA, this represents a challenge only to a limited degree, in that the influence on global properties by local changes is not significant.

Valuable development time can thus be saved, especially in the manufacturing area. An additional positive side-effect is the rising learning curve and with it, engineering designs that become increasingly viable. This processing phase saw continued and extensive use of local topology optimisation. Over long phases, the FE models for verification consisted of hybrid structures, for which a good networking strategy and standards are a prerequisite.

Development and manufacture or assembly were thus parallel activities; this also applies to the complete vehicle body and the cable routing.

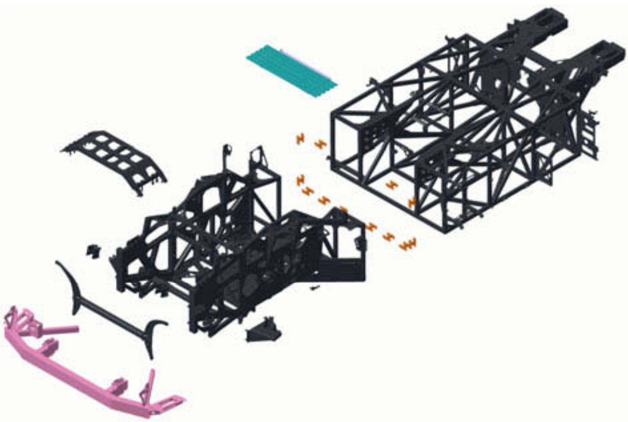
4. Prototype construction

As already mentioned, in the case under discussion, a chronological separation of development, prototype construction and assembly of the complete vehicle was not possible.

Nevertheless, this is an attempt to provide a cohesive description of the contents of the phase dealing purely with construction and assembly. This must be understood in the context of the development method described.

As elements of the supporting structure, open and closed semi-finished materials, flat or simply formed lasered sheets and solid components machined from full material were used. The components were connected to one other using manual MAG welding. Construction was performed on assembly bases in combination with existing jigs and angle brackets. With few exceptions, manufacturing utilised comparatively simple manufacturing machinery.

The evolutionary method resulted in the emergence of a main front segment and a main rear segment, into each of which as many functions and adapters as possible could be integrated. For process-related reasons, certain segments were also formed, constructed separately and joined to the main structure using bolted connections. The interface between the two main segments was additionally influenced by production-related parameters, in this specific case by the size of the dipping plant available for cathodic dip coating (KTL). Arising from the concept, this also serves to indicate a possible modularisation of several vehicle derivatives within a vehicle group. In the event of commercialisation, the current interface would be relocated elsewhere.



Exploded view of the supporting frame segments

For optimal coating of the segments the dipping plant, simulations of the dipping process and wetting were run continually.

5. Complete vehicle and results

The initial measurement result showed a weight saving of 400 kg for the supporting structure with top coating. As expected, deviations from the CAD model were slight - under 2 kg, despite manual welding and painting.

During development, an attempt was also made to simplify the arrangement and connection of the units (control units, valves, compressed-air tanks and so on) by means of optimised cabling and piping. In the braking system, for example, it was possible to eliminate several metres of cable and air piping.

The remainder of the complete vehicle construction may be described as unproblematic, which more than justifies the great amount of effort put into the package models (largely complete and with a high degree of detail).

The complete vehicle in a roadworthy state has a dead weight < 6,000 kg, which translates to a weight saving of up to 1,300 kg or at least 1,100 kg, depending on the running gear and tyre variants.

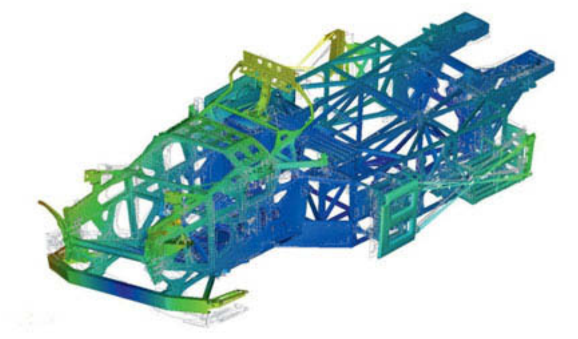
The weight saving forecast was a minimum of 1,000 kg. It was exceeded because of the many small parts, which were difficult to calculate in advance, and because the masses of some of the new prototype units were not available beforehand.

Besides the 400 kg saved on the supporting structure, 250 kg were saved by measures taken on the rear axle, 200 kg on the rest of the driveline and 150 kg on the front axle and steering. The remaining 300 kg result from the modified vehicle architecture and overall concept.

A further, highly important result is the gain in installation space of approximately a cubic metre. Even on the prototype this could be used to realise a tank with a volume of roughly 1,300 litres. In our opinion, the additional installation space is the biggest advantage of this concept for future vehicles with electrical drivelines and alternative drive systems.

As of now, our assumption is that a dead weight of < 5.3 t can be achieved for semitrailer tractor applications where weight is an important factor. With the usual long-haul equipment this would mean a dead weight of around 5.8 t, in each case with a conventional diesel driveline.

With a factor of 5 to 20, the rigidity values are significantly higher than those of the comparison vehicle, as are the relevant natural modes, by a factor of 1.7 to 2.5.



First-order torsion around the vehicle's longitudinal axis

6. Start-up and testing

The research vehicle was registered as a test vehicle. Complete homologation was required for the new rack-and-pinion steering.

This also applied to the brake system due to the wide-ranging modifications in the installation. However, homologation was unproblematic in both cases. Agreements were defined for each of the components relevant to safety, optionally together with the respective supplier. The agreements include separate inspection and replacement intervals.

No separate insulation measures were necessary for the acoustic test despite the relatively open framework construction in the area of the engine and gearbox. This shows that excellent values for sound emission could be achieved with comparatively little effort.

Appropriate adjustments to the running gear air suspension were needed. Good tuning was very quickly realised with minor measures. There is still more potential, which will be tapped in the course of follow-up projects.

Numerous measuring runs were carried out on various test tracks with different variants of running gear, above all with changes to the roll rate. Somewhat more extensive tuning was needed because the greatest stiffening by contrast with the ladder frame was reached here.

Moreover, different tyre variants were assessed, including single tyres on the rear axle. These are necessary on vehicles that react sensitively to weight and on vehicles equipped with electrical drivelines, for example e-axles.

7. Summary and outlook

With the research vehicle under discussion it proved possible to generate a product idea outstandingly capable of taking into consideration both the current boundary conditions and the future developments necessary to the truck market.

We were also able to verify the feasibility of this vehicle idea by experiment. A paradigm change - state of the art for passenger cars and buses/coaches since the beginning and middle of the last century respectively - is thus also sensible and possible for trucks.

Because construction is comparable, advanced projects will be able to draw on a state of the art with already proven and highly developed know-how from the field of body construction. However, the specific boundary conditions and target values must be taken into account here. Relative to the prototypical implementation, there is thus further potential for structural optimisation and lightweight construction.

From our point of view the biggest challenge lies in replacing the product structure of trucks with ladder frames, which has been cultivated for over one hundred years and has seen disproportionately high growth. We believe that it is both sensible and necessary to take a completely new type of approach in order to realise modularisation for the product variance that is essential.

To this end, MAN has already been deliberating ways in which the conceptual potential of the product idea can be fittingly unlocked, also in the areas of logistics and production.

The construction principle can be applied to vehicles for distribution and long-haul transport. Consequently, municipal and construction-site vehicles that operate to only a small extent on poor surfaces, at least in highly developed countries, are also conceivable.

As far as off-road vehicles, WorldWide construction-site vehicles and high-mobility vehicles are concerned, our experience indicates that the ladder frame remains the better supporting structure for trucks.

A new chassis-concept for electrified, light commercial vehicles based on innovative forming technologies

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Abstract

New solutions for inner-city delivery traffic are getting more and more important due to current carbon dioxide regulations. Regarding to that issue, this article presents a new chassis-solution for light commercial vehicles based on alternative drive systems.

The development has been driven by a consequent lightweight design approach, which meets the needs of cost sensitivity within the carrying business on one hand and design requirements of electrified light commercial vehicles on the other hand. It focusses on the customers´ benefits. It also offers a chassis-integrated protection for the energy storage (e. g. the battery system), which is currently one main challenge dealing with e-mobility.

This is accomplished by a bionic inspired chassis topology together with an intelligent mix of lightweight solutions. A new manufacturing technology enables the production of non-linear multi-chambered profiles made of steel to realize chassis integrated protective mechanisms for the battery system. Additionally, the crash behaviour of the chassis structure is optimized by a new composite material, which raises the absorption of energy especially in case of a side crash.

Accordingly, the article combines two main aspects of innovation: a new load adapted product design for chassis of light commercial vehicles and new solutions of lightweight production technologies. In this way it has a share to offer new approaches for the prospective inner-city delivery traffic.

Introduction

Looking at the current trends of consumer behaviour and the resulting requirements to inner-city logistical traffic two diametric tendencies can be observed. The share of online-trading is increasing drastically. People do not want to search for the goods they need in various stores any longer - they expect the goods to be delivered to their home. Different studies show that this trend can also be expected for consumer products in the future, which consequently leads to an increasing need of logistics [1]. At the same time the traffic in urban cities has to be regulated by restrictions on entry to reduce the ejection of carbon dioxide. This dilemma can be solved by developing new solutions for inner-city logistics and mobility. By doing so, the requirements of electrified systems can be achieved much better than it can possibly be done by using conventional vehicle-platforms equipped with alternative drive systems. It offers new opportunities concerning the available freight hold and payload, presupposed the aspects of chassis-design, packaging, battery installation, battery protection and weight are optimized for the changed requirements.

Strategy of Lightweight Design

Weight efficiency is one of the main targets, dealing with vehicles holding a massive energy storage. Especially in case of electric drives the battery weight has to be compensated by lightweight design in order to ensure competitive payload and range of the vehicle. The storage weight composes by the battery weight itself and additionally by the weight of the battery housing, which is necessary to protect the battery system in case of a crash. Developing a lightweight chassis-structure, which is able to protect the battery by itself, could satisfy two aims: saving the weight of a battery housing and saving the costs due to the reduction of single parts and assemblies made of partial high performance material.

Especially due to cost sensitivity within carrying business it is essential to choose the right strategy to fulfil the demand for weight reduction: The lightweight concept of the chassis, presented in the following, represents a bottom-up strategy. It firstly asks for an intelligent load adapted lightweight structure as it can be adopted from nature. In this case topology optimization is an established tool within product development in order to reach load adapted structures with a minimum of weight. But this only comes fully into effect when production technologies deliver corresponding degrees of freedom in order to reproduce the result of the topology optimization in a best way. This is challenging – especially for forming technology. With increasing degrees of freedom in part design, the necessary degrees of freedom within the forming process are rising. This often leads to an inhomogeneous distribution of stresses and states of strain, which have to be kept under control in order to get the required part design [2]. However, this strategy enables realizing lightweight structures with a minimum of weight. Parts can be designed corresponding to the expected loads without having additional costs by using high-performance material.

The second step of the lightweight-concept after having built a load adapted structure is the efficient usage of lightweight material to increase the performance of the structure. Within the presented construction it is used to improve the crash behaviour. Besides realizing a cost efficient chassis-structure this strategy leads to a simplified system by integrating the protection-function of the battery housing into the chassis structure. This means a reduction of weight and complexity by using fewer parts to protect the battery. Furthermore reduced costs can be expected by a load adapted chassis topology. There is no more need for high-performance structures currently added to fulfil crash specifications.

Development-steps of the chassis-concept

Starting with the question of how would nature build a chassis to protect the battery helps to understand how material can be used in the most efficient way. Sharp edges and rectangular forms can hardly be found in structures build by nature. Protective elements such as nutshells or turtle shells are oval shaped. One patent dealing with an oval chassis structure was already published in 1938 [3]. Since then a few chassis following this principle were realized in series-production. One example is the chassis of the Wartburg 353 build from 1966 to 1989. It is known that the crash performance can be significantly increased by using a curved support structure, as shown in [4]. One reason for this is that oval structures are collapsing locally at a much higher load compared to linear ones.

Having these facts in mind a first draft of the chassis shows two chassis-members running linear and parallel to each other at the front- and rearend while forming a biconvex middle segment. In this way the flexibility and scalability regarding attachments and the wheelbase is ensured by the linear front and rearend. The biconvex middle segment protects the internally located batteries and at the same time the available installation space between the chassis-members increases.

Fig. 1: Topology optimization and resulting CAD model of the chassis-concept

With the help of topology optimization the plausibility of the biconvex middle segment gets numerically proven the first time (Fig. 1). For this simulation the overall installation space gets restricted by the front and rear axle, as well as the traction battery. Afterwards preassigned force application points and axle bearing points are implemented. As a conclusion it can be said, that the general idea of the bionic chassis topology got proven by the above described simulation. The subsequent question is how the ideal section for the chassis-members looks like. In this concept they are used as the main beam of the carrying structure and an essential part of the side crash structure. Looking back to natural approaches again shows that multi-chamber profiles take the test of time in terms of lightweight construction and stiffness at the same time. In order to achieve a resistant but lightweight structure the chassis-members are realized as multi-chambered and load adapted steel beams. To evaluate the necessary material thicknesses of the single components the construction is running through a series of static simulations, calculating the stress generated by different load cases and driving scenarios.

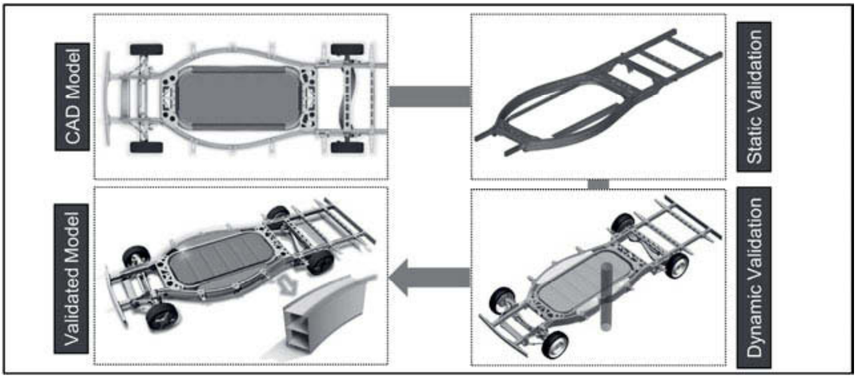

Fig. 2: static and dynamic validation of the chassis-concept

To prove the performance at the crucial side pole impact a crash simulation is done as specified by Euro NCAP with a pole diameter of 254mm, a speed of 32 km/h and the gross vehicle weight of 3.5t [5]. The additional space between the chassis-members and the batteries, gained by the oval chassis geometry, is used to decelerate the impact pole. Accordingly attached composite sandwich panels are supporting the structure, spreading the stress and consuming the remaining crash energy. The results show, that the crash energy can be consumed by the chassis structure before the pole reaches the batteries. Thus the battery gets protected by the chassis itself (Fig. 2). As a result the battery box is only used as a simple carrying structure and housing for the battery modules and does not need to consume additional crash energy to protect the cells.

The demonstrator includes a standard front axle and electric wheel hub drives, located at the rear axle. As already mentioned the overall dimensions of the chassis are freely scalable. In this specific case the wheelbase is 3800mm, the total length is 6075mm with a width of 2060mm. Due to the compact design a continuous low entry height of 490mm can be realized. The current design comes to a payload of 1150kg at 80kWh battery and 3.5t allowed total weight (Fig. 3).

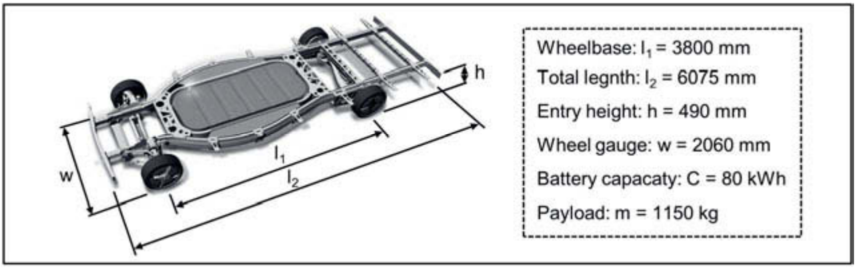

Fig. 3: Parameters of the chassis-concept

Technological Approach – Structural Lightweight Design

Actual approaches for the production of the multi-chambered profiles are based upon aluminium extrusion. It enables the production of a wide range of linear, bifurcated cross sections. However there are going along some disadvantages using aluminium extruded profiles in the present concept as chassis-members: limitation of only constant cross-sections in lengthwise direction, increased material costs, reduced material strength compared to steel and increased tolerances in terms of in-line bending of aluminium extrusion profiles because of the cooling influences, which can hardly be compensated by a closed loop process.

Within the present concept a new technology is used, which enables the continuous production of branched profiles made of sheet metal steel at room temperature. The process is called linear flow splitting, firstly described in [7], whereat sheet metal is moved through a stationary forming stand. It contains two supporting rolls guiding the sheet metal in vertical direction and two diametrical stationary splitting rolls arranged within the sheet-middle-plane (Fig. 4).

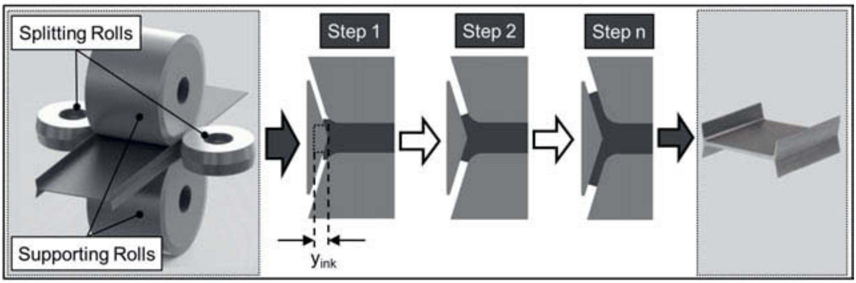

Fig. 4: Principle of linear flow splitting [6]

The gap between the two supporting rolls corresponds with the sheet-metal thickness. When moving the sheet through the tooling system it comes to a defined overlapping between the splitting rolls and each bend edge of the sheet-metal, which is called incremental splitting depth (y_{ink}) [7].

Caused by the arrangement of the rolls a hydrostatic compressive stress state is induced, thus the formability of the material is rising and the material is forced to flow into the gap between splitting roll and supporting roll – named flanges. Within a next forming step the distance between the splitting rolls is reduced again by 2*y_{ink} (y_{ink} for each side), as well as the width of the supporting rolls. Thereby the flange length is increasing caused by the same mechanism of an overlapping between the sheet and the splitting rolls (Fig. 4) [7].

Arranging subsequent forming stands after each other enables the realization of a continuous forming process. The flange length as well as the width of the web of the linear flow splitted parts depends on the number of forming stands the sheet metal is moved through. By adding a roll forming process after the linear flow splitting unit the bifurcated semi-finished product can be formed to multi-chambered profiles within a continuous production line (Fig. 5), shown in [8].

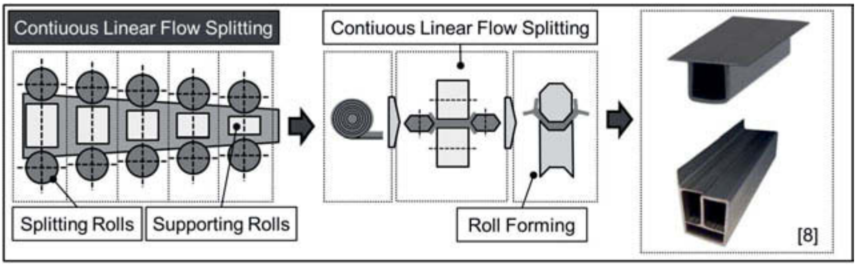

Fig. 5: Linear flow splitting within a continuous process-chain

This offers a completely new class of forming-parts, taking into account that bifurcations made of steel sheet-metal prior to this technology only could have been realized by material-doubling or by differential production strategies such as welding.

However, to produce the intended non-linear progression of the chassis-members within the chassis concept another process-chain based on the linear flow splitting process was implemented: a superposition of the linear flow splitting process with a subsequent bending process, firstly described in [9].

Therefor a bending unit is added directly after the outlet of the final linear flow splitting unit to superpose a bending force to the forming-process of the last linear flow splitting step (Fig. 6). Due to this superposition the plastification of the linear flow splitting is utilized for the subsequent profile bending. This leads to reduced bending forces and to a reduced springback, which is highly beneficial in terms of tolerances of the non-linear profile geometry [9].

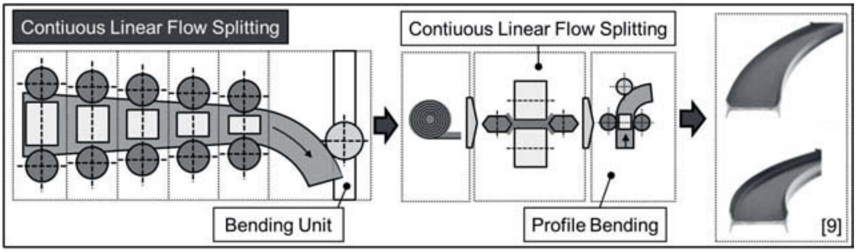

Fig. 6: Bending of linear flow splitting profiles

This process-chain for the production of non-linear profiles can be accomplished without any additional tooling-effort – the bending process of the linear flow-splitted parts itself permits a high flexibility of the profile progression. Thus it is predestined for the application of the described chassis-members because it offers a demanded profile progression corresponding to the variety of lengths and wheelbases of the highly diversified class of LCV.
The actual chassis-member is produced by a differential strategy, using the non-linear bifurcated semi-finished-products. Therefor the bifurcations of the parts are used as joining areas in order to mount a defined number of non-linear single parts with two cover plates, which leads to a non-linear multi-cambered profile (Fig. 7).

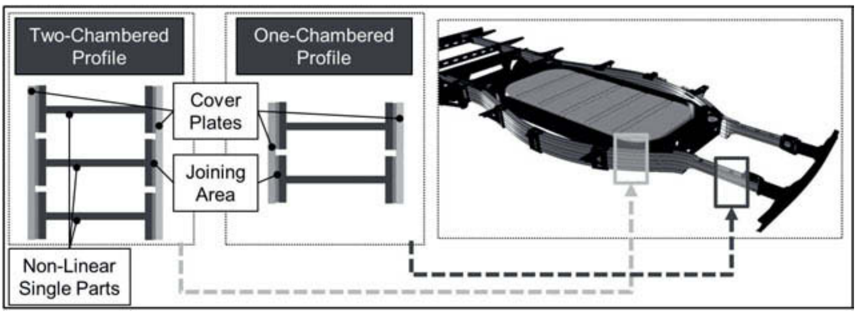

Fig. 7: Design of the multi-chamber chassis-members

This strategy enables an individualisation of the chassis-members adjusted to the expected loads in case of a side-crash. It is possible to adapt the number of layers within the profile to the amount of energy, which has to be absorbed during a crash. Furthermore on the one hand it allows a local insertion of reinforcements into the chassis-members depending on the loads and on the other hand a reduction of the profile height in zones where a reduced cross section is sufficient.

Different technologies are conceivable as mounting mechanisms such as laser welding, riveting, bolting, clinching, blind-riveting, and gluing or hybrid technologies; whereupon gluing offers the advantage that corrosion in the joining area can be avoided.

Based upon that, the advantages of the differential production strategy for the chassis-members can be summarized with: reduced tolerances of the non-linear single parts caused by an innovative process-chain at room-temperature, individualized reinforcements depending on the specific load, raising lightweight-potentials by adapting the profile height, using steel sheet-metal for crash absorption, high flexibility without having any additional tooling effort.

Technological Approach – Material Lightweight Design

The use of plastic materials in heavily loaded structural environments is usually not considered as the typical mechanical properties of the plastics are considerably lower than those of the commonly used metals. The equipment of plastics with fibers, mainly glass or carbon fibers, increases on the one hand the strength, but additionally reduces the ductility. But sometimes the combination of certain possibly weak material characteristics may lead to surprising strength in the application.

Originally the various LWRT-materials like Seeberlite© were developed as an acoustic absorbing material. In order to fulfill the purpose of acoustic absorption, the material must have an intrinsic porosity so that the sound can enter the material and will not be reflected. A suitable material approach is the mixture of glassfibres with polypropylen fibres. Even with reduced mechanical properties this leads already to a lightweight material, as the porosity may reach up to 70%.

In a typical component design, flat, continuous areas are usually made as thin as possible to save weight. By using a porose material approach, the component thickness can be expanded without the penalty of weight increase. The wall thickness increases the section modulus in the third potency. This can tremendous reduce the tendency to be bent or buckle, especially under pressure loads.

But also with a considerable increase of the area moment of inertia, the flexural strength is limited by maximum tolerable stresses in the edge region of the component, which is still low for even reinforced plastic materials. Here a combination of materials can meet the challenges. Adding two thin layers of a stronger and ductile material to the edge fiber will increase the bearable stress and raise the components mechanical properties up to an utilizable level.
Special attention must be payed to the connection between the porous core material and the load-bearing surface layers (Fig. 8). The thin layers need a surface treatment, to ensure a proper and lasting connection grabbing deep into the structure of the material. An adhesion only on the oxide layers of the reinforcing layers would separate in a sudden overload, thus making further energy absorption impossible.
With these requisites, a scalable energy absorption component can be designed. In the application as sidewards added crashpads the Stratura Hybrid material, covered within the frame, will absorb the crash energy under sudden stress. The force level can be scaled by the composition stacking and the thickness of the reinforcement layers. The LWRT-material prevents the reinforcement layers against buckling. The area moment of interia of the Stratura Hybrid crashpads supports the outer frame by backing it back to the inner frame. The area moment of the wall thickness of the Stratura Hybrid ensures that the reinforcement layers cannot buckle and escape the force. When the stress level rises over the bearable stress of the Stratura Hybrid material, the glass fibres of the core material will break, giving way, but due to the ductility of the reinforce layers and the porous structure of the core material fractures cannot spread. So the material recovers immediately after each break and is able to absorb all crash energy above the bearable stress level.

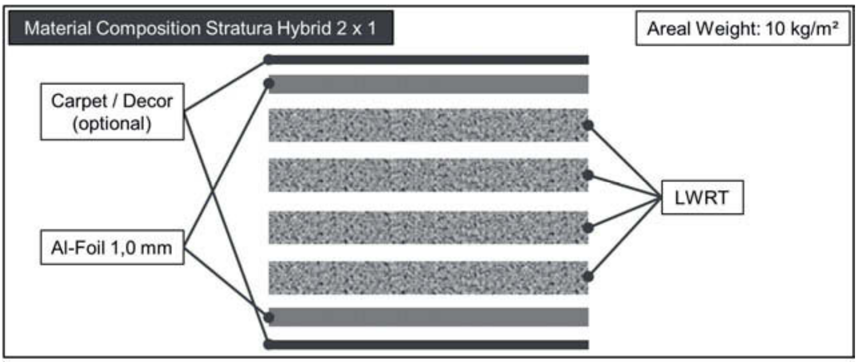

Fig. 8: Material composition of Stratura Hybrid

Customers´ benefits of the chassis-concept

The presented chassis concept for LCV is clearly oriented to the customers´ demands (Fig. 9). It offers benefits concerning costs, flexible usage of alternative drives (battery electric or fuel cell), flexibility in terms of application, payload and shipping volume. Cost advantages can be raised by using an innovative technology, which enables the processing of steel as a very cost efficient material. Furthermore the presented production strategy offers a high variability concerning the realization of different shapes of chassis-members. By this a wide range of vehicle specifications with different wheelbases can be reached without having additional tooling effort. Additional cost effects can be expected by the simplification of the energy storage protection. Integrating the protection mechanisms into the chassis structure, which is accomplished by the bionic inspired topology, leads to a significant reduction of individual parts and part complexity.

It does not only aim to the protection of battery-electric infrastructure. The chassis with its self-protection-mechanism can also be adapted for the usage of fuel cells. Hence it can be used as a rolling platform for future mobility solutions in general.

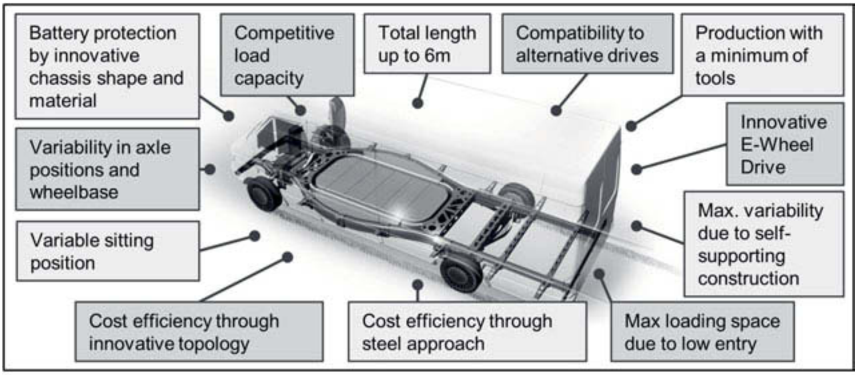

Fig. 9: Summary of the customers´ benefits of the chassis-concept

Due to its self-supporting construction it is applicable for any vehicle superstructure. Thus, a wide utilizability of the rolling platform is given, which can also lead to scaling effects within production. This variety in applicability is additionally expanded by the flexibility of the manufacturing strategy. The chassis-members, as described, can be adapted to different load cases as well as to different profile progressions easily.

The payload of the vehicle is highly influenced by the battery weight and has a direct impact to the payload. This effect develops diametric to the battery capacity, which has an influence to the range of the vehicle. By realizing a multi-step lightweight-approach the total weight of the chassis can be reduced, which allows the installation of a battery-system with a high capacity and a competitive payload at the same time.

Summary

The paper describes the development of a chassis-concept for light commercial vehicles driven by alternative power units. It is based on a bionic inspired topology, which offers advantages in terms of protecting the energy storage without any additional high-performance housing-systems.

Cost effects can be raised by flexible manufacturing strategies, by using cost efficient materials as well as by the applicability of the chassis-concept to a wide range of use-cases.

A competitive payload and range of the chassis-concept are reached by a multi-step lightweight approach and innovative lightweight technologies.

The first step – a structural lightweight design – is achieved with a new process-chain by superposing a linear flow splitting process with a bending process. This enables the continuous production of curved bifurcated profiles, which are mounted to individualized chassis-members afterwards. The second step – a material lightweight design approach – helps to raise the crash-performance of the chassis with a minimum of additional weight by using a new composite material called Stratura Hybrid.

Hence, the paper describes the development of a chassis-concept for prospective mobility with focus on customers' benefits as well as new lightweight technology approaches, which are merged within the present chassis-concept.

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ZF Kit for E-Mobility Products for Commercial Vehicles

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Abstract

E-Mobility has been one of the top-priority subjects for the past few years and will remain so in the future. OEM und suppliers have been struggling to find the ideal, yet equally commercial and technical solution. So far there seems to be not one solution, but many, ranging from Hybrid, Plug-in Hybrid, BEV and FCEV. This discussion is occurring not only in the passenger car segment, but also in the commercial vehicle segment. Since the emotional aspect of E-Mobility is secondary to the commercial aspect, it is vital to meet the needs of the respective segments with components that can be used in as many applications as possible. This article describes one element of the ZF commercial technology approach: A kit that consists of electrical, mechanical and software components.

Introduction/ Motivation

Since the market development of the various E-mobility solutions for commercial vehicles (CV) is still unclear, a flexible approach is necessary. To be able to fulfill both the commercial demands as well as technical demands for E-Mobility driveline for CV, it is critical to supply the respective segments with components that can be used in as many applications as possible. This article describes one element of ZF commercial technology: A kit that consists of electrical machines and inverters, mechanical components, like the transmission which contains cooling for gear & shafts and other as well as the electrical components. Last but not least, the software platform for both inverters and transmissions. Together with the long-term ZF experience and successful products in the CV market, optimal commercial and technical solutions for the emerging E-Mobility market can be combined with low risks for the customer.

ZF's strategic approach for E-Mobility in CV

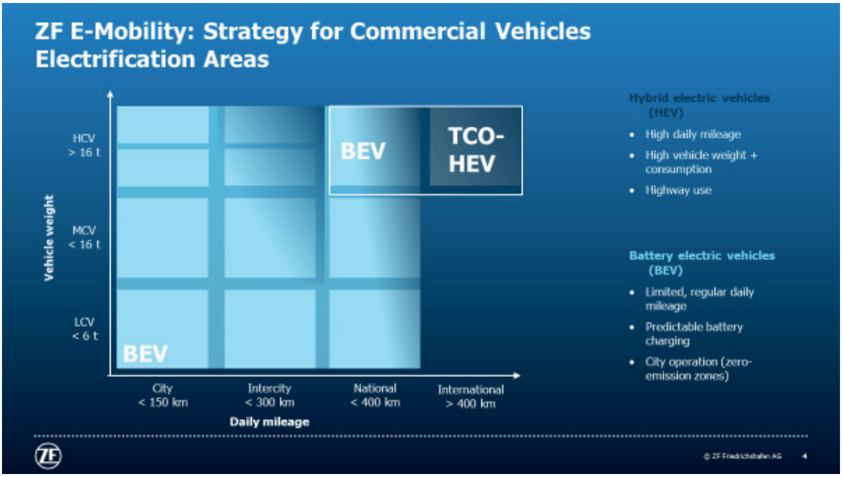

Fig 1: ZF Strategy for CV

Fig. 1 shows the actual ZF strategy for CV regarding electrification areas. It is now understood that for low daily mileage applications, the electrification of BEV will become ubiquitous in almost all vehicle segments, from LCV up to HCV. This is also feasible from a TCO point of view if battery prices develop as expected in the next years.

For high daily mileages exceeding 400 km/ day, however, it would not be possible to install the battery capacity needed for BEV in the vehicle due to installation space and weight limitations. Thus, BEV without FC technology in the HCV/long-haul segment will not be a suitable solution for some time yet. This means that to achieve CO2 targets, the need for HEV to meet the upcoming CO2 reductions is critical.

For HEV, electric driving is also a desirable feature, i.e. to be able to drive the ‘last mile’ without generating emissions. Since, over time, last-mile requirements have risen up to 50 km in current discussions, a split between two different kinds of HEV is evident. On the one hand, the plug-in HEV, which has a sufficient battery size of up to 120 kWh and a powerful electric motor that enables the vehicle to cover the “last mile” of 50 km. Those requirements mean high additional costs for the electric system. On the other hand, a TCO HEV suggests moderate additional costs since its main purpose is to save fuel through recuperation, which means the battery size required is only < 8 kWh, whereas the power of the electric motor here would be sufficient at around 75 kW continuous. According to ZF, a TCO HEV leads to a payback for the hauler and is therefore suitable for higher volumes, whereas PHEV will presumably remain a niche application due to the costly system. This is the reason why ZF is focusing rather on TCO HEV.

Related ZF E-Mobility products for CV

This section briefly introduces the first generation of ZF CV E-Mobility products, summarized in table 1. They have been released over the last few years and are already in volume production or are in various stages of development. All these products use electric motors with induction motor technology and have considerable advantages regarding costs, availability as well a good overall efficiency.

CeTrax is the ZF central drive solution for buses and HCV. It consists of an induction motor with 200 kW continuous power and a one-stage planetary gear set. CeTrax is under development, SOP is scheduled for 2020. There are different models for the Chinese market that have the same design concept but are developed according to local requirements.

AxTrax AVE is the ZF electrical portal axle for low-floor buses where the complete drivetrain is integrated into the wheel hubs. It consists of two 125 kW induction motors with two gear sets and a fixed gear ratio. AxTrax AVE is a volume-production product.

TraXon Hybrid is the ZF hybrid transmission for HCV. Based on a TraXon series transmission, the product features an additional hybrid module with induction motor rated at 130 kW and integrated planetary gear set inside the rotor.

CeTrax lite is the ZF central drive for LCV. This product features an induction motor rated at 80 kW continuous power and a fixed ratio gear set. The electric components come from the ZF volume-produced product Electric Axle Drive of the ZF E-Mobility-Division for passenger car market.

Table 1: ZF E-Mobility CV products, first generation

	CeTrax	CeTrax lite	AxTrax AVE	TraXon Hybrid
				
CV segment	Bus, MCV 26 t	LCV < 7,5 t	Bus 26 t	HCV, coach 44 t
Type	BEV Central drive	BEV Central drive	BEV Axle drive	HEV
Electric motor type	Induction motor	Induction motor	Induction motor	Induction motor
Power peak Power continuous	300 kW 200 kW S2 = 30 min	125 kW 80 kW S2 = 30 min	2 x 125 kW 2 x 87 kW S2 = 30 min	130 kW 75 kW S1
Nominal voltage level	650 V DC	420 V DC	650 V DC	650 V DC
Torque Peak	1.350 Nm	390 Nm	485 Nm	560 Nm
Max. rpm	8.500 rpm	13.000 rpm	10.300 rpm	5.500 rpm

Technical key issues for successful E-Mobility products

The following section describes in detail the key components for successful kit products. These include the electric machines, transmissions, cooling systems, shifting actuator, power electronics and software; and lastly, the high voltage harnesses. Wherever possible, synergy effects between the various E-Mobility products were used as well as synergy effects for already existing ZF volume-production products in the AT and AMT segment. The carry-over of components and parts as well as proven design features in software and hardware has a major impact on development time, robustness and predictability.

Electric motors

As a key component, the electric motors used are described in greater detail. To meet various requirements regarding drivability, installation space and TCO, different induction motor (IM)

sizes and types are used for the vehicle segments. All IM are developed by ZF in-house for optimum performance and durability and since its development is from one source, synergies can be used in an ideal way.
For the LCV segment up to 7,5 t, the already existing induction motor used in the ZF passenger car series application represents a great opportunity because the 400 V level appears to be a good solution for those applications in terms of short-term availability and economic advantages. Lifetime requirements in this segment can be met without restrictions.
For MCV or even HCV, a higher voltage level of 650 V to 800 V is desirable due to the higher power levels required for up to 400 kW. ZF uses mainly induction motors for traction applications because they are robust, cost effective and their efficiency is very good even when compared with PSM (permanent magnet synchronous machine) applications. ZF was even able to prove this in internal testing with an equivalent competitor product.
Since these systems will be continually developed and the requirements regarding full integration (weight, space) and efficiency will constantly evolve, PSM technology, which was already included in different ZF projects, will be considered in future developments. PSM technology allows for various technical design approaches like wave winding or hair-pin systems.
The CeTrax induction motor is rated 300 kW peak power @ 650 V and 8,500 rpm. Since space restrictions are not an issue for state-of-the-art central drive bus applications, the CeTrax installation space meets the ZF AT Ecolife series while remaining compact.
AxTrax AVE is a volume-produced product for buses and also uses induction motor technology. Peak power is 2 x 125 kW @ 650 V / 10.300 rpm.
TraXon Hybrid induction motor with 130 kW peak @ 650 V / 5.500 rpm is a special design meeting strict requirement regarding dimensions and cooling. One of the targets was to make almost no changes to the ZF TraXon AMT series AMT at all.

Power electronics

For power electronics, ZF uses products supplied by its cooperation partner Zapi / InMotion for drives with a DC nominal voltage of 650 V. The power electronics are also designed according to a modular principle which enables the expensive power semiconductor components to be variably adjusted. This makes it possible to match the power electronics precisely to the requirements of the electric motor.
Software functions can be split between the inverter control and a central electronic control unit, i.e. the ZF drive control unit. The split can be flexibly represented. Functions with high-

demand torque dynamics can be performed on the inverter control unit. In contrast, low-dynamic functions such as temperature calculations can be moved from the inverter to the ZF control unit. The ratio may vary depending on the project and ECU resources.

When it comes to power electronics, numerous projects show that two inverter variants enable most projects to be optimally operated in terms of cost, installation space and weight. The two variants feature identical customer interfaces for high-voltage, low-voltage and cooling connections. This also makes it easier to integrate the different drive variants from the modular system.

The interface between the ZF control unit and the inverter is also identical for all inverter power classes. Therefore, the vehicle control unit can be combined with different inverters without additional effort. This makes it very easy to build single- and multimotor drives. The inverters and functions are designed so that induction and PSM motors can be operated.

The following figure shows the characteristic data of the two inverter variants, which have proven to exhibit low installation space and weight costs.

Both power electronic systems allow a DC voltage up to 750 V without derating and without loss of lifetime. At higher DC voltages, these factors entirely depend on the driving profile and other customer requirements as to whether the lifetime is affected or not. The smaller of the two inverters has a 20 second peak current of 340 Arms. The larger version can hold up to 530 Arms. The S1 continuous current is 225 Arms or 375 Arms.

	ACH65M30	ACH65L50
Manufacturer	InMotion	
Type	3-phase drive inverter	
Performance data		
Nominal DC voltage	650 V	
Maximum DC voltage	750 V (without derating)	
Current (peak, 20 s)	Up to 340 A_{rms}	Up to 530 A_{rms}
Current (duration, S1)	225 A_{rms}	375 A_{rms}
Insulation resistance	> 20 MΩ (new hardware)	
Dimensions, weight		
L x W x H (mm)	421 x 362 x 122	583 x 362 x 122
Weight (kg)	20	25
Highlights	• Efficiency > 98 % (nominal value) • Robust design with IP6K9K • Liquid cooling	

Fig 2: Inverters

Software

Due to the very different application scenarios, there are already many commercial vehicle variants today. From ZF's point of view, this diversity can also be expected in E-Mobility, which means E-Systems must be able to support these application variants in an efficient way.

To be able to support numerous variants, ZF has once again decided to use a platform for software functions. The modular system is predominantly made up of series-tested functional components with a high degree of maturity. In addition to economic reasons, the reuse of series-tested components played an important role in the deciding on a modular system. The software platform is used in all E-mobility projects (electric drives and hybrid transmissions). The development and testing of an overall application-specific software based on the modular system reduces the effort and ensures optimum performance and reliability.

The modular software platform confirmed its usability and is successfully used in volume-production projects. The platform concept also shows that it can support a variety of variants. Thus, numerous prototypes with different components could be implemented successfully in a short time. Essential functions of the software platform are shown in Figure 3.

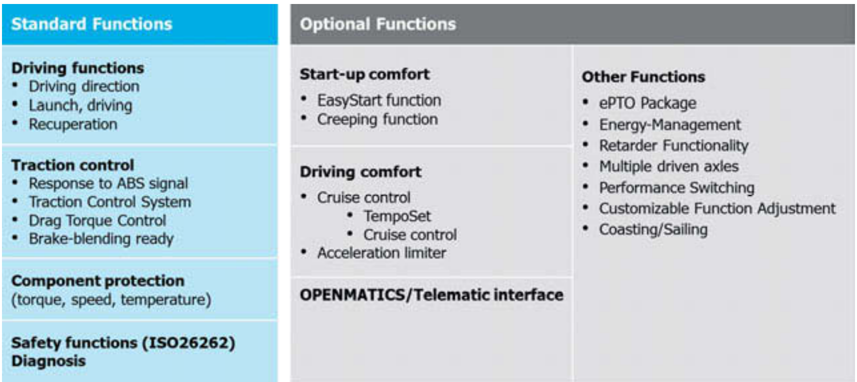

Fig 3: Essential software platform functions

A central electronic control unit coordinates the interaction between electric motors and power electronics, on the one hand, and between the energy storage system and auxiliaries, on the other. The electronic control unit manages the energy flows and driving functions, including interpreting the accelerator pedal and determining the driving condition; the torque and power distribution and recuperation throughout the system. Due to limited ECU resources, in projects fully equipped with multiple drive axles, it may happen that the entire software – including

Vehicle, Powertrain, Energy and Gearbox Control - can no longer be executed on one electronic control unit.

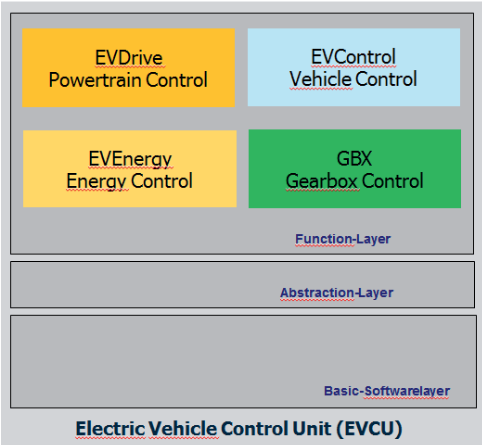

Fig 4: Electric Vehicle Control Unit (EVCU)

Here, the modular software platform offers a further advantage in that individual software modules can be moved between control units, such as inverters and the drive control unit. It is also possible to move modules to a customer ECU.

The vehicle / drive control functions are separated into standard and optional functions. Standard functions:

In conventional vehicles, many driving and assistance functions are installed in the combustion engine control unit. For electric vehicles, these functions must be assumed by other control units. The ZF control unit can assume the functions as a central vehicle / drive control unit. In the software platform, several driving functions are available.

Basic functions essentially include the basic driving and driving dynamics functions, the component protection functions and the safety functions developed according to ISO26262. Figure 3 represents the driving functions for a single-axle drive. The modular drive modules are divided into operational and strategic functions. The strategic functions aim to essentially determine the driving torque, the torque distribution and recognize the driving condition. The operative functions assume the desired torques and convert these into the drive torques and handle component protection.

The combination of several single-axle modules from the software platform makes it easy to create multiaxle drives or a mix of central and axle drives.

Electronic traction control is easy to implement because it not only supports propulsion on a slippery surface. It also prevents the axle gear stage from being exposed to so-called ice plate impacts. These heavy torque impacts are uncontrolled and occur abruptly when driven wheels are spinning and then return to a high friction surface like asphalt. The resulting torque peaks can damage the mechanical drive components so that they fail prematurely. Component protection also includes temperature models that calculate the component temperature at critical points to help protect components.
The optional functions include an easy start function, for example. This ensures, temporarily, that a vehicle does not unintentionally roll back down a slope when the driver switches from brake to accelerator pedal.
There are also other assistant functions available, like cruise control and tempo-set functions. For city buses, limiting the acceleration is important so that standing passengers are not injured during a high-start acceleration.
One of the most important functions in an E-drive system is the regeneration / recuperation of braking energy, which can be implemented in numerous ways. With the ZF recuperation function, one-pedal driving is just as possible as a retarder lever, which is quite common in commercial vehicles and can be used by the driver to influence the recuperation torque.
When combined with a telematics system (i.e. ZF Openmatics), many other functions, such as power or acceleration limits that depend on vehicle position can be presented. The GPS-based power limitation, for example, is usually used in city buses. On the one hand, the power is limited to save energy in city center traffic and on the other hand, full power is necessary when the bus is traveling on a city highway.
The signal interface between the central ZF control unit and the vehicle is identical for all drive variants. This also applies to variants with and without multispeed transmission. This makes it very easy for customers to integrate different electric drive systems into their vehicles. In addition, ZF offers customers certificates such as ECE R10 or ECE R85 for simplified homologation.

Mechanical components: transmission and cooling systems

The ratio between the reuse of components from already existing products and new components was a key point in different E-Mobility systems. ZF, as a driveline specialist, views the gear set and, especially, planetary gear sets, as key E-Mobility components in terms of power density and the required lifetime in the CV sector with strict requirements. Another important component is the oil used, which is what ZF is focusing on together with established suppliers. The oil types used are familiar from other ZF products, impacting durability and serviceability.

Table 2: Transmission and cooling systems

	CeTrax	CeTrax lite	AxTrax AVE	TraXon Hybrid
Transmission type, ratio	Planetary gear set, i = 3,4	Two-stage spur gear set, i = 5,9	Two-stage ratio i = 22,7	Planetary gear set, i = 2,1
Cooling / lubrication system	Stator: water cooled T/M: oil injection	Stator: water cooled T/M: oil injection	Stator: water and air cooled T/M: splash	EM and T/M: oil injection
Pump type	electric	electric	-	mechanic

Since CeTrax is ZF's forerunner central drive for BEVs, as many carry-over parts from the ZF AT Ecolife were used as possible. These parts include one planetary gear set to reduce the input speed of 8,500 rpm as well as both the complete output bearing concept and the output shaft. Since city bus applications have extremely high requirements regarding lifetime and reliability in general, the possibility of having well-proven carry-over components from volume-produced AT products can be regarded as a big advantage. For optimized performance and overall efficiency, ZF decided to use a normal water-cooled stator system combined with an oil circuit for transmission cooling, including an electrical oil pump. Furthermore, some induction motor applications require, under certain conditions like a standstill after high power passages, thorough rotor cooling and the corresponding bearing and sealing components.

For the TraXon Hybrid, a one-stage planetary gear set with fixed ratio is used to reduce the EM speed of 5,500 rpm. The housing, sensor, clutch release and system interfaces are carried over from the TraXon, the oil cooling system was adapted from TraXon using the same oil circuit. The stator is injection oil-cooled but no additional water cooling is necessary. The stator is mounted in the aluminum housing using special bolts to simplify stator assembly, decrease product costs and minimize the thermal expansion effects between stator and housing.

CeTrax lite is the perfect example of an effective carry-over from the existing ZF passenger car volume-produced product, the Electric Axle Drive. This creates high confidence levels right at the development start because off-the-shelf components can be used, thus ensuring cost effective engineering. CeTrax lite features a two-stage spur gear set to reduce the electric machine speed of 13,000 rpm and uses two ratios currently taking into account the same design space. Also, the transfer of the power electronic and parking lock concept from the passenger car product and integration into new packaging variants can be achieved. The stator remains water cooled, whereas the rotor shaft, stator windings as well as the transmission are additionally cooled by an electric oil pump, combined with an extra oil cooler. Thus, the continuous power of CeTrax lite can be considerably increased by some 10 kW.

Mechanical component: electric actuators

ZF considers electric actuators as a strategic component for the next generation of E-mobility products since they are easily adaptable for different applications, allow precise and smooth gear shifting without the need of a pneumatic or hydraulic system supply. The actuators feature one BLDC engine with an integrated planetary gear set and position sensors. Kits with various motor sizes and additional components such as an actuator brake are taken into account to cover every aspect of future product development.

High Voltage Harnesses

Many customers, especially in the ramp-up phase of E-Mobility or with smaller volumes, as is typical in the Bus segment, are increasingly demanding more complete systems from the supplier. ZF has therefore decided to include HV harnesses in the scope of development.

Outlook on future ZF E-Mobility developments

Next generation ZF E-Mobility products are already undergoing further development since costs, compactness and efficiency requirements will increase drastically when volumes rise starting in 2025. For the next generation, even more elaborate electric motors, power electronics and a higher level of sophisticated transmission knowledge will be required, nevertheless first generation E-Mobility products will be needed. To achieve ZF's goal as a market leader, we are introducing two completely new products/ product lines here.

ZF-DHT for HCV

The ZF-DHT (dedicated hybrid transmission) is viewed by ZF as the future HEV in the HCV segment. Whereas the TraXon Hybrid serves as an initial step / bridge for HEV technology in the HCV segment, the above-mentioned requirements demand more elaborate technology approaches. This will be met by following technical features.

The electric motor is fully integrated into the transmission, no restrictions coming from the basic transmission since most parts are designed around the electric motor. For gear reduction and additional versatility, a planetary gear set with multiple functionality is implemented. The advantage of this system is that no clutch is necessary since the electric motor will actuate take-off. Another important feature is power shifting in all gears, with the electric machine providing

support when shifting takes place. The transmission's gear set is based on the TraXon design featuring a planetary gear set but with reduced number of gears due to DHT design.
Since no clutch is needed in conjunction with a compact transmission design, the overall length of ZF-DHT would be the same as the standard TraXon. Prototypes are already available, basic test bench and vehicle tests are ongoing.

Future electric axle kit for MCV and HCV

The ZF products which have been described so far do not cover BEV from 26 t to 44 t. Therefore, it is the goal of a development project to provide electric drive solutions for the MCV and HCV segment.
ZF decided on an electric axle architecture. When designing a battery-electric CV that should be able to cover a daily mileage of up to 400 km, a lot of space is needed for installing the battery capacity. In this case, an electric axle could have an advantage compared with a central drive solution since it frees up some space for the battery. An electric axle solution should also be preferred in terms of efficiency, which is important for applications with higher range.
The axle design is modular and it is also taken into account that the components could be used in other future products. The different electric axle versions will feature electric machines and transmissions that are fully integrated into the drive axle. Two electric motors will be used in versions with higher output requirements. Also, depending on the segment, fixed-ratio or multispeed transmissions will be implemented. Both for the electric motors and for the transmissions, identical parts and components will be used to a great extent.

Benefits of the ZF E-Mobility kit approach

For customers as well as for ZF, the modular ZF E-Mobility kit approach will result in significantly shorter development times, more robust products, improved serviceability and a broader field of applications to cover. Also, modifications based on specific customer requirements can be implemented comparatively easily.

Summary and outlook

The ZF E-Mobility kit represents one approach that will meet customer cost, efficiency, robustness and versatility requirements for HEV and BEV products in almost all CV segments.
The outlook for E-Mobility from 2025 onward with a still unknown number of traditional driveline products will benefit from the combination of well-established AMT and AT product technology, market expertise and a worldwide service organization, along with modular technology based on the same ZF technical standards.

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The eTrailer – Intelligent hybridization for heavy duty commercial vehicles

Electric drive installed in a semi-trailer and integrated in the truck & trailer overall brake system control leading to significant fuel savings

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Abstract

Shown is an industry first solution for integration of an electric drive in a trailer combined with a holistic control approach by the overall vehicle brake system consisting of the trailer- and the truck-EBS without the need for additional truck/trailer communication lines, sensors or ECUs. The eTrailer is forming a hybrid vehicle combination together with a conventional powered towing vehicle and it generates fuel savings by energy recuperation and reuse for traction purposes as well as powering auxiliaries like coolers in trailer. Presented are design and test results of the WABCO eTrailer Prototype including basics of the overall control strategy.

Introduction

The trend towards reducing fuel consumption and emissions in motor vehicles continues unabated and is gaining further momentum as a result of the increasing electrification of power trains and auxiliary units. Especially in the heavy commercial vehicle sector, power train electrification is still in its early stages, as the main obstacles here are limited battery capacity and cost. Hybrid technology has proven to be the bridging technology to fully electrically powered vehicles in the passenger car sector. Hybrid technology enables the energy, stored in the vehicle's mass, to be partially recovered during deceleration phases, so it can then be reused for propulsion by the electric drive. WABCO, the leading innovator and global supplier of technologies that improve the safety and efficiency of commercial vehicles, has now extended this concept by the WABCO eTrailer to a vehicle connection consisting of a conventionally driven tractor and an electrically driven trailer. The electric drive in the trailer is controlled both by the EBS of the truck as well as the EBS in the trailer communicating via the standardised data interface ISO 11992-2. The integration of the eDrive control into the overall truck trailer brake system enables best in class energy recuperation as well as energy efficient traction support from the trailer with ensured vehicle stability and safety.

Design of the electric drive in the trailer

A major advantage of hybrid vehicles over purely electrical propulsion is the elimination of range issues. While ranges of around 500 km can be achieved in everyday use for electric passenger cars, a significant improvement in energy storage density and cost is still required for the conventional 40-ton truck. However, if the electric drive is used as an add-on as part of a hybrid concept, the energy storage system no longer has to be designed for the entire distance to be covered; only an adequate amount of energy needs to be stored from brake energy recovery. The typical power requirement of a semitrailer combination with a total weight of 40 tons and a constant straight line speed on the flat of 80 km/h is approximately 75 kW, due to roll and wind resistance. Even with no losses in the power train, a storage capacity of about 190 kWh would be required for a range of 200 km. On the other hand, a 6 km long downhill gradient of 4% at 80 km/h requires a constant braking power of 190 kW, (roll and wind resistance already discounted). An accumulator with 20 kWh of (free) capacity would be more than sufficiently large to store this amount of energy. However, a purely electric vehicle reduces emissions and diesel consumption by 100%, at least locally, whereas a hybrid vehicle is still mainly powered by a combustion engine. The challenge for a hybrid concept is therefore not to be able to drive as long as possible under purely electrical power, but to achieve high fuel savings using the fewest possible resources and the lowest initial investment costs. Additionally the electric drive has to be integrated as an auxiliary unit in the vehicle, regardless of whether this is a passenger car, a semitrailer tractor or a trailer. However, in the commercial vehicle sector, the EURO6 exhaust emission standard is increasing the space requirement for exhaust gas after-treatment in the towing vehicle [1] and is also reducing the already very limited space available for the battery, inverter and electric motor. The eTrailer concept of WABCO responds to these two challenges by integrating an electric drive into the trailer (Fig.1). The main challenge for the system design is combining appropriate system power to cover a significant ratio of deceleration events with system costs and weight constraints under the special circumstances of a (semi-) trailer regarding installation environment.

Fig. 1: Concept of WABCO to integrate an electric drive into the trailer

Battery cells and designs traditionally used for electric traction focus on the maximum energy density of the accumulator. However, hybrid systems require a high charge and power density. The maximum charging and discharging capacity of a battery is given by the so-called C-rate and depends on the storage capacity. Typical batteries for purely electric vehicles have charging C-rates of < 2 [2]. The use of such a battery design with a meaningful capacity of 20 kWh limits the electrical motor output to about 40 kW, maybe 80 kW peak for some seconds. In order to achieve high fuel savings the system peak power should be in the 300 kW range. For this reason, lithium titanate oxide cells were used for the prototype, which can deliver a charge rate of up to 10 C. Strongly linked to the battery is the question of the additional weight of the electric drive system.

For vehicles under 26 tons with two or three axles and (partially) alternative propulsion, as well as certain bus types, Directive 2015/719 allows up to one ton extra weight according to EC96/53 [3]. WABCO is confident that, given market availability, electrified trailers will also be able to benefit from this regulation in the future. With an additional weight in the prototype of currently about >1 ton and a production target of ~800 kg additional weight, there would be no payload losses.

A transmission ratio for the differential of about 6:1 was selected, which, in combination with the design of the electric motor, guarantees a constant torque of up to about 50 km/h and a peak power of ~300 kW from 50 km/h to 90 km/h. The maximum torque is about 7000 Nm, both positive and negative.

The power of the electrical machine of 300 kW sounds comfortable, but for an adaptive deceleration of 0.42m/s² from 75 km/h to 60 km/h in 10 s, already a deceleration power of 312 kW is necessary for a 40 t vehicle. Considering the rolling resistance and air drag, about 240 kW remain as needed recuperation power for the electrical eDrive system. If this energy would be used in next acceleration event to support the diesel engine, then about 0.16 L diesel would be saved just from this single event. The recuperated energy from a full stop from 80 km/h to 0 km/h would lead to diesel saving of about 0.5 liter.

In a hybrid vehicle and also for the Truck/eTrailer combination the dimensioning for the eDrive components is bound to other constraints than a traction drive of a battery electric vehicle. The dimensioning for a battery electric vehicle has to consider a permanent high power capability of the Inverter and the motor, which leads to high demands to the cooling system. The hybrid vehicle uses the electric drive more event based, with certain gaps in usage. The thermal dimensioning of the components has to cover the majority of the driving cycles, but it is acceptable to reduce the recuperation or traction capabilities of the drive system after exceptional stressing events. Lower system costs by smaller cooling system and lighter components would outweigh the reduced recuperation capability in rare events.

Control approach

The required coordination of the two-drive systems is achieved via the braking system and the point-to-point CAN interface between the towing vehicle and the trailer braking system, which is standardized according to ISO 11992-2. The EBS (electronically controlled braking system) in the towing vehicle represents the interface to the driver or to a future autonomous driving computer, as well as to the conventional drive and the ADAS (Advanced Driver Assistance System) and stability systems such as the ABS and ESC of the towing vehicle. The TEBS (trailer electronically controlled braking system) forms the trailer side interface to the electric drive and the trailer-specific comfort and safety functions, and is responsible for the positive and negative torque control of the drive train in the trailer based on the demands from the Truck. The eTrailer local operation strategy is influenced by parameters such as the battery charge status and component temperatures. Figure 2 below illustrates the system and communication layout of the WABCO eTrailer concept.

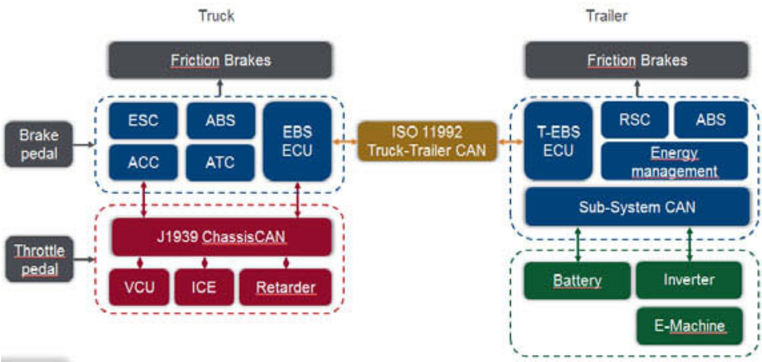

Fig. 2: Schematic diagram of system and communication layout of the WABCO eTrailer concept

At the heart of the concept is the deep integration of the electric drive's energy recovery capabilities into the overall vehicle deceleration control by the EBS systems in the towing vehicle and the trailer. Both systems already have almost all of the relevant vehicle status information available to meet their future tasks. This refers in particular to the determination of vehicle (part) masses, wheel and vehicle speeds, accelerator pedal positions, steering angles and controlled drive and braking torques or forces.
For the integration of the electric drive into the deceleration control, in particular the existing function of the so-called endurance brake integration of the towing vehicle EBS will be modified. According to the state of the art, this function is used to apply wear-free endurance braking in preferred order for vehicle deceleration, when the brake pedal is activated or an external braking requirement arises. Figure 3 illustrates the principle being applied.

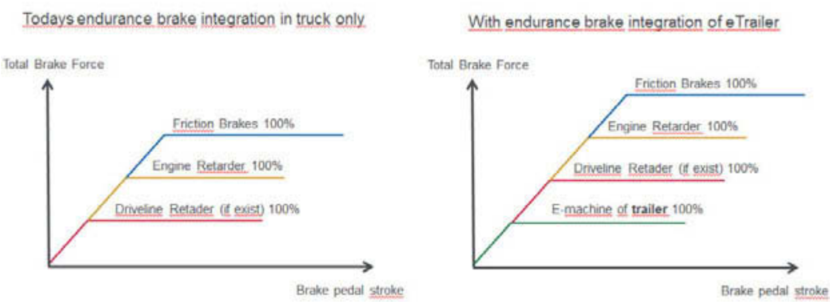

Fig. 3: Schematic integration of the electrical drive into the vehicle deceleration control

In future, the towing vehicle EBS will be informed by the trailer EBS via the ISO-11992-2 interface of the presence of a retarder in the trailer (the electrical motor in the trailer), as well as its absolute performance and the current load, by means of messages that have already been defined in ISO 1992-2 standard, but are currently not being used in the field. Using this information, the towing vehicle can request the deceleration torque (and thus energy recovery) in the event of a desired deceleration by means of a request via the same CAN interface. The local energy management in the trailer brake control unit then decides on the absolute level of the braking torque actually applied. If, for example, the battery charge status prohibits further consumption of electrical power, no deceleration torque is applied and this is fed back to the EBS in the towing vehicle via the current load. In such a case, the wear-free endurance brakes in the towing vehicle or the friction brake system can then produce the desired deceleration. The outcome of the deceleration control is therefore not affected and the vehicle behavior remains stable and calculable. Incidentally, the same applies if a vehicle stability system such as ABS intervenes. In this case, both EBS systems have the necessary information to switch off the energy recovery system in such a way that the function is not affected. By suitable control of the traction drive in the trailer in the composite of the two brake systems with the inclusion of known vehicle parameters is also achieved that the trailer does not defer in the context of traction support and remains a towed vehicle. As a result additional mechanical stress on kingpin is avoided. If the management of the existing endurance brakes of the towing vehicle is not adjusted in the sense that they are no longer used with the highest priority for the braking, the energy recovery by the trailer's propulsion system is significantly hampered. The integrative approach adopted here, taking into account all systems of vehicle combination capable of braking, makes it possible to use recuperation in a much more effective way.

The recovered energy can in principle be used in two ways. On the one hand, a single-phase or three-phase isolated grid can be operated via an additional inverter to supply, for example, a cooling compressor for refrigerated trailers. On the other hand, the stored energy can also be used to support the traction of the electric drive

For stability reasons, it is advantageous for traction support if the trailer continues to be a towed vehicle despite its contribution to propulsion. In order to ensure this, the driving torque currently provided by the towing vehicle drive is determined by the EBS and set as the upper limit for the trailer drive in proportion to the trailer mass. This limit can be influenced by further driving condition signals such as an articulated angle being detected between the two vehicles. This modified upper drive torque limit is communicated to the trailer EBS as a positive torque requirement via an enhanced function of the ISO-11992-2 interface. The trailer EBS then determines the level of the torque actually applied in the same way as deceleration within the scope of local energy management.

Simulation results in VECTO Drive Cycle

The Vecto drive cycles are related to the Vecto tool introduced by European Commission to monitor the CO2 emission level of new build vehicles, considering their equipment characteristics. The drive cycles contain speed profile as well as topology information.

Especially the regional delivery cycle matches to the use case where the eTrailer provides optimum efficiency gain. So it was appropriate to use this cycle also as input for our eTrailer simulation (Fig. 4).

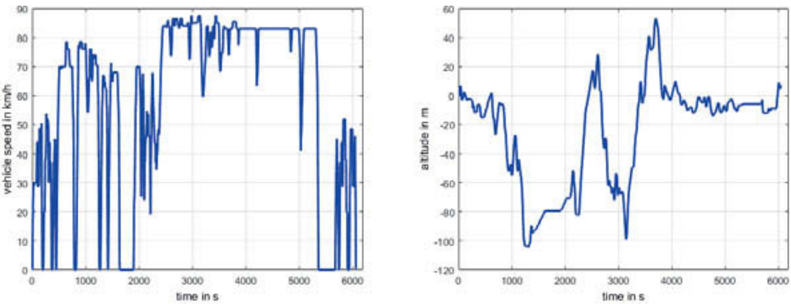

Fig. 4: Vehicle speed and altitude of the VECTO short-haul distribution reference cycle

The simulation for a 40t full loaded truck trailer combination results in a diesel consumption of over 40 liters per 100 km, with the usage of eTrailer about 8 liters can be saved.

The 8 liters represent 66 % of the total braking energy in the vehicle, recuperated and reused to support the combustion engine, taking the losses of the eDrive System under consideration (Fig. 5). With a larger dimensioning of the eDrive system (motor, inverter, battery, cooling) probably more energy could be recuperated, but the chosen dimensioning for the prototype is targeting a balanced cost-benefit ratio. A dimensioning for lower power would result in significantly limited fuel-savings. A larger dimensioning would result in perceptible higher costs for motor and battery.

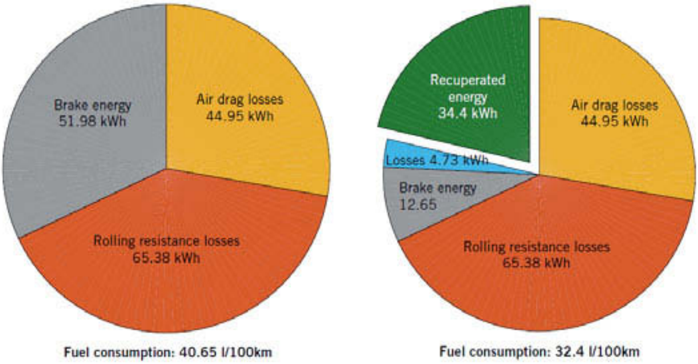

Fig. 5: Energy loss and fuel consumption with and without a trailer hybrid system within regional delivery cycle

Figure 6 illustrates the required axle torque and the delivered torques of the components. The simulation has shown that it is essential to cover the peaks of the deceleration energy as extensively as possible (Fig. 6 area ② and ③). On the other hand while accelerating, it is sufficient to dispense the energy evenly (and correspondingly at lower power) to achieve the desired fuel savings (Fig. 6 area ①).

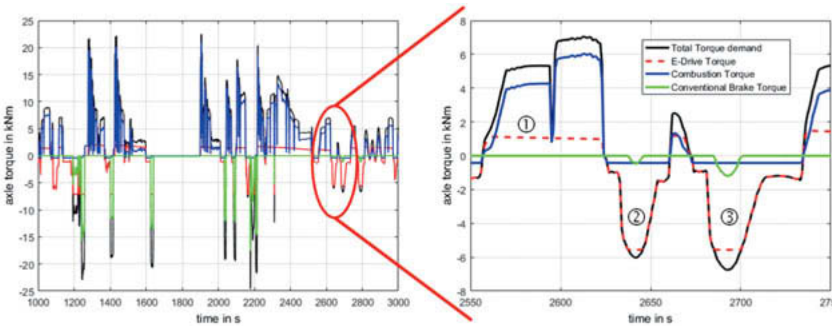

Fig. 6: Torque requirements and torques delivered during the VECTO short-haul distribution reference cycle

Test results from WABCO test track

With real driving scenarios on the WABCO Erich Reinecke Test Track at Jeversen, Germany, it was possible to show that the described consideration of the eTrailer within the endurance brake management works.

Measurements (Fig. 7) show that the prioritization of the eTrailer drive as an endurance brake is carried out as desired (target behavior visualized in Fig. 3). The blending between endurance brakes (retarder and eDrive System) and service brake managed by the unchanged EBS system is seemless.

In Figure 7 different areas are marked. In area ① the deceleration of the total vehicle is fully provided by eDrive of the eTrailer. As soon as the demanded deceleration power is greater than the capability of the eTrailer (area ②), the retarder is activated in addition. At lower speeds the capability of the eTrailer and retarder decreases (area ③). Higher demanded deceleration is now in addition provided by friction brake.

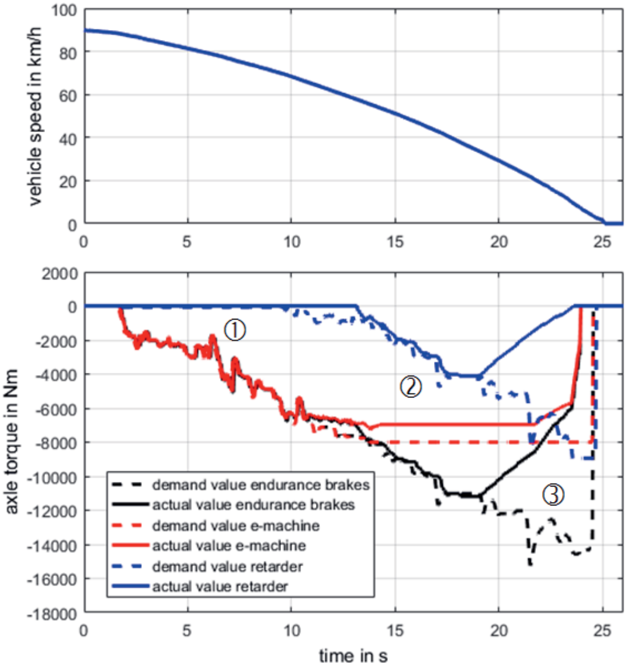

Fig. 7: Measured vehicle speed and axle torque during a brake event

Charging limits of the battery and thermal limits of the e-motor and inverter can lead to derating events which reduce the recuperation power of the system. As a result, the real recuperation capacity is sometimes smaller than it is assumed in the simulation. This is an opportunity for optimization.

Additional data gained during vehicle tests give an insight to the results of the operation strategy (Fig. 8) and to the efficiency of the eTrailer prototype (Fig. 9).

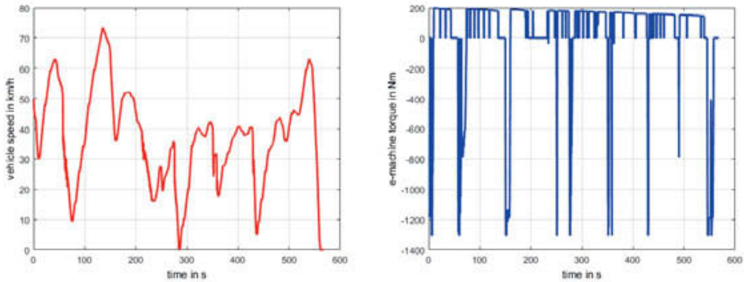

Fig. 8: Vehicle speed and the e-machine torque during the driving scenario on the WABCO test track

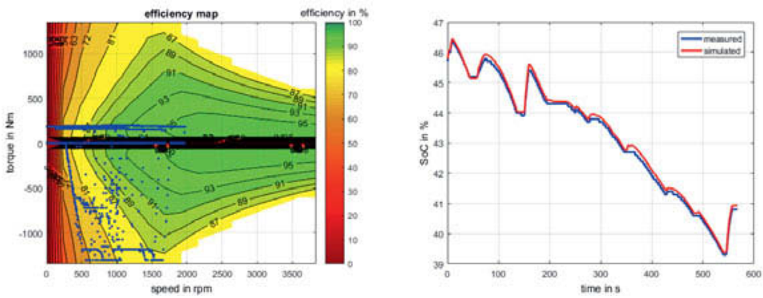

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Fig. 9: Measured operation points of the e-machine and SoC of the battery during the driving scenario on the WABCO test track

Adding the torque and speed operation points into the efficiency map of the e-machine it is comprehensible that with a slightly higher axle ratio the areas of the highest efficiency could be better utilized (Fig. 9), allowing improvements in next generation.

The validation of the simulation of the powertrain using the real measured speed and torque of the machine during the driving scenario, results in a nearly congruent course of the battery state of charge (SoC) between the measurement and the simulation (Fig. 9).

Observed deviations between the measured results and the simulation of the entire system are analyzed. E.g. the gearshift logic of the prototype vehicle tries to support the deceleration by using the engine brake drag torque, but the simulation already assumes that the drag torque effect will be minimized in favor of energy recovery.

The driving tests didn't show any indication that challenges the simulation findings. However, the experience with the eTrailer prototype uncovered areas for improvement that will continuously be addressed to optimize energy recovery.

Conclusion

With the WABCO eTrailer prototype set up, the endurance brake management in the truck has been successfully modified to make use of the recuperation capabilities of the eTrailer instead of wasting the energy in a retarder of the towing vehicle. The existing ISO1199-2 brake and running gear interface between truck and trailer has been used to manage deceleration as well as for acceleration. No additional sensors are necessary, as the information about the vehicle status is available in the connected braking systems. The new functions to control the eDrive in the Trailer can be implemented in the electronic braking systems of the trailer (system supervision and control).

Simulations of the eTrailer in the Vecto short-haul distribution reference cycle led to the dimensioning of components in the eTrailer prototype. 275 kW recuperation peak power was identified as a good compromise to make use of about 75% of the total deceleration energy which otherwise would be wasted. Higher share of recuperation is possible with higher power, but then the costs for the system (electric machine, inverter, battery, cooling system) is violating the return of invest.

The implemented functions and the potential of the eDrive has been tested positive on WABCO test track against the simulation. The test run for a test cycle equivalent to the Vecto short-haul distribution reference cycle will follow soon, giving evidence on the potential 8 liter (20%) savings.

Looking into the future, the eTrailer has the potential to increase fuel savings significantly, when supported by the towing vehicle. The already available retarder management signals on the ISO 11992-2 can be used to optimize recuperation, which saves fuel especially when traction forces are used to reduce combustion engine load. With extension of ISO11992-standard for acceleration purposes and homologation for propelled trailers maximum benefits can be harvested.

Regarding the components for the additional eDrive system in the vehicle, weight and cost optimisation is important. Especially an optimized motor-gear integrated solution as well as a battery with balanced capacity and sufficient charge capability are in focus for improvements. In the end the revolutionary eTrailer concept also competes with hybrid trucks. The eTrailer is an interesting alternative, as it offers some unique advantages in terms of packaging, vehicle stability at high recuperation rate, freedom of combination with different tractors and a longer amortization time as trailers are usually longer used by customers.

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Energy-recuperation as business-case for semitrailers

Smart electrification solution for semitrailers

Dipl.-Ing. **Niki Berger**, Robert Bosch GmbH, Stuttgart

Abstract

An electrified semitrailer axle can reduce fuel consumption, noise and exhaust emissions and thus optimize the costs of freight transport - a new business case for the freight forwarder.

Today, freight transport in the cities and on the highways is steadily increasing. On the one hand, this has an influence on the environmental impact, and on the other hand, the volume of goods at the depot and embark points is growing.

While there are already various optimizations in the tractor, there is still room for improvement in the semitrailer.

What are the benefits for this business case?
The electrified axle recuperates energy during braking and when driving downhill, which can be used for various applications. This free energy is stored in a battery on the semitrailer and can be used for various purposes.

This enables a quiet, emission-free and CO_2-free semitrailer operation (tank-to-wheel)

- of transport refrigeration units (TRUs)
- when maneuvering at the depot and port facilities

and get an additional boost on uphill stretches without consuming more fuel.

How does it pay off?
This saves e.g. up to 30 liters of diesel per day or 9,000 liters of diesel per year on a refrigerated semitrailer. In addition, staff can be relieved, driving restrictions can be avoided and the use of cheaper tractors due to engine downsizing can be made possible.

Bosch supplies compact, efficient and proven electric drives from mass production that are easy to integrate into axles.

Energy-recuperation as business model

What are today's challenges with semitrailers?

- Today's refrigerated semitrailers use a diesel engine to power the TRU. This usually has neither emission control nor noise reduction and consumes about 2-3 litres of diesel per hour.
- Trucks need a strong engine to pull the semitrailer because the semitrailer does not have its own powertrain.
- The shunting operation at the depot generates high costs due to the driver, vehicle and potential accident damage.
- Fleet operators are facing city restrictions due to noise and exhaust gas emission.
- Upcoming CO_2 regulations will challenge TCO due to higher invest in technology.

Solving these challenges is a chance for truck and semitrailer OEMs, axle manufacturers or TRU suppliers to safeguard and enlarge their turnover with innovations like the electrified semitrailer axle.

Bosch-components for this business-case

What are our solutions for this?

Bosch can provide the electrification system and engineering support out of one hand:

- the stand-alone electric motor or its active parts (rotor, stator, resolver to be integrated inside the axle tube) in various power & torque variants
- power electronics
- vehicle control unit HW and SW
- engineering support as system approach

This can also help the truck OEMs to meet further CO_2 regulations if the contribution of the semitrailer will be taken into consideration.

Further information:

https://www.bosch-mobility-solutions.com/en/products-and-services/commercial-vehicles/powertrain-systems/electrified-axle/

Modular Platform Approach for Electric Drive System in Commercial Vehicles

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Abstract

The electrification of commercial vehicles requires modular solutions to address the heterogeneous requirement regarding packaging performance scaling while at the same time considering the target conflict consisting of the number of variants on the one hand side and the cost pressure in the other hand side.

With a modular platform approach for electric drive systems the requirements of light up to heavy duty commercial vehicles can be covered. Especially the high degree of modularization of the power electronics enables solutions adapted to the available packaging space. With regard on functional aspects and optimized efficiency the balancing of the interaction between electric motor, power switches and motor control has essential impact.

Zusammenfassung

Die Elektrifizierung von Nutzfahrzeugen erfordert modulare Lösungen, um die heterogenen Anforderungen bzgl. Bauraum und Leistungsskalierung bei gleichzeitiger Berücksichtigung des Zielkonflikts aus Variantenvielfalt und Kostendruck zu adressieren.

Mit einem modularen Baukastenansatz für elektrische Antriebsysteme können Anforderungen für leichten bis hin zu schweren Nutzfahrzeugen abdeckt werden. Insbesondere der hohe Modularisierungsgrad der Leistungselektronik ermöglicht Bauraum-angepasste Lösungen. Mit Blick auf Funktionalität und optimale Wirkungsgrade ist das Ausbalancieren des Zusammenspiels aus Elektromotor, Leistungsschaltern und Motor-Regelung wesentlich.

Introduction

The electrification of commercial vehicles is relevantly driven by more and more restrictive legislation, cf [1]. It is to be expected that electrified commercial vehicles especially for the use in inner-cities will gain a significant share until 2030 – of course dependent on regional specifics. For inner-city bus transportation we will see a share of electrified vehicles of more than 50% until 2030. Again driven by legislation, especially local legislation.

The commercial vehicles market will thereby follow the passenger car market concerning electrification of the powertrain. Although the commercial vehicles market will show considerably more heterogeneous. The requirements with regard to operational area weight classes and ranges are much more manifold than known from the passenger car area. The first differentiation can be made regarding the operational area “city”, “regional” and “long haul”. Out of this we can derive the required ranges of < 150 km, < 300 km and 600 km. In the next step this has direct impact on the durability and lifetime requirements of the vehicles and powertrain systems of more than 1 mio. km.

Besides the weight class the performance scaling depends strongly on the operational area of the commercial vehicle and covers performance range from 150 kW for light duty vehicles up to 450 kW and even more for heavy duty vehicles. Furthermore the necessity of a drive for auxiliary devices has to be taken into account.

Last but not least the penetration of electrification in the different operational areas will strongly depend on the availability of powerful storage systems for electric energy at a competitive cost level and with high energy density. To address this far-ranging and heterogeneous requirements of electric drive systems for commercial vehicles for at the same time partly low numbers and attractive cost modular approaches are necessary to offer solutions suitable for the respective application by realizing a high degree of re-use.

Electric Drive System Platform

Starting from applications in the passenger car area Schaeffler designed a modular technology platform for electric drive systems (EDS) which besides electric motors contains power electronics hardware as well as software.

The electric motors form the basis of the EDS platform, fig 1. Due to the different requirements regarding operational area, packaging space, performance a powertrain concept he electric motor platform comprises different types of motors to address the respective application in an optimal way. For “classical” hybrid solutions the torque density at shortest possible axial length has to me maximized. This is realized usually with electric motors with concentrated windings. Electric motors with distributed windings with short winding heads as e.g. electric motors with wave winding technology are also suitable for such applications.

For application at higher speed as typically found for electric axle drives usually only electric motors with distributed windings will be used. The rotor can be realized with or without permanent magnets depending on the distinct application and the given boundary conditions.

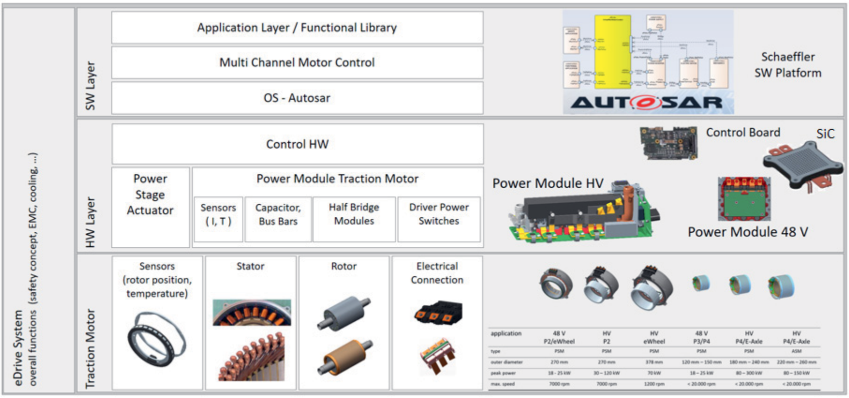

Fig. 1: Schaeffler's EDS platform approach

In the middle level of fig. 1 the power electronics platform with all its key components as power switches, capacitor, bus bars, driver stages and sensors is shown. A further essential part of the modular concept is the cooling and carrier frame that on the one hand side carries the power switches and therefore acts as basic structure of the whole power electronics and on the other hand side is flowed by cooling media and acts as the heat sink for all components of the power electronics. Additionally, this second level comprises the control board, the electric hardware for the drive control. The specification of his control board is determined by functionals requirements of the power electronics and he electric motors as well as to a significant extent by superordinate vehicle requirements as e.g. the bus communication system.

The third level in fig. 1 shows the software level. The function-oriented approach is abstracted from the micro-processor hardware by a consequently realized Autosar architecture. A core element of the software is a generic and therefor re-usable motor control platform which can be adapted and calibrated to the different motor types by a data driven approach.

Electric Motors

The electric motor is one the three core elements of an electric drive system. His basic function is the conversion of electric energy into mechanical energy according to a defined speed-torque behaviour. Besides this basic function there are numerous functional and non-functional requirements for electric motors:

- Ideal cooling capacity regarding load cycles and performance parameters

- High copper filling ratio to ensure long-lasting continuous performance
- High efficiency, especially in the relevant operational areas of the respective application
- Minimal use of materials in order to optimize costs
- Minimized harmonically occurring radial and tangential force effects in the stator for NVH optimization
- Minimized harmonics, which for their part likewise generate force effects, but also induce eddy-current-driving voltages and ultimately contribute towards losses and stator/rotor heating
- Minimal cogging and ripple torques
- Very flexible and scalable production technologies to simultaneously address different kind of (low-volume) applications

And the list goes on and on, as any detailed analysis of the individual phenomena will show. Thus there is an optimization problem, the solution for which must be oriented towards the requirements of the application and the expected load cycle.

As shortly stated in the section above different technologies have establish for the use in electric motors in automotive applications which among others depend on the geometry or he electric motor. The relation between outer diameter and axial length as well as the absolute axial length are basic differentiation criteria. Electric motors with a high ration of outer diameter and axial length and an absolute axial length of less than 50 mm will be realized with concentrated windings. This winding technology is characterized by short winding heads and therefore maximized usage of the given axial length to generate the magnetic field. On the other hand side this motor type typically brings up challenges concerning the NVH behavior. Preferred application area of this type of electric motors are co-axial hybrid modules in P1 or P2 configuration.

For rather compact electric motors with a lower ratio between outer diameter and axial length as they can typically found for electric axles drives or hybrid modules in parallel configuration electric motors with distributed winding technology turned out to be advantageous regarding a high torque density along with low harmonics and good heat flow from the current-carrying winding into the stator’s laminated core. With this winding technology the winding heads require more axial space compared to an electric motor with concentrated windings.

Conventional distributed wingding technology as known from industrial electric motors has proven not to be qualified for automotive applications. Therefore more and more solutions can be found using the hair-pin or I-pin technology.

Fig. 2 shows the basic classification of the application areas of concentrated and distributed winding technology.

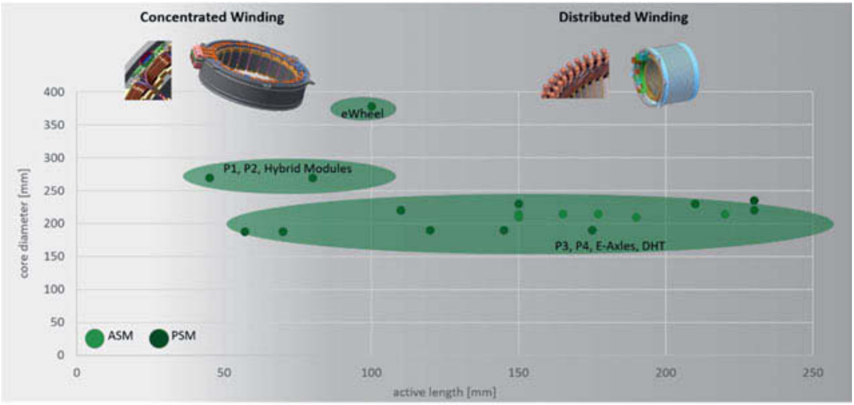

Fig. 2: Application areas of concentrated and distributed winding technology depending on the axial length of the electric motor

Schaeffler has investigated whether there are alternatives to hair-pin winding that utilize the advantages, yet minimize the disadvantages. One good alternative is wave winding, in which the distributed winding is produced in a kind of braiding process and then joined in the stator slots. By allowing certain concessions with regard to the copper filling ratio, it is possible to work with smaller cross-sections. The potential number of slots is thereby increased and the effect of the eddy current losses reduced. A more in-depth illustration of a comparison of the different winding technologies can be found in [2].

Modular Power Electronics Platform

The specific requirements for power electronics in automotive applications result from their integration in electrified powertrain systems such as electric axles, hybrid modules and dedicated hybrid transmissions, their quantities and broad range of performance.

- Realization of the power electronics as integrated electronics or external electronics
- Application-specific conditions as operational voltage or requirement on performance and current
- Type of electric motor, physical principle and number of phases

- High level of robustness, since the variance of the user profiles increases at high quantities, on the other side environment-related requirements get tougher in highly-integrated powertrains concerning e.g. vibrations and ambient temperature
- High lifetime requirements in the commercial vehicles area given by the high mileage of the vehicle or the specific load cycles as e.g. frequent start / stop
- High power density in limited installation spaces, resulting in special requirements regarding heat dissipation
- Flexibility of the design, as the installation spaces vary strongly in the different applications
- Optimal current forming to minimize harmonic losses and optimize efficiency
- High torque accuracy under all operating conditions
- Operational reliability in a wide range of operating voltages in order to respond to specific battery configurations
- Fulfilment of functional safety requirements

Schaeffler developed a modular concept for power electronic that covers different voltages levels of 48 V, 400 V and 800 V and is as well as usable for different electrification solutions in commercial vehicles and adaptable to the different given heterogeneous packaging spaces. As an example Fig. 3 shows a high voltage power electronics for a P2 hybrid module with maximum power of 85 kW which is suitable for the use in light commercial vehicles.

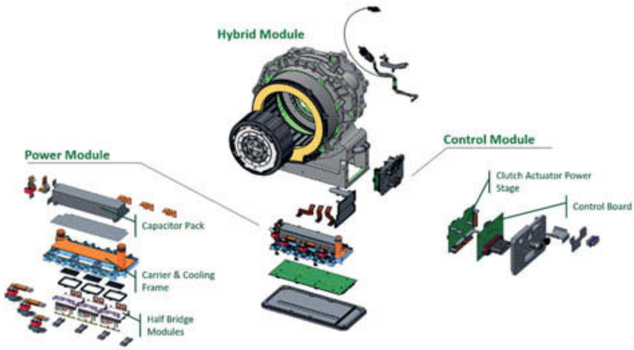

Fig. 3: Modular power electronics concept for P2 hybrid modules

One of the basic paradigms of the modular approach is the strict separation between the control module and the power module. The control module consists of the control board, the actual intelligence of the power electronics, and an optional actuator power amplifier stage. As a rule, the control board can be used to control two engine control channels. In the sample case, the second channel is provided for controlling the K0 actuator in the P2 hybrid module. As an alternative, it can also be used for a gearshift actuator in a two-speed axle, a parking lock, or a second traction drive in a power split transmission.

In the power module, it is first necessary to consider the scaling of the power semiconductors which make up a large portion of the value and entail a lot of the effort needed for the qualification. Schaeffler has decided to use half-bridge modules as the smallest unit, since they also enable the construction of multiphase drive systems (with more than three phases). In order to satisfy the range of requirements, two mechanical sizes and one basic population quantity (chip size and number of chips) were defined, Fig. 4.

The outside power and signal interfaces to power and signal contacting as well as to the cooling system are always identical for these power switches. Furthermore special attention was turned on the avoidance of soldered connections and aluminum bond wires in the mounting and connecting techniques used at critical points in the module for the sake of robustness. In the current design, the IGBTs (Insulated-Gate Bipolar Transistors) and parallel diodes are made by using silicon semiconductors for applications in the voltage level of 400 V. The typical PWM control frequency is 10 kHz. With 3-phase electric drive systems at 400 V voltage level maximal power of approximately. 200 kW can be realized. For maximum power beyond 200 kW a transition to the HV 3 voltage level with typically 800 V is a productive solution. With this technology a peak power of 450 kW and more can be realized. Moreover, the 800 V voltage level offers the advantage that the ohmic losses are reduced by the lower currents. The ohmic losses in the wires of the electric motors increase by the power of 2 with the magnitude of the current. To halve the currents reduces the ohmic losses to a quarter of the initial value. In this 800 V voltage range power switches with silicon carbide (SC) semi-conductors that can be realized in the same geometric base module show advantageous characteristics concerning switching losses and therefore higher switching frequencies up to 20 kHz. These higher switching frequencies offer an optimized current forming which results in an improved efficiency of the overall electric drive system. Fig. 5 shows exemplarily the potential to improve the efficiency of power switching by using silicon carbide semi-conductors in comparison to silicon semi-conductors

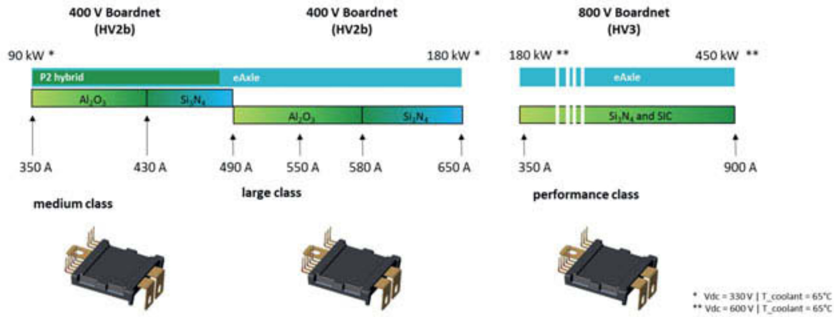

Fig. 4: Power scaling of IGBT power switches

The consistent use of sinter technology increases the cycle stability of the above described IGBT modules by a factor of 10 in comparison with conventional aluminum bond wire technology which strongly addresses the use of these power switches in commercial vehicles applications. Other basic components involved in carrying current are the capacitor and the bus bars, which also lead to a loss of power due to the flow of current.

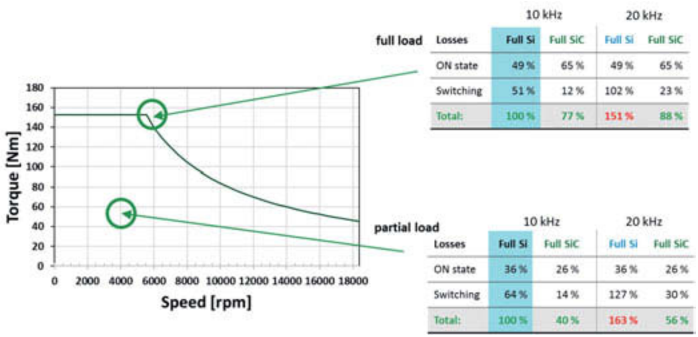

Fig. 5: Comparison of the losses of Si and Sic technology for power switches

The flexibility of the installation space is controlled by the central carrier frame (fig. 3, "carrier and cooling frame"). This injection-molded part controls the flow of coolant, connects the current-carrying components to the heat sink, and arranges the basic components with respect to each other. CFD simulation is used to optimize this component in order to ensure symmetrical warming of the half bridges. Moreover, the electrical connections are optimized with regard to parasitic inductances and capacities. In the specific example, a power density of more than 30 kW/l was able to be represented.

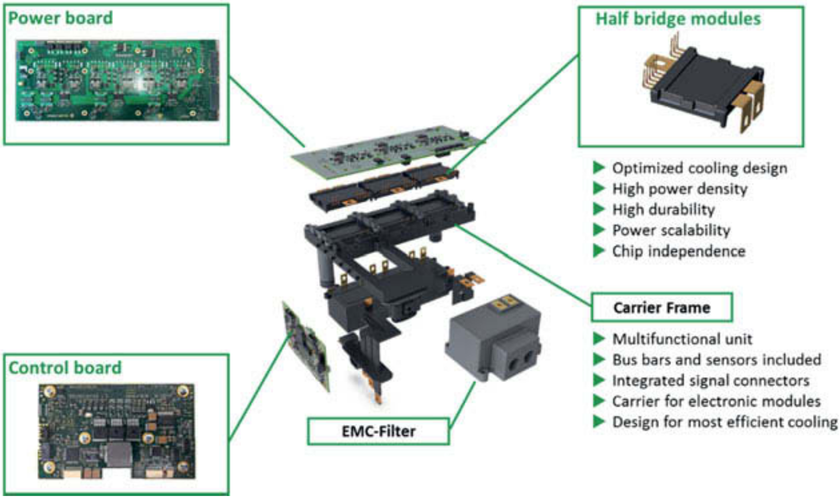

Fig. 6: Example of a modular power electronics for an electric axle

The flexibility regarding packaging and the modular approach easily allows to react on diverging and application-specific requirements. Fig. 6 shows the example of a 400 V power electronics for the use in an electric axle with a maximum performance of 150 kW. All EDS platform elements shown above as control board, power board, the described power switches and sensors are applied. An EMC filter can be integrated on the DC side as an option and can be dimensioned in a way to omit shielding for the DC supply. This represents a good option for optimizing the system costs at the vehicle level.

Software

The approach pursued by Schaeffler involves the development of an extensive function-oriented software library, which also includes the specifications for the required hardware. Besides HW-related driver software all further software modules are developed in a model-based way. The following are key elements of the library:

- Analysis of sensor signals, such as for determining the rotor position, the phase currents, or temperatures at defined points

- Functions for motor control as a function of the motor type used (PSM, ASM)
- Functions for current control, such as a field-oriented control system that considers all relevant influencing variables (e.g. field weakening)
- Variable PWM frequency control to improve EDS efficiency
- Superordinate controllers for functional integration in the powertrain, which can also be integrated as customer modules upon special request
- Monitoring functions, such as for controlling power derating for thermal reasons and for providing functional safety

In addition to software modules, the library also contains any necessary hardware circuits, along with their definitions and preferred components. Special rules define the implementation in the final layout to guarantee optimum heat dissipation or electromagnetic compatibility. This layout is prepared specifically to the application in order to react to special customer requirements. The various communication network options (CAN, FlexRay, CAN-FD) have already been mentioned as examples.
With regards to the architecture, the software strictly follows the AUTOSAR paradigms in order to guarantee a high level of re-use, Fig. 7.

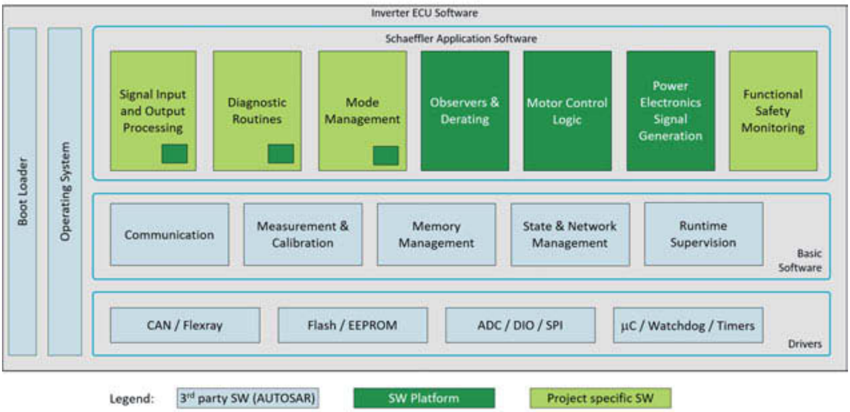

Fig. 7: High level software architecture

Summary

The expected variety of variants of electrified powertrains of commercial vehicles concerning wide-spread performance range, application area and heterogeneous packaging spaces requires new approaches for the electric drive system that especially puts focus on cost efficiency and re-use of the technical solutions. The answer to this challenge is a scalable technology platform for electric drive systems to master the balancing act between variety of variants and standardization.

The technology platform comprises the electric motor as well as the power electronics with the respective hardware and software scope for the drive control. By means of different applications (hybrid modules, electric axles) it has been shown that the chosen approach allows to access a broad field of applications.

The technologies and solutions used in the platform correspond to the highest requirements on efficiency, power density and scalability. The platform's modularity allows the integration of hardware elements and especially software modules of 3rd party.

Future generations of electric drive systems distinguish themselves by a further increasing degree of integration of electrics, electronics and mechanics. Consequently using the opportunities offered by the presented technology platform numerous improvements concerning function, efficiency and packaging can be realized on a system level.

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Citaro hybrid

The first commercial vehicle with profitable 48V mild hybrid system

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Abstract

The new Citaro hybrid opens a new era for city and interurban buses. The Citaro hybrid was developed especially to meet the demands of scheduled services in urban areas, it stands for contemporary mobility with reduced consumption and the perfect synergy of profitability and sustainability. With its compact hybrid system the Citaro is an economical and ecological all-rounder in urban centres.

In our presentation different aspects from development up to economic feasibility are described. Concept and dimensioning of the electric powertrain including energy storage will be illustrated. Topics like energy throughput, cycling and fuel saving are considered. An insight into the operating strategy is given. The decision for the - in commercial vehicles new - 48V power net is explained. The selection of components as well as their integration into the vehicle are shown. A view on the optimized total cost of ownership rounds the presentation down.

System overview Citaro hybrid

Core functions of the Citaro hybrid system are recuperation and boost. As figure 1 illustrates main components are energy storage based on supercapacitors on the roof as well as permanent magnet electric motor installed between combustion engine and gearbox.

Fig. 1: System overview Citaro hybrid

The hybrid technology is available as special equipment for an exceptionally wide range of city buses with diesel and gas engines (Fig. 2). Instead of individual independent hybrid buses, numerous Citaro models with the 936 engine series benefit from the forward-looking hybrid module.

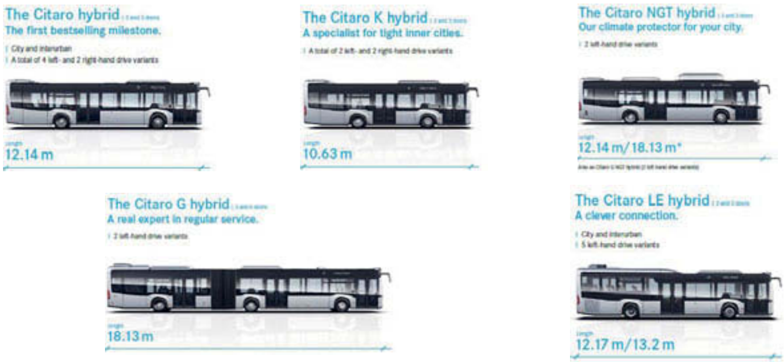

Fig. 2: Citaro models with option for hybrid system

Dimensioning

With the aim of an optimized dimensioning, a deep energy analysis has been done for parallel hybrid vehicles, linked to the specific application scenarios of a city bus. As figure 3 shows the operation profile of a city bus is characterized by repeated stop and go cycles.

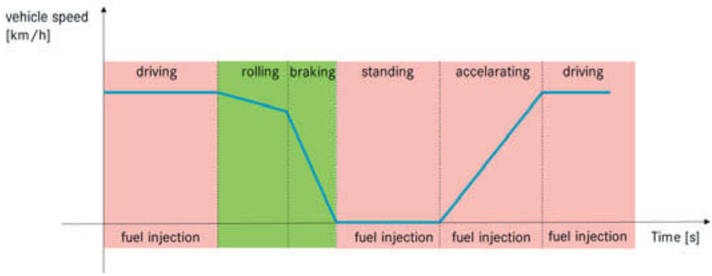

Fig. 3: Operation profile of a city bus

Dependency of fuel saving potential from storage capacity on the one hand and mechanical recuperation power on the other hand became clear. Increasing both doesn't lead to a linear increase of fuel saving potential – as figure 4 shows this dependency is asymptotical and beginning from a specific point increase of fuel saving potential is very small. This results in choosing an electric engine with power of ~15 kW and a storage capacity of approx.100 Wh. Although electric drive off is not possible, the dimensioning results in maximum fuel saving potential at minimized system costs.

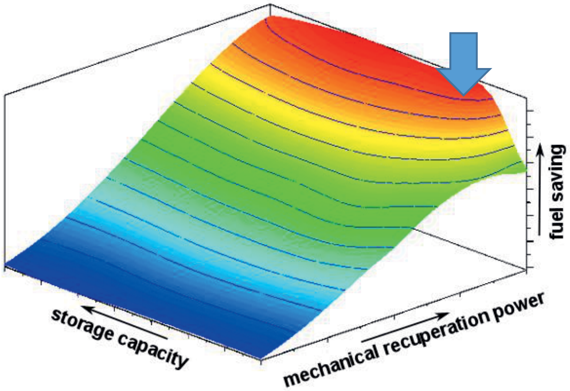

Fig. 4: Dependency of fuel saving of storage capacity and recuperation power

The components have to be designed for the use in heavy urban application. With typical requirements for

- mileage: 60.000 km per year
- number of stops: ~3 per km
- specified life time: 600.000 km or 10 years

This results in >1.8 Mio cycles of recuperation and boost as well as 40.000 operating hours over lifetime.

Motivation for choosing 48V

The 48V technology offers substantial fuel saving along with moderate cost:

	24V	48V	High Voltage
Power	o	**+**	++
Fuel saving potential	o	**+**	++
Cost	++	**+**	-

The 48V power net is specified with voltages <60V (Fig. 5), therefore no contact protection is required. This leads to simplified vehicle integration and handling in production plant and workshop.

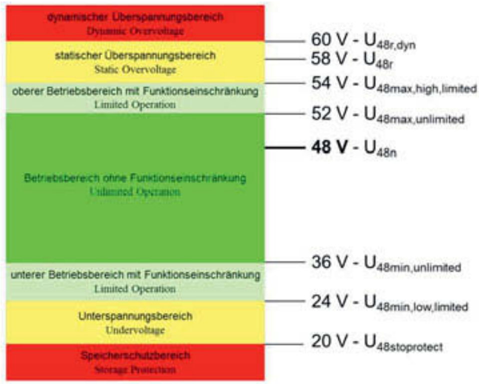

Fig. 5: Definition of voltage levels in 48V power net (according VDA 320)

E-motor technology

Belt-driven and integrated e-motor technology have been evaluated. Belt-driven e-motor components are usually cheaper but the transferable torque is limited and the belt-durability is challenging. On the other hand integrated e-motors lead to higher integration cost but provide higher robustness as well as system performance. Permanent magnet e-motors gain maximum power out of the available installation space. For the Citaro hybrid an integrated permanent magnet machine was chosen.

Energy storage technology

Most common energy storages for hybrid and electric vehicles are Lithium-ion batteries. In comparison with supercapacitors based energy storages the advantages of Lithium-ion batteries lie in capacity and cost per cell, while supercapacitors provide a very high cycle stability and a simple convection based cooling. Simulations showed, that a massive over dimensioning of Lithium-ion battery is needed in order to achieve the specified life time, cannibalizing the cost advantages and adding weight to the vehicle. Since the market introduction of Euro6 the Citaro is already available with a 24V recuperation module based on supercapacitors. The Citaro hybrid energy storage has been developed on this platform providing a robust and already proven energy storage technology perfectly fitting to the demanding cycles of a heavy urban application.

Operating strategy

The system operates in different modes depending on the driving situation. As shown in figure 3 a city bus operates in driving, rolling, braking, standing and acceleration mode. This results in the following operation points for the hybrid system:

- Regenerative braking = Recuperation (Energy recovery)
  - If the vehicle is in rolling or gliding mode and neither accelerator nor brake pedal are operated, the system recuperates energy by a moderate regenerative braking.
  - When the driver presses the brake pedal, means that he is actively braking, the maximum regenerative braking is activated with the maximum of possible electrical engine torque.
- Drive support = Boost (Support of combustion engine)
  - If vehicle is in stand still with engine running in idling mode a low auxiliary torque support is activated. This results in a big effect related to inefficient operating point of combustion engine.
  - In case of drive off or acceleration during normal driving an ascending torque until half of possible electrical engine torque supports combustion engine.
  - Torque generated by e-motor replaces torque generated by combustion engine (no additional torque/power)

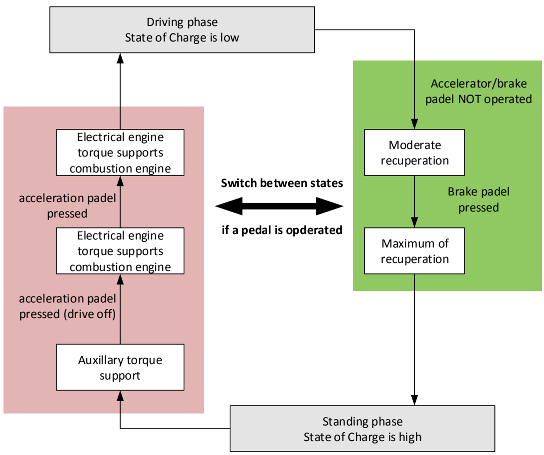

Fig. 6: Operation modes of hybrid system

Figure 6 illustrates operation points as well as transitions graphically. The main idea of this operation strategy is to reduce load on the combustion engine leading to lower fuel consumption. In addition, the system is imperceptible to the driver, so that the Citaro hybrid can be driven like a conventional Citaro.

Mechanical integration

In order to integrate the e-motor in the drive train additional space had to be created between combustion engine and gearbox. As illustrated in figure 7, the rotor is attached to the fly wheel of the combustion engine on one side and to the shaft of the gearbox on the other side. The stator as well as power electronics are fixed to an additional housing (spacer) between engine and gearbox. By this the impact on surrounding vehicle structure could be minimized. Both, stator and power electronics are water cooled.

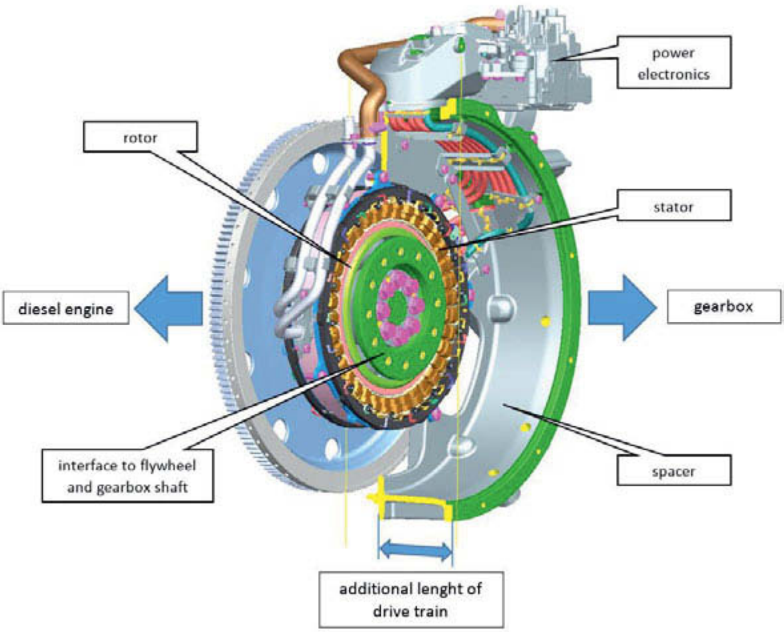

Fig. 7: Mechanical integration of e-motor and power electronics

Business Case, Total Cost of Ownership

The hybrid components, mainly e-motor, inverter and energy storage, add additional cost to the vehicle. This extra cost will be paid back in terms of fuel savings.

An important role plays the right size of the components. Considerable bigger e-motor and energy storages lead to significant higher system cost, but only to disproportional additional fuel saving. The Citaro hybrid system represents the optimal trade-off between cost and fuel saving. By this, the Citaro hybrid does not only contribute to a better climate and environmental protection, but also to a more profitable public transport.

The Mercedes-Benz Citaro hybrid won the “Bus of the Year 2019” award as well as the “Sustainable Bus Award 2019”.

ZF Assistance Functions for Swap Body Trucks

Functional innovations support trucks for the autonomous, safe and efficient handling of containers at depots

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Abstract

The lifting, shifting and stacking of swap bodies – in other words, the unloading of a container and the centimeter-precision reverse maneuvering for loading of a new container – are among the most challenging tasks at the depot. These procedures tie up driver resources the most, demand a high level of experience, cost time and often lead to accidents and expensive damage. Shown for the first time in the ZF Innovation Truck [1] in 2018, the Swap Body Assistance will help trucks perform this task autonomously in the future without any human assistance. As soon as the driver enters the premises, he can get out of the truck, activates the innovative ZF function and take a break while the truck carries out the job autonomously on site. To turn this innovation into reality, the Group has utilized its technologies such as the main computer, ZF ProAI, the active electrohydraulic commercial vehicle steering system, ReAX, and TraXon Hybrid, the automatic transmission system, which are combined with a cost-effective, camera-based and laser-assisted sensor setup as well as with telematics by the ZF subsidiary Openmatics and a GPS system. The Swap Body Assistance is another example of how ZF is applying its "next generation mobility" solutions to the logistics sector – and helping to make logistics processes more efficient, safer, more reliable and faster.

1. Logistics under pressure

On an international level, the logistics industry has been under massive pressure in terms of costs and performance for several years now. The industry is also witnessing a continual increase in flexibility requirements. These factors affect virtually all areas of the process chain, starting with long-distance traffic and ending with package delivery on the "last mile" to the end customer. Alongside increasing competition, the problem is also accentuated by population growth and the demand for an ever-faster turnover of goods within the same time as well as the individualization of consumerism. When it comes to the question of how processes can be restructured to improve performance, logistics companies themselves have little power to influence this, particularly as they have another pressing issue to deal with in many countries: the shortage of qualified drivers - an issue which will drastically intensify in the future.

ZF's response to this problem is to design innovations that aim to achieve smart and therefore high-performing logistics. This vision involves developing automated driving functions and using intelligent networking in the vehicle environment and beyond. One example is the ZF Innovation Truck: Presented for the first time in mid-2018, this truck can autonomously loads, shift and unloads swap bodies at the depot.

Fig. 1: The ZF Innovation Truck: Fitted with Swap Body Assistance, it autonomously masters lifting, shifting and stacking at depots and other premises.

2. "Swap body" challenge

Manually maneuvering the rear of a truck under a narrow swap body is one of the hardest skills to master when transporting goods. It requires a great deal of skill, experience and attention. Drivers can usually only perform this demanding maneuver in different environments and under various conditions without mistake if they have had extensive training beforehand.

However, there is usually not enough time or money available for this level of training. As a result, expensive damage occurs during maneuvering, which results into damages to the swap body, such as bent supporting legs, or damages to the vehicles and depot infrastructure. According to estimates, two-thirds of all vehicle damage generally occurs at the depot – as well as an average of €3,500 to €5,000 in damage a year. Beside that there is always the risk of accidents and injuries to persons working at the depot.

Fig. 2: Maneuvering errors often lead to expensive damage of the swap body as well as to the vehicle and depot infrastructure.

Gross errors which occur when driving under the swap body will usually cause an interruption, delaying the entire logistics process: High costs can then be incurred if delivery times are not met, especially with sensitive goods. Working under time pressure, the driver has a great responsibility on his shoulders but is paid only moderately for his efforts. This is one reason why interest in this profession is falling sharply and there is a serious lack of qualified young drivers. This is all the more reason why new technologies have to be developed to bring relief not only to the logistics companies but also to their drivers.

3. Delegating the task of complex maneuvering to the vehicle

In response to the swap body challenge, ZF came up with the following potential solution scenario: As soon as the driver arrives at the depot, he sends a command, for example via a app, to the digital depot management to take over the control of the truck. The digital depot management registers the truck, tracks the job for this truck and sends a task and route to the vehicle. The truck then autonomously follows the instructions given by the routing system: As shown in Fig. 3, the vehicle maneuvers unmanned over the depot (Fig. 3.1), autonomously unloads the currently loaded swap body at its destination (Fig. 3.2), then moves to a new swap body and loads it (Fig. 3.3) and finally waits for the driver at the depot exit to drive off (Fig. 3.4). In the meantime, the driver can use the time to carry out other tasks or take a break.

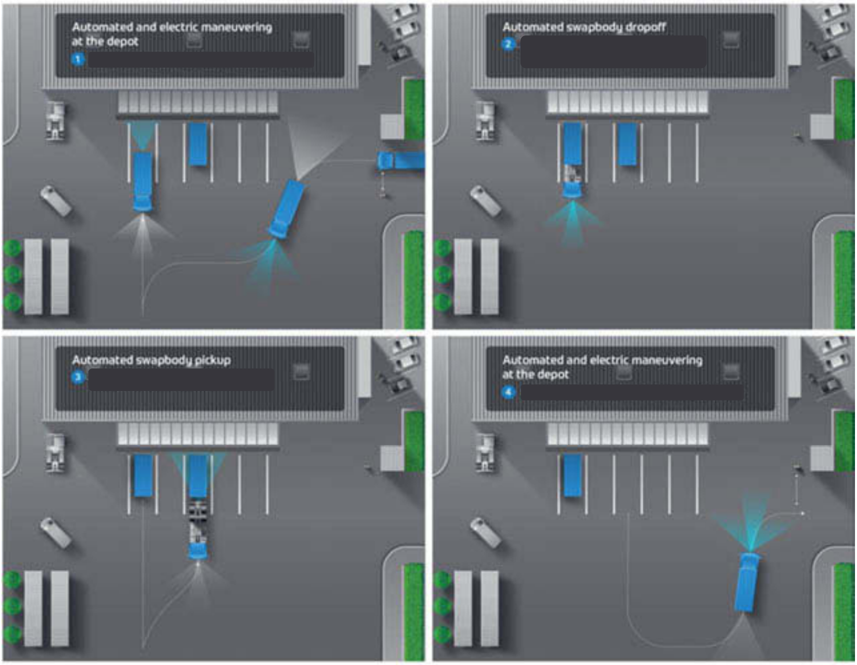

Fig. 3: Driving maneuver of a truck with ZF Swap Body Assistance.

One particular advantage: Reversing underneath a swap body and sliding into it, a difficult challenge even to experienced truck drivers, is completed by the Swap Body Assistance quickly, precisely and at the highest level of safety.

4. Basic vehicle and depot functions

This reliable, autonomous vehicle operating mode requires a variety of technologies and systems as well as their intelligent interaction. This is reflected by the other supplementary subfunctions which are required for maneuvering around the depot and are explained briefly in Fig. 4. The "Ramp docking pilot" [2] shows an alternative way designed to maneuver the truck to the ramp. The idea behind the "Swap body assist" is a reduced assistance function which offers major support while manual maneuvering (see Chapter 7).

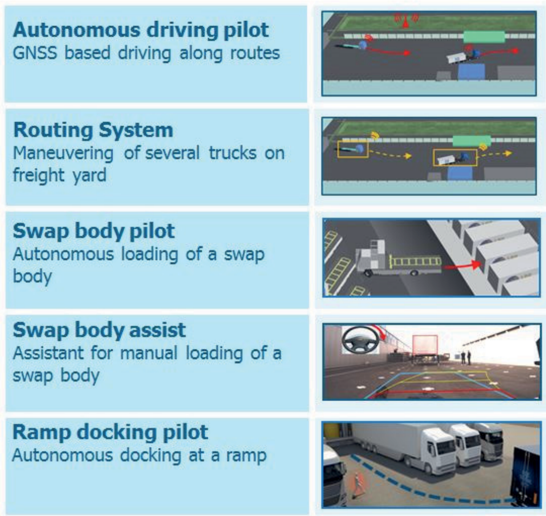

Fig. 4: Overview of individual ZF functions for autonomous driving at the depot.

For the "Autonomous driving pilot" as well as the functions based on this pilot, the following solutions were used with the ZF Innovation Truck on the vehicle and actuation side: The automatic transmission system TraXon Hybrid [3] has been implemented with which a driveline can be efficiently actuated and controlled. With the TraXon Hybrid's integrated electric motor and lithium-ion battery module, the truck can cover the last mile in a very environment-friendly way and locally maneuver at the depots using electric power only and with zero emission. Due to the fact that it is a hybrid powertrain, the vehicle can also be powered without a charging station and recharged when needed at specific positions with accepted emission levels. Beside that, the truck is fitted with the ZF ReAX commercial vehicle adaptive steering system [4]. This steering system fulfills the mechatronics demands required for the electronic control of the transverse dynamics: ReAX can fully substitute every steering-wheel torque which otherwise the driver would have to apply. The electrohydraulic servo pumps installed in the system also allow steering with the combustion engine switched off.

Beyond these features, the ZF Innovation Truck is also equipped with the following system modules for performing autonomous driving tasks: The high-performance ZF-ProAI [5] main computer tailor-made for real time applications and artificial intelligence; the sensor set comprising three camera and laser units; a receiver for precise, global navigation satellite system

(GNSS) and, last but not least, the onboard unit from ZF telematics specialists OPENMATICS [6]. More details on the individual tasks will be provided later in the document.

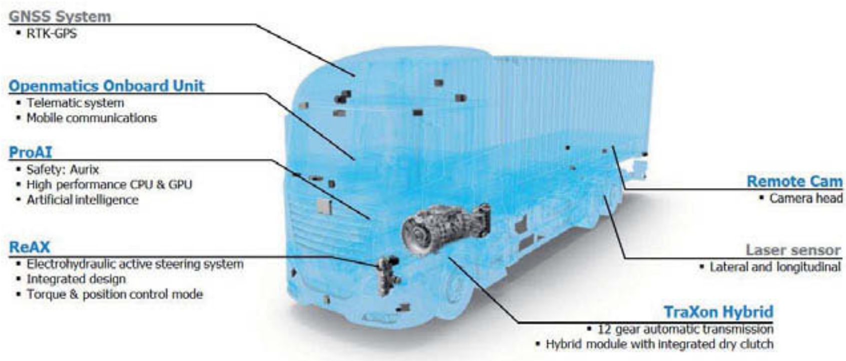

Fig. 5: Overview of vehicle-end systems for autonomous driving functions fitted in the ZF Innovation Truck.

The routing system is elementary for guiding the vehicle within the depot. The routing system transfers data to the vehicle, ideally over a secure, wireless connection, about what job the vehicle has to perform on-site. The command could be, for example: Drive from your current position A to an intermediate position B and from there drive to your destination position C – which could be a deposit area or swap body, for example. The Innovation Truck communicates over the OPENMATICS on-board unit. The routing application developed to demonstrate the function runs in a Cloud. This allows the routing task to be separated from the assigned job and implemented regardless of the location - a major advantage if this innovation is to be used in practice. In addition, this system is also capable of coordinating 50 vehicles at the same time.

For the vehicle to be guided by the routing system from its starting point A to intermediate position B (phase 1), the "Autonomous driving pilot" requires efficient localization capabilities. The current application deploys an RTK-GNSS which promises a relatively high level of precision. If larger deviations in operation can be tolerated, GNSS systems can also be used which involve more significant errors. In areas overshadowed by high buildings or hall roofs, even advanced satellite-based solutions reach their limits. These satellite-based systems do not provide the level of accuracy required to detect a minor change in a swap body's position or enable the truck to drive under the swap body with centimeter precision. As a consequence, other, additional types of localization technologies are required when a high level of precision and redundancy are needed.

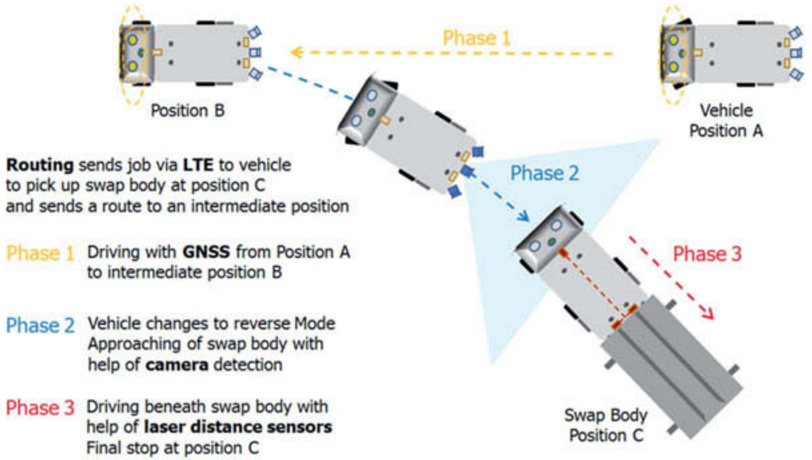

Fig. 6: The three phases of autonomous swap body loading at the depot.

5. Autonomous maneuvering under the swap body – the "Swap body pilot" in detail

The "Swap body pilot" function provides the accuracy needed when approaching and driving under swap bodies which need to be loaded.

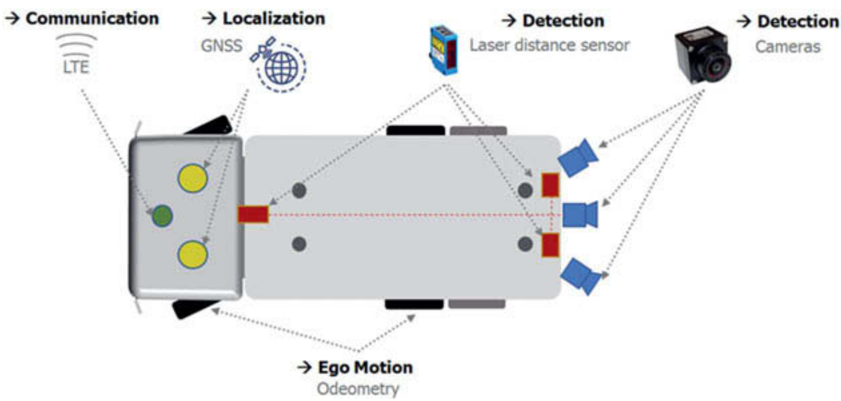

Fig. 7: Sensor set for V2X communication and for vehicle localization.

In phase 2, the remote cameras, installed at the vehicle rear, identify the target destination. These cameras transfer the images to the ZF ProAI main computer. The computer deploys a complex algorithm – a combination of a neural network and conventional image processing - at a sample rate to detect the relative swap body.

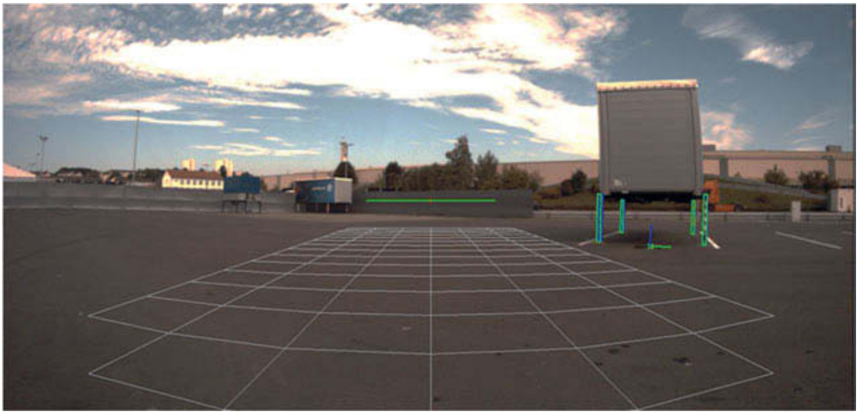

Fig. 8: Result of detection algorithm.

The camera focuses on the lower part of the swap body to identify the position and orientation of the swap body in relation to the vehicle. Finally, the relative pose, from which the target trajectory can be calculated, is determined by the relative position and orientation. However, differences in track conditions or other interferences can cause the truck to deviate from its target trajectory while moving. To counteract this problem, the target trajectory is continuously re-calculated. This means that no explicit trajectory controller is required. With this system setup, the camera detection enables a maximum of 4 cm lateral precision with an angle error of 2° to 3°. Although this degree of precision is comparatively exact to determine the relative pose of the swap body, it is not accurate enough to drive under the swap body almost without any collision or to load the swap body correctly without any damage.

This is why as soon as the vehicle approaches the swap body, the laser sensors will activate in phase 3. The sensors deliver the necessary lateral precision of 1 to 2 cm and an angle error below 0.2°. This enables an extremely precise measurement of the relative pose between the vehicle and swap body while driving beneath the swap body. A laser distance sensor is fitted in a longitudinal direction behind the driver's cab and two other sensors are located on the left and right at the vehicle rear (see Fig. 7). The sensors attached at the rear and an intelligent vehicle control make it possible to correct any unacceptable errors before the pair of centering rollers located at the rear are aligned. The angle error is also corrected during this procedure to allow for an almost non-contact alignment of the second pair of centering rollers behind the driver's cab.

Fig. 9: The combination of sensor set, actuators, high-performance computer and intelligent algorithms enable the precise, autonomous driving of the truck under the swap body with high precision.

The ZF ProAI main computer delivers far more than just the evaluation and preparation of sensor data as explained before. It also merges all the information together to detect any handling errors for the engine, transmission, steering system and brake. In addition, the Aurix processor fitted on the ProAI is located on hardware isolated from the mainboard and is used for safety purposes. Aurix and the high-performance CPU/GPU on the mainboard monitor each other's status in order to bring the vehicle into a safe state in the event of an error – in this case to a standstill.

6. Results

The entire "Swap Body Assistance" system was tested under various conditions. As expected, the autonomous procedure with the help of GNSS localization delivers excellent results. The communication between the routing system and the vehicle across the LTE infrastructure as well as Cloud was very stable and reliable.

However, the main focus of the project was a robust, autonomous swap body detection and loading. For this reason, these processes were also tested under different lighting and weather conditions whereby the benchmark process was conducted under ideal conditions as a reference.

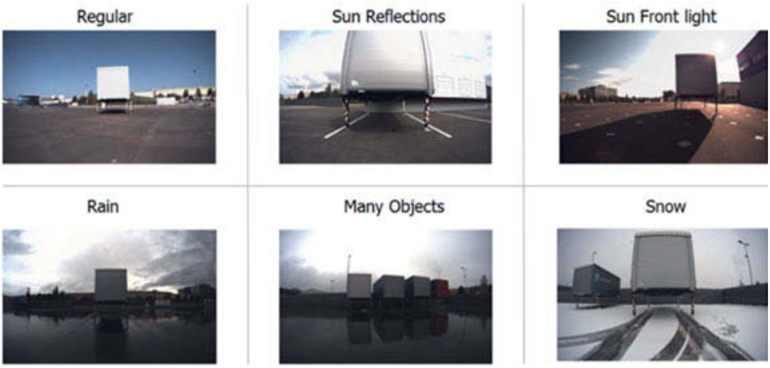

Fig. 10: The autonomous swap body detection from ZF works reliably even in difficult lighting and weather conditions.

Further tests were then performed for various swap body positions and for different situations, such as poor visibility due to sun reflections, sun front light, rain or snow. Another important question was if any difficulties are encountered when several swap bodies are located next to each other. In this respect, it is necessary to restrict the so-called "region-of-interest" in advance: The detection algorithm cannot assign the identified features to a specific swap body. Therefore the destination area must be explicitly included in the job which the routing system sends to the truck. In all cases, the ZF solution achieved good results.

7. Manual maneuvering support with "Swap body assist"

The "Swap body assist" function can be considered as a simplified version of the autonomous "Swap body pilot". This provides valuable visible assistance whenever this difficult maneuver has to be performed manually: Although vehicle actuation and monitoring is the responsibility of the driver, he is given specific maneuvering instructions on screen. Fig. 11 shows how useful information can be provided to supplement the image from the rear camera.

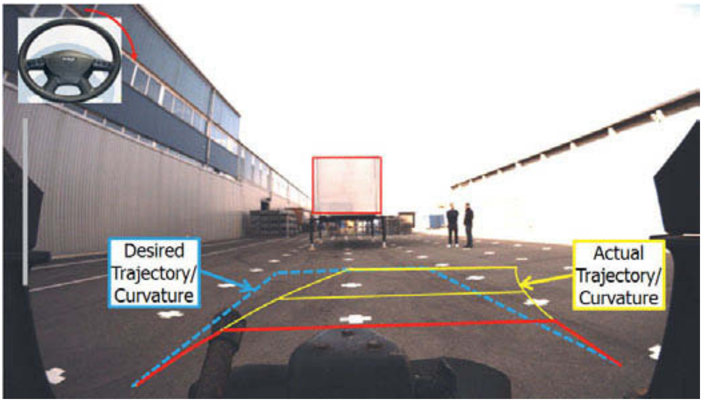

Fig. 11: "Swap body assist" screenshot to provide effective driver assistance for manual maneuvers.

The trajectory to be driven appears in the form of a blue line on the screen ("desired trajectory", dotted line in the photo). At the same time, the red and yellow lines ("actual trajectory", continuous lines) show the driver how the selected trajectory changes during maneuvering – and how much it deviates from the target trajectory. Whenever all trajectories overlay each other, the vehicle is moving in the correct direction toward the swap body. If the lines deviate from each other, the driver needs to correct the position by turning the steering wheel.

The assistance function helps the driver to correctly assess the situation. In addition, "Swap body assist" can also help the driver to drive the truck smoothly to the end by visualizing on screen the remaining distance to the final position. This can prevent the swap body from moving in longitudinal direction; a common occurrence witnessed at the depot.

Tests conducted by ZF revealed that even unexperienced drivers who had little to virtually no experience in handling trucks and swap bodies managed to handle this difficult maneuver thanks to "Swap body assist" with surprisingly positive results. This underlines that even this solution can make everyday logistics situations easier. It also offers an attractive solution in view of the ever-increasing shortage of drivers as extensive training is no longer required to perform this maneuver.

8. Prospects

The ZF Swap Body Assistance shows one approach to how trucks can perform highly complex driving maneuvers fully autonomously at the depot in the future: The loading of a swap body can be managed quickly and without any damage. This releases the pressure on drivers and saves cost – especially because emphasis was placed on keeping the TCO of the assistance system to a minimum. The driver can also save valuable time.

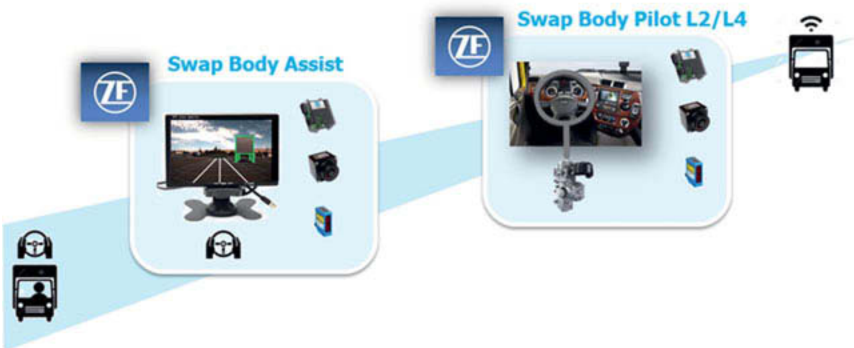

Fig. 12: ZF assistance functions are available in every level of automation - up to autonomous driving - for the more convenient handling of swap bodies.

However, certain infrastructural and legal framework conditions need to be clarified before this function can provide answers to key issues regarding depot logistics of the future. However the "Swap body assist" function based on the Swap Body Assistance can already provide valuable support in this respect.

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Born digital

How BPW is revolutionising the configuration, ordering and production of running gears

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Abstract

Complexity of global markets and individual customer requirements will be the great challenges of the coming years. These challenges can only be mastered with suitable product architectures, such as platforms or modular designs.

At the same time, the expectations for the digitisation of products and processes will rise sharply and enable new business models, even for conventional products.

The aim here is to create tools that help to keep diversity under control and support new business models. These tools are considered in all phases of the product lifecycle, from the beginning of product development, to the configuration of the product at the customer's and the production at one's own company, up to the spare parts supply.

In the past, great attention was paid to reducing variations, but the credo of the future is to make complexity controllable through digital tools.

BPW has found an approach that allows a complex modular product to create customer benefits through configuration in a web-based shop system, the BPW running gear configurator.

As a B2B platform, the running gear configurator differs significantly from the B2C web shops that are widely used today. The most noticeable functions are possibilities to separate user roles, map workflows and save user-specific or company-wide presets.

BPW started to pay special attention to clean product data early on. This was systematically structured in a digital kit, creating the basis for today's web shop within a decade. Today, up to 10^{14} running gear configurations can theoretically be derived from this kit.

Motivation

Our goal is to increase customer benefit. This overriding goal can be divided into subgoals. These subgoals are primarily the reduction of processing times until ordering and delivery, the improvement of customer service and last but not least supporting the internal processes of our customers.

Subgoal 1: Reducing processing times

The technical development of several thousand new, customer-specific running gear variants per year involves considerable effort. Each new product essentially requires production documents such as parts lists (bill of material – BOM), work schedules and article master records to map the commercial and logistical processes. Last but not least, costs must be calculated and a price fixed for each new product. In addition, there are commercial topics such as customs, account determination, BI, etc.

Additionally, 3D CAD models or (assembly) drawings are created, and installation analysis, braking calculations, circular driving analysis and centre of gravity height examination are carried out on customer request. There is also spare parts documentation consisting of spare parts lists, exploded views and various manuals.

All these activities require long processing times during the order handling process, which are currently several days.

The aim is to reduce the processing time for these technical, sales and commercial clarification activities to just a few minutes!

Subgoal 2: Improving consultation

A running gear system is individually adapted to the respective vehicle application of the manufacturer. The multitude of vehicle types have very different running gear requirements. Not only do drawbar trailers and semi-trailers differ in principle, but also the body types such as tipper, silo, tank and curtainsiders, car transporters and other body types. Different requirements require different braking systems, adapted suspension systems or an individual wheel end.

This is why running gear systems require a lot of advice. Only very few customers are able to specify the required running gear on their own using the provided documents without consultation.

Order clarification thus entails high costs that are part of the so-called "transaction costs". Transaction costs are defined as the costs incurred in the transfer of goods – here: commercial vehicle running gear – from one economic subject to another.

The aim is to emancipate customers to the extent that they are able to independently specify suitable running gear according to their individual requirements. At the same time, this should reduce transaction costs!

Subgoal 3: Supporting internal processes of our customers
When purchased parts or supplier components are used, there is often still a gap in the area of digital product data. While suppliers and customers have optimised their respective processes according to their needs, there is potential for improvement at the interfaces between companies.
Within the companies, PDM and ERP systems regulate the relationships between the individual data objects and the product. This allows a better central availability of all relevant product data such as CAD models, drawings, calculations, circuit diagrams, test and material reports, catalogues, technical documentation, etc. for a single product. Across company boundaries, such availability of data objects for a product is desirable, at least in some areas, but is only available rudimentarily or not at all.

The aim is to provide customers with all relevant data objects for the product that they have specified without any further search or query effort. These data objects should be integrated as seamlessly as possible into the customer's own processes and digital product data.

This article describes how BPW achieves the above-mentioned three subgoals with the BPW running gear configurator. First, however, the history of the project and the various stages on the way to the goal will be discussed briefly.

How it all began

Clean product data is the basis of every digitisation strategy in manufacturing companies. In 2005, BPW provided a basis for its current success by structuring the individual product modules and defining a company-wide, comprehensive product structure.
In 2009, the first version of a self-developed product search engine went live. Right from the start, it was based on the SAP ERP system used at BPW.

Since many users have found the user interface of the ERP system not to be user-friendly, a separate web-based application was created to search for running gears already in the system, the Product Finder (ProFi).
This is still in use today throughout the group, and the first version was based on Adobe Flex for interface design and on SAP's own search engine SAP TREX and SAP e-commerce.
Due to new technologies in the rapidly developing environment of the Internet, updates became necessary in the following years. Currently, the back end of the Product Finder is based on an HEC (Hana Enterprise Cloud) solution. The front end was implemented with the help of SAP-UI5.

Fig. 1: Product search for product configuration in the web shop supported via a modular structure and software

In addition, the ProFi was expanded into a shop system that allows the worldwide subsidiaries, which have very heterogeneous system technology, to trigger orders at the company headquarters.
The basic idea of the Product Finder in 2009 was to make product searches as simple and convenient as possible while keeping the manual effort for data entry as low as possible and automating it completely.

Nevertheless, the master data (material master data, parts lists and work schedules) for the finished product – the running gear system – was created manually in the final step if required for a customer order.

Integrated configuration – the birth of the digital twin

This last step of manual product data creation was to be eliminated, thus going from the selection of a product to an individual combination from a predefined solution space – taking into consideration interdependencies between the components.

The underlying manufacturing approach, "make to stock" at the component level and "assemble to order" at the product level, suits perfectly for such a scenario.

If you enter the word 'configurator' in an Internet search, the first two result pages are 80% configurators from different automotive groups.
Why is this the case? The possibility of selecting a specific product from a large number of product variants is often no longer sufficient today. Customers (private individuals or companies) want to order 'their' custom-made product or 'their' individual solution beyond the standard range of variants. In the automotive industry (and the furniture industry) this, and the need to build a product modularly, was recognised early on. These two branches of industry therefore also lead in the use of configurators.
In the automotive industry, configurators are primarily used to record customer requirements and as a marketing instrument (order acquisition process), while the furniture industry focuses primarily on controlling internal manufacturing processes (order fulfillment process).

The aim must be to combine both processes and thus simultaneously use the digital twin of the order fulfillment process for the order acquisition process.
This procedure can be described as an integrated configuration. The central product model is extended and presented in a modern UI in a valuable and customer-friendly way so that the customer defines the digital twin in such a way that it can be used directly for the order fulfillment process.

At BPW Bergische Achsen KG, we refer to this procedure as Digital Born!
Customers design their products individually right from the start. Customer requirements are incorporated directly into the self-creating product model and then supplemented with process data in the order fulfillment process.

The trend towards selling individualised products will increase along with digitisation, and configurators integrated in Internet portals with ordering functions and additional functionalities will continue to gain in importance.
The following illustration, which gives the results of a current survey of companies from the DACH region on questions of complexity and variant management, shows this connection very clearly.

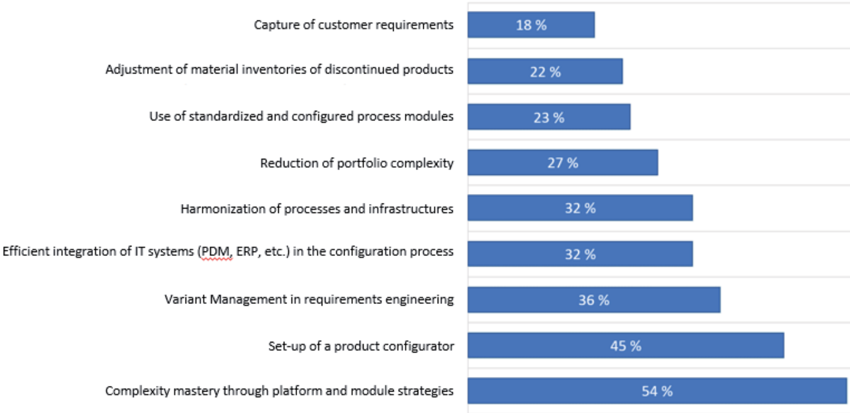

Fig. 2: Main topics for companies from the DACH region [Source: survey WE.connect global leaders among 120 companies from the DACH region]

The four topics regarded as most important reflect the problem identified by BPW Bergische Achsen almost perfectly. The configuration of a running gear by the customer defining his specific requirements with direct, efficient integration of the PDM and ERP systems into the configuration process. The whole thing builds on a clearly defined product structure based on a well thought-out platform or module strategy.

Implementation – configuration, ordering and production of running gear systems

A configurable product is created by the customer! The challenge is that our current processes do not support this approach. Between the formulation of the customer requirements and the realisation and/or production of the product, there are numerous sub-processes that are caused by a lack of IT support in this phase. First, the customer's requirements are taken up by a sales employee. Then, technical clarifications take place with an employee of the development department, CAD models are created, and initial digital installation tests follow at the customer's. At the same time, the commercial clarification takes place. The product is calculated and a price is given. In the worst case, this process will be repeated several times, as contradictions with customer requirements are discovered during detailing.

The aim of developing a configurator integrated in a web shop thus had to involve the customer directly in the IT processes and the birth of the digital twin!

To do this, the subgoals described in the chapter 'Motivation' 'Reducing processing times', 'Improving consultation' and 'Supporting internal processes of our customers', are taken up again and realised in the configurator with the customer benefit potentials visualised in the following figure.

Fig. 3: Customer benefit potential of the BPW running gear configurator

The starting point is the B2B web shop. This is based directly on the product data relevant to the production process in BPW's PDM and ERP systems, so that there is no gap in the systems at this point due to missing synchronisation.

Some of the customer benefit potentials indicated in Fig. 3 will be discussed in more detail below.

Guidance

In order to offer customers the most pleasant and intuitive working environment possible, a corresponding graphical user interface was created in cooperation with software ergonomists. This is based on Internet technologies that can be used in all common web browsers and mobile devices without plugins.

After logging in with their user name and password, customers see the dashboard as the home page.

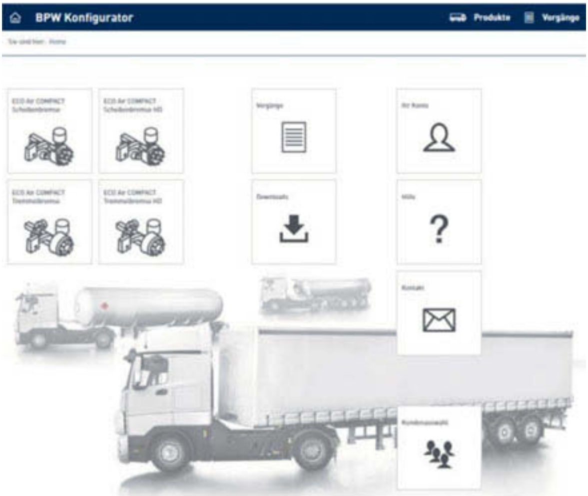

Fig. 4: Dashboard of the web shop system

Based on today's common web-based systems, the shop allows new users who enter to find their way around very quickly. On the left side of the dashboard, users can enter the configuration of different product series; on the right side they will find various shop functions. General functions can also be found at any time via the menu bar.

Failure minimisation, favourites, visualisation and CAD export

When jumping into the configuration, the customer sees the configuration interface shown in Fig. 5. In the left area, requirements for the system can be entered on different tabs. The input should take place in such a way that the most important customer requirements are entered first. This step-by-step input from important to less relevant helps to avoid errors.

Unlike in other configurators, the remaining entry possibilities are limited by the entries that have already been made, so that only valid configurations can be created. Therefore, there are no contradictions that have to be resolved. The system does not reverse any entries made by the user in a previous step. Technically nonsensical or commercially undesirable entries are also intercepted.

There is also the option of saving so-called favourites, so that customers do not have to start each new configuration from scratch. Here, for example, company-specific default values can be stored, which the configurator then automatically sets again for each configuration. On the one hand, this reduces the input effort, and on the other hand, customers can develop their own production to a certain standard if needed.

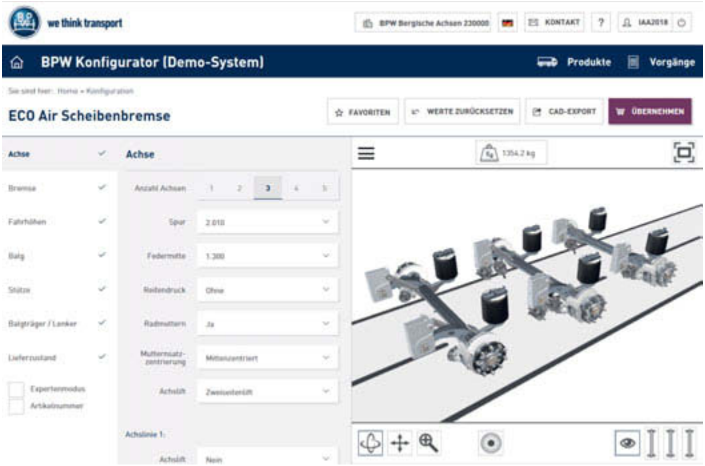

Fig. 5: Configuration interface

At each configuration step, the system checks to what extent the configured product can be visualised in the right-hand area of the configurator. The respective status of the configuration is visualised to the customer here as a 3D model according to the principle "What you see is what you get".

This visualisation is created in real time. It is therefore not a predefined render model, as it is the case with configurators in the automotive industry, for example. The advantage is that the displayed model corresponds exactly with reality and it can be rotated, moved and zoomed in the browser at will. As soon as a component can be clearly determined by the configuration, it is also displayed in the visualisation. The complete model is thus built up step by step, and the designer who makes entries can withdraw any unwanted ones early on – and not only after the configuration model is complete.

Once a customer has configured a suitable product in this way, the corresponding CAD data can be downloaded in any neutral format. Currently the formats STEP, JT, Parasolid and DXF are available. In less than five minutes, an individually created CAD model will be presented in the download area of the shop – corresponding to the entries and the visualisation displayed in the shop. The actual automatic CAD creation process takes less than 35 seconds. The CAD creation is controlled directly from the configuration. A designer can then install the CAD model in his or her system and, for example, continue to use it for a digital mockup, carry out collision checks or show the end customer a finished representation of the vehicle.

Weight, dimensions, documents

However, the visualisation method used offers even more advantages. For example, individual components can be displayed separately in a special so-called isolation mode. Fig. 6 illustrates this using the "air bag" component as an example.

Important connection dimensions for customers and their vehicle designs are shown here. Rotating, moving and zooming are also possible. Furthermore, the individual weight of the component appears in the upper area of the window. In overview mode, the total weight of all displayed components is shown (see Fig.5).

In the upper left area of the illustration, the user will find a so-called "hamburger menu" (three horizontal lines of equal length). Via this menu it is possible to display or download various documents relevant to the current configuration for the designer and assembly. These include, for example, brake reports, pendulum tests and catalogue overviews. All these documents are valid specifically for the current configuration and always up to date. Searching in electronic or even paper-based documents belongs to the past, as the shop directly accesses the associated data sources in BPW's ERP system.

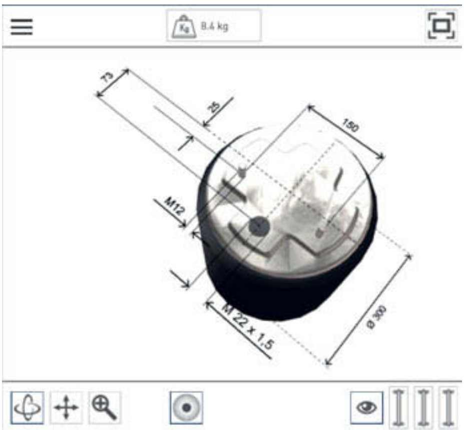

Fig. 6: Visualisation / isolation / weight

Orders, pricing and ERP integration

Once the designer has decided on a configuration, they can forward it to the responsible purchaser via a system-supported workflow.

In contrast to other industries, it is now possible for the purchaser to determine which components are to be included in the purchase order and whether they are to be delivered assembled

or unassembled. This feature also distinguishes our system from B2C business. The delivery and the assembly condition are based on the requirements of the customer. Depending on the value chain and production processes, the customer determines whether certain components should be delivered earlier than other components, for example, or the assembled product.
The price for the configured product is determined individually for each customer on the basis of conditions negotiated with the customer or according to standard price lists. This means that nothing stands in the way of dispatching the order. In some ERP systems, it will also be possible in future to start the configurator within the customer's own system and thus to interlink customers and the system supplier BPW even more closely in terms of data technology.

Summary

The trend towards selling individualised products will become stronger with increasing digitalisation. Configurators integrated in Internet portals with an ordering function are a solution approach that offers an advantage to business partners – i.e. customers and suppliers – as part of this trend towards individualised products while simultaneously reducing transaction costs.
In order to implement such an approach, the customer processes must be connected with the supplier processes and a representation of the digital twin of the supplier product must be made available to the customer. The digital twin is thus not only used for the supplier's order fulfillment but also for the order acquisition process.
So-called integrated product configurators serve as tools in this case.

BPW Bergische Achsen KG consistently pursues this approach and tries to increase customer benefit in this way. This has been achieved within the shop system by covering twelve identified customer benefit potentials
In further expansion stages, the digital twin personally created by the customer will be further supplemented with information over the entire life cycle. This could be information from BPW's own production, assembly at the customer's, use at the forwarder's or data from maintenance and repair.

At BPW Bergische Achsen KG we call this process Born Digital!

Validating the fuel consumption of trucks featuring a dynamic electronic horizon in real world traffic: methods and results

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Abstract

CO_2 emissions from road transport have continued to grow, despite continuing improvements in heavy duty vehicle fuel economy. The EU will mandate a 15% reduction in fleet CO_2 emissions relative to 2019 levels by 2025, with a proposed 30% reduction relative to 2019 levels by 2030. To meet the long-term targets, technologies such as carbon neutral fuels, hybridisation, full electrification or conversion to hydrogen as an energy carrier may be required. In the nearer-term, significant CO_2 reductions may also be achieved through optimal operation of the vehicle and engine through the application of predictive control strategies.

The benefit from predictive control can be enhanced when coupled with an electronic horizon system that provides preview data about the road ahead of the vehicle. Current state of the art electronic horizon systems provide static topology information to vehicle ECUs, next generation electronic horizon systems will add cloud connectivity and include dynamic data, such as real-time traffic, variable speed limits and weather.

In-vehicle measurements provide definitive information about the performance of a vehicle on a given mission under a specific real-world traffic situation. However, the real-world traffic is not repeatable. This presents a challenge when assessing predictive controls that utilise dynamic electronic horizon. Alternatively, if the vehicle, controllers, environment, traffic and connected electronic horizon infrastructure can be modelled in an integrated way, then simulation may be used to make repeated assessments of performance under a given traffic situation. When in-vehicle measurements are used to validate the models, the simulation environment can be used to assess and make a model-based validation of the performance of predictive control advances enabled by dynamic electronic horizon under consistent situations.

This paper presents a proposed method for conducting model-based validation of demonstrator trucks featuring a variety of predictive control advances developed by the IMPERIUM re-

search consortium. In-vehicle measurements are used to support validation of the vehicle models. A range of traffic situations are then simulated over an IMPERIUM drive cycle enriched with traffic and the performance of each vehicle is compared to baseline vehicles under equivalent conditions using a meta-model (model of models) approach. The results presented represent an 'intermediate' snapshot of the developments conducted within the project and the methods that will be applied to perform the final validation.

Electronic Horizon at a Glance

Digital maps were introduced more than three decades ago to aid with on-road navigation. It became apparent within approximately 15 years that that these digital maps could be used as vehicle sensors to enable predictive control functions. In 2006, Siemens VDO (today Continental) developed the first electronic horizon worldwide in the BMW 5 Series to improve the adaptive cruise control (ACC) to avoid unwanted dangerous acceleration of the vehicle when the radar loses the preceding vehicle, especially in situations where a reduction in the speed of the vehicle would be appropriate. This can happen, for example, in sharp bends or when leaving a highway on the exits.

To accelerate time-to-market, dramatically reduce development costs and complexity, and broaden the options for OEM/supplier cooperation, the ADASIS Forum was launched by ERTICO, Europe's Intelligent Transportation System (ITS) organization. The forum addressed the interface specifications necessary for the information exchange of Advanced Driver Assistance Systems (ADAS) [1] [2], now generically known as 'Electronic Horizon' or 'Static Electronic Horizon'.

Its purpose is to:

- Define an open standardized data model and structure to represent map data in the vicinity of the vehicle position (i.e. the electronic horizon), in which map data are delivered by navigation and/or by a general map data server
- Define open standardized API(s) to enable ADAS applications to access the electronic horizon and position-related data of the vehicle.

As defined in the ADASIS Forum the electronic horizon provider calculates the position of the vehicle based on information from GPS and if available from other sensors like a gyroscope and/or speed sensor. The electronic horizon provider also contains a detailed digital map enriched with additional ADAS attributes.

These attributes may be:

- Current vehicle position
- Current speed
- Current direction
- Type of street currently being travelled (highway, rural road, urban street ...)
- Number of lanes (single-lane or multi-lane)
- Radius and distance of the next curve
- Slopes
- Heights
- Any intersections ahead
- Speed limits
- Potential stopping points
- On-road / off-road / off-map
- Quality indicators

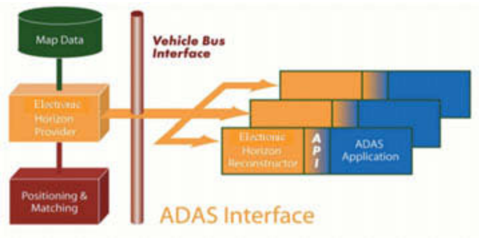

Fig. 1: Architecture ADASIS Forum [2]

Based on the current position of the vehicle, the driving direction and the digital map, the system calculates the most probable path ahead of the vehicle. The most probable path is the route with the highest probability assuming that the driver will follow the roads

- with the highest classification (e.g. interstates),
- with minimal change of the degree of the driving direction,
- but also considering turn restrictions and
- in roundabouts leaving the first exit with a higher or equal road classification as the current road.

In the current version of the ADASIS specification Version 2.x the most probable path can have a maximum length of 8,192 meters and can be conFig.d as a single path (considering no alternative paths) or as a multi path (considering also all possible alternative paths). Multi-path configuration can be used in safety-relevant applications to achieve a fast re-calculation of the electronic horizon if the driver does not follow the most probable path.

Based on the calculated position, the electronic horizon provider will transmit the most probable path ahead of the vehicle and all available attributes of this path up to a defined horizon via the in-vehicle bus to other electronic control units (ECUs) for functions such as cruise control, engine control or transmission control. In the current version of the ADASIS protocol (V2.x) a CAN bus is foreseen as a vehicle bus. All electronic horizon data are presented in 64-bit CAN frames. Due to the fact that the CAN bus offers only limited bandwidth, the use of CAN messages must be very efficient, i.e.., to provide as much information as possible with the lowest number of messages. This protocol is defined in such a way that it does not generate much load on the CAN bus, up to 10 - 50 messages per second, depending on the configuration. There are many ways to conFig. the transmitted path:

- Multi-path / single path
- Path length
- Transmitted attributes
- …

Fig. 2 and Fig. 3 show examples of what is received in the electronic horizon reconstructor module of an ECU in the case of the single path and multi path.

Fig. 2: Most Probable Path conFig.d as Single Path

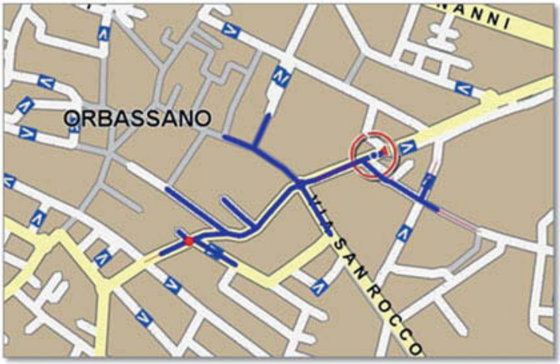

Fig. 3: Most Probable Path conFig.d as Multi Path

It can take up to 25 - 30 seconds to build up a path of 2 km length depending on the number of segments and the number of ADASIS attributes which must be transmitted. If the path is built up and the driver follows the most probable path, only the missing additional information on the path ahead will be transmitted during driving.

For these ECUs, the ADASIS Forum developed a reference implementation of the so-called electronic horizon reconstructor, a slim, small software module which can easily be integrated. The reconstructor receives the data from the vehicle bus, re-builds these data and provides the information via a specified API, defined by the ADASIS Forum, to the ECU application software. The ECU application software can be improved using this information.

In passenger cars an electronic horizon is mainly used to improve safety and comfort functions such as adaptive curve lighting or ACC. In contrast, in commercial vehicles it is used mainly to improve efficiency.

The effect of a technology that can save, for example, 3% fuel has a different influence in the commercial vehicle market than in the passenger car market, as a simple calculation shows:

A heavy-duty long haulage truck drives approx. 150,000 km per year, has an average fuel consumption of around 30 litres per 100 km. That is a saving of around 1,800€ per year for the end customer, assuming fuel costs of 1.30€ per litre. Thus, the investment is easily amortized within one year. Running the same calculation for a passenger car with an average mileage of 15,000 km per year, one gets a cost saving of less than $50 per year. An amortization of the investment within an acceptable period of time becomes difficult.

In commercial vehicles the electronic horizon provider can be a stand-alone solution or a software module in the telematic unit. In passenger cars the electronic horizon provider is a software module in a navigation system sharing the positioning module and the digital map with the navigation system.

Current production commercial vehicles use electronic horizon systems to provide static topology information to vehicle ECUs. In the years between 2012 and 2016, many manufacturers introduced features such as predictive cruise control and predictive gear shift control. These features can provide significant benefits on clear roads. However, this benefit can be reduced when the vehicle faces dynamic traffic situations that cannot be predicted with static data. Today, next generation electronic horizon systems are being developed that will add cloud connectivity and include dynamic data, such as real-time traffic, variable speed limits and weather conditions.

Self-Learning Electronic Horizon

As a first step, the technology of the electronic horizon can easily be expanded to a self-learning electronic horizon by forwarding data from the vehicle to the map via the vehicle bus (typically CAN) and storing these data in the map as geo-located ADAS attributes.

A good example is slope data measured by a slope sensor in the vehicle. Slope data is not available in all regions of the world in the necessary quality, however learned slope data can simply be included in the map. The following picture shows a map segment of around 800m. The red dots show slope data actually measured after the same segment was traversed 5 times.

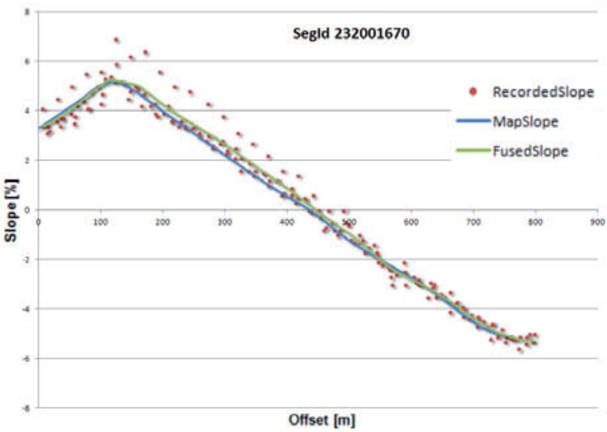

Fig. 4: Learned Slope Data

The green line is the fusion or merge from the measured slope data calculated by a least squares fitting using Floater-Hormann rational functions. It fits very well to the slope data in the map (blue line).

This method is the key to early introduction of predictive applications even in regions with little or no coverage of slope data, such as in Eastern Europe, South America, South Africa etc.

The memory footprint required to store the learned slope data as attributes is quite small; Only 170 MB would be necessary to store all slope data of all interstates of the US (50.000 mi).

Another important example is the learning of traffic signs. Many commercial vehicles already have a camera in the front of the vehicle for Lane Departure Warning (LDW) and Traffic Sign Detection (TSR), which transmits the detected traffic signs via a vehicle bus (typically CAN). This means traffic sign information can easily be stored as ADAS attributes in the digital map.

Connected Electronic Horizon

The next logical step is to transfer learned data to a back end via connectivity (e.g. 3G / 4G / 5G, V2V, V2X or WiFi) and to make this data available for subsequent vehicles travelling the same stretch of road. This is particularly simple in the case where the electronic horizon is implemented in the telematics unit. In the back end, the data of the individual vehicles are aggregated into a single large data set and can then be downloaded to all vehicles via the connectivity of the vehicle. In doing so, the vehicles make their own contribution to constantly improving and updating the map material and the additional information. That means a constant calibration of the map as a sensor.

Similar methods are used by map manufacturers as well as Google to generate their digital maps including current traffic information based on the position and speed data provided by smartphones.

Since any connectivity interface is a prominent part of the potential hacker attack surface, it is very important that the entire electronic horizon architecture (inside and outside of the vehicle) is integrated in a holistic automotive security architecture to ensure data privacy or to avoid software manipulations for instance. The building blocks of a holistic automotive security architecture are secure hardware (including a hardware security module (HSM)), encryption, decryption, signatures, keys and an Online Trust Centres (OTC) taking into account the specific automotive security challenges, as long product lifetime, end customer usage, heterogeneous distributed systems, no global time base or missing fall-back networks.

Dynamic Electronic Horizon

Up to now only static data, which does not change significantly with time, has been considered. A logical next step would be to extend the data available to the vehicle to include dynamic information. This can be equally significant especially considering the rapid fluctuation in traffic flow, weather conditions etc. Providing the vehicle systems with this data opens the door for further predictive algorithms which can save fuel in real life traffic conditions.

The predominant use for long-haul trucks is more or less constant driving on highways or wide country roads. Nevertheless, there are many situations that force the truck driver to slow down, such as traffic jams, road works, stop-and-go traffic, severe weather conditions, highway exits, urban areas and so forth. To give an example: an electronic horizon which includes this real-time information would give the vehicle advanced information on a traffic queue, so that the vehicle could start coasting well in advance and hence save fuel. Such an approach is referred to as ‘predictive eco coasting’ [3].

A possible architecture for a dynamic electronic horizon solution which collects and receives slope data and provides real-time traffic data is shown below.

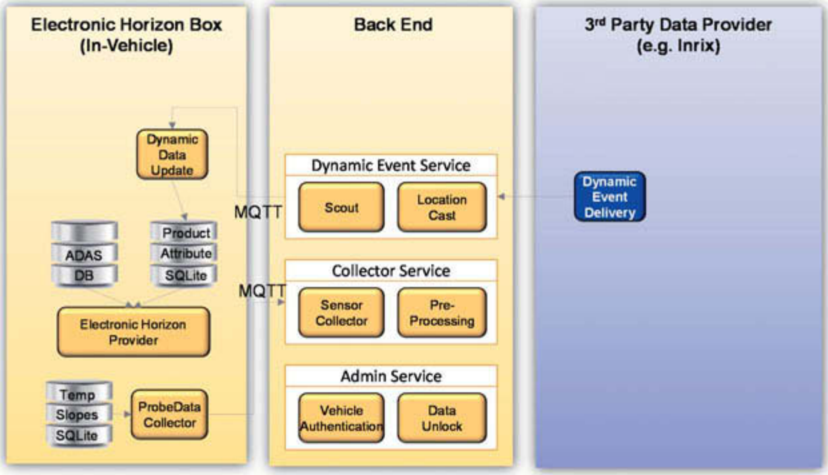

Fig. 5: Block diagram back End / in-Vehicle Box for the connected electronic horizon with dynamic real-time data

The left side of the diagram shows the in-vehicle electronic horizon which both collects the slope data and acts as the electronic horizon provider. A software module, called “Probe Data Collector” transmits the learned data to the back end using the MQTT protocol.

The “Dynamic Event Services” receives external real-time data from a 3rd party data provider as traffic information and/or traffic light information and sends it directly to the vehicle, where its spatial extent is described by means of dynamic location referencing. This information is then map-matched in the vehicle and thus linked to the locally installed digital map [4].

In this way, dynamic real-time information is provided via the ADASIS protocol, enabling implementation of various new predictive control technologies.

Predictive control technologies for improving efficiency

Predictive control strategies utilise an estimate of the future state of the system being controlled, in this case the truck and its subsystems, to determine the best control action to take in order to maximise a performance index or avoid a constraint. Predictive control has been is used by process control industries since the 1980s to provide improved performance and robustness compared to classical control techniques such as PID. With increases in computational power of embedded control devices, the application of predictive control in automotive applications is now feasible. Predictive control applications can be enhanced when preview data is available to improve this estimated future state. Therefore, by coupling predictive control with the dynamic electronic horizon system described above, additional performance and efficiency may be realised.

The IMPERIUM project partners have applied such control advances, utilising the dynamic electronic horizon, to a range of vehicle system and subsystem applications, including:

- Predictive Cruise Control
- Predictive gear selection and eco-coasting
- Predictive combustion control
- Predictive aftertreatment system control
- Predictive hybrid system power and energy management
- Predictive Waste Heat Recovery control
- Predictive Auxiliary control
- Global supervisory energy management control
- Enhanced driver coaching systems using preview data
-

Challenge of validating the fuel consumption reduction due to connected technology in real-world situations

In-vehicle measurements provide definitive information about the performance of a vehicle on a given mission under a specific real-world traffic situation. However, the real-world traffic is not repeatable. This presents a challenge when assessing predictive controls that utilise dynamic electronic horizon, as a significant proportion of the benefit is related to the interaction with real-world traffic, which can be anticipated due to the dynamic electronic horizon data.

Therefore, to make an accurate judgement of the real-world fuel consumption reductions using in-vehicle measurements, one would need to collect a large volume of measurement data, using both baseline and improved vehicle fleets, under closely monitored traffic, road topology and weather conditions. This is rarely feasible, particularly during early development phases.

An alternative, and preferable, approach is to make such a judgment using a model-based approach. If the vehicle, controllers, environment, traffic and connected electronic horizon infrastructure are modelled in an integrated way, then simulation may be used to make repeated assessments of performance under a given traffic situation. When in-vehicle measurements are used to validate the models, the simulation environment can be used to assess and make a model-based validation of the performance of predictive control advances enabled by dynamic electronic horizon under consistent situations.

Therefore, an integrated simulation environment is required to get the reproduceable traffic needed for the validation.

A simulation environment integrating models of vehicle, traffic and connected infrastructure

To meet the need described above, an integrated, model-based simulation environment has been developed that can be used to assess the potential of the application of the IMPERIUM advances under simulated 'real-world' traffic conditions. This simulation environment is based on the commercially available vehicle simulation package from Ricardo, which provides a library of forward-facing component models, including vehicle platforms, engines, exhaust aftertreatment, transmissions, motors, batteries, thermal systems and waste heat recovery systems. This library of components allows a wide variety of vehicle architectures to be investigated. Using a forward-facing modelling approach is an advantage in this application as the correct causality allows the controllers under test to be integrated with the vehicle model.

The simulation package has been extended to include the ability to interact with traffic microsimulation tools and to include a connected electronic horizon data provider. The whole simulation environment is illustrated schematically in Fig. 6.

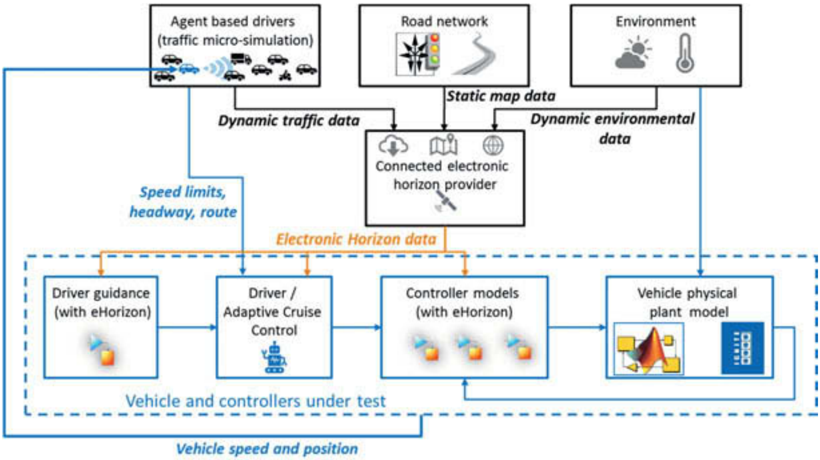

Fig. 6: Schematic of the simulation environment

Virtual road networks can be generated for this simulation environment based on mapping data of real roads, available from public domain projects as well as commercial data providers. However, for the IMPERIUM project a virtual road network based on the VECTO [5] long-haul cycle was used as the basis for the creation of a virtual road network. This is illustrated in Fig. 7. An elevation profile was created by integrating the defined gradient against distance. The cycle was divided into a set of 32 road segments, with varying combinations of speed limit, number of lanes, and stop junctions. The variation in road speed limit and number of lanes provokes varying traffic flow conditions. Within Europe, the typical number of lanes on a motorway varies by country and region. Whilst some motorways may have four or more lanes in a single direction, particularly around dense urban population centres, motorways with two and three lanes in a given direction are common. Therefore, the motorway lane structure defined incorporated two and three lane dual carriageway. It was assumed that trucks were prohibited from using the third lane for overtaking, however no prohibition was applied for two lane sections. A global road-speed limit for trucks of 85km/h was applied. Road speed limits varied between 90km/h and 120km/h for unrestricted traffic, unless a lower speed was imposed by the original VECTO definition. In these cases, the lower limit was applied for all classes of traffic.

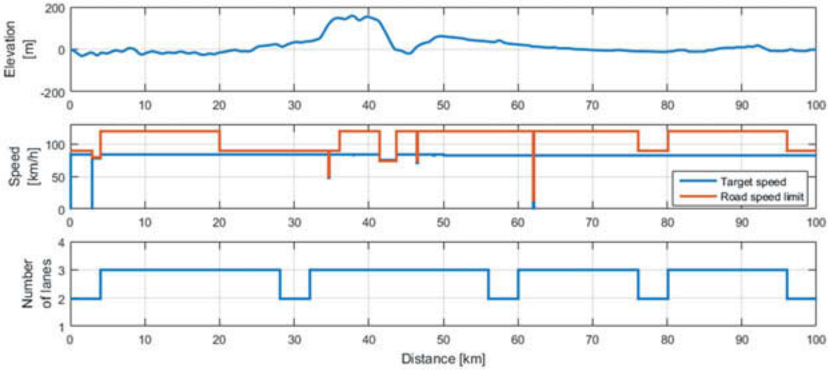

Fig. 7: IMPERIUM virtual road definition, based on VECTO long-haul cycle

Traffic is added to the simulation environment by means of multi-agent traffic micro-simulation, which produces naturalistic traffic flow patterns. Each vehicle in the simulation obeys a set of rules that govern the vehicle and driver's behaviour with respect to the other vehicles in the simulation. As each vehicle interacts with the surrounding vehicles, complex traffic flow patterns emerge, such as congestion and traffic jams. In this work, the SUMO (Simulation of Urban Mobility) [6] simulator and TraCI4Matlab [7] tools were used to perform the traffic micro-simulation. Traffic flows are defined such that the volume of traffic on the road network increases and decreases over a three-hour period. The resulting average traffic speeds are shown in Fig. 8. This Fig. shows the average traffic speed as a function of distance and time, with colour indicating the speed at a given spatiotemporal point. Here we overlay the trajectories of two vehicles (labelled Vehicle #0 and #8). Vehicle #8 experiences significantly more interaction with slow moving traffic than vehicle #0, leading to mission delay. This shows that the starting time of the vehicle under test is critical in determining the traffic situation it will face.

We describe the combination of the virtual road network and simulated traffic scenario described above as the 'IMPERIUM cycle'.

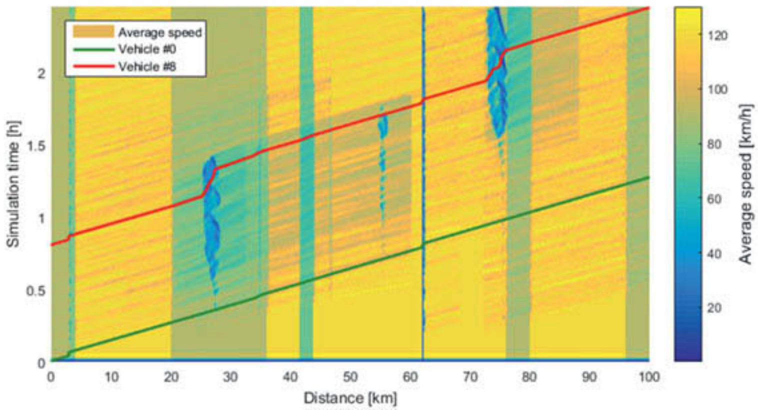

Fig. 8: Average traffic speed

The traffic micro-simulation described above is used to feed data to a software component designed to emulate the properties of the remote dynamic electronic horizon data server. This emulated electronic horizon data stream was conFig.d as follows:

- Static data horizon up to 8192m, corresponding to the maximum length of the Most Probable Path (MPP) according to ADASIS Protocol V2.x.
- Static data resolution nominally 50m
- Dynamic data horizon of 4000m
- Dynamic data resolution of 250m
- Dynamic data update rate every 60 seconds

As the simulation environment is forward-facing, a driver model is required. The driver model was parameterised based on measured data collected during the project. It implements the following features:

- A nominal speed target as a function of distance along the route.
- Speed target modification based on road speed limit
- A car following model, modifying the speed target based on headway time and distance to the vehicle in front
- Look-ahead coasting and braking in case of speed reduction, parameterised to match the VECTO nominal configuration for driver look-ahead
- Closed loop velocity control using a gain-scheduled Proportional-Integral (PI) controller

The need for traffic metrics influencing vehicle fuel consumption

For the next step, the IMPERIUM cycle and the corresponding simulation environment is used to simulate a range of vehicle configurations, both baseline and with advances, under reproducible environmental conditions.

In order to respect confidentiality requirements, the fuel consumption resulting from a given simulation is rated against a reference fuel consumption from the corresponding baseline vehicle (Model Year 2014) operating under 'no traffic' conditions.

Fig. 9 shows traces of velocity and relative fuel consumption (FC_{rel}) for the baseline vehicle. The definition of FC_{rel} is shown in the Fig.. Fuel consumption (FC) is defined as the actual fuel consumed divided by the distance driven. FC_{rel} is a normalised value for FC, defined as the ratio between a fixed 'reference FC' at the end of the reference cycle and the FC of the vehicle being evaluated. As such FC and FC_{rel} can be evaluated at any point in the cycle. In the Fig. below, the FC_{rel} traces are evaluated using the baseline vehicle under no traffic as the reference FC. Consequently, the final value of the 'no traffic' situation for the baseline vehicle (green dashed line) reaches exactly 100.0% at the end of the IMPERIUM cycle.

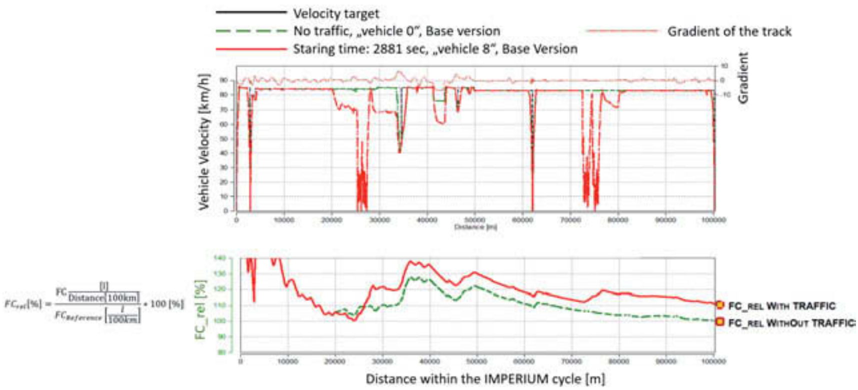

Fig. 9: Relative Fuel consumption in the IMPERIUM cycle - without and with traffic

When the baseline trace is compared with the same vehicle simulated under traffic conditions (red solid line), one can clearly see the phases of increase in FC_{rel} correspond to the periods of low velocity (upper part of the Fig.). These periods of lower velocity are imposed by the heavy traffic, as can be seen by comparing with Fig. 8.

Fig. 10 shows a detail of the first of these heavy traffic sections. Whilst the baseline vehicle (without traffic, in green) can follow the velocity target of 85 km/h steadily, the same vehicle with traffic (in red) needs to decelerate and re-accelerate frequently in order to follow the traffic flow. This leads to a significant increase in FC_{rel}.

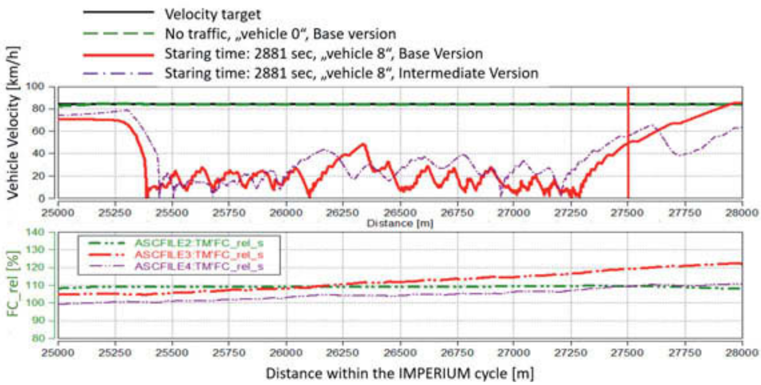

Fig. 10: Interaction of ego vehicle velocity and traffic for different vehicle versions

When a vehicle with different performance characteristics is compared under the same traffic boundary conditions (starting at the same time into the same simulated IMPERIUM cycle) the response develops differently. In Fig. 10 an 'intermediate' vehicle is shown (violet dot-dash line), representing a hybridised variant of the baseline vehicle. It can be seen that the velocity trace versus distance develops in completely different way. This is notable, as it illustrates that the simulated traffic observed by the vehicle is sensitive to both position and time, and that delaying or advancing the vehicle's progress in the simulation by a small amount will result in a different response.

As a consequence, it will not be sufficient to simply compare the fuel consumption of two different vehicles commencing a defined traffic situation at the same time.

Fig. 11 illustrates this by comparing three FC_{rel} results for baseline and intermediate vehicle pairs with the starting times numbered 8, 9 and 10. When viewing these results, it is difficult to judge whether the improvement is 5.0% or 9.9%. Even when rating the simulation results statistically by comparing the average values for the reference and intermediate version separately, the measurement uncertainty (95% confidence interval) remains at 2.7%, which is very high.

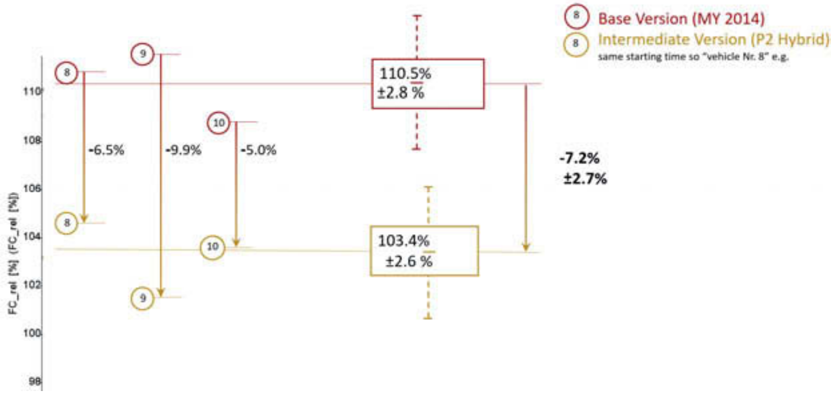

Fig. 11: Challenge to judge FC_{rel} improvement based on vehicle results under traffic conditions for one pair of vehicles

Therefore, we established that both the measured and simulated traffic situations needed to be judged against relevant KPIs, in order to compare the different vehicle variants under the same values of 'traffic strength'.

Development of traffic metrics

To develop the required traffic metrics, 21 IMPERIUM cycles with differing starting times were run for each vehicle variant under investigation. The resulting FC_{rel} values showed a range from 93% to 112%, depending on traffic and vehicle variant. Using the data generated, a metamodel approach using AVL CAMEO was used. Whilst model-based calibration methodologies have already been proven to be beneficial in many calibration projects, the approach of 'meta-model based validation', as shown in the following, is comparably new [8]).

Initially, two input parameters were selected:

- Average vehicle velocity of the vehicle under test over the whole IMPERIUM cycle
- The statistically rated 'mass related power demands' – so called $(v.a_{pos})_{k[95]}$

The conceptual basis for the second KPI was taken from [9], where the so called $(v.a_{pos})_{k[95]}$ is also used for light duty vehicles in the context of RDE measurements (COMMISSION REGULATION (EU) 2016/646 of 20 April 2016 amending Regulation (EC) No 692/2008 as regards emissions from light passenger and commercial vehicles (Euro 6)). Fig. 12 shows the effect that traffic has on that KPI using an example of a reference vehicle. Here 'no traffic' (green) is compared with 'heavy traffic' (red). The distributions are clearly different, with bias toward higher power demands seen in the traffic case, indicating the measure may have some merit in differentiating the cases.

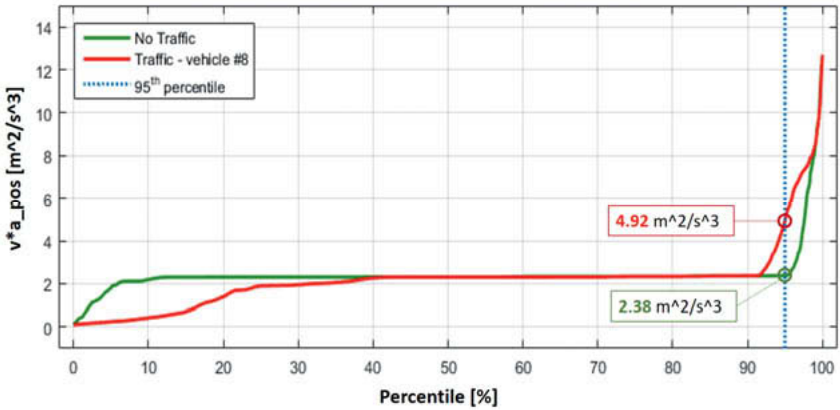

Fig. 12: Comparison of $(v.a_{pos})$ by percentile for no traffic and traffic conditions

Further kinematic traffic parameters were considered in a subsequent sensitivity study:

- $(v.a_{neg})_{[05]}$, which is the braking equivalent to $(v.a_{pos})_{[95]}$. This was investigated to capture the degree of braking, as this is a significant source of wasted energy
- Standard deviation of the vehicle velocity

To check the potential of these parameters in explaining the influence of the traffic on FC_{rel}, all the simulation results generated were used to train a 4-dimensional meta model. This meta model was designed to predict the FC_{rel} as function of the traffic KPIs listed above. Such a model can be imagined as a 'lengthy formula', where its parameters are tuned in order to minimize the squared error between the training data and the model prediction.

Fig. 13 shows an intersection plot through the resulting FC_{rel} model. While the average speed of the vehicle under test can explain most of the influence, the $(v.a_{pos})_{[95]}$ metric can contribute to explain the trends, while the other two parameters showed no statistical significance.

A polynomial model with an order reduction algorithm was applied. The so called ‘forward backward method’ was used to check whether additional terms of a polynomial model, up to a maximum 5th order, could describe the dependency of the FC_{rel} trends more accurately. Terms that did not contribute significantly to the model result were removed from the equation. As a criterion for this, the term itself as well as the lower and upper 95% confidence interval for the corresponding term needed either to be all negative or all positive values. In this case a simple relationship containing only the average velocity as linear term and the interaction term between the average velocity and the $(v.a_{pos})_{[95]}$ remained, as visualized in Fig. 13:

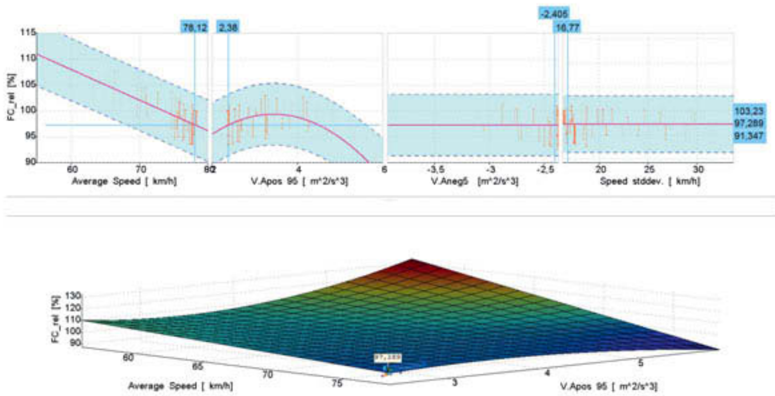

Fig. 13: Sensitivity check to find the most significant kinematic traffic parameters for FC_{rel}

Therefore, these two traffic KPIs are used to conduct the evaluation of the fuel consumption results shown in this paper, as they are showing the strongest statistical ‘explanation potential’ for fuel consumption changes due to traffic variations.

However, the question of ‘how to measure traffic?’ will be investigated further within the IMPERIUM project, as there is one aspect that is not fully satisfying in the KPIs proposed so far. Namely, the strong influence of the behaviour of the vehicle under test on the judgement of the traffic situation, as it is based in principle on the vehicle’s own velocity. Ideally, a judgment on the traffic situation should not depend only on the state of the vehicle under test, only its position in the actual traffic flow.

Therefore, we give an outlook to a possible further traffic KPI judgement developed from the electronic horizon data stream, received by the vehicle during its drive.

Outlook to traffic KPIs, which will most probably used to sharpen the final validation result

For the first KPI, the average vehicle speed is replaced with an average of data from the 8 upcoming electronic horizon road segment traffic velocities. This value is updated frequently during the drive and thus the average of those values is used.

For the second KPI, a ‘power demand of the traffic’ is calculated, analogous to the $(v.a_{neg})_{[05]}$ described above. This value ‘meanpctl0210_S1_vAGneg’ compares the quantity of energy loss in the traffic ahead of the vehicle through decelerations, factoring in the road gradient upon which those decelerations occur (see Fig. 14 and the corresponding explanation below).

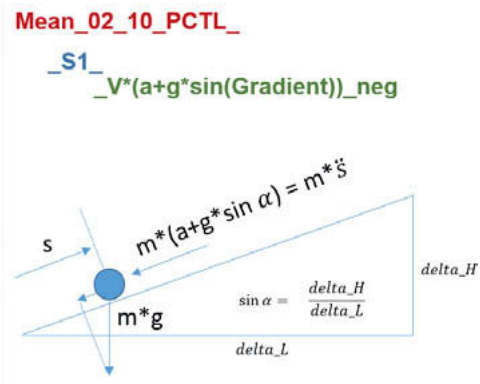

Fig. 14: Concept of relevant percentile average values for traffic forced mass related power demands

The resulting meta-model is illustrated in Fig. 15, which shows the FC_{rel} dependency on the electronic horizon based KPIs described above. In this case a ‘Robust Neural Network’ (RNN) [10] was selected by CAMEO for the behaviour model for FC_{rel}. This consists of 3 linear models, which are smoothed together with Gaussian weighting functions.

Here we see that when the average traffic velocity KPI reduces into the region of a truck’s velocity, the stronger ‘meanpctl0210_S1_AVGneg’ KPI leads to increasing FC_{rel}. Likewise, if the traffic is significantly faster, that KPI appears to be less relevant, which is plausible.

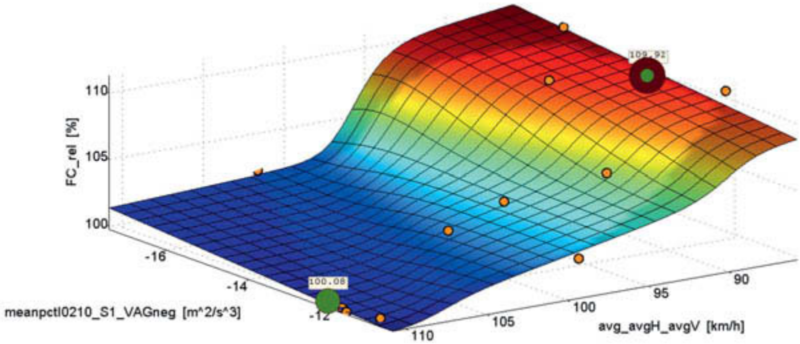

Fig. 15: FC_{rel} model as function of electronic horizon traffic KPIs

One can see in Fig. 15 that under 'traffic conditions' (large red-green circle), the FC_{rel} increases by circa 10% compared to the 'no traffic situation' (large green circle). Here the 'traffic condition' is derived as the average position in the Traffic KPIs of all the traffic cases for the vehicles 8 to 10 in the reference and intermediate versions.

Fig. 16 shows a comparison of the two FC_{rel} models at the comparable 'traffic position' in the intersection plot. The 95% confidence interval (dotted lines around the FC_{rel} models) can be improved by a factor of 2.8, to below 1%, when considering the selected two traffic KPIs.

Therefore, one can determine a clear FC_{rel} reduction in the range of 6.9 ±1%.

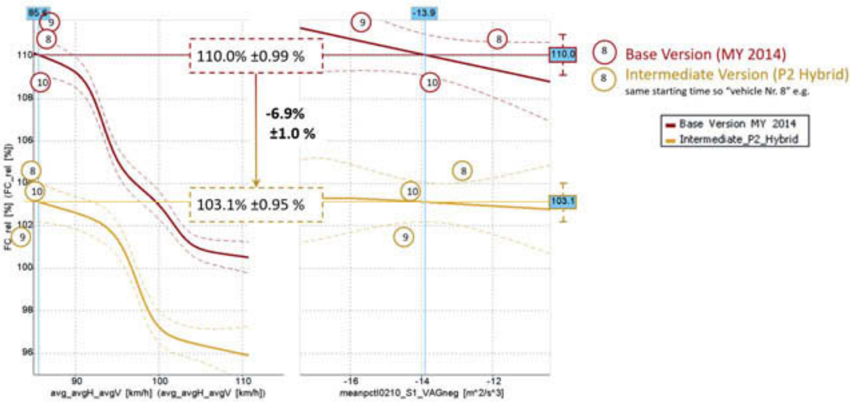

Fig. 16: Mode based validation with improved 95% confidence interval

This result is comparable to the result gained with the ‘ego vehicle-based traffic KPIs’, within the statistic uncertainty stated. The expectation is that this traffic judgement delivers a more robust comparison, particularly when it comes to control strategies that change the vehicle’s driving behaviour.

Comparison of three technology packages

Three vehicle configurations have been modelled that each incorporate different advances providing fuel consumption reduction benefits. The content of these packages is summarised in Table 1 along with the predicted change in fuel consumption in no traffic and simulated traffic conditions based on the meta-model analysis.

The models used in this simulation were parameterised and validated based on available test data and control developments at the time of writing. As such they represent a snapshot of an ‘intermediate’ level of development within the IMPERIUM project. Some additional technologies, such as waste heat recovery and e-turbo are not yet included in the analysis. Furthermore, developments are continuing on the technologies that are included. Therefore, it is expected that further benefit will be unlocked in the finalised demonstrator vehicles.

Table 1: Technology packages and estimated fuel consumption reduction benefit

Technology package	Studied Content	Relative Fuel Consumption	
		No Traffic	Traffic
Baseline	MY2014, 320-340kW EURO VI turbodiesel engine and 12-speed AMT	Baseline 100%	110% (+10.0%)
A	Engine friction reduction, vehicle measures and micro-hybridisation	93.5% (-6.5%)	103.5% (-6.5%)
B	Full hybridisation and downsized engine	95.4% (-4.6%)	103.4% (-6.6%)
C	Predictive energy management using dynamic electronic horizon	97.3% (-2.7%)	104.9% (-5.1%)

The meta-model based methods described in the previous sections were applied to determine the FC_{rel} improvements listed in Table 1. Each vehicle was simulated under 21 traffic conditions and the resulting data was used to generate the described KPIs used to fit the meta-model. The ‘traffic’ and ‘no traffic’ numbers then result from evaluation of the meta-model at the described positions. Values are given as absolute FC_{rel} results as well as delta values from the ‘traffic’ and ‘no traffic’ baselines (in brackets).

The three technology packages presented incorporate different technological advances. If a simple combination of the technologies were to be applied an indicative improvement of circa 18% may be assumed. However, there is expected to be a sharing of benefit between some of these technologies, which is likely reduce the total benefit of the combined system.

Development work is ongoing in each work-package to unlock additional benefit from these technologies. Therefore, further improvements in fuel consumption reduction are anticipated in the final demonstrator vehicles.

Conclusions

Rapid advancement is ongoing on the topic of electronic horizon. Originally, the electronic horizon provider utilised static map data only. Now, the state-of-the-art electronic horizon provider is capable of self-learning and includes connectivity to the internet, enabling both upload and download capability. This download capability allows the integration of dynamic data, such as real time traffic and weather into the ADASIS electronic horizon stream, unlocking many potential improvements in vehicle control and on-line optimisation.

To judge the benefit of on-line optimal control influenced by connected data in real-world conditions, a simulation-based approach is required to ensure comparable results are generated. Direct measurement can be used to validate models under specific conditions. These validated models can then be assessed against traffic metrics under specific traffic scenarios using a meta-modelling approach.

An integrated, model-based simulation environment has been developed to extend the boundary conditions of the typical vehicle simulation to include environmental, road, traffic and connected technologies. This allows model-based validation of fuel consumption reductions for vehicles equipped with advanced control utilising dynamic electronic horizon preview data under a range of different traffic conditions.

By using data from the simulation environment with a meta-modelling approach based on the proposed key performance indicators, a judgement can be made about the benefit of a connected control technology in the presence of traffic, which would not be feasible using direct measurement alone.

The assessment methodology presented here is a relevant new approach, as traffic is an ever-increasing factor on European roads and thus the fuel consumption improvement under such conditions is important.

The results presented show that advanced control, using preview data provided by a connected dynamic electron horizon will provide significant progress towards the proposed fleet CO_2 reduction targets under real-world driving conditions. Evaluation at this intermediate stage of development indicate an achieved fuel consumption reduction due to this technology of between 2.7% and 5.1%, depending of traffic. When combined with other technologies studied, reductions of 13.8% to 18.2% are indicated. Once development work is completed, a final evaluation of the combined technologies will be made using the techniques described here.

Finally, the tools and methods described here could be used to evaluate the benefits of other fuel consumption reduction technologies, such as the variable aero devices, energy management systems and alternative powertrain topologies evaluated in the TRANSFORMERS [11] and being considered in AEROFLEX [12] projects.

Acknowledgements

The research leading to these results has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n° 713783 (IMPERIUM) and from the Swiss State Secretariat for Education, Research and Innovation (SERI) under contract n°16.0063 for the Swiss consortium members.

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Lean product development process for a Chinese commercial vehicle supplier

Preparation and implementation of changes in the thinking and acting of a Chinese production company on the basis of Lean Production Management

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1. Abstract

ZHUCHENG YIHE AXLES CO., LTD (YIHE) is the world's largest brand-independent manufacturer of commercial vehicle steering axles. YIHE has an annual capacity of 1.2 million axles and in 2018 delivered more than 1.0 million units to almost all Chinese commercial vehicle manufacturers. YIHE is also growing above average in the Chinese market against state-owned companies, but nevertheless faces a continuous decline in margins. This was the reason to introduce an overall product development process based on the German model.

After some benchmarks, also with Japanese providers, Ebertconsulting GmbH was selected to accompany this process with their MSCDPS® method. The MSCDPS® method is specially tailored to the needs of large SMEs and combines continuous improvement based on the Japanese model with the European approach to revolutionary development leaps. The method is based on the close integration of production optimization with the establishment of a development landscape with continuous search for cost savings with simultaneous quality improvements.

The introductory pilot has been the development of a standardized hub unit (wheel bearing unit) which will also be offered in the world market.

As part of the project, the assembly and in-house logistics were synchronized as a pilot project, the result is the personal reduction in the assembly of the so-called M4 axle (for trucks from 5.5t to 12t total weight) from existing 16 to 10 workers. In parallel a cost-optimized hub unit was developed, as a paragon for the future development landscape.

The main objective has been to set up and demonstrate a German like product development process. With support of EC GmbH in the mid of this year this service life-optimized hub unit will be launched worldwide.

In addition to the commercial-technical content, the presentation also deals with the cooperation between different cultures and how the resulting intensive confrontations can be used for innovation and quality improvement.

2. Two worlds encounter

In the beginning it sounds like a simple task. ZHUCHENG YIHE AXLES CO., LTD, the world's largest brand-independent manufacturer of commercial vehicle steering axles, is planning to introduce a holistic product development process based on the German model in order to be able to compete with its products not only on the Chinese but also on the world market. For this purpose, a structure is to be created and established, which at the same time promotes the continuously optimized production process in addition to a development process for new, innovative products.

YIHE currently produces approx. 1.0 million steering axles per year, split in approx. 350 different axle types. It is based on a historically grown, typically Chinese production structure, which relies on maximum flexibility both in terms of personnel requirements and the processes themselves. This extends throughout the entire process from purchasing through production to sales. For example, there is no integrated production planning and control system in place across the enterprise, instead WeChat is used (a counterpart to WhatsApp and other messenger services), which is very popular in China, to communicate for both internal and external production control.

The production system is now facing, due to the rapid growth of the company in recent years, its theoretical total capacity of 1.2 million axles per year, calculated purely by the optimal cycle time of the assembly lines, so the typical marginal phenomena which occurred before in sooner developed economic regions of the world have led to a rethinking of production towards the methods of Lean Production Management.

Massive supply bottlenecks of components, frequent downtime of production lines due to unplanned set-up processes, high employee turnover due to the compensation of these production losses with extremely flexible overtime or lack of correction measures for quality issues along the production process are just some of the typical problems.

It seems logical and easy to complete the previous production structure strictly with the methods of Lean Production Management as described above or to replace it completely in some places.

During planning phase and with ongoing implementation, however, the fundamental strength of the Chinese production system became evident, especially the cultural, anchored in education clear, hierarchically very flat top down structures using maximum disciplinary enforced flexibility for the introduction of a production system, that counteracts team building as well as continuous improvement by free thinking of each individual on the basis of extreme standardization. A system shall be created in which highly trained employees are able to implement predefined processes, and to develop them for all applications to create standards along the entire supply and production chain, to guarantee individually optimized but reliable processes based on a solid database.

3. The MSCDPS® product development process: agile and lean

An early definition of agility from the 1980s states that "Corporate agility, the capacity to react quickly to rapidly changing circumstances, requires a focus on clear system output goals and the capability to match human resources to the demands on changing circumstances." (Brown and Agnew, 1982, p. 29).[1]

With this definition, the special focus is already on

- Swift response to environmental changes
- Requirement of clear targets

[1] As 3), p. 7

- Evaluation of human resources

Later on it reads: “Since the late 1990s, there is greater emphasis on individual customer value as well as on product development initiated by customer requirements.”[2]

To a large extent, our approach is in line with a model from the turn of the century that was designed as an “agile-manufacturing model” in cooperation with various authors.

Fig. 1: Generic Framework of agile manufacturing (based on Gunasekaran & Yusuf, 2002, P. 413)

“The framework comprises the attributes strategy, technology, organization, and people, to which various concepts are applied. The attribute strategy includes the concepts reconfigurability, flexibility, virtual organization, strategic alliances, integration, and parallel development.

[2] As 3), p. 8

As concepts of the attribute technology, Gunasekaran mentions modular software components, real-time checks, information technologies, multimedia, graphic simulators, and more. The attribute people include the concepts flexibility, IT, top-management support, and employee knowledge and under the attribute systems are grouped MRPII, Internet, WWW, electronic trade, CAD/CAE, ERP, JIT, etc. (Gunasekaran, 1999, p. 100)."[3]

The characteristics quality, training, education, and incentives system are key components of this framework, also in terms of organization and people. In the end, Foerster und Wendler (2012, p. 13) describe agility from the angle of organization theory as a "conglomerate of elements from various theories and concepts, that […] are continually expanded with new approaches [...]. Its strength may be that the term agility continues to be adapted to current developments and can therefore be considered as 'modern' in spite of its 20-year history."

3.1 **Agility in companies**

Employees with their skills and qualifications are unquestionably the key resources of companies. For example, another strand of agility theory—a psychosocial and systems-theoretical strand—includes team theory. "The self-organization theory (a variant of the systems theory, dA) and team theory were selected (by Foerster und Wendler, 2012, dA), because the requirement of self-organised groups, who independently accomplish complex tasks as a team, constitutes a distinctive attribute of agility."4 From the point of view of organizational theory, various approaches play a role herein. In the field of psycho-social organizational theories, they include the

- **Human-relations approach**, an alternative to Taylor's principles of assembly-line work with fixed cycle times, as well as the

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[3] As 3), p. 12

[4] As 3), p. 14

- **Human-resources approach**, a motivation-oriented model with focus on development opportunities for employees and self-control instead of external control: “The idea is to shape the organization so that through the achievement of individual targets organizational targets are achieved simultaneously. Work is no longer seen as ‘plight, but as ‘joy,’ as a source of needs fulfilment” (Schreyoegg, 2003, p. 54). Parallels can be drawn to lean production and agile organization that pursue flat hierarchies, in which decision-making is transferred to lower hierarchical levels.5

Among other things, process orientation plays a central role in the self-organization theory (a variant of the systems theory).

In the team theory, the team is seen as “a target-compliant group of actors whose members perform various tasks, which they may complete using non-identical information. The members pursue similar targets, so there are no conflicting goals (Wolf, 2011, p. 141; Hofmann, 1973).[6] So this is about job-sharing, communication of information exchange, and rules of conduct for team members.

“The teams work with various team models, although the concentration on self-organized teams in a decentralized organizational form is a key agility hallmark. The architects of the agility concept relied on insights of the team theory, established for several decades and already an integral component of various organizational models (including lean production), before it was incorporated into agile models.”[7]

3.2 **The flexible company—agile and lean**

In times of change and restructuring, it becomes apparent whether companies manage to operate flexibly and make readjustments. Increasingly, companies must be able to adapt ever faster to environmental changes with regard to product variants, time, and costs, which makes

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[5] As 3), p. 15

[6] As 3), p. 18

[7] As 3, p. 20

their effectiveness measurable. Company flexibility is the requirement for an unequivocal focus on customer requirements.

Foerster und Wendler (2011) comment on flexible manufacture and lean organization: “The manufacturing concept known as lean production, as with flexible manufacturing, represents a direct answer to the mass-production system and already contains many agility characteristics” (p. 25). Although the practice originated in the 1950s in Japanese companies, the concept continues to be a familiar and current approach. Having said that, the Japanese model has met with increasing criticism in subsequent years: a study of the Massachusetts Institute of Technology (MIT study) points to worker strain, high levels of fluctuation, and an inadequate environmental approach.8

Shah and Ward (according to Foerster and Wendler, 2011) count 10 characteristic dimensions for lean production:

[8] Compare: as 3), p. 25

Table 1: Dimensions of lean production (Shah & Ward, 2007, S. 799)[9]

dimension	description
supplier feedback	provide regular feedback to suppliers about their performance
JIT delivery by suppliers	ensures that suppliers deliver the right quantity at the right time in the right place
supplier development	develop suppliers so they can be more involved in the production process of the local firm
customer involvement	focus on a firm's customers and their needs
pull	facilitate JIT production including kanban cards which serves as a signal to start or stop production
continuous flow	establish mechanisms that enable and ease the continuous flow of products
set up time reduction	reduce process downtime between product changeovers
total productive/ preventive maintenance	address equipment downtime through total productive maintenance and thus achieve a high level of equipment availability
statistical process control	ensure each process will supply defect free units to subsequent process
employee involvement	employees' role in problem solving, and their cross functional character

With regard to the production system, it shows that a lean factory "(transferred) a maximum of tasks and responsibilities to those employees who actually added value to the car on the assembly line, and (has) installed a system of fault detection that quickly traces each identified problem to its final cause" (Womack et al., 1992, p. 103).[9]

In this concept, teamwork is of great importance, both in manufacturing and product development: "Lean product development/construction is largely a construct of four basic elements management, teamwork, communication, and simultaneous development."[10]

To be able to quickly respond to customer requirements, we develop close ties to customers. This makes it possible to quickly obtain feedback, for example on trends. A comparison of lean and agile principles is given.[11]

4. The pilot project to practice

In order to develop and implement the new methods and processes, a highly efficient assembly line was selected as a pilot project, so that from the beginning as many as possible issues occur with the pilot project and as an advantage, the resulting improvement potential can be demonstrated holistically in a the Chinese culture compliant, standardized recipe structure for roll-out to additional company divisions.

Initially, however, it was necessary to introduce further hierarchical levels throughout the company structure, thus creating the basis for the necessary team building.

In a parallel, continuous training process, the methods of Lean Production Management were presented again and again at each newly introduced level, and the most helpful methods were selected in a joint decision-making process.

During the pilot project, for example, the first step was to record and independently analyze workflows and process times using value stream mapping charts and with the help of video recordings of the entire process.

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[9] As 3), p. 27

[10] As 3), p. 28

[11] ***Hochschule Koblenz, BPM-Labor - Labor für Business Process Management und Organisational Excellence,*** *Prof. Dr. Ayelt Komus,* Version 1.0 vom 06.05.2014

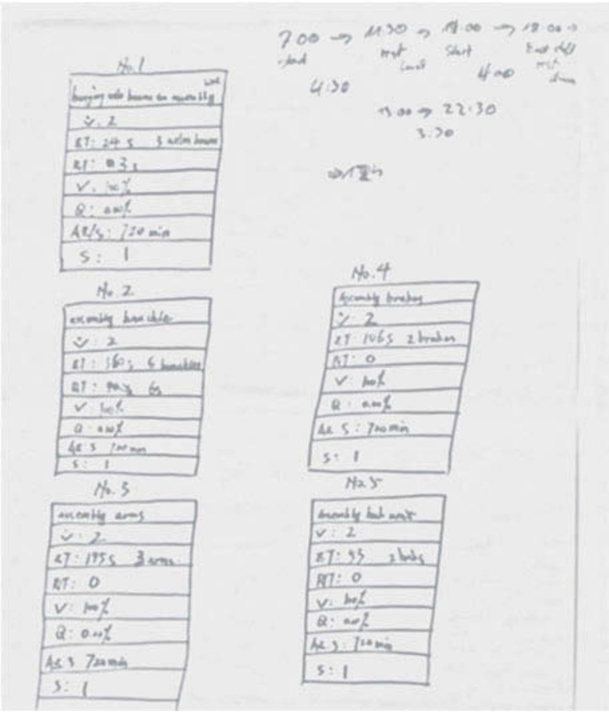

Fig. 2: Value stream map of the processes at the assembly stations

After all kinds of waste was detected both in the material and information flow as well as in the areas of handling and quality, workshops under guidance of EC experts together with YIHE workers for continuous improvements of the processes were executed. Previously established one-piece-flow structures, which are lean according to the recipe definition, were abolished for areas in which they make no sense, such as the supply of the assembly line with miniature fuse elements such as standard nuts or screws, and a KanBan-System replaced.

The difficulty of implementing the use of two different supply strategies at the same assembly line, demonstrated the mental balancing that employees were repeatedly exposed to in this process of change.

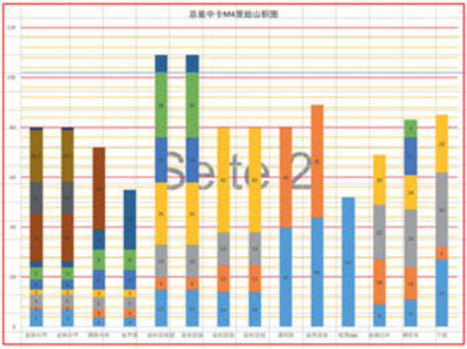

Fig. 3: Process times of non-optimized and non-synchronized assembly processes

After the most obvious wastes had been skipped with suitable measures, the optimized processes were synchronized as far as possible for all assembly stations. This synchronization resulted in a significant reduction in average cycle time at the slowest station on the line, resulting in a 6 Employees saving on the entire assembly line.

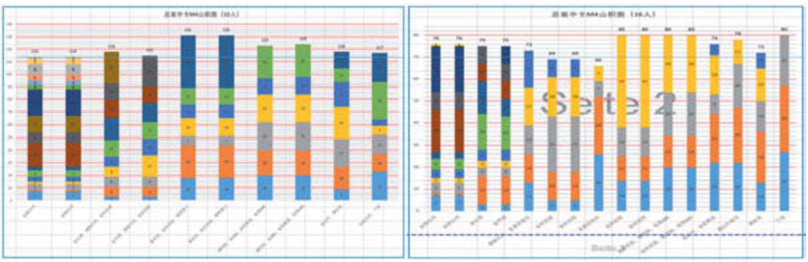

Fig. 4: Process times of optimized and synchronized assembly processes (left for today's capacity requirements with 10 persons, right for possible capacity requirements with 16 persons)

The future challenge is now to stabilize the newly created structures in general as well as going on with a strict, sustainable continuous improvement process.

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Application of a universal simulation environment for deriving specification premises of commercial vehicles with alternative and conventional drive trains

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Abstract

The current claim for new vehicle concepts to reduce the CO_2 emission of commercial vehicles increase the necessity of a simulation based engineering at the beginning of the product development process. Therefore, Daimler Buses is using a universal concept simulation environment for deriving the specification premises of vehicles with alternative drivetrains. This simulation environment is introduced and subsequently demonstrated by examining an exemplary new hybrid vehicle concept.

Introduction

On the web page of the European parliament can be found that “Heavy-duty vehicles are responsible for 27 % of road transport CO_2 emissions and almost 5 % of EU greenhouse gas emissions (2016 data)” [1]

That is one of the reasons why the European parliament has recently passed a legislation which forces a 30 % CO_2 reduction of new trucks by the year 2030. And it is also in discussion to set ambitious regulation targets for buses. Thus, the reduction of CO_2 is one of the commercial vehicle industry’s major challenges of the upcoming years.

These challenging targets can only be achieved by the aid of alternative vehicle concepts, like conventional drivetrains with a significant emission reduction, fuel cell technology and/or hybrid and electric drive trains – to just mention some of them. For all of these powertrain technologies the specification premises must be defined and the CO_2 saving potentials have to be investigated.

To face these challenges Daimler Buses extended the classical v-model process by a model based concept design phase with the aid of a universal simulation environment, which is introduced below.

Model based systems engineering process

The classical systems engineering approach is based on different development steps, beginning with the requirements engineering or vehicle specification, through the system and subsystem specification as well as the component design and implementation. These development steps are linked to the following testing phase which ends with the vehicle system validation [2], see Fig. 1. The link is given by the definition of the testing criteria in the specification and design phases as well as in a know-how feedback while testing.

In contrast, Fig. 2 represents the model based systems engineering process at Daimler Buses. This approach contains two additional phases which are based on different simulation models. At an early stage of the development process (requirements specification and system design phase) only some constraints and rough information of potential components are available and therefore a dedicated concept simulation environment is necessary. This simulation environment is applied to investigate the impact of different powertrain configurations and to test them within typical use cases. At a later stage of the development process there are more information about the system, sub-systems and components available and therefore a more sophisticated simulation environment can be used. This simulation environment contains all powertrain components and their respective controller functions. Therefore, it can be used to support the function development and to test them within their sub-systems and the whole vehicle system. Furthermore, the detail simulation is used to verify the models of the concept simulation and to validate the specified vehicle requirements.

After the implementation of the vehicle functions the testing phases are used to verify the vehicle functions and specifications as well as to verify and validate the different simulation environments.

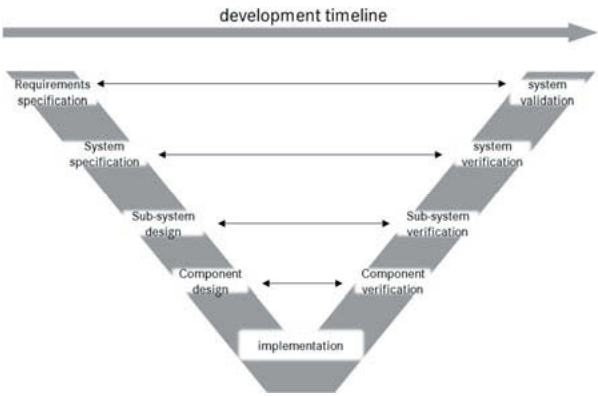

Fig. 1: Classical systems engineering development process

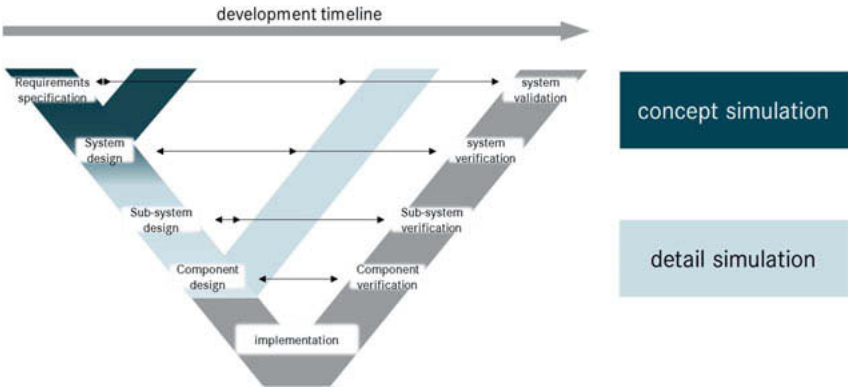

Fig. 2: Model based systems engineering development process

By the aid of the simulation environments the vehicle concept and functions can be tested and improved much earlier compared to the traditional systems engineering approach. This leads to shorter development timelines and lower expenses because the time effort and costs rise exponentially the later a certain mistakes appear [2].
Therefore the concept simulation, which is in focus of this work, is an important part of the development process, as it supports the requirements specification and the system design at the very beginning of the development process.

Concept simulation environment

The in-house developed concept simulation environment consists of two parts – a simulation and an analysis tool.
The simulation tool is based on a dynamic vehicle model which supports the following vehicle concepts:

- Conventional vehicles with combustion engines
- Parallel hybrid vehicles
- Serial hybrid vehicles
- Fuel cell electric vehicles
- Fully electric vehicles

Therefore, almost all vehicle concepts which are currently in discussion can be analysed. The powertrain components and loads are mostly defined by their interfaces, lookup-table data and a specific interpretation function, see Fig. 3.

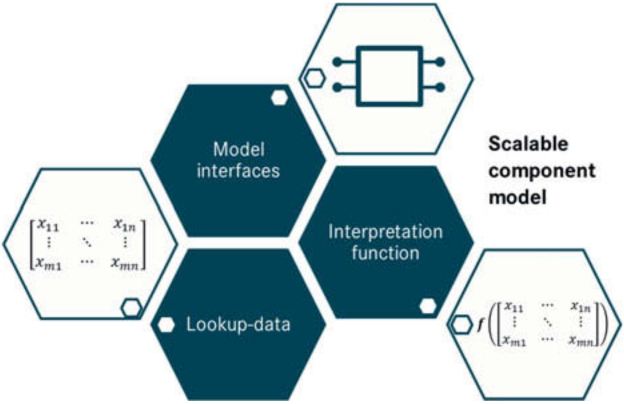

Fig. 3: Modular structure of a component model [4]

Furthermore the powertrain components can be scaled to allow the investigation of new components by the aid of existing data sets. This modular component definition combined with the scaling capability leads to a high flexibility which is important at an early stage of the development process.
Furthermore, at the beginning of the development cycle there is normally no operation strategy given. That is why the concept simulation tool has several rule based and automated operating strategies integrated. These operating strategies are described in detail in [4] and are shortly summarized below.

For conventional vehicles the shifting strategy has the highest impact on driving performance and fuel consumption. This strategy is implemented based on the VECTO tool which has been developed by the TU Graz to rate the CO_2 emission of commercial vehicles. This procedure has the advantage that we receive the same CO_2 reduction potential of a certain measure as in VECTO which will be the mandatory tool for the CO_2 limitations of the European Union [5]. The strategy is based on shifting polygons in the torque speed level, see Fig. 4. Above a certain torque-speed line the transmission shifts up (red region) and below a certain line it shifts down (green region).
For electric vehicles the battery state of charge (SOC) limits and power limitations at high and low SOC levels are very important. The former values are defined by constant parameters and the power limitations are calculated in operation by calculating the maximum power quantum to fully charge or discharge the battery at the next time step.

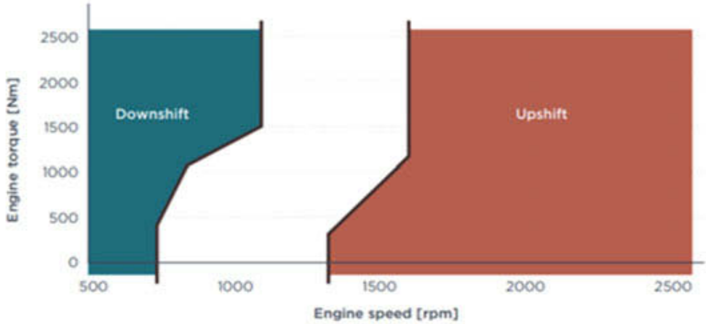

Fig. 4: Shifting polygons
Source: VECTO user manual [4]

Most complex is the operating strategy of hybrid electric vehicles with a big influence on driving performance as well as on energy and fuel consumption. On top of the SOC and power limitations of full electric vehicles, the power split must be set in every time step. The power split defines the ratio between electrical power and power from combustion engine or fuel cell. To solve this complexity, without knowledge of the final implementation of the energy management, an optimization measure is applied – the so called dynamic programming algorithm (DP) [6,7]. This algorithm is a non-causal optimization method which uses the information of the whole driving cycle to deliver the global optimum power split for each time step in terms of fuel consumption. Therefore, in the subsequent analysis it has to be noticed that the resulting fuel consumption can only be achieved by an operating strategy with an infinite prediction horizon. Which in fact, can be possible in close future by consideration of big data approaches and street map information. [8]

With the capability to investigate conventional and hybrid electric vehicles in one universal simulation environment we have the opportunity to evaluate the potential of different hybridization grades with respect to CO_2 emissions. Such an evaluation process is explained in the following section. As part of that, there will be also shown some functionalities of the evaluation tool which is a substantial part of the simulation environment.

Application example: hybrid vehicle concept

The focus of this example is set on the concept analysis process and not on the evaluation of a certain drivetrain. The task in this fictive example is to find the optimum hybridization concept in terms of battery size and electric motor power for an existing conventional city bus.

As a first step, the relevant field of application and as such a suitable driving cycle has to be defined. In this example we are focusing on a city bus and therefore the ACEA CO_2 Urban is used to demonstrate the following investigations. The cycle with its topography and target speed is depicted in Fig. 5.

Furthermore, the vehicle configuration of the conventional and the hybrid vehicle has to be defined. Most of the components can be copied from the existing conventional vehicle except the battery and the electric motor.

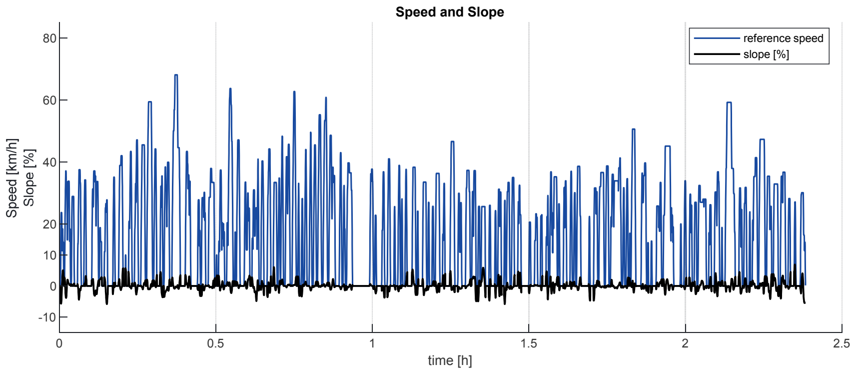

Fig. 5: ACEA CO_2 Urban driving cycle

These components are not defined and so their properties must be estimated and they shall be investigated in different sizes. As described above, the concept simulation provides a scaling function from a certain base component. The properties of this base component can either be taken from research, supplier's data or from former vehicle projects. For the investigation of the exemplary hybrid vehicle a linearly scaled battery with a usable energy of 1.2 kWh to 70 kWh and an electric motor with a nominal power between 15 kW and 240 kW is used.

Thus, different degrees of hybridization are covered by this study:

- Mild hybrid with a very small battery and electric motor (e.g. 1.2 kWh & 15 kW)
- Full hybrid with a medium battery and electric motor (e.g. 18,5 kWh & 60 kW)
- Plug-In hybrid with a large battery and electric motor (e.g. 70 kWh & 240 kW)

The last mentioned plug-in hybrid allows full electric driving and charging of the vehicle which is not in focus of this investigation. All vehicle configurations are operated with balanced SOC, i.e. starting the driving cycle with a SOC of 50 % and end with a target SOC of 50 % – In-between the SOC level can vary.

After the simulation is completed by using the DP-algorithm, the whole results can be analysed in one diagram. As such, the resulting fuel consumption impact of the different vehicle configurations in reference to the conventional vehicle is shown in Fig. 6.

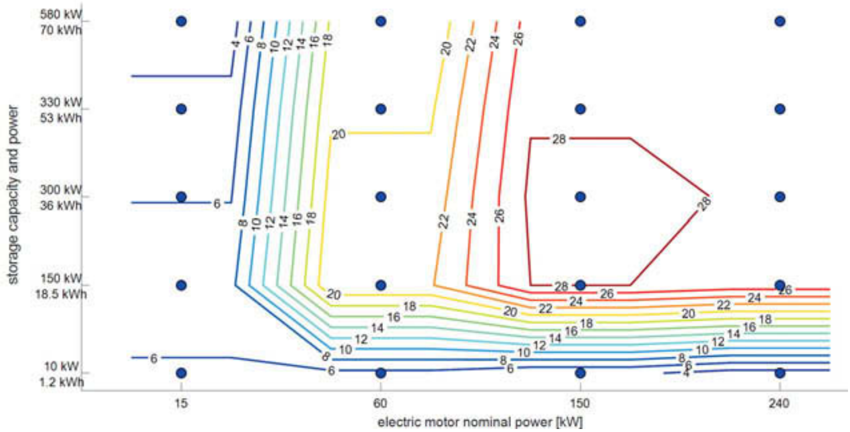

Fig. 6: Resulting fuel saving potential of different degrees of hybridization in %

Every blue point in this 2D grid represents one vehicle configuration with a given battery size (y-axis) and electric motor power (x-axis). The fuel saving potential is shown in the contour. It can be seen that the potential tends to rising with a larger battery and more powerful electric motor but not throughout the whole area, as with larger components also the vehicle weight increases.

These saving potentials can now be related to further requirements, such as:

- CO_2 saving requirements of the vehicle fleet in therms of legislation
- Availability of the respective components
- System costs

And thus, this simulation environment is a powerfull tool to support decision making and to derive the specification premisis.

One promising concept of the analysis above is a cost effective mild hybrid system with a small electric motor of 15 kW and a storage system with 1.2 kWh which already delivers a fuel saving potential of around 6 %. Another interesting opportunity is to chose a full hybrid system with a 150 kW electric motor and a battery with 36 kWh capacity which promises a fuel saving of more than 28 %. Both concepts can be further optimized but therefore extended investigations are necessary. Based on those concepts, some of the opportunities for optimization by the concept simulation environment are introduced below.

First, the energy flow between the powertrain components and the component losses can be visualized within a Sankey diagram. Such Sankey diagrams of the conventional vehicle and the two promising concepts can be seen in Fig. 7 – 9.
The amount of energy per kilometer is represented by the thickness of the arrows. It is obvious that the hybrid concepts can recuperate a relevant amount of energy which must not be dissipated through the mechanical brake and so the overall efficiency increase can be explained. Furthermore, it can be seen that the full hybrid concept allows a larger energy throuput of the battery than the mild hybrid concept which explains the higher efficiency of this concept.

The different energy throughput is also reflected by the SOC trajectories, which are depicted in Fig. 10 and Fig. 11. There, however, can be seen that the SOC variation of the mild hybrid system is much higher than the SOC variation of the full hybrid system due to a larger storage capacity. From this result can be deduced that for the storage capacity and for its power limitation there is room for improvement because an optimum system should exploit the full range between the defined SOC limits.

That the relation between the power limitations of electric motor and battery is not perfectly balanced can also be seen in Fig. 12. There, the energy throughput within the speed-torque-level of the mild hybrid concept is depicted.

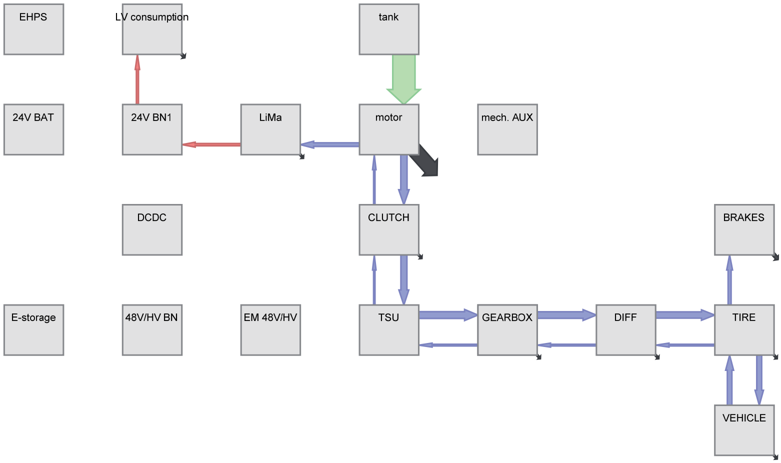

Fig. 7: Sankey diagram of the conventional vehicle

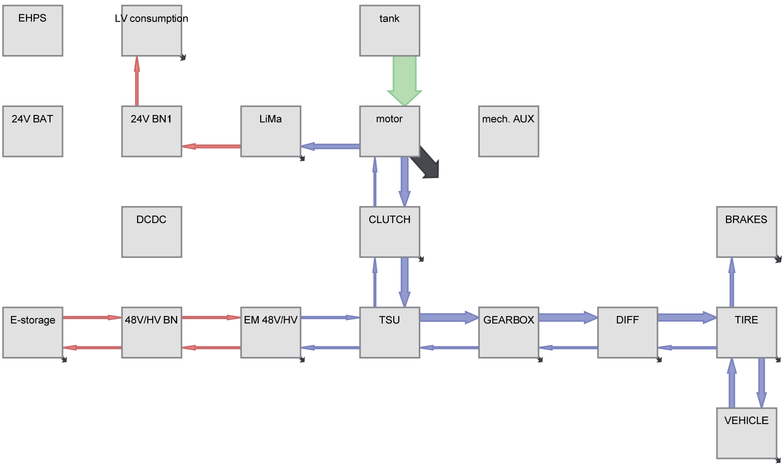

Fig. 8: Sankey diagram of the mild hybrid concept

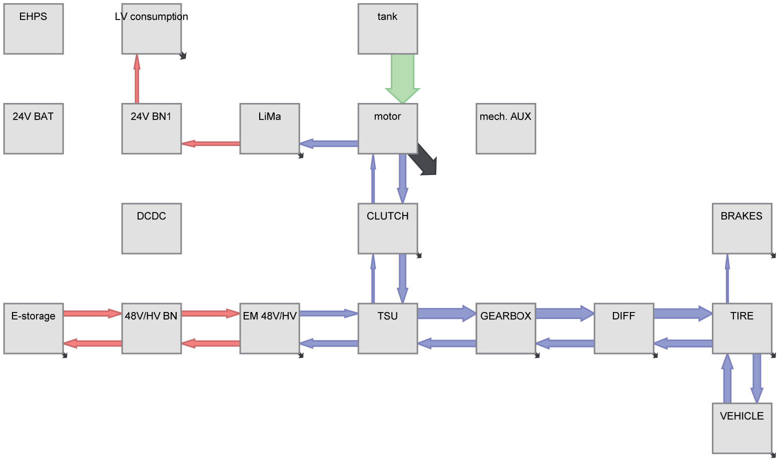

Fig. 9: Sankey diagram of the full hybrid concept

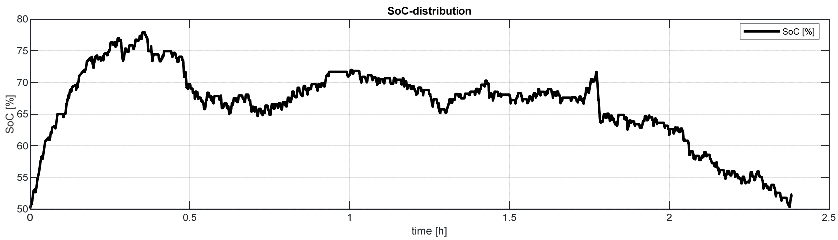

Fig. 10: State of charge trajectory of the mild hybrid concept

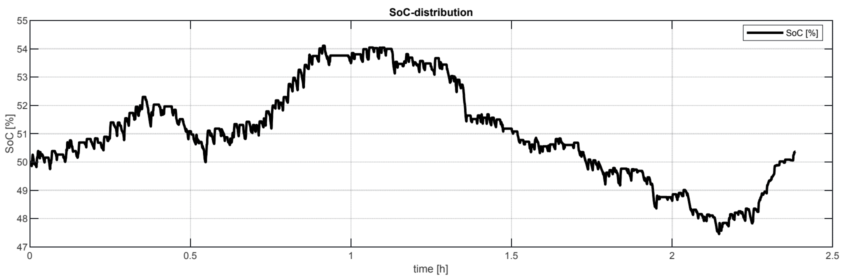

Fig. 11: State of charge trajectory of the full hybrid concept

In this diagram the maximum torque vs. speed, the efficiency and the power curves of the electric motor is shown. The amount of energy converted at one operating point is increasing from blue to red colour. It can be seen that most of the red coloured operating points while recuperation (in the negative half-plane) are located at the -10 kW power curve. The reason for this behaviour is given by the limitation of the battery recuperation power. Therefore, to optimize the system either the battery power should be increased or the electric motor can be down-sized to save weight and costs.

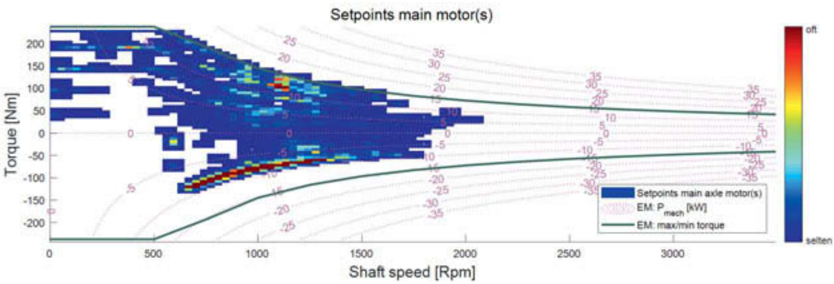

Fig. 12: Energy throughput within the speed-torque-level of the mild hybrid concept

These have been some examples how the concept simulation environment is used at Daimler Buses to support the concept phase discussions. Additionally, the tool is applied to derive the specification premises and to further optimize the promising vehicle concepts.

Conclusion

In this work has been described how Daimler Buses extends the classical systems engineering approach by different simulation environments. At the beginning of the development process the concept simulation environment makes a big contribution to find better vehicle concepts and to define the powertrain specification premises.

In order to reduce the CO_2 emissions of the vehicle fleet, different alternative technologies have to be investigated. As such, the analysis of two promising concepts at an early design stage has been introduced – a mild and a full hybrid vehicle. These results can then be used to make a decision towards a certain concept which will then be further optimized and developed.

An example where such an analysis was performed is the Citaro Hybrid. In this case, the decision has been made on a mild hybrid system due to low additional costs and a nevertheless remarkable fuel saving potential.

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The key role of the Tertiary Safety in the vehicle concept design to preserve the occupants and road users life

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Abstract

With 1.35 million of fatalities in 2016, road crashes are one of the leading causes of dead worldwide (much more so than HIV/AIDS or tuberculosis) [1]. Since many years, all the vehicle manufactures (OEM's) are focused to develop innovative solutions to improve both Primary (also called Preventive) and Secondary Safety. More than 90% percent of road accidents are caused by "human mistakes" and the Primary Safety acts to alert the driver in critical situations and, ultimately, by supporting the driver to improve his behaviour and to monitor the level of attention. Then, if it's not possible to mitigate the crash, the Secondary Safety solutions aim to protect the vehicle occupants and road users from severe injuries during the impact. Only recently the OEM's have discovered that plays a strategic role also in minutes after the crash event. In fact, the Rescue Services require detailed but readily-understood information regarding the construction and the propulsion solution of the vehicles to extricate trapped occupants as quickly and safely as possible. This is becoming more demanding as vehicles become stronger (i.e. use of high strength steels or composite materials), use different sources of power (i.e. electric, natural gas, hydrogen) and are equipped with increasing numbers of active safety devices (i.e. autonomous emergency braking, line departure warning). This paper is intended to illustrate how the Tertiary Safety effectiveness could take substantial advantages if it's approached in the vehicle concept design. Some virtuous vehicle manufactures in recent years have invested in "Rescue sheets" but their availability and dissemination among the stakeholder's is not fully covered and definitely not enough to preserve the life of the occupants.

Introduction to the Tertiary Safety

As usual the automotive industry divides safety into three main timeframe: what happens to prevent a crash, what happens during the crash and what happens after the crash. In the past, main focus was to protect vehicle occupants in a crash event. Then it moved to primary safety where it starts acting to prevent the crash from happening.

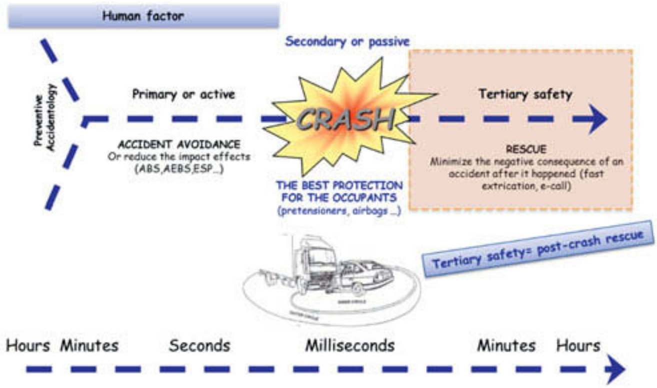

Fig. 1: Road safety accident evolution vs. time

The first substantial approach with tertiary safety (post-crash) came with the e-Call system. It automatically alerts the rescue services after a vehicle has crashed, communicating the exact position of the vehicle.

A key objective of the tertiary safety is to achieve a fast & safe extrication from vehicle of trapped occupants in case of a severe road accident in different scenario.

In the emergency services organisations, firefighters are the technical leaders in the rescue operation management taking into account three key needs to address: limit the risks exposure for their personnel, extract the injured individuals avoiding further injury and reducing the time to transfer them to the trauma centre. The new materials used in the cab structure to provide better mechanical properties or greater resistance (i.e. high strength steel) and the alternative propulsions system (i.e. electric, hybrid, fuel cell) represent a potential threat for the rescue personnel [6].

In addition, new vehicles now have airbags spread around in different positions. These outline a risk of severe injury if unintentionally deployed, so rescue services need to know exactly where they are and the procedure to de-energize the electrical power sources on the vehicle. With the same purpose, the electrified powertrains, typically equipped with a high voltage powernet, require a de-energization (through the high voltage batteries disconnection) to mitigate the electric shock risk for the first responders.

Standardization of the rescue information: the ISO 17840

The ISO 17840 “Road vehicles - Information for first and second responders” [2] defines the content and the layout of the “rescue sheet” providing necessary and useful information about a vehicle involved in an accident to support the rescue team extricating the occupants as fast and as safe as possible. The contents and layout takes into account that the rescue sheet has to be easy to use by rescue teams of all over the world and can be available in paper or electronic format (see an example in the Fig. 2).

The rescue sheet template does not only concern information about the location of the components, but the event to be dealt with (e.g. fire in vehicle and/or battery, dangerous systems in vehicle, submersion and new technologies).

Iveco Stralis NP (Natural Power) - Rescue Sheet

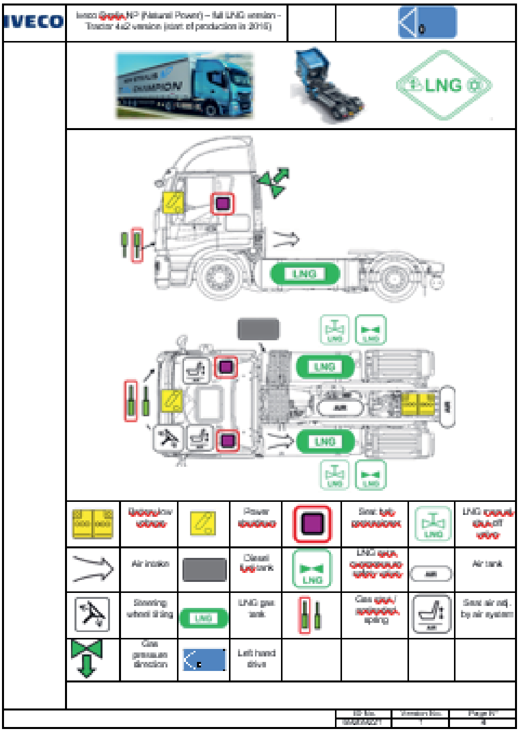

Fig. 2: Rescue Sheet of LNG 4x2 Truck

A second relevant document (described in ISO 17840 parts 1 and 2) called ERG (Emergency Response Guide) contains key and in-depth information linked to the rescue sheet to inform training and development of rescue procedures. The ERG information acts as an extension of the related rescue sheet.

Lastly, the ISO 17840 parts 4 is dedicate to the “Propulsion Energy Identification”. In a road vehicle accident, a quick and correct identification of the propulsion fuel and/or propulsion energy by the rescue team allows the correct actions with respect to the vehicle technology concerned. This document defines the labels and related colours for identification of the fuel and/or energy used for propulsion of a road vehicle, especially for the case of new vehicle technologies and/or power sources, including hybrid/electric propulsion systems (see an example of the propulsion energy identification for an electric urban bus in Fig. 3).
The communication of the propulsion energy and the related hazards is made in a logical and modular way to facilitate the understanding also from a certain distance from the vehicle.

Fig. 3: Propulsion energy identification (label) for a full electric urban bus

There are clear benefits to having a common template, using standardized colours and pictograms to make it easier for first and second responders and vehicle manufacturers to understand each other without Countries limitations. It also facilitate for the vehicle manufacturers to know what kind and how the first and second responder workers want their crucial information for the towing operations.
The achievement of this target requires a constant and close collaboration between the OEM’s and the rescue organizations taking into account the respective needs and concerns. In particular, the CTIF (International Association of Fire and Rescue Services) [3] gives a strong contribution in the partnerships success considering also the formal role of leader in the dedicated ISO Working Group (WG).

Euro NCAP role in the Tertiary Safety spread-out

As well known, the Euro NCAP's role is to reward industry's innovators and early adopters to help create and facilitate the market for safety.

Even if the finalization is on passenger car safety, recently the Euro NCAP has started to address the Tertiary Safety topic for the first time, underling key priorities for improvements in its Roadmap 2025 [4]. It's focused on an integrated approach to safety, counting primary, secondary and tertiary features through a more holistic approach to the "Vision Zero" EU target (zero fatalities by 2050). Most probably, road fatalities will not be cut by 50% in the current decade until 2020, as called for in the EC Policy Orientations on Road Safety 2011-2020 [5]. Extrapolating the current trend, the EU is not likely to move close to zero fatalities by 2050. For this reason is essential to introduce in the safety roadmap cost effective solutions to mitigate the injuries consequences when the impact is unavoidable.

In this direction, a relatively low-technology approach is proposed for assisting rescue teams to extricate occupants from a crashed vehicle ensuring the availability and diffusion of standardized Rescue Sheets accordingly to ISO 17840.

Introduction of the Tertiary Safety in the Product Development Process

To ensure the development of a new vehicle taking into account the Tertiary Safety needs, it is fundamental to address each item in the project milestones of the usual Product Development Process (PDP) under specific list of sequential deliverables:

- *Tertiary Safety system requirements*: propulsion energy source identification (as well as the specific labeling); direct hazard disable procedures (i.e. High Voltage batteries disconnection); way of access to the occupants (considering the restraint systems and steering wheel/seat adjustment modes); easy lifting points identification and ways of vehicle immobilization.
- *Technology and competitors benchmarking*: analysis of state of art for a similar vehicle application (including the competitors evaluation) in the term of Tertiary Safety solutions and implemented systems.
- *Components requirements*: description of the risks for the critical parts in case of fire and crash (batteries, air/fuel tanks, air conditioning agents, carbon/magnesium materials, gas cylinders,…); Material Safety Data Sheet (MSDS); emergency procedure and instructions in case of accident occurrence.

- *Digital mock up (DMU)*: it can show whole vehicle CAD models and does accessibility and functional verification of the preferred and alternative direct hazards disabling devices (i.e. disabling High Voltage or shutting off gas valve); virtual aesthetic assessment of the propulsion energy identification (label).
- *Virtual validation:* definition, modeling and verification of the cutting points to facilitate the occupants extrication in case of accident.
- *Physical validation:* verification of the cutting points effectiveness on a proto vehicle; post-crash test analysis; abuse and fire tests on specific safety critical components; operative test on direct hazard disable procedures also on crashed vehicles.
- *Tertiary Safety documentation:* creation of both the Rescue Sheet and the Emergency Response Guide (ERG) accordingly to ISO 17-840 and their assessment with firefighters; definition of the appropriate fire extinguisher solutions for the vehicle and its systems; explanation of the vehicle management in case of water submersion; description of the information and points of attention to handle vehicle post-crash/fire such as expected by towing services (second responders).

The strategic role of the Partnerships

The active collaboration between the vehicle manufacturers and the firefighters, that are in charge of the technical rescue in case of accident or fire events, requires the involvement of the respective experts and the sharing of the expertise coming from the field. A rational working plan should include the:

- definition of experimental sessions (fires, accidents emulation) involving firefighters' expertise. They program includes also real scale simulations.
- support to firefighter in the operative action cards creation, concerning extrication approach, safe management of the vehicle and fire extinguishing procedures.
- Periodic technical meetings between OEM's engineer teams and skilled personnel from the firefighters to share the best practices or to evaluate any possible improvement to introduce in the product design.
- sharing info on new components, system novelties and the corresponding functionalities and possible misuses.
- support the firefighters training and initiatives in the road rescue field through: including donation of proto vehicles used in firefighters' for full scale training sessions, participation to road rescue events (technical congresses, fair, promotion events and forums)

and participation to international working group among firefighter experts with the purpose to standardize the best procedure in term of methodologies and tools to adopt.

Future challenges

Technological enhancements in safety will continue to accelerate and find their way into the vehicle fleet and transport systems. With these innovations, new questions will arise regarding methodology and approach also in the rescue management. As we get closer to the widespread deployment of autonomous vehicles, new challenges appear in front of both the rescue teams and the OEM's in case of accident or fire. For example, a novel operational procedure for the vehicle neutralization and energization will be fundamental to approach an apparently motionless vehicle in an accident scenario.

Fig. 4: Autonomous vehicle sensors vision based

Most probably the firefighters should receive safe, reliable and merged info from both the vehicle involved in the accident and the close environment infrastructure via wireless communication channels.

On the other hand, any autonomous vehicle must handle a scenario in case of an emergency vehicle is approaching a road intersection close to its position with the siren activated. In some urban scenario with high traffic congestion, the typical siren "sound" is the only way to recognize an emergency vehicle direction of approach in a safe amount of time and through a sufficient space in the surrounding area to execute any appropriate manoeuvre.

In fact, when an emergency vehicle (police, fire and medical) approaches, all other traffic must stop or move to the right side to allow the emergency vehicles pass through. Adding a sense

of "hearing" is not considered an high priorities on autonomous vehicle (Fig. 4), if even considered at all sensing platform.
The constant awareness of autonomous vehicle sensors provides better circumstance awareness, but some information is not within visual range and emergency vehicle response is one potential issue to solve.

Conclusions

The Tertiary Safety is a quite new area in the road safety environment with a high potential to offer cost effective solutions at vehicle level. The OEM's should enlarge the investment on their commitment to mitigate the consequences of severe injuries for the vehicle occupants in case of unavoidable accident. First of all, it's a matter of social responsibility and secondly a real way to contribute in the 2050 "Vision Zero" achievement as excepted by EU Safety Roadmap. Advanced materials, electrified powertrain and infrastructures, gaseous fuels, autonomous vehicles represent the key challenges to face in the next years for the whole Tertiary Safety stakeholders.

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Next Generation Active Safety Systems for City Buses

The Foundation for Automated Driving

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Abstract

In 2015 we as Daimler Buses have drawn our road map to the future of accident free driving [1]. In order to realize this vision Daimler Buses is still pushing the evolution of sophisticated active safety systems and defend its position to be the leader in safety. The strategy is to focus on critical driving maneuvers with the highest risk of injuries and reduce these specific risks sustainable by developing autonomous active safety systems. As we are talking about level 1 and 2 autonomous driving systems [2] the driver is still present and he/she has the full responsibility for the vehicle. If for any reason the driver fails to react, the systems will initiate the necessary action to avoid an accident or at least reduce the fatality.

Another promise back in 2015 was to emphasis on protecting pedestrians and cyclists. By introducing the next generation of emergency braking systems - the Active Brake Assist 4 (coach) and Preventive Brake Assist (city bus) - we made a big step in order to fulfill this promise. Now the most vulnerable traffic participants can be protected as well.

In real life urban traffic turning maneuvers are another category where fatal injuries occur. Cyclists and pedestrians are mostly involved in these accidents as well. This is why Daimler Buses introduced a blind spot assistance system – the Sideguard Assist. It warns the driver if an object is in the endangered area next to the bus.

By developing and integrating those systems Daimler Buses is continuously increasing real life traffic safety for all road users. Additionally this is the basis for autonomous driving because for level 3, 4, or 5 it is essential to react properly in every dangerous situation.

1. Introduction

1.1. Mile Stones of Safety

For many decades Daimler has been working on improving road safety. Therefore many technologies and systems have been introduced which could increase safety in both passenger cars and commercial vehicles. Speaking of safety systems two different clusters have been defined. While passive safety systems take care of the situation during and after an accident (e.g. Airbag), active safety systems focus on preventing the vehicle getting involved in an accident (e.g. ABS).

One important innovation was the world's first safety car body with integrated deformable zone by Béla Barényi, introduced in 1959. In 1964 Daimler presented the first coach with a wearless brake system. The Anti-lock braking system has been presented to the world in 1978 followed by an introduction of this system in 1981 for commercial vehicles. Innovations for commercial vehicles like the first traction-control-system (1987), a lane departure warning system (2000) and the Telligent Stability Control system (2001) illustrate the desire of Daimler for accident free driving and more is yet to come...

Figure 1: Evolution of safety systems for commercial vehicles

1.2. Accident statistics for buses

Traveling by bus in general is a very safe way of transportation. In only ~2% of all accidents in Germany a bus was involved [3]. Most of those accidents (~88%) take place in an urban environment. Those statistics show where the main focus for active safety systems should be. The major cause of accidents and physical injuries is an inappropriate distance to other vehicles in front (~25%) [3]. Statistics also show that a lot of physical injuries are caused inside the bus, the passengers often fall due to unexpected braking/deceleration of the vehicle [4]. These two major causes constitute a conflict of objectives when it comes to active safety systems like the preventive brake assist. The major goal is to prevent collisions and protect passengers from falling at the same time.

People not only get injured by accidents during a drive straight ahead, also turning maneuvers take a big portion of urban accidents. 15% of all urban accidents happen during a turning maneuver, 12% with unprotected road users like cyclists or pedestrians [3]. For fallen cyclists,

there's a great risk of getting run over, which leads to heavy injury or even death. In Berlin, 25% of the analysed accidents with cyclists found a deadly end [8].
Since especially in conurbations the road traffic and the share of cyclists is growing and it is the necessity of systems to protect those unprotected road users.

2. Active Safety Systems for City Buses as derivates from Coaches

2.1. First Active Safety Systems for buses

2.1.1. The Electronic Brake System as enabler for Active Safety Systems

The Electronic Brake System (EBS) as the evolution of the traditional pneumatic braking system is the basis for many active safety systems. With its electro pneumatic valves safety systems can directly control the deceleration of each wheel.
The first feature in the field of active safety systems was the Electronic Stability Control (ESP) which was introduced in Mercedes-Benz and Setra coaches end of 2003 as standard equipment.
After ESP the Adaptive Cruise Control (ACC) was introduced as a comfort system, which reliefs the driver and therefore increases the so called conditional safety. The driver can select a maximum speed just like using a regular cruise control. The advantage of the ACC is the autonomous speed reduction in case of a vehicle in front. The Adaptive Cruise Control has also some safety characteristics because it can decelerate the vehicle in dangerous situations, but has a maximum deceleration rate of 2 m/s^2. In 2012 ACC was extended by Stop & Go which enables distance control down to standstill and autonomous restart within 2 seconds. Deceleration is also limited at low speeds to 3 m/s^2.

2.1.2. ABA: Pioneer and success story for emergency braking systems

In 2008 Mercedes-Benz introduced the first emergency braking system for coaches in the Travego. Like ACC systems most emergency braking systems are based on a radar sensor. Current automotive radar sensors have a range of about 150m to 200m [5]. With the information of this radar sensor the emergency braking system continuously calculates the criticality of the situation. If the situation in front of the vehicle becomes critical the system starts a warning cascade (cf. fig. 2). Up to today's ABA4 all emergency braking assists at Daimler Buses have used the following warning cascade:

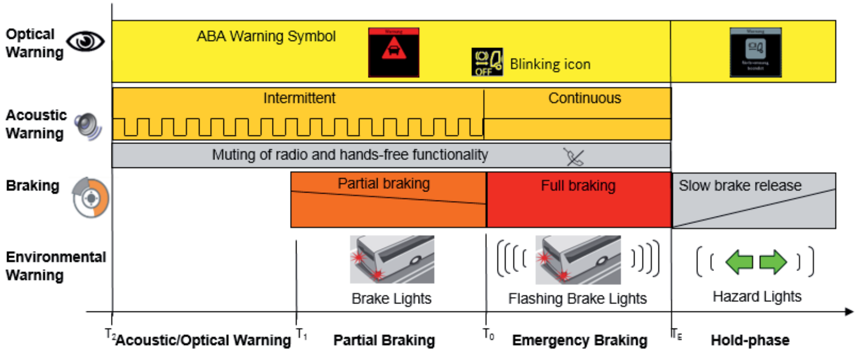

Figure 2: ABA warning cascade

At the beginning of this warning cascade the driver is alerted via optical/acoustic warning and should then react meaningful regarding the situation. The warning cascade can be aborted by using several driver activities such as kickdown or evasive action. If the driver does not react properly the system starts partial braking. The partial braking gives haptic feedback to the driver which should alert him again and gains valuable reaction time in which he might be able to avoid the accident by himself.

Especially in buses and coaches the haptic feedback should also alert the passengers. When they are warned they can brace themselves. If they do not, they can be injured because of a crash or by the last ABA warning phase which is the emergency braking [6]. The system performs a full braking in case the driver does not react at all within the previous warning phases. For the passengers a sudden full braking is as dangerous as a crash because in both situation they can lose control and fall inside the bus. Also the traffic behind has to be warned early and effective to avoid rear end crashes. Therefore flashing brake lights are used.

While Daimler and some other automotive companies were developing and selling emergency braking systems the EU recognized these activities and decided to publish a legislation to ensure that in the future every heavy commercial vehicle has to be equipped with an "Advanced Emergency Braking System (AEBS)". The AEBS regulation [7] defines requirements both on collision avoidance and avoiding false reactions.

All vehicles with a registration after November 1st 2015 and a class 3 registration (coaches) have to have an AEBS system (class 1 for city buses and class 2 for interurban buses are still not covered). Especially on stationary targets the todays AEBS requirement is very low. Starting with 80 kph, speed has to be reduced by at least 20 kph before crashing a stationary

target in front of the bus (AEBS step 2 since 11/2018). In other words: Crashing a stationary target with 60 kph is permitted by the current regulation.
Therefore ABA3 was introduced in 2015 by Daimler Buses, designed to perform the best possible emergency braking performance using state of the art radar sensors. While ABA1 didn’t react on stationary targets at all and ABA2 only performed partial braking, ABA3 was the first emergency braking system performing full braking both on moving and stationary targets. The AEBS requirements on stationary objects were far exceeded by ABA3 with avoidance speed up to 70 kph under optimal conditions.

2.2. The Active Brake Assist 4 as basis for active braking in city buses

In 2018 Daimler introduced ABA4 for coaches, the first emergency braking system that also reacts on moving pedestrians. Taking over the radar system also used by Daimler passenger car and truck, now it is possible to detect moving pedestrians although radar reflection of vulnerable road users such as pedestrians or cyclists is very low. Therefore, micro doppler signals are used. To avoid false warnings on pedestrian objects, ABA4 starts optical/acoustic warning and partial braking at the same time. On pedestrians no full braking is performed. The warning cascade is designed so that the driver takes over control as soon as ABA4 starts a warning on pedestrian objects.
On moving and stationary objects, ABA4 achieves collision avoidance comparable to ABA3, but starting about 10 meters later at 80 kph, due to an improved warning cascade. On the one hand, the new warning cascade helps to prevent false warnings, on the other hand the driver and passengers now are warned more effective during partial braking than with ABA3.
Driver overriding activities were optimized and also an automatic reactivation was implemented to increase the system availability in case of ABA4 deactivation by the driver.

Because of the huge performance difference between AEBS regulation and ABA4, both on stationary objects and pedestrians, Daimler decided to set ABA4 as series for all current Mercedes and Setra coaches. This decision underlines the Daimler Buses claim to keep its benchmark position in the field of active safety.

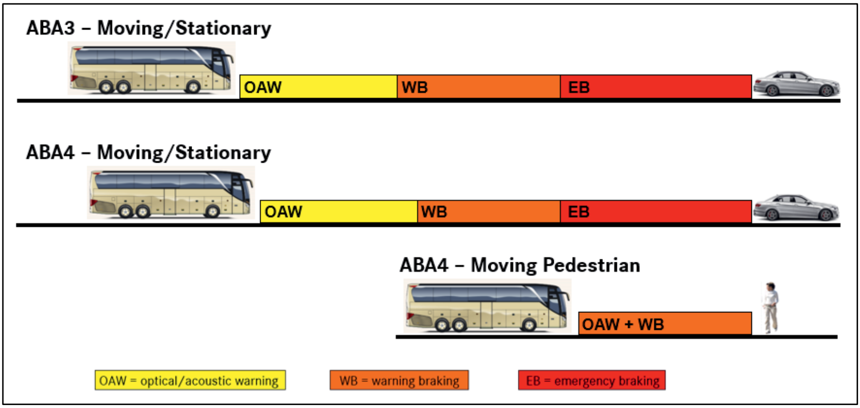

Figure 3: Comparison of ABA3 and ABA4

But if ABA1 to ABA3 wouldn't have been developed the ABA4 wouldn't have the same performance. The evolutionary development approach helps to increase a systems performance each time a new evolution stage is released. With the experience of the development team, the subjective feedback of many customers and the evaluation of thousands of customer kilometers, several small and bigger improvements of the system could be realized.

As Daimler Trucks already demonstrated ABA5 with sensor fusion on the IAA2018, this could also be the way for Daimler Buses to further improve the functionality and performance of ABA4/Preventive Brake Assist by merging today's radar objects with objects detected by a mono camera.

2.3. Preventive Brake Assist for City Buses

With the ABA4 and the underlying AEBS regulation coaches are well equipped regarding emergency braking systems whereas the city buses do not have any system considering frontal crashes. City buses aren't covered by AEBS, because the use conditions of these buses don't match with AEBS requirements and test conditions (high speed, no vulnerable road users, assuming only straight ahead traffic, etc.). An active braking system for city buses has to face more complex situations both inside and outside the bus. Because of mainly standing passengers inside the bus or sitting passengers not wearing a seatbelt, full braking is prohibited in every case to avoid so-called "non-crash accidents". Also the environmental conditions around the bus are much more complex with a lot of different road users (pedestrians, cyclists, motorcyclists, trams,…), in general high dynamic city traffic and a lot of "potential" objects. An active braking system for city buses thus has to represent the ideal compromise between best possible energy reduction in case of a threatening impact and an acceptable warning rate respectively few false warnings. These are the reasons why until 2018 there was no active braking system available worldwide for city buses. Some competitors may provide OEM or retrofit solutions with warning but no active braking.

On the IAA 2018 Daimler Buses now presented the first active brake assistant for city buses called "Preventive Brake Assist". Daimler has taken on the challenge to merge the experience out of four ABA stages with the known and above described requirements of city traffic. To protect passengers in case of an active brake intervention, Preventive Brake Assist preforms no full braking in any case. The warning concept of ABA4 including reaction on moving pedestrians was completely taken over by Preventive Brake Assist. To achieve an acceptable warning rate despite of challenging high dynamic city traffic the ABA4 warning cascade on pedestrian objects (optical, acoustic and haptic warning all starts at the same time) is used for every object type (moving object, stationary object, pedestrian):

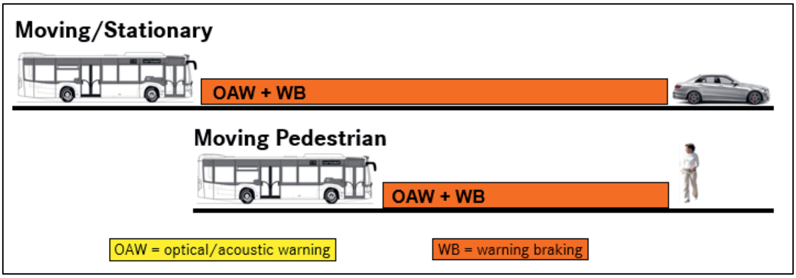

Figure 4: Preventive Brake Assist warning cascade

Since complexity both of the system and the use conditions is very high, one big focus during development was on testing. Each testing step from software model (MIL, SIL, HIL) to vehicle testing is important, but in the end real life performance only can be tested and evaluated in real life environment and under real life conditions. Daimler Buses provided Preventive Brake Assist to several customer trial partners to cover the best possible variety of use conditions (location, city bus type, driver, traffic and other environmental influences) before introducing this system to the market. The data being collected during customer trial can be both used for possible further improvement of the existing series functionality through use-case evaluation and resimulation, but also for development of future active safety systems in urban and suburban context.

2.4. Sideguard Assist for City Buses and Coaches

In 2018, Daimler Buses introduced the first vehicle in his lineup with a turning assistant system to the public. This system was a takeover of the so called Sideguard Assist developed by Daimler Trucks, which was introduced back in 2016. This radar based system is observing the passenger side of the vehicle by two radar sensors located behind the passenger's side front wheel. By sensing the position and heading of any participant road user and combining it with the vehicles dynamics and intentions of the driver, this system will inform and alert the driver accordingly. The system is differing from other aftermarket products in the capability to observe a large area stretching even behind and in front of the vehicle. The tight integration in the electronic architecture of the vehicle results in a system, which meets also the quality standards of Setra and Mercedes Buses. Not just in systems behavior, but also in systems diagnostics and material quality.

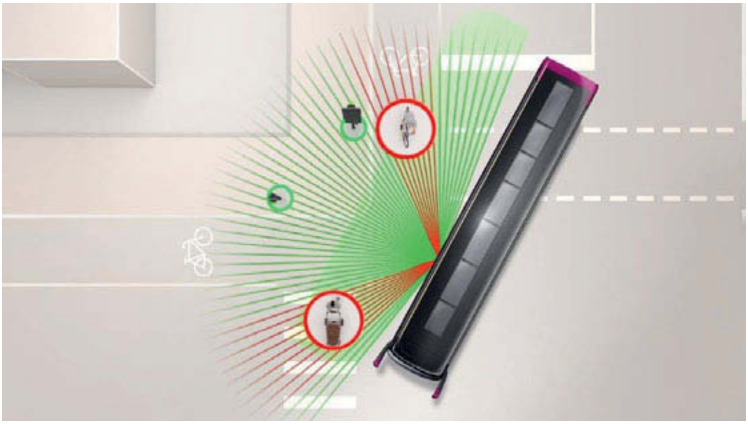

Figure 5: Observed area of Sideguard Assist

Here’s a short, simplified overview of the implemented algorithms, to better understand the systems behavior in common situations.

To rise the attention of any present participants in the blind-spot-area a yellow LED element in the A0-pillar (city bus) / rearview mirror (coach) is lit. This assists the driver in complex driving situations, particularly in urban traffic. If the situation is getting critical - critical by means that the driver takes further actions towards the endangered pedestrian or cyclist - the driver will be warned by turning the warning element to flashing red and by a seat vibration motor on the respective side. The optical-haptical warning should get the attention of the driver to react properly. The decision if an information or warning should be issued is mainly based on the

location of the object. The tight integration into board electronics makes is possible to take the drivers behavior into account, as well as the vehicles odometrics.
The system also reacts on stationary objects. If the potential risk of a collision with a stationary object such as traffic lights or road signs is detected, an optical-haptical warning is triggered. In this special case, the yellow LED isn't lit before the warning to make the warning on stationary objects distinctive from other warnings. This shall prevent a collision with objects that are within the turning radius of the bus.
The system is already available for most coaches and city buses of the Daimler Buses portfolio. As written before, the system is mainly overtaken by the trucks Sideguard Assist. Since the vehicles geometries, driving behaviors and variances of buses differ from trucks, adaptions of the systems were necessary.
The passengers comfort is -besides safety- one of the most important concerns in the development process. This is why we also focus on clearly arranged and distinctive warning elements. The acoustical warning, which is used for Daimler Trucks, is substituted by a haptical warning, which is issued over the driver's seat. The warning element (LED) is relocated in the A0-pillar (city bus) / rearview mirror (coach), so that the drivers' attention is directed to the critical situation and side immediately.
Also the HMI is adapted to the needs of a typical bus driver, in this case by means of simplification. For buses there's no such variance in trailers and vehicle types. It's either a solo or an articulated bus. Therefore, the warning concept within the driver's display can be simplified to the basics with no differentiation between a coach, city bus or articulated vehicles.

As well as the geometry and driving dynamics, also the use-cases -especially for city buses-differ from the typical usage of a truck or coach. Therefore, the Sideguard Assist had to be tested with focus on urban-bus scenarios.
In order to test and validate the Sideguard Assist, it is not sufficient to just merge down the most common city-maneuvers to a few use cases and test these in a clinical environment. In city traffic, there's a great complexity and variety of critical -and uncritical- situations. This diversity makes it indispensable to do the testing as close to the reality as possible. Therefore, additionally to the common SIL-, MIL-, HIL- and standard use-case testing, testing in reality is applied. Measurement data from tests in the real world can also be used for resimulation of new software or software components. This procedure gives the opportunity to test software from the scratch and also gives great advantage for agile software development. The importance of agile software development -of course with respect to functional safety-increases, especially when it comes to future applications.

As of today there is no regulation in place to make that kind of system mandatory. This is likely to change, because the public is pushing politics to address the issue of tragic accidents in urban environments. With the release of the General Safety Regulation a “BSIS - Blind Spot Information System” will be mandatory for heavy duty vehicles. Since the General Safety Regulation - or at least its draft - differs from the current warning concept of the Sideguard Assist, changes to the system need to be and will be made. Also Daimler is pushing even further by looking for possibilities to incorporate automatic braking to the Sideguard Assist.

3. Perspective

3.1. The General Safety Regulation

In order to protect all road users and especially the vulnerable ones the EU created a new General Safety Regulation (GSR) [9]. From 2022 several safety systems will become mandatory in the different vehicle categories. To tackle a huge variety of accident causes the GSR includes technologies which focus on all kinds of critical real life traffic scenarios:
For cars, vans, trucks and buses: warning of driver drowsiness and distraction, intelligent speed assistance, reversing detection, and data recorder in case of an accident (black box).
For cars and vans: lane-keeping assistance, advanced emergency braking for pedestrian and cyclist, and crash-test improved safety belts.
For trucks and buses: specific requirements to improve the direct vision of bus and truck drivers and to remove blind spots, and systems at the front and side of the vehicle to detect and warn in case of endangered vulnerable road users, especially when making turns.

The timeline for the introduction is ambitious for most of the systems as the first of them become mandatory for new vehicle types from March 2022 (March 2024 for first registrations).

3.2. The future of active safety systems

Some decades ago mechanical solutions were designed and proved their effectiveness regarding safety. Today these systems are called passive safety systems. Meanwhile electromechanical and electronic systems demonstrate a huge leverage on safety by decreasing the consequences of an accident or even the numbers of accidents itself. When the skills of the driver (road and traffic experience) are combined with the advantages of a fast and reliable sensor - algorithm - actor network a very positive impact on real life road safety will be generated. The major intention of all today’s safety systems is still to get the driver back into the loop and make him react himself. But to reach the vision of accident free driving we have to enhance the active aspects of those systems. Looking at the turning maneuvers especially in city traffic, we already introduced a warning system - the Sideguard Assist. But today there is no active or autonomous part in case the driver does not react on the systems warning. To further enhance the safety of the weakest traffic participants - cyclists and pedestrians - one possibility could be to implement autonomous brake interventions into the Sideguard Assist. This should result in even lower numbers in accident statistics.

3.3. The foundation for automated driving

Looking at autonomous driving the safety relevant critical situations in real time traffic are the challenging ones. Therefore existing and proven systems which are able to handle these challenges are an advantage in this context as well. First the longitudinal support of the driver even as a safety function (Active Brake Assist) and a comfort function (Adaptive Cruise Control) was established and show good real traffic performance. Alongside the lateral support for the driver is evolutionary increased by Lane Departure Warning and Sideguard Assist. Combining these first important steps and adding vehicle intelligence for navigation etc. may create a first autonomous driving basis. Nevertheless designing driverless vehicles which are safe and practicable is a huge challenge at all.

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5. Appendix

5.1. Abbreviations

ABA	Active Brake Assist
ACC	Adaptive Cruise Control
AEBS	Advanced Emergency Braking System
MiL	Model-in-the-loop
SiL	Software-in-the-loop
HiL	Hardware-in-the-loop
HMI	Human-Machine-Interface
GSR	General Safety Regulation

Knowing the Truck Driver

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Abstract

Driving a heavy-duty truck over long distances and over many hours a day can be both tedious and stressful. Truck drivers perform this task day after day. This may lead to dangerous situations for both the driver, the vehicle and other road users. Modern sensors can assess the state of the driver. Today technology is already available to detect if he/she is attentive or distracted. No doubt this will find its way into future solutions for highly automated driving (HAD) as well. In the future further sensors and analysis will be able to determine the drivers' wellbeing and health and thus allow a conclusion if the driver is fit to drive. The target of this is to enable an early detection of critical situations and make recommendations on driver actions. This presentation will explore present and future passenger car technology and explore possible extension of these technologies into the truck domain for the sake of the driver, fleets and society.

Why technology matters in reducing risks for truck drivers

The topic of road fatalities involving commercial vehicles arouses much public attention. In 2017 there were 4761 (source: Insurance Institute for Highway Safety) fatalities on US road involving trucks. In Europe the number was 4002 in 2016 (source: European Commission). As if the absolute numbers are not bad enough, looking back over the last years there is an identifiable trend that these numbers are increasing year on year and not decreasing as one might assume with the availability of modern technology e.g. assistance systems such as emergency brake assistants.

Almost all statistics paint a similar picture; the primary cause of vehicle accidents is human failure. The percentages given are typically around 90%. Our assumption is that these human related accidents can be reduced by knowing the drivers even better and by giving clear warnings in case of driver inaptitude. The current assumption on the number of accidents, which are related to driver drowsiness alone, are typically in the range of a quarter of the numbers.

Quite frankly it is amazing to what levels the automotive industry goes to satisfy the needs of passenger car drivers, considering that these use their cars for less than 1 hour a day on average. In comparison truck drivers sit for 8-10 hours a day typically at a constant speed. That can be incredibly monotonous, creating a dangerous “underload” situation for the driver. But if we add real life traffic conditions and the desire for just in time deliveries to this, the result can also be a very high stress level, resulting in an overload situation. Both are not good for attentiveness, and the driver in general as published in the Yerkes-Dodson law [1] and by Sergio Garbarino in 2018 [2]. Truck drivers around the world operate in a stressor-filled environment that exerts substantial adverse influence on drivers’ physical health and well-being, with access to healthcare services partially hindered despite the stringent governmental and corporate regulations. Truck drivers are vulnerable to a variety of health risks and are also a medically underserved population. [2]

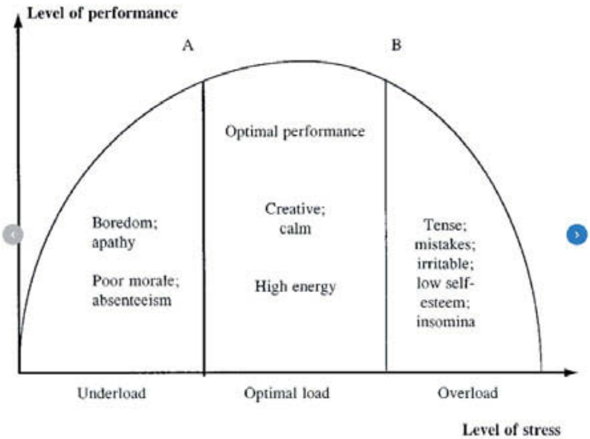

Fig. 1: The underload-overload inverted U diagram, reported by Sutherland & Cooper, 1993-35.

As with many (but not all) automotive technologies we see a trend to establish these in passenger vehicle first due to the high volumes and associated possibilities for monetization of upfront investments. If they add value for the commercial vehicle market, they can then be adapted and re-used in trucks and busses. This paper will follow a similar approach. Current and upcoming technologies for detecting and assessing the state of the driver in passenger cars will be explained in detail. After this, the technologies will be filtered as to their viability for the commercial vehicle market.

The assessment of the driver has two levels. The first is whether he or she is currently focused on the driving task. The second level is whether he or she is fit to drive. Both levels will be covered. To close with we will address the sensitive subject of what to do if the technology establishes that the driver, for whatever reason, is not fit to drive. We will attempt to see this from the perspective of the truck owner i.e. the fleet and consider their specific interests.

Passenger Car Approach – Knowing the Driver

Originally motivated by the reduction of accidents caused by fatigue or distracted driving, the first driver monitoring systems (DMS) were introduced in 2007 (Lexus). It took the industry over one decade and additional needs to reach a wider spread of DMS systems in the passenger vehicles (PV) market beyond one brand. Two factors provide the impetus behind wider scale DMS. One is a commercial push for DMS triggered by Euro NCAP. Another is the introduction of advanced driver assistance systems (ADAS) and gradual introduction of automated driving. Recent Uber and Tesla crashes have exposed how difficult it is for drivers, put at ease by "smart" technology, to re-focus in a sudden critical situation. [3]

Especially the higher levels of automation partially put the driver in a passenger role, allowing new in car activities, but also requiring a close cooperation between man and machine with smooth transitions between manual and automated driving modes. Driver monitoring will become a mandatory system to ensure full operation of the L3+ highly automated vehicles (HAV).

Besides the influence by higher automation and requirements on safety, the growing digital eco-system around us also finds its way into the vehicle of today, substituting the driver for a "user". This term "user" includes all people in the car, or "mobility space", both driver and passengers, independent of their temporary roles. When thinking about the car as "third" space, driving is no longer the central task. Other fields are becoming more important, such as relaxation, entertainment, shopping and working. Driving will be the new "secondary" task and former so called "non-driving related tasks" (NDRT) will be the primary activities of users in modern mobility spaces.

With this in mind "knowing the user" is a necessity for optimizing the services and comfort for the users in the vehicles. Parameters of interest range from gender and age to emotional states and stress level. This deep relationship to the user, which is based on a broad knowledge enabled by collecting valuable information by interior sensing technologies, is seen as a unique selling proposition, especially by upcoming EV brands like Tesla, Byton, etc., who are currently transferring the “user” monitoring and behavioral analyses from internet business to automotive. Various interior sensing technologies used in passenger vehicles will be explored in the next chapter. Following this the relevance of these technologies will be analyzed for use in commercial vehicles

Current Passenger Car Technologies

State of the art technologies for DMS in passenger cars use two main technologies; firstly, driving behavior analysis via indirect measurement and secondly driver camera systems via direct measurement. Both technologies are trimmed to identify the most severe driver drowsiness and distraction conditions to avoid fatal accidents.

For the indirect analysis of the driving behavior, the steering and/or the lane keeping behavior of the driver is evaluated over a certain time. The advantage of the steering behavior analysis is that no additional hardware is required in the vehicle. The solution is based on software algorithms in an ECU which is already present. The disadvantages are the indirect measurement itself, which allows false predictions and the analysis time periods which inherently lead to a delayed response time. In addition, the systems need some customization time (reference driving time) to be able to classify “abnormal” driving behavior. This leads to a challenge if a driver enters the vehicle and starts a trip in which there is a severe condition in the very first minutes. The system does not really have enough time to compare normal to this abnormal behavior and thus to detect the danger.

The driver camera typically captures the drivers head and upper body from a frontal position and has a slightly lower position than the eyeline of the driver. It is usually positioned close to the cluster instrument or on the steering column of the car. Near infrared technology (NIR) with a spectrum between 850nm and 950nm is typically being used to guarantee full functionality at day (bright sunlight) and at night. The illumination by NIR also has several other advantages about eye pupil tracking and eye gaze calculation, etc. Global shutter sensors are used to obtain appr. 30 frames per second (fps) of the driver. The field of view and position of the camera are selected to guarantee a high-quality picture of the drivers’ head, taking the big variety of drivers into account. These pictures and the resulting video sequences in conjunction with computer vision technologies enable direct measurement of key features, which are highly related to safety, e.g. open/closed eyes, head position and gazed direction. This is the key advantage of DMS systems based on camera technology, as they provide direct and clear information about the driver state with a minimum usage of approximations, assumptions and modelling. Drivers which have their eyes closed or off the road for extended periods of time are behaving in a dangerous manner. The detection thereof can be used to trigger driver warnings as well as safety systems and functions This leads to a benefit for the driver, vulnerable road users (VRU) as well as for fleets and society in general. Continental delivers such solutions to passenger car OEMs.

Fig. 2: Schematic of camera-based driver monitoring system

Latest systems promoted by passenger car OEMs combine both technologies, making use of all available information about the driver in the car. They give maximum performance of DMS systems, enable short response times in crises, and a high quality of prediction thereby making our street safer.

Future Passenger Car Technologies

Looking into the future, DMS technology will extend in several dimensions. The first dimension will be who the system will also observe. In The future this will include

passengers and the driver in a passenger role, both of which are equally important. We can talk about going from “Driver Monitoring” to “Driver and Cabin Monitoring”, looking at all passengers, i.e. “users”.
The second dimension will be about what the system detects and how this information is intelligently combined with environment and vehicle information to provide context and situation awareness information. Continental conducted a research project, PRORETA 4, together with the Technical University of Darmstadt. In this project Continental also demonstrated the benefits of the combination of driver’s eye gaze information together with object information in the vehicle environment, thereby allowing a driver perception classification of the objects. This information was used in conjunction with adaptive maneuver assistance at urban intersections using driver behavior modeling as seen in Fig. 3.

Fig. 3: Schematic of adaptive maneuver assistance at urban intersections using driver behavior modeling

In the future detection capabilities will also include further parameters beyond drowsiness and distraction. In future the system will be able to detect fitness to drive, stress level, emotions, user health as well as situation and context understanding inside/outside the car. In addition to this, the situation in the cabin is of high interest: are the users sleeping or having a conversation for example. Looking at the next generation of digital assistance, it is important for these dialog systems to better understand when and how to start a conversation.
The third dimension is the use of the driver/user information for enhanced functions and additional use cases based on the additional information from the users. We see three application areas: safety, comfort/well-being, and health. First ideas include new safety functions by establishing if the driver is “fit to drive”. Further ideas come from the field of comfort which would enable a well-being atmosphere for the passengers (and driver). In a further step health related functions based on the safety functions, e.g. monitoring the heart rate and respiration rate of

the driver could be used in a safety function and trigger an MRM (minimum risk maneuver) in case an abnormality with the driver is detected (no respiration, no heart rate…). In addition, this information could be used to monitor the drivers' state of health.

New technologies need to be utilized to fulfill this wider scope and the needs of "driver and cabin monitoring". High resolution sensors with fish eye lens cameras or multi antenna GHz radar sensors are in discussion to assess all areas of the cabin. The electro-magnetic spectrum offers further possibilities on top of NIR. The visual spectrum, VIS (400-700nm), MIR/FIR, THz and GHz are all under investigation. The visual spectrum enables features like emotions and heart rate detection when looking at the face with RGB sensors, MIR/FIR sensors/detection offer the possibility to capture body temperature information, whereas GHz/THz technologies can be used for respiration and heart rate detection. The seat, the rear mirror and the center of cabin are interesting locations for future sensors, especially when considering the high degree of freedom passengers will have in future.

New AI technology opens the door for interesting new possibilities, enabling features, with less information from the sensed persons themselves, thus providing the opportunity to optimize sensing hardware. Behavior analyses enters totally new fields by applying AI technology, e.g. LSTM (long-short term memory) neural networks. Personalization (including identification) is a key for many of these new features, functions and use cases, as higher precision in the prediction of the models comes with higher degree of individual model optimization. Much of the analytics will be based on or consider historic data, providing higher levels of accuracy for the "fitness to drive" analyses and open new dimensions in the field of user health analysis. These new technologies provide the foundation for a valuable personal assistance as "co-driver" or "health prevention" systems.

Suitability of technologies for use in commercial vehicles

There are considerable differences between the cabin passenger cars and heavy goods vehicles. The first difference is that the driver is not in one fixed position all the time since he/she usually sits on a seat which has its own suspension. There will be vertical oscillation in the position of head and body. Many of the sensors would typically be positioned on or in the dashboard. The angle between this and the driver's head/body can be substantially different between PVs and CVs. The most obvious difference is the size of the cabin which is considerably larger. Having said that we believe that must of the relevant passenger car technologies could be positioned for the optimum usage. No doubt modification in algorithms would be required to adapt to the different surroundings. Passenger car technologies could even be reused with some optimization on sensor location and with respect to algorithms. Continental has performed this work in its Innovation Truck over the last years. This has helped to identify relevant approaches and adaptations. In summary there is no reason to exclude any of the passenger car technologies/approaches based on a geometrical standpoint.

The electrical and electronic environment do not pose any insurmountable hurdles. Even if trucks in Europe typically work with 24 and not 12V power supply, these adaptations are well practiced in all domains of the vehicle E/E architecture. The extremely high mileage and associated environmental conditions in a truck can play a role though in establishing which technologies are suitable. Ideally the sensor should have no moving parts and have a very high resistance to vibrations and other external influences (dust, humidity etc.)

Looking further, it is fair to say that only a subset of passenger car approaches seems relevant since only the driver needs to be monitored, as there is usually only him/her in the cabin. All sensing pertaining to passengers can be ignored for the sake of simplification. The selection which of these technologies could find their way into future trucks will be decided by the fleets and the respective business case. This will be addressed in the next chapter.

No doubt automated driving will drive the introduction of driver analysis technology in commercial vehicles. We expect most of this technology to come from passenger cars since the use cases and requirements will be very similar.

Alignment of technologies to interests of fleets

Heavy good vehicle drivers are on the road considerably longer than passenger car drivers. Their monotonous daily chore of driving for hours is prone to drowsiness without a doubt. Therefore, it is quite surprising to see that no manufacturer actively promotes driver monitoring technology. What is visible in the market are numerous aftermarket solutions to detect drowsiness and distraction such as those from Lytx, Rear View Systems et. al. These are based on driver facing cameras with associated algorithms. By the way, these types of solutions also seem to be popular in taxi fleets in China for example. At least these solutions indicate that there is a market for such solutions, but driver monitoring still seems to be quite a green field in summary. Why is this the case if these technologies offer such advantages for improved safety on the public roads? To answer this, we probably need to investigate the interest of the truck owners – commercial vehicle fleets.

At first glance it seems that the most relevant data relates to the field “fit to drive”. This covers multiple facets on the state of the driver including drowsiness, workload, stress level and physical health. A drowsy driver reacts slower, something which is critical for responding to critical road situations like tail ending. A driver with a very high workload may be distracted and not able to react in time in a critical situation. It is common knowledge that a person under stress is more likely to make mistakes than an unstressed person, once again increasing the likelihood of an accident. Lastly a driver with a critical health condition could momentarily be incapable of driving. If negative, each of these could lead to either a recommendation to the driver, a situation that the driver is forced to take corrective action or in the long run that the vehicle takes over control and performs a minimum risk maneuver. This would certainly add value for highway safety by reducing the number of suboptimal drivers on the road.

Seems straight forward until here, but when analyzing the interests of the fleet, a conflict of interests becomes apparent. For the fleets it is of primary importance that their goods reach their destination on time and with lowest possible costs. A driver that decides to take a break is temporarily grounded, increases the likelihood that the goods will not be on time and increases the overall cost of the fleet (vehicle downtime). This could explain the current seemingly slow uptake of these technologies. An accident free vehicle is obviously also in the interest of the fleets. In the past this has led to the introduction and partial success of safety functions like emergency brake assist or forward collision warning prior to these being mandated. Their availability and the widespread acceptance of their value did in the end lead to the legal mandate for these in all new vehicles.

An interesting example going forward is blood alcohol testing. The German media widely reported that German authorities in Hessen performed an alcohol test on 1200 truck drivers; almost 200 had alcohol in their blood, 79 were not allowed to continue their journey due to too high alcohol levels. The European Transport Safety Council has called for an alcohol interlock to be mandated in all professional vehicles (light and heavy, truck and bus). This could be a role model for other technology which would improve road safety like sensing if the driver is fit to drive.

There is another lever which could catalyze the uptake of this technology. There is a shortage of truck and bus drivers especially in Europe and the US. Current Fig.s speak of over 50.000 drivers missing in the US. The use of such technology and acceptance of the implications by fleets could help these to demonstrate their interest in the well-being of drivers and thereby reduce attrition rates. The first usage of such driver monitoring solutions for this purpose is visible in the US market.

Further technology is available which can help to reduce the number of fatal truck accident

Interior sensing technologies offer attractive functionalities which can contribute to an improved understanding of the situation/capabilities/limitations of truck drivers. Action taken based on this information can help to reduce the number of road fatalities involving commercial vehicles. Passenger cars OEMs will lead the development of this technology and thereby offer interesting economies of scale if this is re-used in commercial vehicles. From a technical standpoint there are not unsurmountable barriers which is good news. Motivating truck owners to use this technology poses a significant challenge since they increase vehicle costs in a first step. But the desire for less accident can motivate fleets to invest in this technology. This desire could also lead to a legal mandate for this technology one day, further improving road safety.

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Bryan Reimer, a research scientist in the MIT AgeLab and the associate director of the New England University Transportation Center at MIT, told EE Times, "Humans are irrational. Just as automatic transmission became the tipping point that allowed a driver to do texting and driving at the same time [it's hard to text when you have to shift], humans will always use the newly found freedom for doing something else [other than driving]." [3]

Links

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Over The Air Software Updates for commercial vehicle trailers

How to ensure latest software in all trailer ECUs

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Abstract

Over The Air software update of in-vehicle software is either implemented already or on the roadmap of all major passenger car OEMs. Also the commercial vehicle industry is expected to pick up this trend. This paper is focused on the trailer specific challenges and will present solutions for updating them with new software.

Over-The-Air Software Updates in the Automotive World

In the passenger car industry, the benefits of Over The Air (OTA) updates for in-vehicle software has been proven already: E.g. Tesla has shown how fast reaction on issues found in the field may reduce cost for field claims, and how updates can be used to introduce new features and to earn money by selling additional software-based functionality over-the air, also increasing customer satisfaction.

A typical OTA system consists of three major parts that need to interwork efficiently as shown in Figure 1: the OTA Backend, the OTA update client in the vehicle and the ECUs to be updated.

Fig. 1: The three major components of an Over The Air software update solution

OTA Backend

The central component of an OTA update solution is the backend. It is used to control update campaigns: it bundles update files, allows specifying which vehicles will receive an update, and how fast updates are pushed out. It then sends the updates to the update clients in the selected vehicles and will continue to monitor the update procedure for the vehicles to collect feedback on issues detected during update.

OTA Update Client

The second system component required in the vehicle is the update client. The client controls all updates in a vehicle, coordinates the right flashing sequence when several ECUs need to be updated in one package, and controls rollback to previous version if an update fails for some reason. Typically, the update client also stores current and previous software for all or some ECUs to ensure that update and rollback can be done from the update client when required. This is especially important if an ECU cannot store more than one software version in parallel. Finally, the update client also acts as a single point of contact for the OTA update backend in the cloud.

In-Vehicle ECUs

Finally, the in-vehicle ECUs need to be capable to do updates and need to be connected through a data bus with an update client. There are three degrees of support for OTA software updates in embedded ECUs, as shown in Figure 2.

With only minimal OTA support (Figure 2-A), an ECU will receive software over the vehicle's data bus and store it in its program memory immediately. This requires very little changes to traditional ECUs that are already programmable in the repair workshop. Conceptually, the only difference is that the update is not pushed from a workshop PC connected to the vehicle, but from an update client that is part of the vehicle electronic architecture.

This level of support typically requires the ECU to be taken out of service for several minutes, until the new software is loaded over a relatively slow data communication line, checked for consistency and finally started once download is complete and all checks passed. Fall-back to an older version requires loading the old version again from the update client.

A more advanced OTA support in the embedded ECU (Figure 2-B) implements additional non-volatile memory on the ECU that can store additional software versions. That way, it is possible to download a new version to the ECU already in the background while the current software is executing, and perform checks to the update software in advance. In this case, the ECU only needs to be taken out of service for a few seconds to copy the software

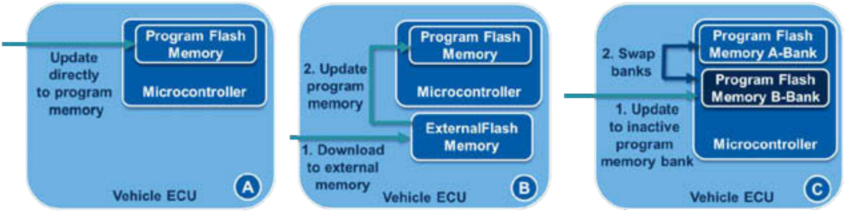

Fig. 2: Hardware/software architecture options for OTA update support in embedded ECUs

from the external backup memory to main program memory in the controller over a fast ECU-internal data line.

The highest level of support is given by controllers that support A/B swap of its memory (Figure 2-C). In this setup, the program memory in the microcontroller is partitioned into two banks, called A-bank and B-bank. In such a configuration, only one bank is used at a time to execute the currently active program, while the other bank can be loaded with new software. Again, correctness of the new software can be checked in the background. Then, the new software can be started without any delay, e.g. at the next ignition cycle of the vehicle. That way, almost zero downtime can be achieved.

While A/B swap may look like the best choice for all updateable ECUs, it comes with quite some cost: First, it requires a microcontroller that supports A/B swap, which is typically only the case for the latest controller families of the silicon manufacturers. Enabling A/B swap on a microcontroller may also have negative impact on performance, which also must be taken into account. Secondly, program memory seems to be always full in embedded projects, no matter how much is available on a microcontroller. Splitting it in two and thus using only 50% of it for the active executable is often not possible. Finally, ECUs manufacturers need to look after each penny – adding a few dollars to duplicate program memory just for over-the-air updates is thus often not appreciated.

In the end, the choice for one of the three above hardware options is determined by the required availability of the ECU in question, the downtime customers are willing to accept and the cost upcharge acceptable. In a typical vehicle, a mixture of different ECU architectures for different systems will be likely.

For all the elements required for OTA updates, cyber security is a critical topic. This requires additional means to secure the backend and transmission, and to supervise the update in the vehicle, which are beyond the scope of this paper.

Evolution of the Electric / Electronic Architecture of a Commercial Vehicle Trailer

In a traditional commercial vehicle trailer, typically there are only a very limited number of electronic control units, see Figure 3. The only mandatory control unit on the trailer is the trailer antilock braking system / rollover stability system. It is present in almost all trailers over 3,5 tons in Europe since 2012, when it was mandated by European Commission Regulation 661/2009.

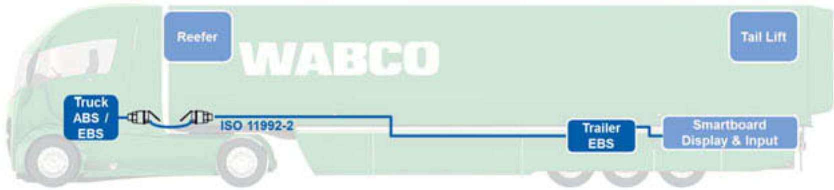

Fig. 3: Typical electronic architecture of a current semitrailer. Elements shown in light blue are examples for optional equipment

Available configuration vary from minimal braking system with a two wheel speed sensor / two modulator configuration to complete trailer control systems that include features like electronically adjustable air suspension, tire pressure monitoring, rear obstacle detection and a display/input ECU with a dot matrix display and a few keys to enter commands, called *SmartBoard* in WABCO terminology.

Other electronic control units on the trailer vary depending on the usage profile and control the trailer body functions, such as the refrigerating system of a reefer, tail lifts, door lock systems and tipper functions just to name a few. Today, these functions are typically not connected in an electronic data network, but work stand-alone.

Recently, the need for connecting these trailer body builder devices in a standardized manner to telematics devices has been recognized, and the upcoming DIN 4630 will provide an aligned interface to these units,.

There is also an increasing trend seen in the transport industry to equip trailers with telematics units (examples are shown in Figure 4). They range from simple battery-powered track and trace units such as Transics TX-GEO, that have no connection to other trailer ECUs, to full-fledged FMS systems such as TX-TRAILERGUARD. The latter system allows readout and control of trailer ECUs and supervision of safety and security of the cargo, by reading different sensors and issuing alarms. Some FMS devices also focus on specific customer segments; such has TX-TRAILERPULSE that provides basic track and trace and in-detail supervision of the braking system.

Fig. 4: TX-GEO, TX-TRAILERPULSE and TX-TRAILERGUARD (from left to right) are examples of the wide range of trailer telematics solution

Also, increased levels of commercial vehicle automation up to full autonomous driving will require the trailer to supervise the space on its sides and rear, which will require Advanced Driver Assistance System (ADAS) functions to be added to the trailer. In summary, in near future the trailer electronic architecture of many trailers would look as shown in Figure 5.

Fig. 5: A feature-rich trailer with all relevant ECUs connected to a trailer connectivity unit

While the need for OTA updates in trailers may be disputed for simple vehicles in use today, these future functions will drive the demand for fast updates to keep up with increased innovation speed in the trucks and to fix issues in the complex system structure arising from the variety of combinations of truck and trailer brands and models.

State of Standardization on Trailer Connectivity

As mentioned before, electronic control of the trailer is limited today. Still, there are a few standard interfaces that are relevant for the discussion of Over The Air update in trailers. Table 1 gives an overview over these standards.

Most prominently, there is the Truck-Trailer interface standardized in ISO 11992 family. It uses a 125 Kbit/s CAN bus with fallback ability to single wire operation for safety reasons, and comes in two versions. The best known one is used between the truck and the trailer brake system as a point-to-point communication to enable brake-by-wire. This drastically increases brake performance and safety of truck/trailer combinations. It is standardized in ISO 11992-2 and referenced as part of the brake system in UN R13 regulation. Thus any changes to this interface are homologation relevant and require a long lead time. Every trailer equipped with trailer EBS provides this interface.

There is a second, less-used interface using the same link layer specification as the brake CAN, intended for non-braking related functions and standardized in ISO 11992-3. The ongoing update of this standard will include position information for objects around the trailer. It paves the road towards combined truck / trailer ADAS functions where also the trailer is required to supervise its surrounding, e.g. to determine whether it is safe to change lanes.

Also, there is ongoing discussion on the need for a new high-speed truck-trailer link, to enable transmission of low-latency camera images and other data with high demands on bandwidth (see e.g. [1]), but there has not been any standardization finalized on this.

Another important standardized interface in the trailer is the TCAN or Trailer CAN. The development of the TCAN is an initiative of the European Transport Board and is supported by all major electronic trailer brake suppliers. It provides the interface between trailer braking system and trailer telematics, including diagnostic interface, which could also be used to build OTA update services upon.

Challenges for OTA updates in trailers

Unfortunately, there are several aspects that make OTA updates more complicated in trailers than in passenger cars or trucks, some of them of technical nature, others from the organizational side. From a system perspective, the most prominent challenge is that the trailer is a stand-alone vehicle, but without the infrastructure that other vehicles have on board. Typically a trailer does not have its own power supply, but depends on the power line from the towing truck. Thus any interruption of power from the truck will immediately abort an ongoing update. Even worse, the truck may be completely disconnected and be replaced by another vehicle with another driver that may not be informed about an interrupted software update.

Furthermore, means to display status to the users are very limited. As stated above, only a small fraction of trailers come equipped with a SmartBoard that may display messages to the end user and may accept commands. Also, display possibility on the truck is limited, and only two warning lights for trailers are standardized.

Table 1: Relevant Standards for trailer data exchange

Reference	Title	Relevance
ISO 11992	Road vehicles — Interchange of digital information on electrical connections between towing and towed vehicles	Specifies truck-trailer communication over CAN bus
ISO 11992-2	Part 2: Application layer for brakes and running gear	Specifies braking related messages. Includes PGNs to switch red and amber warning in the truck's dashboard
ISO 11992-3	Part 3: Application layer for non-braking equipment	ISO/DIS 11992-3:2018 includes ADAS object detection messages e.g. of other vehicles around the trailer
ISO 11992-4	Part 4: Diagnostic communication	Specifies diagnostic access with addressing schemes to reach all trailer ECUs with diagnostic commands; even for road trains with multiple towed vehicles
T-CAN	European Transport Board: Road vehicles — Interchange of digital information on electrical connections between braking and auxiliary data collection systems on towed vehicles	Specifies the interface between trailer telematics systems and trailer brake systems
DRAFT DIN 4630	Road vehicles — Data parameter specification for body application units in commercial vehicles	Specifies the interface between telematics and body equipment such as tail lifts, refrigerating units etc.

From an organizational perspective, the challenges come from the fact that the trailer market is much more diverse with many very small OEMs. While passenger car and truck OEMs have established channels to keep a business relationship with the vehicle owners, that may also be used to get approvals for OTA updates, this is often not the case for the trailer market. Also, cost pressure on trailers is extreme, which makes the business case for investment in additional hardware for OTA updates more complicated.

Potential paths for new software into the trailer

Looking at the trailer electronic above, there are two potential paths for OTA software updates to trailer ECUs: Either the new software could be downloaded through the truck telematics and managed by a truck update client, as shown in Figure 6, or the trailer own telematics is used for downloading the software. Both methods have their advantages and challenges that will be presented in this chapter.

Using the truck as the master also for trailer updates has a lot of advantages at first glance:

- There is an ongoing trend by truck OEMs to equip all their vehicles with connectivity units to provide end users with continuous health monitoring of the vehicle.
- The connectivity offering of the truck OEMs will most likely include OTA software for truck electronics updates pretty soon, so there will be systems in place to build on.

- Every truck has displays and input means like buttons or touchscreens for interaction with the driver. So timing a scheduled downtime of the trailer for software updates can easily be done in interaction with the driver of the vehicle.

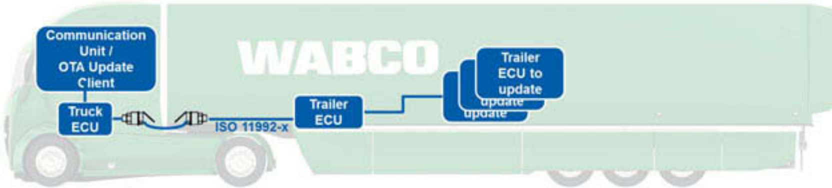

Fig. 6: Trailer update using truck infrastructure

Thus extending the scope of a truck update client to also cover the trailer seems natural from that perspective. But there are also aspects that make an update through the truck less attractive:

- By definition, trailers are not fixed to a single truck, thus configurations will vary over time. Thus unlike for OEM-built ECUs in the truck there is no knowledge of the truck builder on the electronic architecture of the trailer currently in tow.
- The data connection between truck and trailer as defined today in ISO 11992 is pretty slow, so a full update for a trailer will take a long time. This in turn results in a long downtime for both the towing and the towed vehicle. For example, updating 4 megabyte of software in the trailer over an ISO 11992 CAN bus with nominal data rate of 125 Kbit/s will take more than 20 minutes, assuming that 50 Kbit/s can be reached for data transfer.
- Even if the driver is informed and consent for a software update is given, it is conceptually not ensured that the update is completed. If an update is interrupted and the truck is decoupled from the trailer, the ECU in question may not be taken back to service by the next truck connected if that one does not support OTA updates. Even worse, the next truck may not support OTA trailer supervision. Thus the driver may not notice that it has a trailer in tow that has components with partially flashed (and thus probably broken) software, since there might be no means to indicate failures to that truck.

An alternative to this approach is using a trailer connectivity unit to perform the update. This means that the trailer must implement its own update client, as shown in Figure 7.

Fig. 7: Trailer update using own trailer infrastructure

In this scenario, the functionality of the communication unit is extended to also work as an OTA update client that orchestrates and supervises the updates for all ECUs.
A big advantage of this scenario is that the trailer can be updated independently from the truck infrastructure. A disadvantage is that most trailers do not have means for interaction with the driver, so getting driver consent and awareness on the update is tricky.

Safety Requirements on Over The Air Software Updates in trailers

This finding leads to the question whether user interaction is required for an update. Consent of the fleet owner needs to go via another channel anyway, since the driver is in most cases not the owner of the vehicle. The remaining reason to ask for consent is safety and availability of the trailer during updates. If you consider the trailer electronic brake system EBS, those safety requirements are obvious – drivers rely on the EBS to ensure vehicle stability while braking even in difficult situations, so it is pretty clear that drivers must be warned if functionality is unavailable. In practice, there are currently two warning lamps specified in ISO 11992-2 to be available in the truck dashboard with four modes: no warning, yellow warning constant, yellow warning blinking and red warning. During an update of the brake ECU, the red warning lamp should be set, since only the pneumatic backup is available.
By using these lamps one could argue that system safety can be ensured, assuming that the driver takes appropriate precautions on illumination of the warning lamps. But deliberately creating a potentially unsafe condition by taking a brake ECU out of service for Software update while the vehicle is driving is definitely not a good idea.

Considerations for standardization

As pointed out above, proper information to the driver is key for successful OTA updates in trailers, but is currently not adequately possible. Thus there is a strong argument to amend current standards. ISO 11992-2 and 11992-3 are seen as suitable means to transmit this information. It turns out that two bits in each direction could do the job for providing a minimal set of information:

From towed vehicle to towing vehicle a parameter *Over the air software update request* is required as shown in Table 2:

Table 2: Proposed specification of *Over the air software update request* parameter

Attribute	Value
Data length	2 bit
Data range	00_2 – No over the air update requested nor ongoing 01_2 – Over the air update requested 10_2 – Over the air update ongoing 11_2 – Not available
Type	Status

From towing to towed vehicle, a similar parameter *Over the air update acknowledge* is required to acknowledge requests, as shown in Table 3:

Table 3: Proposed specification of *Over the air update acknowledge* parameter

Attribute	Value
Data length	2 bit
Data range	00_2 – No over the air update requested from towed vehicle or no acknowledgement from driver 01_2 – Over the air update acknowledged by driver, waiting for finalization 10_2 – Error / Over the air update refused by driver 11_2 – Not available
Type	Status

Typical sequences of values for these two parameters could look as shown in Figure 8. These two parameters would fit in already existing parameter groups specified in the standards and could thus be transmitted without increasing bus load.

Fig. 8: Sequences for truck-trailer signaling and status information on Over The Air updates

Trailer request	Truck Acknowledge	Sequence explanation
01	00	Trailer requests over the air software update, truck displays this request, no answer from driver yet
01	01	Driver granted request
10	01	trailer starts SW update, both sides stay in this state until update is completed
00	01	Indication to truck and driver that SW update was completed successfully, truck will inform accordingly
00	00	Ready for operation

Trailer request	Truck Acknowledge	Sequence explanation
01	00	Trailer requests over the air software update, truck displays this request, no answer from driver yet
01	10	Driver refused request, trailer will not attempt an update
00	10	Indication to truck and driver that SW update will not be done
00	00	Ready for operation, trailer will not update this ignition cycle

Trailer request	Truck Acknowledge	Sequence explanation
10	00	Trailer starts (urgent) SW update immediately not requesting driver consent. (should be accompanied by amber or red warning signal)
10	01	Truck acknowledges ongoing update
00	01	Indication to truck and driver that SW update was completed successfully, truck will inform accordingly
00	00	Ready for operation

Trailer request	Truck Acknowledge	Status
*	11	Truck does not support indications to driver, trailer needs to rely on other means to inform driver or not do update
11	00	Trailer does not support over the air SW update, no indications to driver
11	01	Eror while update, go to workshop (should be accompanied by amber or red warning signal)

Who should run the OTA update backend?

So far, this paper has been focusing on the technical requirements and potential solutions for Over The Air software updates. Equally important are answers to the questions who can take the lead for hosting the OTA update backend, the business relation with the vehicle owners and the execution and timing of updates. Figure 9 gives an overview on the ecosystem that exists around commercial vehicle trailers and the business relationships between the parties.

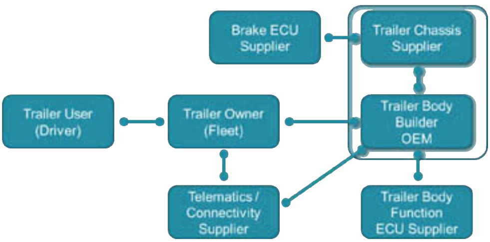

Fig. 9: Business relationships in the trailer ecosystem

As mentioned before, whoever does the OTA software upgrades must have a business relationship with the trailer owner with a contract that covers the update over lifetime of the vehicle. From that perspective, it should either be the trailer OEM or the telematics provider (which in many cases are different companies today) that supplies the update service. At the

same time, whoever manages the update needs to have contracts with all ECU suppliers to receive update files, which by itself will be a major effort. Thus most of the trailer OEMs, which are often quite small, will not have the capacity and capability to provide update services by themselves. Also, most fleets source their trailers from several trailer manufacturers. Thus especially bigger fleets may prefer to have a single update provider that ensures that the complete fleet across all trailer brands gets updated on a regular basis.
This may open a window of opportunity for trailer telematics / connectivity providers to provide updates as a service to the fleets and trailer OEMs. That way, the service provider could both extend its offering to fleets to also provide OTA services, and provide update capabilities to trailer OEMs that delegate responsibility to its connectivity provider.

Conclusion

This paper highlighted very different aspects and challenges regarding trailer OTA software updates namely:

- Triggered by the increasing complexity of the trailer electronic architecture and the need for closer interoperability with many different truck types, Over The Air Software Update will become an important feature for future trailers.
- To avoid the risk of unfinished updates in trailers, the trailer must provide own means for storing alternate software versions, either through an own update client, or though ECUs that can store old and new software versions themselves. Otherwise the risk is too high that an update is interrupted leaving some of the trailer functionality unusable.
- For safety relevant system components such as brakes, A/B swap architecture is recommended to achieve zero downtime. Alternatively, proper information to the driver is required to avoid that the trailer is moved while the safety relevant system is unavailable.
- An addition to ISO 11992 truck-trailer interface is recommended to ensure that the driver understands that updates are ongoing.
- Over The Air update is seen as a new business opportunity for trailer telematics / trailer connectivity providers, both serving the fleet and the trailer manufacturer market.

[1] Goers, Andreas; Kühne, Sebastian: CAN over Automotive Ethernet for Trailer Interface. Fahrerassistenzsysteme 2018, Proceedings (2019) pp. 166-177

Predictive Maintenance for TraXon

Business Model and Technical Solution

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Abstract

For several years, the digitalization megatrend has been moving more and more into the focus of the commercial vehicle industry. This implies different consequences. One of them is that vehicles are brought into the Internet of things via connectivity solutions. This brings along an increasing amount of real-time vehicle data both on the vehicle level and the component level leading to "Big Data". These data are nowadays typically stored and administrated in clouds, and are therefore available in large quantities for new forms of data analytics. On the basis of these data, new business models can be developed. One trend regarding new data-based business models is Predictive Maintenance. With the development of a Predictive Maintenance function, ZF is preparing its TraXon transmission for the digital future in the commercial vehicle industry. Starting in 2019, vehicle manufacturers and fleet operators can use the cloud solution to proactively plan vehicle maintenance. The primary customer benefit of TraXon Predictive Maintenance is a significant reduction of the Total Cost of Ownership.

Drivers of Digitalization

The digitalization megatrend started to reveal its impact on various industries more and more several years ago. Digitalization is defined as the transformation of current business through digital technologies and new ways of working [1]. It materializes at different speeds in different industries. Whereas, for example, in the media industry, digitalization has already become state-of-the-art, the automotive industry is quickly following, but has not yet reached the tipping point [2].

The digitalization megatrend implies various consequences for the automotive industry. One is that vehicles are brought into the Internet of things via connectivity solutions. This results in an increasing amount of real-time vehicle data both on the vehicle level and the component level leading to "Big Data". Modern cars produce about 4.000 GB of sensor data per day [3]. In general, about 75 billion devices will be connected to the Internet of things in 2025 [4].

Another consequence of the digitalization megatrend is that it increases the added value of software in vehicles. By 2030, average cars will contain about 300 million lines of software code, which is triple the amount of 2019 [5].

Digitalization brings along both chances and risks for established companies. On the one hand, new competitors are arising that have not been in the automotive and commercial vehicle market before. Many of them are software-focused companies or start-ups. Current suppliers risk becoming commodity suppliers if new entrants find a space in the value chain between them and the OEMs. Additionally, it is clear that the percentage of sales in the commercial vehicle industry generated by digital solutions will strongly increase in the future. This will be a challenge for all companies that focus on hardware products today. On the other hand, new business chances are also arising for every established company. The data that are generated by vehicles are nowadays typically stored and administrated in clouds, and are therefore available in large quantities for new forms of data analytics. On the basis of these data, new business models can be developed.

One trend regarding new data-based business models is Predictive Maintenance. Predictive Maintenance is sometimes used as a synonym for Condition Monitoring. This, however, is misleading, and the two topics should therefore be differentiated. Condition Monitoring is a digital solution that detects existing problems that have already occurred to a vehicle. As a consequence, the guiding question is: "What has happened to the product in the field in the past". The benefit to the customer is quicker resolution of field problems, which leads to a reduction of failure costs. In short, Condition Monitoring can be considered to be a measure of customer retention, but the customer benefit in many cases is not strong enough to generate new value streams. Predictive Maintenance, on the other hand, is a digital solution that is able to predict upcoming problems that will occur to the vehicle in the future. Thus, the guiding question is: "What will happen to the product in the field in the future". The benefit to the customer is more uptime and better planning of downtimes. This results in a significant reduction of the Total Cost of Ownership. Predictive Maintenance is therefore technically more challenging than Condition Monitoring on the one hand, but, on the other hand, the benefit of Predictive Maintenance for the customer is also much higher than that of Condition Monitoring. Thus, the Predictive Maintenance digital solution usually provides the potential for new value streams. This article will focus on Predictive Maintenance in the following.

ZF Digitalization Strategy

Digitalization is one important measure of ZF's "Next Generation Mobility" corporate strategy, and it therefore plays a highlighted role within ZF. ZF's corporate digitalization approach comprises all aspects of value creation: Digital products and services, manufacturing and supply chain, digital business processes as well as culture and workplace. The digitalization of ZF's products and services refers to all industries where ZF is active: Passenger Cars, Commercial Vehicles, and Industrial Applications. Digitalization is meant to be an enabler for ZF's key fields of activity automated driving, vehicle motion control, integrated safety, and electric mobility.

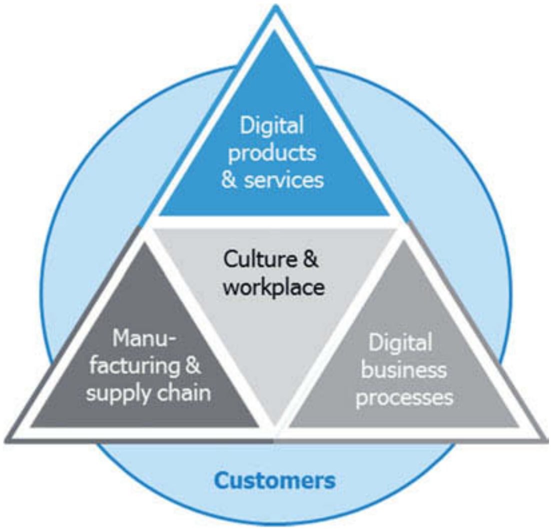

Fig. 1: Spheres of digitalization at ZF

ZF allocates all digitalization projects at ZF that refer to products and services into three dimensions: Safeguarding business, enriching business, and expanding business. This helps to cluster the manifold digitalization projects by their natures, characteristics and targets. As Predictive Maintenance enriches existing products, such as truck transmissions, Predictive Maintenance concepts are allocated to the area of enriching digital products and services.

In order to create new digital products and business models, such as TraXon Predictive Maintenance, a digital mindset and digital capabilities are necessary. The corporate Digitalization team leads the transformation of ZF by bringing together traditional products with new digital technologies, digital trends and a networked ecosystem of internal labs, start-ups, academia, and strategic partners. As of March 1, 2019, the Commercial Vehicles and Industrial Applications divisions have additionally opened a common Digital Products and Predictive

Maintenance project house. The project house will help to leverage synergies between the various digitalization projects of both divisions and supply them with professional digital skills. Regarding technical feasibility, ZF has built up a corporate ZF IoT platform on Microsoft Azure as the technical backbone to support various new digital solutions. It comprises five technical stacks: Devices and Sensors, Connectivity, Back-end Infrastructure, Analytics and Big Data, and Applications. Due to its generic approach and scalability, the ZF IoT platform is open and interoperable and can be leveraged to analyze data trends across industries and use the results to cross-pollinate best practices in a more agile manner. The platform enables use cases for passenger cars, commercial vehicles and industrial applications.

Technical Solution of TraXon Predictive Maintenance

More and more digital operation and status data on powertrain components are available in commercial vehicles. A lot of activities and various developments are currently running on both sides, on the OEM side and on the component suppliers side, to make these data from vehicles available for use.

TraXon Predictive Maintenance is a digital service that analyses transmission data in the ZF IoT platform in real-time, predicts the remaining lifetime of ZF components and provides specific recommendations for action to the OEMs. These lifetime predictions will be sent via cloud-to-cloud communication from the ZF IoT platform to the OEM IoT platform.

For developing the digital business model TraXon Predictive Maintenance, the first step was to identify the key components for TraXon. These are the TraXon wear parts, namely the oil and the clutch disc. Depending on the application, both the oil (for oil change intervals, see ZF's lubricants list TE-ML 02) and the clutch disc are replaced at least once during the transmissions' lifetime. From a commercial and technical point of view, it is not possible to monitor all transmissions components. For Predictive Maintenance, the TraXon oil and clutch disc were chosen because they provide the most attractive cost-benefit ratio.

By bundling the specific ZF expert know-how from various departments such as Software and Function Development, Design, Testing, Quality and Service, ZF is in a position to create the technical basis for predicting the remaining lifetime of key components. This technical basis was used to develop the Predictive Maintenance functionalities for the oil and the clutch disc. The input variables for this are the operating and status data from the transmission and their change over time, together with the linking of various datasets with each other. The methodical basis for these Predictive Maintenance functionalities are a combination of design- and diagnostics-based analyses.

During use, the transmission oil is subject to qualitative aging, which can be attributed to the thermal and mechanical aging of the fluid. To prevent consequential damage, oil changes are carried out regularly, usually after a certain mileage or elapsed period of time. So far, however, the individual quality of each transmission oil is not taken into account.

The Predictive Maintenance function of determining the oil lifetime allows for calculation of the damage to this fluid mainly on the basis of the thermal load during the time since the vehicle was put into service or since the fluid was changed according to the oil change intervals. This damage value can then be used to calculate the remaining oil lifetime. The oil damage increases rapidly if the fluid is subjected to high temperatures. The time the oil remains in various temperature ranges and the resulting temperature collectives are monitored and recorded by a temperature sensor. The validation of this function is based on a large set of oil samples from different applications with different mileages over many years and vehicles.

The clutch is also subject to mechanical wear during use. This wear can be attributed to wear on the friction lining and on the mechanical clutch components. To prevent vehicle breakdowns, the clutch is replaced at regular intervals, depending on the application and OEM. By using mainly the travel sensor information, the clutch wear calculation function allows for the prediction of the damage to the clutch disc by observing the position of the clutch actuator in a defined condition. During the clutch's lifetime, this position moves within a characteristic range. By comparing the current position with the position when the clutch was new, the difference provides a measure of the current wear condition of the clutch. If the progress of this wear condition is tracked over time and mileage individually for every transmission, the remaining lifetime can be determined through an appropriate extrapolation.

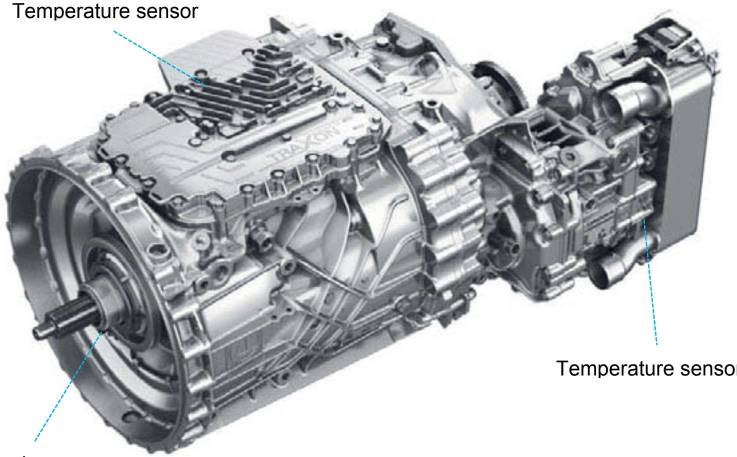

Fig. 2: Location of important sensors used in the TraXon transmission for Predictive Maintenance

The TraXon Predictive Maintenance algorithms are implemented into the ZF IoT platform. As a consequence, specific processing time and data storage capacity has been allocated to the Predictive Maintenance use case within the ZF IoT platform. To correctly calculate the remaining service lifetime, it is necessary to receive frequently raw transmission data (operation and condition data). To do this, ZF usually uses the OEM sending device that is installed in the vehicle ex works. This sending device reads out the raw data from the TraXon control unit via Unified Diagnostic Services (UDS) and forwards it to the OEM's cloud. The OEM data platform is in contact with the ZF IoT platform through an API (Application Programming Interface). The ZF IoT platform processes the supplied raw data and generates detailed reports on the condition of the transmission components, which will be sent to the OEM's cloud.

Using the standardized UDS communication protocol is necessary because this communication protocol enables controlled retrieval and provision of the necessary data. For this purpose, the vehicle must be in a safe driving condition so that the increased data rate via CAN (Controller Area Network) between the TraXon control unit and the vehicle control unit does not lead to vehicle malfunctions.

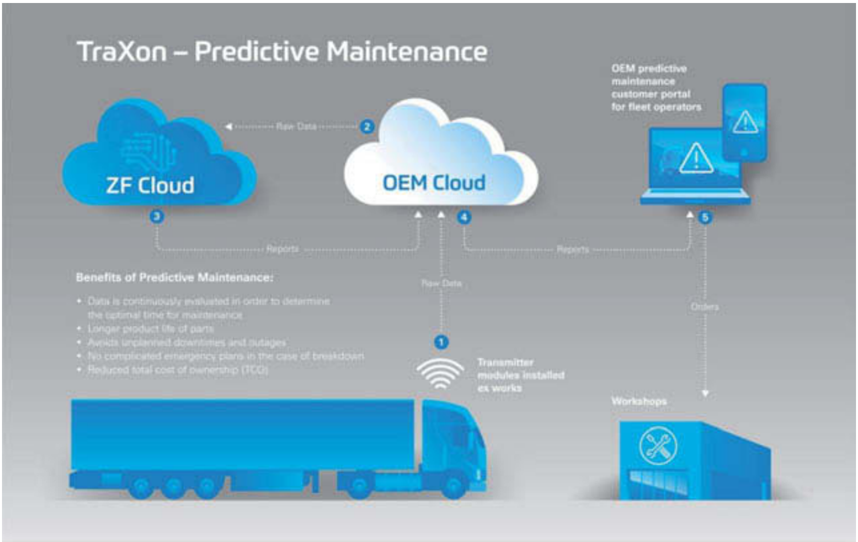

Fig. 3: Data transfer model for TraXon Predictive Maintenance

As previously mentioned, the interface between the TraXon transmission, the OEM's cloud and the ZF IoT platform is usually a customer-dependent telemetry. For customers who have not installed a proprietary sending device, ZF offers ZF's in-house sending devices from OPENMATICS.

By using the now frequently available transmission operation and condition data and in combination with further sources such as end-of-line data, population data and the digital twin, additional analyses based on big data analytics methods are possible. This leads to further improvements of existing lifetime predictions. In addition, analyses based on big data will also provide the possibility of monitoring additional and more complex transmission components and of developing new forecasts, which will ultimately generate further added value for OEMs and fleet operators.

Beginning in 2019, the globally successful TraXon transmission will be available with Predictive Maintenance functions by the customer. One central customer benefit of TraXon Predictive Maintenance is that the available cloud solution, and thus the ongoing data evaluation will make it possible to determine the optimum time for maintenance. Additionally, the maintenance intervals for wear parts can be extended due to individual remaining lifetime predictions for every single transmission in the field. Besides, unscheduled standstill periods

due to breakdowns and unplanned service work will be shortened or at best avoided. This allows for the avoidance of complex emergency plans in the event of a breakdown. All this will lead to a significant reduction in the Total Cost of Ownership.
Besides TraXon, the ZF group has several other ongoing activities in the field of Predictive Maintenance, such as in the area of bus drivelines for the EcoLife transmission or in the area of industrial applications for wind turbine gearboxes. All in all, ZF is facing the challenges of the digitalization megatrend in order to improve its products, differentiate them from those of the competition and offer customers new benefits.

[1] Corporate ZF definition based on Wikipedia.

[2] J. Gottlieb, P. Willmott (2014), The digital tipping point, New Jersey, London.

[3] J. Davison (2018), The connected car data explosion, Guernsey.

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[5] Roland Berger, Lazard (2017), Global Automotive Supplier Study 2018, Munich.

Open Platforms as A Solution Approach for Smart Logistics

Increase connectivity in networked commercial vehicles

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Abstract

It's a familiar picture nowadays: employees come home, and a yellow parcel notification slip is waiting in their mailbox. Then they must go to the nearest post office to pick up the parcel. This could soon be over, because the plan is to digitalize the delivery process and to place the delivery in the hands of robots and drones. What sounds like science fiction at the moment could soon become reality. But although the advantages of a digital supply chain are convincing, there are still many challenges: How can the problem of the last mile be solved, what about the connectivity of networked delivery vehicles and what is the best solution for efficient coordination of the stakeholders involved in the delivery process? In this article, Dietmar Schnepp, Product Director at Molex, shows how important End2End digitalization is for logistics, how the benefits of digitalization can be exploited, what role an open platform plays and what OEMs need to do to make digitalization safe and efficient.

German logistics market on the rise

The logistics market in Germany is booming. It's the third largest economic sector[1] in the Federal Republic of Germany after the automobile industry and trade. The European market amounts to approximately one trillion euros, to which Germany contributes about a quarter. The truck remains indispensable here, both in local and long-distance transport: the truck transport market in Europe has an annual sales volume of 221 billion euros. In Germany, the share of transport vehicles in freight traffic has remained stable at 70 percent in recent years, with up to 500,000 truck tours per day. Around 60,000 predominantly medium-sized companies are active in the logistics sector in Germany.

[1] Source: https://www.bvl.de/service/zahlen-daten-fakten/umsatz-und-beschaeftigung

Online trading plays an important role in the logistics market: more and more goods are ordered online and delivered to private households. By 2016, more than 3 billion parcels had already been delivered to German households. The Parcel and Logistics Association BIEK expects the volume of parcels in Germany to increase by 30 percent by 2021. According to the Fraunhofer Institute, the volume of parcels in Europe will almost double by 2021.

What is on the one hand a blessing for companies is, however, increasingly becoming a curse. This creates new challenges, especially for the logistics industry. For example, for the so-called "last mile", the transport from the depot to the customer's front door. Small delivery quantities and distributed delivery points ensure that the goods can hardly be bundled here. In addition, it often happens that residents are not at home and cannot accept the parcel, which forces delivery services to make a second, expensive delivery attempt. Research has shown that the last mile is the largest cost factor in parcel delivery and accounts for more than 50 percent of total costs.

Additional burdens due to traffic density, shortage of skilled workers and environmental concerns

In addition to the last mile, increasing traffic density is also a growing problem for the logistics industry. Apart from to the existing mass of passenger cars, there is also an increasing number of delivery vehicles. According to calculations, delivery vehicles already account for 30 percent of traffic within cities today. On the one hand, this causes high noise pollution for residents and, on the other, environmental pollution due to exhaust fumes. Moreover, the increase in traffic is causing a drop in the productivity of delivery vehicles because they are stuck in traffic jams and are therefore unable to keep to specified routes and times. Furthermore, this increases fuel consumption, and, drivers accumulate overtime that has to be paid or compensated for, thus causing additional costs for the supplier companies. Another problem is the lack of parking space in densely populated areas, which means that vehicles have to stop in second row, often making it difficult to deliver parcels and at the same time causing discontent among other drivers and local residents.

A shortage of skilled workers and a lack of fleet capacity are also noticeable - especially during the high season, e.g. before Christmas. Last year, for example, the forwarding companies Dachser and Nagel sounded the alarm before Christmas and spoke of acute capacity bottlenecks due to a shortage of manpower and loading capacity.

A further challenge for logistics service providers are same-day-deliveries. Especially when food comes into play, the cold chain must be guaranteed, which further increases the pressure. However, more and more business models are relying on such same-day deliveries to reach new urban target groups. In order to solve these complex processes economically and to optimize them further, logistics companies are looking for targeted solutions. Networking and digitalization offer great potential.

Advantages of networked logistics

Networked logistics offers an answer to many of the challenges that logistics companies are currently facing. On the one hand, a functioning network in which vehicles communicate with each other can significantly reduce the risk of congestion. Vehicles are warned when a vehicle in front of them brakes and automatically adjust their speed. In addition, they are informed when a road is closed, or an accident has occurred and can automatically calculate and take alternative routes. In this way, accidents can be avoided, and the safety of road users can be increased. Reduced congestion and effective route guidance also minimize exhaust emissions, which benefits the environment.

Another advantage of networked logistics, which results from the avoidance of traffic jams and effective route guidance, is cost savings for the supplier companies. On the one hand, fuel consumption is reduced if cars are less stuck in traffic jams and on the other hand, delivery tours can be carried out on time so that no overtime is incurred. Ideally, even more deliveries can be made per shift, which further increases productivity.

The expectations of consumers are also better met by networking logistics: Fixed delivery dates can be met and deliveries can be planned better and carried out on the same day - even taking into account the cold chain, as is important for example with food or flower deliveries. Thanks to an open platform, new innovative ideas can also be quickly integrated when demand arises.

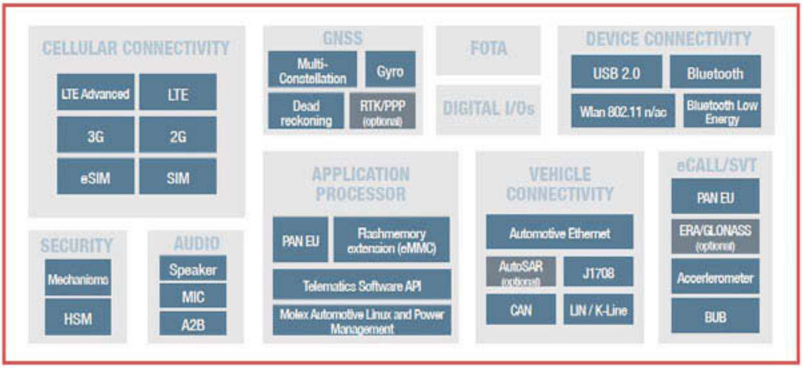
The challenges of End2End digitalization

But even if the advantages are obvious, there are still some challenges to overcome. For example, there is no clear position on the part of the various parties involved. Within the industry sector there are sometimes different requirements based on different company sizes, development and innovation cycles, legal requirements and certification processes as well as business models. This results in challenges in innovation partnerships, the development of new use cases or time-to-market. However, building solutions for smart logistics requires flexibility on all sides to move forward. On the technical side, too, the flexibility of the solution is indispensable and it offers an open, modular platform architecture.

Open modular solution

With the dynamics with which the logistics market grows and changes, monolithic systems slow down innovations and prevent or complicate adjustments and updates during the long-term operating phase of the systems. Application providers and service providers are developing new, attractive solutions in ever shorter cycles. Network providers are constantly expanding their offerings and change structures and prices. Vehicle manufacturers and logisticians must benefit from these changes and orient themselves to the best offers on the market. The overall system used should be flexible and expandable throughout its lifecycle.

These requirements are met with an open and modular platform. When an open telematics platform is developed while taking into account the demand for flexibility and scalability, it allows use in different vehicle models, operation in different geographical regions, etc., with minimal development effort and short market launch times, compared to a completely customer-specific solution. Software Update Over-The-Air (OTA) via different interfaces (preferably Wlan or mobile radio) allows the firmware and application software to be updated throughout the entire life cycle of the vehicle. Full flexibility is also guaranteed in the middleware/application layer, so that a combination of software applications from different providers is also possible via APIs. Thanks to the use of multi-profile SIMs (supporting the eUICC standard), it is also possible to switch network providers during the operating phase. A secure connection with the cloud and the backend is guaranteed so that the applications can be changed or complemented.



Networked deliveries by drone or robot as a solution approaches

The networking of logistics offers the opportunity to turn largely rigid value chains into dynamic value creation networks. Networked logistics and production systems could react much more flexibly to short-term changes in demand or failures within the value chain.

Currently several solutions are in the test phase. For example, parcel delivery by drone, which only makes sense if a dedicated delivery area is available. The drone could fly to a P.O. box, open it by using a code, insert the parcel and close the box again. However, it would have to be very close to the recipient's home so that he or she could simply pick it up. Delivery companies could thus save the cost of multiple journeys when the resident is not at home, and plan and design routes more efficiently.

Another delivery method currently being tested is robotic delivery. These are to be used primarily in city centers, where delivery is difficult and time-consuming. The aim is to reduce congestion and traffic noise.

Another possibility would be to deliver goods to the customers' car boot. However, two hurdles have to be overcomed first: First, the luggage compartment to be supplied must be precisely located so that, for example, the parcel delivery can be handled on the company car park during working hours. Secondly, the security concepts must be so sophisticated that they are not misused when the vehicle is opened.

However, all these projects can only be implemented if all key players are networked: the warehouse, the transporter, the drone or the robot.

Open platforms for comprehensive communication

Due to the complex value chain of logistics, a flexible networking solution is required. The ideal idea of many logistics companies is to combine both existing and newly acquired communication solutions. An attractive solution for this challenge is an open platform that guarantees this networking securely, flexibly, reliably and with a short time-to-market. It's important that the platform provides customers and partners with open and flexible software and hardware components. Application developers can thus concentrate fully on the requirements of complex use cases, while the platform solves the problems of integration in the vehicle and ensures communication between the vehicle and the outside world.

This is important in order to link the different requirements of the various players that play a role in logistics: warehouse employees who have to deliver goods efficiently; transport drivers who have to meet customer requirements quickly and in an environmentally friendly manner; and finally the customers themselves who want their goods delivered within one day. Thanks to increasing networking, goods can be delivered faster and more environmentally friendly.

Robust and secure connectivity is another requirement required for complex wireless networking. This is provided by a connectivity platform embedded in the vehicle, which is securely networked both externally and internally. It must be scalable to allow a wide variety of vehicles such as forklifts, robots, drones, cars and trucks to communicate with each other and also function without Internet access. For optimized and autonomous logistics traffic, real-time data and fast data analysis must be guaranteed as well as a network-independent and permanent connection to other, sometimes autonomous vehicles. It is important here that connectivity solutions include all technologies including mobile communications (from 2G to LTE-A, in future 5G), WLAN, Bluetooth (e.g. BLE - Bluetooth Low Energy) and that vehicle-internal communication guarantees a high database width.

The solution for secure, functioning and robust networking therefore lies in the interplay of functioning end-to-end digitalization, a flexible and scalable networking solution, robust and secure connectivity and an open and modular telematics unit in the form of a Connectivity solution.

BOX: Considering cybercrime from the outset

A point that companies must not lose sight of when searching for the right networking solution are cybercriminals. Logistics and networked vehicles are lucrative targets for cyberattacks. Already today, more and more malware for mobile devices is being tailor-made and hackers and security experts are in a constant race against each other. The first attacks on networked vehicles have already hit the headlines. For example, access to the CAN bus, which networks many ECUs within the vehicle, has been gained via a wireless connection. Hackers were able to take control of a vehicle from a distance and switch off the engine while driving. Other attacks were aimed at gaining control of brakes, door locks, air conditioning and windscreen wipers. As more and more vehicles are equipped with interfaces for data exchange, hackers can use these to break into criminal activities. This risk will continue to increase in the course of increasing networking. Networked vehicles must be regularly supplied with updates in order to protect them from newly emerging dangers, which is a great challenge in view of the mass of networked devices to be expected.

Firmware Over-the-Air (FOTA), the installation of software via mobile radio interfaces, is one way of supplying the large number of devices in vehicles with updates in a short period of time. This allows vulnerabilities to be continuously and quickly patched, new functions to be integrated and cryptographic procedures to be modernized, for example to secure ECUs. A control unit equipped with a mobile radio station takes on the role of an intermediary between the backend and the devices to be updated within the vehicle. It accepts all software packages via the air interface and distributes them to the target devices via CAN bus systems or high-performance communication systems such as Automotive Ethernet. In addition, the electronic control unit Gateway-ECU (ECU = Electronic Control Unit) controls and coordinates the entire update process as the master.

The FOTA process itself must be safe and fast and must not offer any additional attack potential. The consequences for data security and wireless security would be incalculable if FOTA were used to install manipulated software on a device. A prerequisite for this is, among other things, the cryptographic protection of the air interface, for example by encryption using the TLS protocol. The keys and certificates required for this must be inserted into the devices secretly and tamper-proof and stored in a protected memory area. A dedicated hardware security module (HSM) is important in order to implement a secure memory and to execute cryptographic procedures securely.

Venture the steps towards comprehensive networking

Logistics is only at the beginning of a smart supply chain. A survey conducted by shipping service provider Hermes among 200 logistics decision-makers from German companies revealed that only eight percent have begun the digitalization process of their supply chain. And the current trend study "IoT in Production and Logistics" by the market analysis and consulting company PAC on behalf of Deutsche Telekom and its major customer subsidiary T-Systems even certifies that only four percent of the companies have "created a completely networked environment". For the survey, 150 IT and business decision-makers from the manufacturing and logistics sectors were interviewed. The survey also shows that efficiency pressure (77 percent), the necessary increase in competitiveness (73 percent) and the increase in agility and flexibility (71 percent) are important motivating factors for companies to invest more in IoT projects. However, as the study also shows, logistics companies are already much better networked than companies in other sectors, such as production. Furthermore, they are very interested in using IoT technologies to make logistics processes more transparent and efficient. And, due to the pressure for innovation caused by online trading, they are striving for new delivery concepts.

These studies show that although many companies are aware that digitalizing their supply chain processes is important, they lack experience and best practice examples. Without this guidance, companies feel too insecure to start the process. Individual logistics companies can only partially afford this large investment, but in the long run development is too expensive for them. Therefore, the further development will depend strongly on the large companies of the automotive industry. They have a strong interest in networked vehicles - also in the logistics market. After all, automotive companies want to use and sell their networked vehicles and concepts here in the future.

Emissions during braking

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Abstract

As tailpipe emissions from cars have continuously decreased over the recent years, the emissions from brakes have raised increasing attention. Assessment of the release of particles from brakes is challenging, because brakes are no confined sources like a tailpipe. We here present the development of a test rig that allows the reproducible and representative assessment of the particles released from a passenger car brake on a dynamometer test bench. Besides the experimental set up, a testing protocol, based on the WLTP driving cycle, has been developed and tested. The experiments conducted underpin the high reproducibility of the measurement results and the representativeness of the chosen set up and scenario. Emission factors were determined for a front brake of a large SUV. The emission factor calculated for all four brakes of the vehicle, determined with this set up was around 22 mg/km and thus higher than those found in the literature (6-8 mg/km). However, this is reasonable, since the literature data report only average emissions of the entire car fleet, whereas here the brakes of a much larger than average car were tested. Further, the literature data reports emissions from cars, whereas we determined only the immediate emissions from the brakes. Rather large discrepancies between the two can be expected due to particle losses near the brake, e.g. in the wheelhouse or on the rim.

Introduction

Epidemiological studies have established a link between exposure to particulate matter and the number of cases of disease and premature deaths [1, 2]. Airborne particles with an aerodynamic diameter of ≤10 µm are referred to as PM_{10}, particles with a diameter of ≤0,1 µm as ultrafine particles (UFP). PM_{10} and UFP originate from both natural sources, such as soil erosion or volcanoes, and from anthropogenic sources, e. g. industry, road traffic or domestic heating. In urban areas, road traffic is regarded as one of the main sources of UFP and PM_{10} and in some places leads to exceedance of the limit values. Currently, the daily mean value of PM_{10} concentrations may exceed 50 µg/m³ on no more than 35 days per year; the annual mean limit value is 40 µg/m³. Particularly critical are busy street canyons, because depending on the buildings and weather conditions, the exchange of air can be hindered and the particulate concentrations can accumulate. In recent years, research has increasingly focused on ultrafine particles in addition to PM_{10}. By definition, ultrafine particles are smaller than 0.1 µm (100 nm) and can therefore penetrate very deeply into the lungs and into the alveoli. The toxicological effects of ultrafine particles seem to be stronger for the same mass dose than for larger particles [3, 4]. Since the particle mass scales with the third power of the particle diameter, the mass concentrations of ultrafine particles are usually very low, so that they only have very small contributions to the PM_{10} mass concentrations, although ultrafine particles make up the majority of the particle number concentration in the outside air. For this reason, the particle number concentration, not the mass concentration, is used to determine ambient ultrafine particles. However, as of now no limit values for UFP exist. In contrast, the tailpipe emissions from automobiles are also regulated based on the particle number.

Ultrafine particles are mainly generated by thermal processes such as combustion. These processes produce vapours which supersaturate during subsequent cooling and lead to the formation of molecular clusters and ultimately very small particles in extremely high number concentrations. This process is called nucleation. Nucleation particles usually have sizes below 20 nm. Due to their very high number concentrations the particles agglomerate quickly and thus grow. Coarser particles with sizes above several hundred nanometers mainly originate from mechanical processes, e. g. abrasion.

Besides tailpipe emissions, brake and tyre wear are the main contributors to particulate emissions from road traffic [5], with brake wear amounting to 21% of the total urban PM_{10} emissions and 55% of the total non-exhaust traffic emissions [6]. Brake dust emissions originate mainly from two processes: abrasion and nucleation following the thermal release of vapours. Consequently, different size fractions can be released; on the one hand rather coarse particles due to abrasion and on the other hand very small particles due to nucleation. The latter, however, only occurs at elevated brake temperatures, leading to the evaporation of brake material and resulting in very high number concentrations of very small particles [7].

A recent study reported about the release of particles as small as 1.3 nm [8]. For the brakes studied here, we found that the onset brake disc temperature for nucleation to occur is around 180-200°C, which agrees well with values found in the literature. A main challenge in the determination of brake dust release is the reproducible and representative sampling and measurement of the emissions. Several attempts to measure brake wear have been published, which include pin-on-disc set ups and systems to measure the release on a dynamometer test bench. While the prior are more intended towards better understanding the underlying processes leading to particle formation, the latter are mainly designed for quantifying the release under more realistic conditions. A main challenge in the determination of the release is that -unlike in the case of tailpipe emissions- the particles are not emitted from a confined source. Instead, the formation occurs at the interface between the brake pad and the disc, while the disc is rotating at a certain speed and the brake is flushed with air with a typically unknown flow rate and profile.

The aim of the study presented here was to develop and validate a set up that allows for the representative and reproducible determination of the PM_{10} and UFP emissions from a brake on a dynamometer test bench. Besides the hardware and measurement equipment, the representative determination of the emissions also requires the development of a driving cycle that mimics real-world driving.

Development of a test set up and driving cycle

In order to reproducibly determine the emissions from a brake, it needs to be placed inside an enclosure with a defined flow through the enclosure that captures the particles, keeps them airborne and carries them out of the enclosure to the measurement devices. A cuboid enclosure (1010 mm × 920 mm × 565 mm, see Fig. 1) was laid out based on computational fluid dynamic simulations using Ansys Fluent. The numerical simulations were carried out to determine which air flow rate is required through the enclosure to ensure that released PM_{10} particles remain airborne and are carried away with the flow without being lost to the walls due to particle inertia. The calculations revealed that a flow rate of at least 500 m³/h is necessary to properly sample 10 µm particles at a driving velocity of 100 km/h and a disc of approximately 400 mm diameter. The flow rate through the enclosure is provided by the dynamometer test bench (Link Engineering) and filtered with a HEPA H13 filter prior to introduction into the enclosure. A stainless steel grid is placed just downstream of the airflow inlet to homogenize and laminarize the flow.

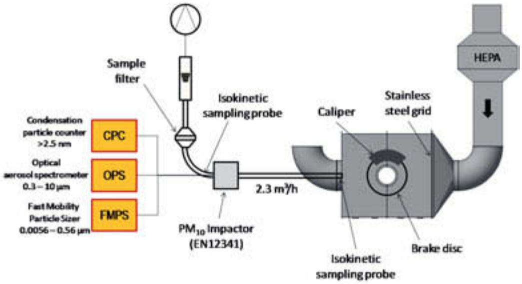

Fig. 1: Experimental set up to study brake dust release (from [9])

Since the flow rate through the enclosure is higher than the total flow rates of the measurement instruments employed, the test aerosol is sampled from the outlet flow of the enclosure through an isokinetic probe. It first passes a PM_{10} impactor, which removes all particles that do not comply with the convention for PM_{10} according to EN 12341. The particles downstream of the impactor are therefore by definition only PM_{10} particles. Two simultaneous routes for characterization of the released particles were chosen. Firstly, particles are sampled through a second isokinetic probe and their number concentrations and size distributions measured with direct reading instruments. Secondly, particles are additionally sampled on a filter to gravimetrically determine the mean PM_{10} concentration during the sampling. While this procedure is certainly more labour-intensive than future regulatory measurements may be, it provides full flexibility regarding the determination of different metrics, i.e. particle number and mass concentration as well as their size distributions. A condensation particle counter (CPC; TSI, model 3776) is used to measure the total particle number concentration of particles with sizes ≥2.5 nm. The number size distributions of the released particles are measured with a combination of a Fast Mobility Particle Sizer (FMPS; TSI, model 3091, size range 5.6 nm - 560 nm) and an Optical Particle Sizer (OPS; TSI, model 3330, size range 0.3 µm - 10 µm). The FMPS first electrostatically charges the particles and then classifies them in an electric field, based on their electrical mobility. The size distribution is thus represented as a function of the electrical mobility equivalent diameter. The OPS measures the particle size distribution based on light scattering and consequently delivers size distributions as a function of the optical equivalent diameter. All three direct reading instruments deliver the results as number concentration or/and number size distribution, respectively, with 1 Hz time resolution. The translation of number size distributions into mass size distributions and size integrated particle mass concentrations (PM_{10}) requires the knowledge (or assumption) of several particle properties, mainly their optical light scattering behaviour, the particle density and particle shape. These are subsumed here in an effective density that is determined by correlating the volume concentrations, calculated from the number size distributions assuming spherical particles and the mass concentrations determined gravimetrically from the filter samples. The volume concentrations are determined by assuming that the particles are spherical and the optical or mobility equivalent diameter would represent their geometric size. The resulting effective densities for the investigated brakes were found to be in a range between 3,000 kg/m³ and 3,300 kg/m³.

Initial tests of the set up revealed that the results obtained with this set up are very reproducible for repeated identical brake tests. However, the question on the representativeness of the results remained, due to the lack of a harmonized driving cycle. We therefore decided to develop a braking cycle based on the existing WLTP (Worldwide Harmonized Light Vehicle Test Protocol) cycle for class 3b, i.e. for vehicles with more than 34 kW/t. The WLTP cycles have been developed to test cars for both their fuel consumption and tailpipe emissions. The chosen cycle has a duration of 1,800 s and covers a distance of 23.262 km in four phases: low (max. speed 56.5 km/h), medium (max. 76.6 km/h), high (max. 97.4 km/h) and extra high (max. 131.3 km/h). The cycle is intended to mimic typical driving behaviour. The driving cycle has been translated into a braking cycle, by determining the deceleration in terms of brake pressures and durations necessary to obtain the same velocity profile prescribed for the driving cycle. To assess the repeatability of the measurement, each test run contains ten consecutive WLTP cycles, thus covering a total distance of 232.26 km. Each new WLTP cycle is started, once the brake disc temperature has decreased to 50°C. Before each test run, the brakes are bedded using 3 × 192 braking operations from the AK Master burnish section, to ensure that the brakes always have the same initial conditions.

Results and discussion

Fig. 2 shows the velocity and applied brake pressures during one WLTP cycle along with the resulting brake disc temperatures during ten repeated WLTP cycles within one test run. The measurements have been conducted on a front wheel brake of a large SUV (weight ~3 t). The Fig. shows the very good repeatability of the temperatures during each of the ten cycles, with only the very first cycle being slightly different, likely due to a difference in the brake pad surface immediately after the bedding and after each of the WLTP cycles. It can further be withdrawn from the Fig. that the disc temperature sharply increases, whenever a high brake pressure (approximately >10 bar) is applied. Eventually, the velocity is decreased from the highest speed of 131 km/h to zero, which causes the brake temperature to increase to >200°C, although the brake pressure remains <10 bar.

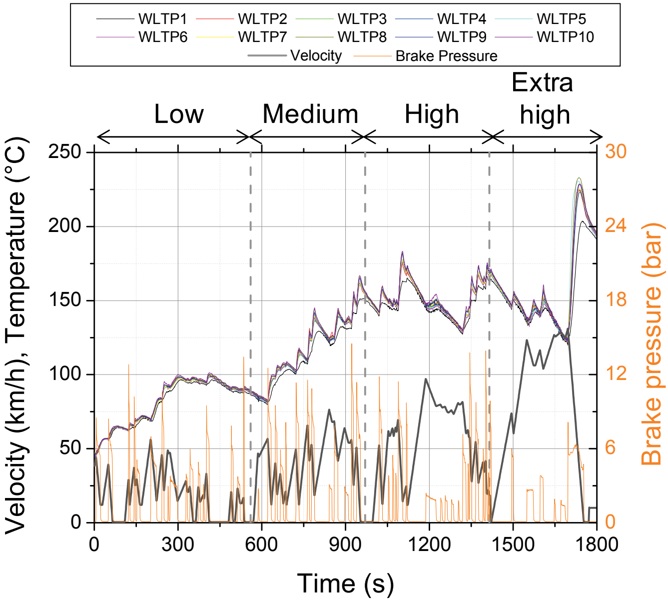

Fig. 2: Velocity and brake pressure applied during one WLTP cycle and resulting brake disc temperatures during ten repeated cycles

The number concentrations measured with the FMPS and OPS during the ten WLTP cycles are shown in Fig. 3. The repeatability of the number concentration measurements during the ten WLTP cycles is equally good as for the temperature shown in Fig. 2. It can be seen from the OPS data that the particle number concentration in-between braking actions quickly drops to zero, which proves that (a) the HEPA-filtered air provided to the enclosure is indeed very clean, (b) no air is sucked into the enclosure from outside and (c) the air does not recirculate inside the enclosure and there are no dead volumes. The number concentration measured with the FMPS does not drop to zero. However, this is caused by electronic noise, because the instrument measures the particle induced current as a measure for the number concentration using highly sensitive electrometers. Measurements with a CPC showed that also the concentrations of ultrafine particles are nearly zero (data not shown here). The Fig. furthermore shows that the number concentrations emitted during the initial “low” phase of the WLTP cycle are very low. Later during the WLTP cycle, the emissions increase and reach the highest concentrations during the final braking from ~130 km/h to zero in the "extra high" phase.

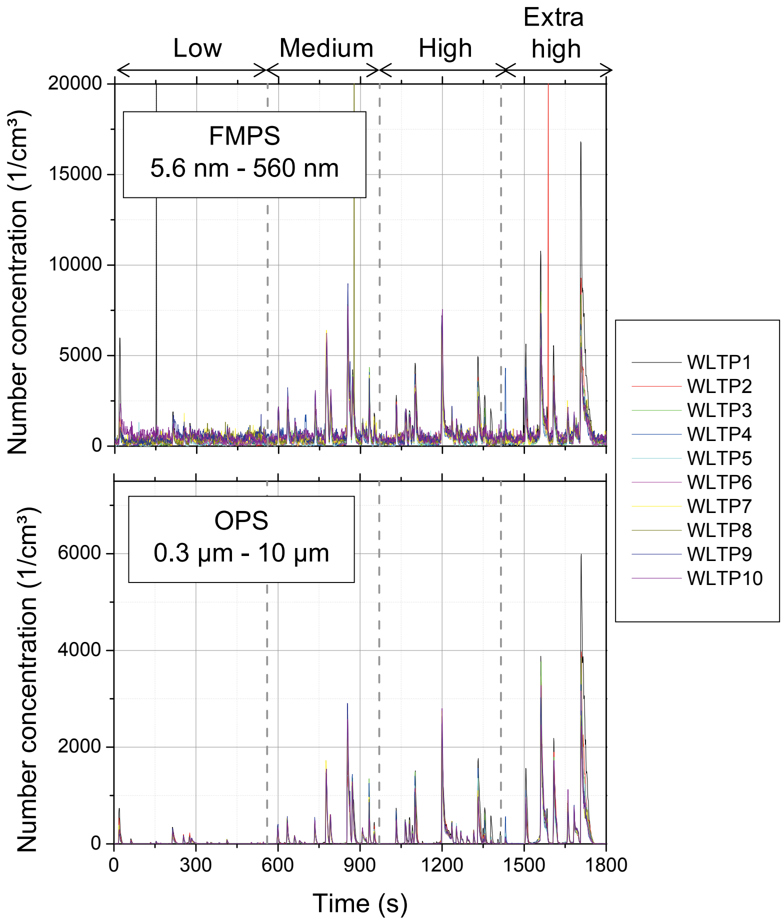

Fig. 3: Number concentrations measured with FMPS in size range 5.6 nm - 560 nm (top) and OPS in size range 0.3 µm - 10 µm (bottom) during ten repeated WLTP cycles

The mean particle number and mass size distributions during the ten WLTP cycles are presented in Fig. 4. It can be seen that the size distributions during all ten cycles are very similar, with only the first measurement showing higher concentrations than the others. Similarly like for the brake temperatures this is also likely caused by the different condition of the brake pad surface after the bedding procedure and after each WLTP cycle. Comparing the number and the mass size distributions, it is apparent that the majority of the particle number concentration is comprised of submicron particles with a peak at around 0.18 µm (180 nm), whereas the main mass concentration stems from micron-sized particles around 2 µm. This shows that considering the WLTP cycle as representative for the general driving, nucleation generated, i.e. very small particles only play a minor role, because the brake temperature rarely reaches the critical level for the onset of nucleation, whereas the released particles mainly seem to stem from mechanical particle generation processes.

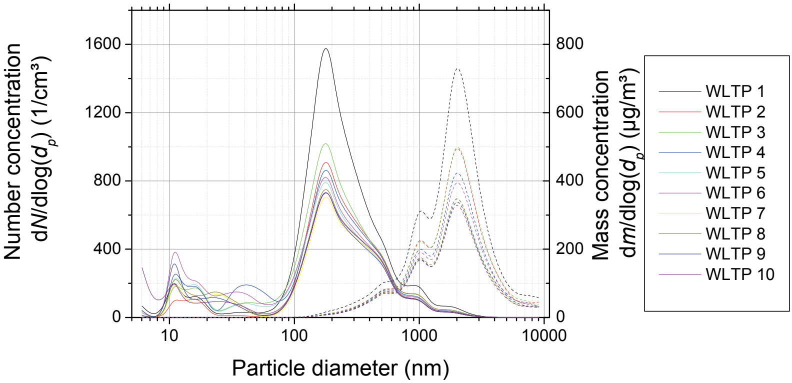

Fig. 4: Mean number (straight lines) and mass (dotted lines) size distributions during each of the ten WLTP cycles of one test run.

Based on the measured concentrations, the known flow rate through the enclosure and the known distance travelled, emission factors of the single front brake tested were determined to be $(1.93 \pm 0.21)\times10^{10}$ 1/km for the particle number and (7.44 ± 1.07) mg/km for the particle mass (PM_{10}). Assuming a typical load ratio of 2:1 for front to back wheels and that the same ratio would apply to the particle emissions, the total brake dust emission factors of all four brakes were estimated to be 5.8×10^{10} 1/km and 22.3 mg/km, respectively. While no number based emission factors for brakes can be found in the literature, those for the particle mass are substantially lower and between 6 mg/km and 8 mg/km [10]. However, it should be noted that on the one hand, these values are average values for the entire car fleet. The brakes tested here are from a large SUV, which due to its weight will certainly emit more than the average fleet. On the other hand, the emission factors found in the literature reflect the particle mass emitted from vehicles, whereas here, only the immediate particles emission from brakes has been studied. Upon emission, many particles will be deposited in the wheel house, on the rims or on the ground, without being released to the outside air. This particularly applies to larger particles, which will be lost due to their inertia. The discrepancies between the literature data and those measured here are therefore reasonable. When comparing the emission factors determined here with the current limit values for tailpipe emissions according to Euro 6 (6×10^{11} 1/km and 4.5 mg/km, respectively), it becomes obvious that the number emissions from passenger car brakes still seem to be an order of magnitude below, whereas the mass emissions are of the same order of magnitude as in the regulation for tailpipe emissions.

Conclusions

A new test set up has been built up and a realistic testing cycle developed that allows for the reproducible and representative assessment of the PM_{10} and UFP emissions from passenger car brakes. The system includes an enclosure of the brake to be tested on a dynamometer test bench. A high air flow rate is passed through the enclosure which carries away the released particles and cools the brake. Particles are sampled from this flow and their size distributions measured with two spectrometers based on light scattering and electrical mobility analysis, respectively. The testing cycle comprises ten repeated WLTP cycles, thus covering a total distance of approximately 232 km with velocities up to 131 km/h. The tests revealed that the emitted particle number is dominated by submicron particles with a peak at about 0.18 µm. Thermally generated nucleation particles only seem to play a minor role in these tests. In contrast, the mass concentration is dominated by micron sized particles, with a peak at around 2 µm. The determined emission factors are around 22 mg/km and thus about a factor of three higher than those found in the literature. However, the literature data refer to emissions from an average car, whereas here only the emissions from the brakes of a large SUV have been investigated. Particle losses in the wheelhouse, on the ground and on the wheel are hence not considered here, but may significantly decrease the emissions from the vehicle to ambient air compared to the immediate emissions from the brakes. Particle emissions from larger and heavier commercial vehicles may be different from the ones presented here, if higher brake temperatures are reached. In this case, nucleation becomes the dominant particle generation process, which would lead to the emission of high number concentrations of ultrafine particles.

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The new vehicle energy consumption calculation tool (VECTO) for heavy-duty vehicles

Scope and limitations

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Abstract

According to the European Commission (EC) - DG Clima, heavy-duty vehicles (HDV) are the responsible for a quarter of CO2 emissions from road transport in EU and around 6% of the EU's total CO2 emissions. In May 17th 2018, a legislative proposal was submitted by the Commission in order to settle down the first CO2 emission standards for these vehicles in the EU. The EC main goal is to achieve between 2019 and 2025 a 15% reduction of new HDV CO2 emissions, being able to increase this reduction up to 30% in 2030.

In order to evaluate CO2 emissions and fuel consumption for HDV, the Commission has set that, as of 1 January 2019, truck manufacturers will have to declare the CO2 emissions and fuel consumption of new vehicles they produce for the EU market. The instrument to calculate their emissions will be the Vehicle Energy Consumption Calculation Tool (VECTO). This information shall be declared in the Certificate of Conformity (COC) for the registration of vehicles under the EU type-approval legislative framework, in application of the EU Regulation 2017/2400 implementing EU Regulation No 595/2009 and amending Directive 2007/46/EC and EC Regulation No 582/2011.

Regulation (EU) 2017/2400 has been amended recently by Regulation (EU) 2019/318 which, among other features, introduces the provisions for considering efficient technical solutions as well as zero emission vehicles (ZEV).

Furthermore, the Commission has published a proposal for a new regulation, COM/2018/284 final, which will set CO2 emission performance standards for new heavy-duty vehicles.

The purpose of this paper is to determine the scope and limitations of VECTO tool by analysing its input data and its operational mechanism. In addition, work under discussion carried out by EC working groups will be examined, as well as the COM/2018/284 proposal for a new regulation. According to the EC, EU Regulation 2017/2400 is just the first step towards a more stringent control of CO2 emissions and fuel consumption for HVD. Furthermore, this document pretends to be a guide to know and understand the future step of the future of CO2 emissions standards on heavy-duty vehicles.

1. Introduction

Over the past decade, heavy-duty vehicles (HDVs) have joined passenger vehicles in becoming the object of regulatory measures aimed at curbing their tailpipe CO2 emissions. HDVs are responsible for more than the quarter of CO2 emissions from road transport and around 6% of the EU's total CO2 emissions and around 25% of total road transport emissions. Unlike light-duty vehicles, the HDV CO2 certification approaches implemented in most regions around the world use a combination of component testing and vehicle simulation. The simulation tools used for certification are physics-based models that use certified component data as input, in order to model the fuel consumption of HDVs over a given driving cycle and vehicle payload.

This approach requires a joint effort for the different manufacturers involved in the process of building a HDV, as each of the TIER 1 will be responsible for the efficiency related performance and certification of the parts produced by them.

2. Overview of VECTO certification in the EU

2.1 Scope

The main scope of Regulation (EU) 2017/2400, as regards the determination of the CO2 emissions and fuel consumption of heavy-duty vehicles, is to cover all possible policy steps, such as:

- Monitoring, reporting and certification
- Improvement of market forces
- Labelling
- Improvement and enhancement of foot-printing schemes
- Offering a reliable real world picture of the fuel consumption/CO2 emissions
- Fit for the future, including new technologies
- Minimisation of burden on OEMs

The application of the requirements for CO2 emissions and fuel consumption of HDV has been designed to be stepwise. This means that, even if the regulation defines the whole range of existing HDV, only the requirements for several truck groups have been set until now.

In the case of multi-stage building procedure, currently the Regulation is only applicable to the base vehicle equipped, at least, with chassis, engine, transmission, axles and tyres.

2.2 Component oriented certification

As described under section 1 of this paper, Regulation (EU)2017/2400 considers each vehicle as a group of components or agents whith an own impact of the whole vehicle fuel consumption and CO2 emissions. As a consequence, a series of components need to be tested in order to produce the necessary input data for VECTO to calculate the CO2 emissions and fuel consumption to be declared.

The tests results are converted into standardised .xml files that can be read by VECTO.

Fig. 1: VECTO Input group. Source: internal IDIADA

Specific methods (including measurements or fall-back options to reference values) are described for:

- Air drag
- Engine fuel consumption and CO2 emissions mapping
- Transmission losses
- Torque converter losses
- Axle losses
- Retarder losses
- Auxiliaries losses
- Tyres rolling resistance

2.2.1 Air drag

The air drag approach is the most newfangled parameter introduced and taken into account by VECTO as a contributor to the fuel efficiency. It is based on a simplified approach: a higher air drag of the vehicle supposes a higher fuel consumption (and, consequently, a higher CO2 emission level) to avoid this resistance.

The way for the determination of this parameter is a calculation using a post-processing tool, sub-module of VECTO, named VECTO Airdrag. The input for this tool is the result of a constant speed test (CST). This tests relies mainly on measurement of the driving torque during vehicle operation at two different constant vehicle speeds (high speed and low speed). The vehicle speed, air flow speed, and yaw angle are also measured to enable the estimation of the drag area.

The test sequence begins with a warm-up phase, followed by a low speed run between 10 and 15 km/h, followed by a high-speed test between 85 and 95 km/h, and finalizing with a low-speed run. At least 10 valid high-speed runs shall be reacorded in each direction.

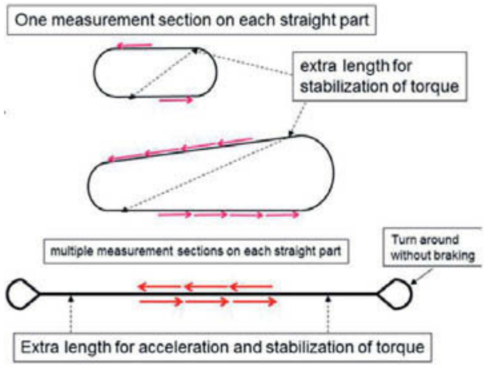

Fig. 2: Aerodynamic drag section requirements. Source: [3]

With all these constant-speed measurements being used as an input, the value returned by the post-processing tool VECTO Airdrag, is the C_DA value. This value is calculated based on the instantaneous tractive force powering the vehicle at the different constant-speed segments using the measured driving torque, the wheel angular speed, and vehicle speed.

2.2.2 Engine fuel consumption and CO2 emissions mapping

The engine evaluation of Regulation (EU) 2017/2400 is mainly based on the tests set in the UN/ECE Regulation 49 Rev.06, except for the transient behaviour of the engine, which is not considered by VECTO, as it is based on the fuel consumption measured in different steady state points. So, as a solution for this, a transient correction factor based on the actual WHTC measurements is used.

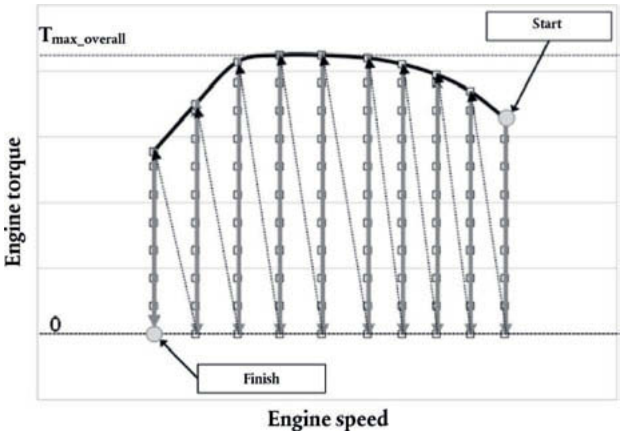

Fig. 3: Fuel consumption mapping cycle (FCMC). Source: [1]

As for the air drag calculation, VECTO has its own module for the pre-processing of the engine data in order to generate the component .xml file. The inputs that are needed by the VECTO engine pre-processing tool are:

- Engine full load curve
- Engine motoring curve
- World Harmonised Transient Cycle (WHTC)
- World Harmonised Stationary Cycle (WHSC)
- Fuel consumption mapping cycle (FCMC)

WHTC and WHSC are based on the requirements stated in the UN/ECE R49.06. However, the main test on which VECTO calculations are based is the fuel consumption mapping cycle.

This new cycle is a map of different steady-state points where the fuel mass flow consumed by the whole engine system is measured, not considering the transition behaviour between

one and each other. Previously to the FCMC, for a correct definition of the map of points, two additional test pre-cycle are necessary: the engine full load curve and the motoring curve.
The engine full load curve defines the power and torque curves of the engine, while the motoring curve, measures the negative torque required to motor the engine between maximum and minimum mapping speed with minimum operator demand.
The output data of the engine pre-processing tool is the final result of the engine tests procedure and shall be documented.

2.2.3 Transmissions and axle general provisions

The transmission of power from the engine to the tyres and wheels involves changing the rotational speed from the engine, including enabling the engine to idle when the vehicle is stationary.It is noted that the overall efficiency depends on a range of components, including the gearbox, clutch and the rear axle. Further, the deep integration of the engine and transmission to optimize vehicle gearing to engine performance, and enhanced communications between the engine ECU and the transmission controller to optimize operation, provides potential for reductions in fuel consumption.

The principal current transmission technologies can be summarized as:

- Manual transmissions (MT)
- Automatic tranmissions (AT)
- Automated manual transmissions (AMT)
- Dual clutch tranmissions (DCT)
- Continuously variable transmissions (CVT)

And related to the axles, that could be considered as part of the transmission system from the engine output to the wheels, the types considered are:

- Single reduction axle (SR)
- Single reduction tandem axle (SRT) / Single portal axle (SP)
- Hub reduction axle (HR)
- Hub reduction tandem axle (HRT)

The checking of all these components is based on the measurement of the input torque versus the output torque, with this are defined the different torque losses for several rotational speed and torque points.

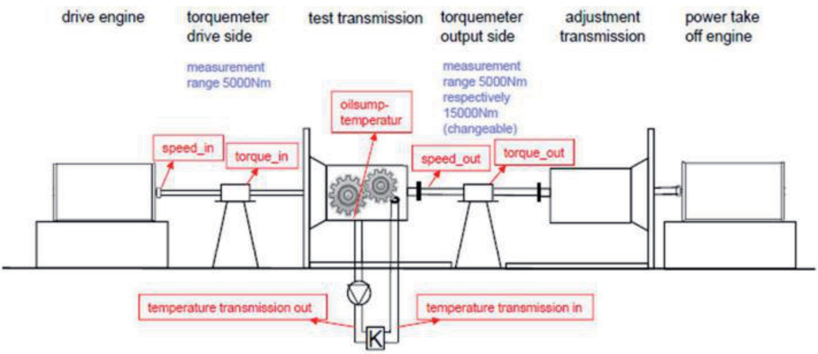

Fig. 4: Transmission testing assembly. Source: ACEA

2.2.4 Tyres

The rolling resistance of the tyres is one of the most importnat contributions to the loss of efficiency in HDV. Thus, this value is also considered as an input to VECTO simulation tool.

The rolling resistance coefficient is obtained from the testing according UN/ECE Regulation No. 54 and UN/ECE Regulation No. 117 and it applies to each tyre type supplied to the original equipment manufacturers.

2.2.5 Auxiliaries

VECTO also considers the power consumption of some of the auxiliaries that can be installed in the vehicle.

In this case, as auxiliaries have a wide range of variations and most of the manufacturers may not be able to afford the costs related to the homologation procedures, standard values are defined.

The following auxiliaries shall be considered within the calculation tool by using technology specific average standard power values:

- Fan
- Steering system
- Electric system
- Pneumatic system
- Air conditioning (A/C) system
- Transmission power take off (PTO)

These loads are variable, depending on when and where a vehicle is driven. The mechanically coupled systems that the electrical systems replace are often engine speed dependent, but relatively load independent. Consequently, the absolute fuel consumption of the mechanical accessories is both time and engine speed dependent. Therefore, the relative proportion of fuel consumption of these accessory loads is lower at higher speeds.

2.3 Monitoring and reporting of CO2 emissions

The manufacturer's records file together with certificates on CO_2 emissions and fuel consumption related properties of the components, systems and separate technical units shall be stored by the vehicle manufacturer for at least 20 years after the production of the vehicle and shall be available to the approval authority and the Comission at their request.
As Regulation (EU) 2017/2400 does not define any limits currently, the results from the manufacturers will be used for monitoring purposes. In order to check the status of the current situation, those data should form the basis for determining the reduction targets to be achieved by the groups of the most emitting heavy-duty vehicles in the Union, as well as for determining a manufacturer's average specific emissions in a given calendar year.

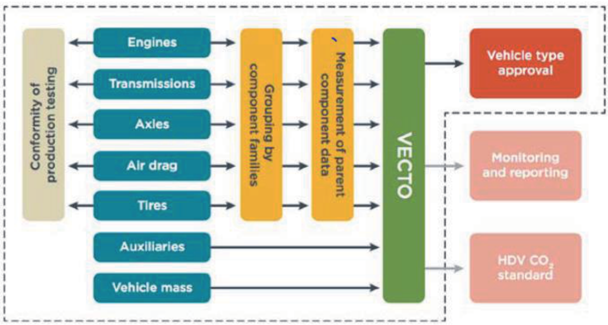

Fig. 5: EU certification flow. Source: [4]

2.4 Verification Testing Procedure

Regulation (EU) 2017/2400, as last amendment Regulation (EU) 2019/318, considers a method in order to verify the use of VECTO by the vehicle manufacturer's, named Verification Testing Procedure (VTP).
For this purpose, on-road tests shall be performed by the vehicle manufacturer and verified by the approval authority. The main parameters to be measured are:

- Engine speed

- Torque and speed at the driven wheels
- Fuel consumption

After the test is performed, the same cycle is used as an input for the VECTO VTP mode, which will return, as an output, the calculated CO2 emissions and fuel consumption for the actual driving cycle.
Then, both the measured fuel consumption and the simulated one are compared.. The criteria for the pass/fail check, is based on the wheel work specific fuel consumption in g/kWh from the VTP measurement, and it has to be lower than the VECTO simulation result, plus a tolerance of 7.5%.

3. Overview and comparison with other methodologies

VECTO is not the only methodology used for measuring the HDV CO_2 emissions, but only the approach that is being used in EU. There are other methods with the same aim and with good results also, such as GEM, which is the official methodology for the USA certification.

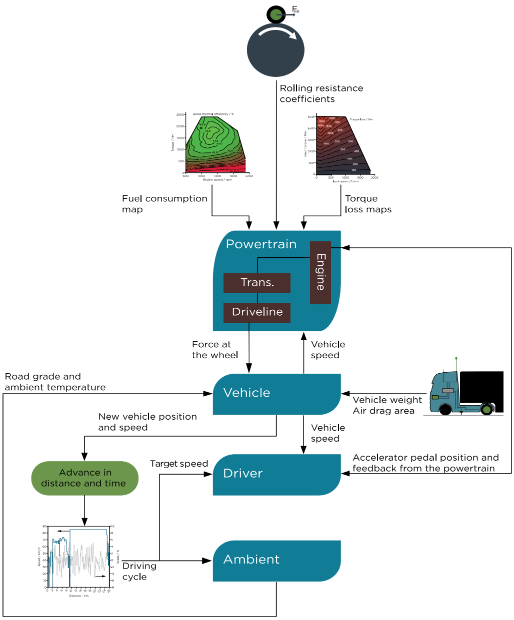

Fig. 6: GEM's architecture flow chart. Source: [2]

There are, however, substantial differences between both approaches. On the one hand, the GEM's model does not feature a graphical user interface as VECTO does. It was developed in Matlab Simulink as a forward-looking model (the simulation flow runs from the accelerator pedal to the wheels). The GEM architecture is comprised of four main modules: powertrain, vehicle, driver (which is a closed-loop controller) and ambient.

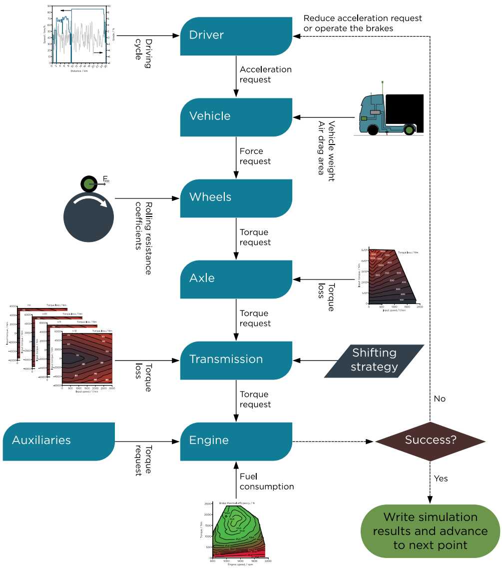

Fig. 7: VECTO's architecture flow chart. Source: [2]

On the other hand, VECTO was developed in C# as a backward-looking model (the simulation flow runs in the opposite direction to the way it takes place the actual vehicle). This means that, the driver model converts the drive cycle information into an acceleration request, to ultimately locate an appropriate operating point in the engine fuel map. Once a valid engine operating point is found, the simulation moves to the next point in the driving cycle.

4. Gaps and future steps

As it has been explained in the first paragraph of this paper, VECTO is mainly focused in trucks, tractors and buses currently, with the only chance to be used for certification in the case of trucks and tractors. Buses and vehicles built in multi-stage procedure are not yet included in the procedure.

Additionally, in the last years different technologies have been put into the market which reduce significantly the fuel consumtion. Some of those technologies cannot be correctly represented in VECTO, so that manufacturers have complaint about the lack of advantadges, in terms of official CO2 emissions declaration, of investing in innovative technologies.

4.1 Latest modifications and work in progress

In order to cope with the gaps defined in the previous paragraph, the Europen Commission, through its subsidiary bodies (such as DG-GROW and DG-CLIMA) continues the work to amend and update Regulation (EU)2017/2400 and VECTO simulation tool. An example is the latest amendment published, Regulation (EU)2019/318, which considers how vehicle with low emissions technologies shall be considered.

For example, dual-fuel vehicles have been incorporated to the Regulation, as vehicles with combustion engines that can be powered with diesel or gas indistinctly have a different behaviour and emissions impact depending on which fuel is being used.

Zero emission heavy-duty vehicles, which are defined as a heavy-duty vehicle without an internal combustion engine or with an internal combustion engine that emits less than 1 g CO2/kWh have also been considered in the regulation, where they are not required to report any level of emissions, but shall be declared as ZEV.

4.2 Future steps

Automotive industry in Europe is pushing forward to innovative solutions with the purpose of developing new and efficient vehicle configurations.

EU founded projects, such as AEROFLEX and TRANSFORMERS are an example of such new technologies, where the energy source can be distributed between truck and trailer, or where advanced aerodynamic solutions are studied

5. Conclusion

HDV have an important contribution to CO2 emissions which has been identified by the European Commission. Even if the proposed tools, such as Regulation (EU) 2017/2400 and VECTO are yet in an initial phase and require several upgrades in order to be really representative of the actual emission values, they have proven to be a powerful method to initiate the strategy of CO2 emissions reduction in Europe.

As it is frequent in rulemaking forums, industry is one step forward of the regulations being developed, but great efforts are put to reduce this gap.

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AEROFLEX – Advanced Energy Management in Distributed Powertrains

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Abstract

This paper is part of the AEROFLEX – *AEROdynamic and FLEXible Trucks for Next Generation of Long Distance Road Transport* – project. It concentrates on the concept of the Advanced Energy Management in Distributed Powertrains. Powertrains in long-haul vehicles can be distributed by installing additional electric powertrains in trailers and dollies. This enables two very interesting possibilities: 1. reducing fuel consumption by hybridizing the whole vehicle combination and 2. improving the driveability of longer and heavier long-haul vehicles by adding additional drive axles, which e.g. improve gradeability. This paper gives an overview over the concept, the control approach and the communication between the individual parts of the vehicle combination. It also discusses the torque demand of different vehicle configurations and provides furthermore, simulation results for the fuel consumption. Both underline the potential of distributed electric powertrains in future long-haul vehicles.

Introduction

The AEROFLEX – *AEROdynamic and FLEXible Trucks for Next Generation of Long Distance Road Transport* – project, which receives funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 769658, investigates aerodynamic and flexible trucks for the next generation of long distance road transport. The project website [1] and a first publication [2] provide an overview over the different project developments. In addition to aerodynamic measures, smart loading units and safety developments, a distributed hybrid powertrain is investigated. The developments in combination target to improve transport efficiency by up to 33%.

This publication focusses on the new distributed powertrain concept. It will describe the powertrain's structure and the idea of the torque distribution among the different powertrains. Furthermore, first simulation results of the fuel consumption reduction are given.

Already in the EU-project TRANSFORMERS a conventional truck was combined with an electrified semitrailer to create a hybridized combination, which reduces the fuel consumption even with a simple energy management strategy, [3]. This system is called Hybrid on Demand (HoD). The AEROFLEX project enhances this idea towards the Advanced Energy Management Powertrain (AEMPT). The AEMPT contains a global energy management in the truck, which can use all powertrains – especially electric powertrains – in the whole vehicle combination as driving and recuperation devices. In contrast to the simple strategy, used in the TRANSFORMERS demonstrator, higher fuel savings can be achieved with this new global approach. Furthermore, the global approach enables a supervisor safety controller, which ensures driving stability for the vehicle combination.

Fig. 1 shows the vehicle combinations, which are considered in this publication. For testing purposes, also conventional versions, e.g. a standard tractor semi-trailer combination, are used as references. The first combination is the HoD demonstrator known from TRANSFORMERS. It consists of a conventional tractor and a Schmitz Cargobull semitrailer whose last axle is fitted with an electric powertrain. In contrast to TRANSFORMERS, the tractor is an MAN brand. This shows that the retrofitting idea of TRANSFORMERS works. With minimal effort the MAN tractor is coupled to the semitrailer to create a hybridized vehicle combination. The second combination is a 25-m configuration called EMS 1 (European Modular System). The pulling unit is a diesel 6x2 rigid truck with the Global Energy and Torque Management System (GETMS). To the truck a dolly is coupled, which has a steerable front axle and an electrically driven rear axle. This combination is the major development focus for the AEMPT in AEROFLEX. The third combination is a 32-m configuration, referred to as EMS 2. The GETMS is now included in a diesel 4x2 tractor. The first semitrailer also comes from the TRANSFORMERS project, but is in this case the Aerodynamic demonstrator from Van Eck. The same dolly and semitrailer as from the EMS 1 configuration are coupled to this semitrailer. This vehicle combination shall show the flexibility of the AEMPT for different vehicle combinations. In addition it shall show, that distributed powertrains can help to power longer vehicle combinations, with a smaller than normal diesel engine in the pulling unit as they would be powered fully by the truck or tractor. The following section will give an overview about the distributed powertrain system and how it is controlled.

Fig. 1: Vehicle Combinations considered: TRANSFORMERS HoD as advanced reference, AEROFLEX EMS1 as development focus, AEROFLEX EMS2 as possible show case

An important aspect during the development of the distributed powertrain is functional safety. Even though no homologation of the vehicles is planned in the project, a reduced safety process based on ISO 26262 is performed, because testing on public roads is planned. The safety process includes a Hazard and Risk Analysis (HARA) and deducted safety measures. To support the HARA and for the development of the powertrain management system, multi-body simulations are carried out. The section below will give insight into the simulations about vehicle stability.

After dealing with the general concept and torque demand and distribution, another section will focus on the first simulations regarding fuel consumption. It will show, what savings can be expected when installing additional electric powertrains in longer vehicle combinations.

Overview of the Distributed Powertrain

A first simple version of a distributed powertrain was developed in the EU-project TRANSFORMERS. Some details about the concept can be found in [4] and [5]. Two scenarios were considered there, which were named Case A and Case B. In Case A, a largely standard tractor is used with a conventional engine. The semi-trailer is fitted with an electric powertrain and an internal energy management system. This energy management system applies the torque of the electric machine in addition to the tractor's engine torque during driving and performs a brake blending during braking. Because the tractor does not know about the trailer's actions, the fuel saving potential is limited. However, a retrofitting of legacy tractors is possible. Case A was developed as demonstrator in TRANSFORMERS and used with Volvo and DAF pulling units. In the AEROFLEX project, the trailer is used again, but this time with a retrofitted MAN tractor. Case B in TRANSFORMERS shifts the intelligence of energy management to the tractor. So the tractor knows about the capabilities of its own and the additional powertrain in the trailer. This allows for more sophisticated energy management strategies, which enable higher fuel savings, because the usage of the conventional engine and the electric engine can be better coordinated. This was only shown by simulation in the TRANSFORMERS project, [6]. Because of the promising results, the AEROFLEX project will consider this Case B and extend it to support not only tractor semi-trailer combinations, but arbitrary vehicle combinations, in particular EMS1 and EMS2 combinations, see Fig. 1. For compatibility reasons the number of trailer units is limited to five, like in the ISO 11992 communication.

Fig. 2 gives an overview of the AEMPT structure. The backbone of this distributed architecture is the Automotive Ethernet network, which connects the individual vehicle units. This technology has a substantially higher bandwidth than CAN and allows therefore to transmit more information. It is planned to use the two ISO 11992-2 pins of the standard tractor-trailer connector for Automotive Ethernet. Thus, each vehicle unit needs an Automotive Ethernet Router/Splitter (AE Router), which also routes the standard ISO 11992 messages between the Electronic Braking Systems (EBS). On the tractor unit the Vehicle Control combines:

- A Global Energy Management, which uses the tractor engine and the electric powertrains in the trailer units in the most efficient way
- The Advanced Driver Assistance Systems (ADAS), like cruise control, ECO roll, etc., which also can share information with the control of the distributed powertrain
- A Driving Stability Guard, which ensures vehicle stability, especially when the trailer units start pushing
- A Global Torque Controller, which combines the torque requests and limits from the systems above

On the trailer units a Local System Management (LSM) handles the control of the underlying powertrain (Energy Storage, Electric Machine, etc.) and provides a standard interface towards the EBS and the tractor. This enables different powertrain architectures in each trailer unit, which are controlled locally, without the need for the tractor unit to know the exact powertrain layout in the trailers. For example the dolly in the project is fitted with an electric drive axle with integrated motors, whereas the semi-trailer has a central motor with a standard drive axle. The trailer units send their current capabilities to the tractor, which uses this information e.g. for the energy management. The Local System Management also needs to communicate with the

EBS, so that the EBS knows about the additional torques on the wheels during driving and also to support brake blending between electric braking and friction brakes.

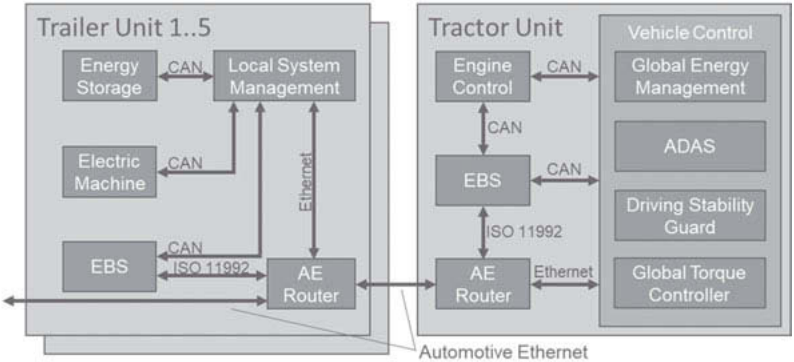

Fig. 2: Structure of the Advanced Energy Management Powertrain

This powertrain architecture allows the tractor unit to take the responsibility for the energy management and stability of the whole vehicle combination, with as little information to share between the units as possible. Each trailer unit is responsible for a safe operation of its internal systems and to provide information to the tractor unit. Of course, the EBS on each trailer also contributes to the vehicle stability with its standard functions, like ABS, Roll over Protection, etc.

Torque Demand

The AEROFLEX powertrain concept will allow to flexibly combine vehicle units into efficient combinations. Besides working efficiently in terms of fuel saving, the powertrain always needs to provide sufficient torque to ensure a good driveability of the vehicle. A today's typical tractor unit for long haul 40 ton transport is equipped with a 420 to 500 hp engine. However, such a tractor unit configured to operate together with a single semitrailer is not suited for pulling a double trailer 74 ton EMS vehicle. Directive EC96/53 requests a minimum load on driven axles of 25%. One driven axle in EMS vehicles above 25.25 m is not sufficient to reach this value. For a 25.25 m, 8 axle EMS 1 vehicle, an axle weight of 11.5 ton results in a percentage of about 19%. For a 10-axle EMS 2 vehicle of 74 tons, 11.5 tons on a single driven axle result in a percentage of merely 16%.

Jarlsson et al. [8] investigated an EMS 2 A-double configuration up to 74 tons by real world tests. Numerous wheel spin events showed, that traction of a 6x2 tractor unit is not sufficient for pulling such a high load.

On the other hand, a 6x4 high powered tractor unit configured to pull a heavy EMS vehicle will not work efficiently together with a single semitrailer. Apart from the second driven axle, for such a purpose the tractor unit will normally be equipped with a 15 to 16 litre engine above 600 hp and a rather large rear axle ratio. For operating together with a single semitrailer, such a configuration increases weight, fuel consumption and cost of investment.

In summary, today the engine, gearbox and rear axle ratio is always configured to operate efficiently together with a specific trailer configuration. Here the AEROFLEX approach provides new possibilities by including additional electric torque if needed. As an example, for startability of a 60 ton vehicle, 10,000 Nm electric wheel torque at trailer axles result in an additional 3 degrees of slope which can be overcome on both wet and dry road conditions. For a flexible vehicle portfolio, it can be assumed that the powertrain of a truck or tractor itself is optimally configured for pulling a 40 ton configuration. As a requirement for startability of EMS vehicles a 12% slope is considered. This value is in line with the findings of the FALCON project which applied Australian Performance Based Standards (PBS) to EMS vehicles. To compensate gravity force of load exceeding 40 tons on a 12% slope, the trailer units have to provide additional 600 Nm of electric wheel torque per ton of additional load. For a 60 ton vehicle this results in an electric wheel torque requirement of 12,000 Nm.

Electric torque can only be provided if there is enough energy available in the battery. For the powertrain management system this results in the requirement that if possible, enough energy shall be kept to be capable of providing good driveability for driving situations which demand high torque. To support gradeability on longer slopes, a predictive preconditioning of the batteries can be useful and of course battery capacity has to match the energy demand on specific routes.

The 25.25 m demonstrator vehicle which is currently built in the AEROFLEX project will comprise two electrically driven axles. The dolly is equipped with a ZF AVE 130 axle providing a wheel torque of up to 17,000 Nm for the complete axle. The trailer axle provides additional about 2,500 Nm. Looking at the wheel-road contact, this equals an increase in traction potential of about 40% on dry roads (μ = 0.8). At wet road conditions (μ=0.5) this results in a rise of traction potential of about 70%.

Fuel Consumption Simulation

In order to derive requirements for battery capacity and the Electric Motor Generator (EMG) as well as to get a first impression of the fuel consumption performance of AEMPT vehicles, low detail simulations have been conducted. A detailed explanation of the simulations and results can be found in the public deliverable [7]. The simulations have been conducted with the TNO in-house developed model called MEO (Multi-level Energy Optimization). Fig. 3 shows the main structure of the model. A physics-based road load model calculates the wheel power demand from vehicle characteristics and a mission profile. The mission profile is a representation of a driven or simulated route, consisting of road topology (elevation profile), vehicle velocity and payload. A (linear) Willans Line Powertrain model is used to estimate the fuel power demand (and consequently fuel used) from the wheel power demand.

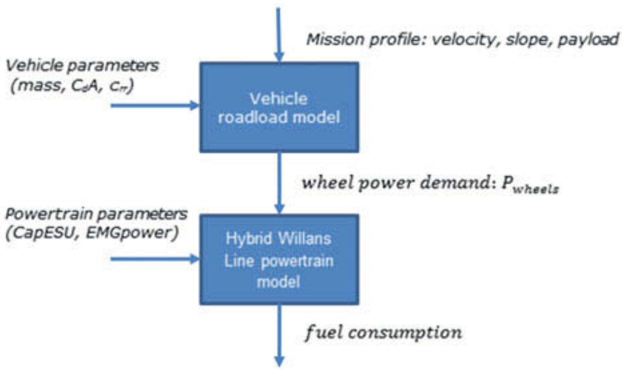

Fig. 3: Structure of the MEO modelling approach for a conventional power vehicle

The model has been extended with a power split controller in order to realistically model the State Of Energy (SOE) of the battery. The controller chooses the preferred control mode based on the current SOE and the power demand, aiming to keep the SOE around 50%. The possible modes - Charging while driving (C), Internal combustion engine only (ICE only), Motor Assist (MA), Motor Only with ICE idling (MO) and Regeneration (R) – are shown in Fig. 4.

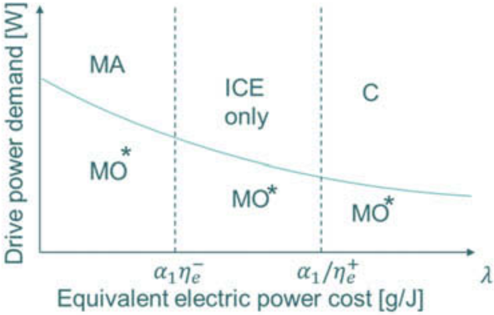

Fig. 4: Hybrid modes allowed by the power split controller

For these simulations, three simulated mission profiles (Motorway flat (S1), motorway frequent elevation changes (S3) and motorway steep hills (S4)) from the TRANSFORMERS project have been used (see [6]). It has to be noticed that the same 40 ton Tractor-semitrailer (TT) based mission profiles have been used for all simulations. This means that the absolute fuel consumption figures for the heavier EMS 1 and EMS 2 combinations might be overestimated (they are forced to accelerate as fast as a conventional TT). The vehicles are simulated with payloads ranging from 0 to maximum allowable payload of 40, 60 and 74 ton for TT, EMS 1 and EMS 2, as well as intermediate steps of 10 tons. Different values of EMG power ranges from 80-720 kW in total and battery capacities from 1-60 kWh have been simulated.

Table 1 shows the main findings of the simulation study. For the three different routes and payloads as well as vehicle types, the (numerical) optimal solution is given. Based on the fuel efficiency gradient in EMG and battery size directions, an engineering-based selection can be made. Especially, where the gradient is flat a smaller EMG or battery can be selected without significantly penalizing fuel savings (full load conditions). This is depicted as example in Fig. 5. The hybrid system has the highest potential in mountainous conditions obviously, resulting in 7-17% reduction of fuel consumption for all three vehicle types dependent on its weight compared to its equivalent conventionally driven vehicle. On ordinary (flat or with moderate elevation changes) motorways, the maximum fuel reduction is between 5-8% depending on the vehicle type and payload. The optimal EMG and battery size per ton Gross Combination Weight (GCW) can be calculated and are 4 kW/ton and 0.35 kWh/ton, respectively.

Table 1: Results of the simulations, optimal hybrid configuration and resulting increase in fuel efficiency in l/km

		Flat highway (S1)		Frequent elevation changes (S3)		Mountain pass (S4)	
		20 [t]	full	20 [t]	full	20 [t]	full
TT	Battery [kWh]	20	60	20	60	20	60
	EMG [kW]	480	720	400	560	400	480
	Fuel efficiency [%]	6%	7%	5%	7%	15%	17%
EMS1	Battery [kWh]	20	60	20	60	20	60
	EMG [kW]	480	720	400	720	320	720
	Fuel efficiency [%]	6%	8%	5%	8%	13%	17%
EMS2	Battery [kWh]	30	60	20	60	30	60
	EMG [kW]	560	720	480	720	480	720
	Fuel efficiency [%]	6%	8%	5%	9%	15%	16%

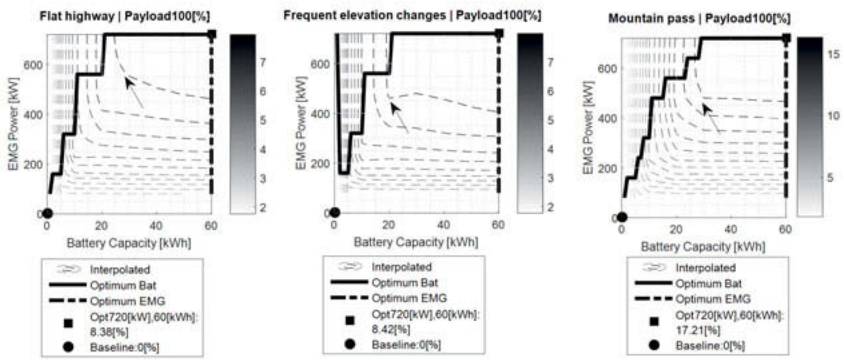

Fig. 5: Simulation results of EMS1 at full load (GCW 60t) for different routes with different combinations of EMG and battery size. The black arrows show engineering-based selected EMG and battery sizing based on the flat fuel savings gradient.

Summary and Outlook

The results from TRANSFORMERS as well as the above studies regarding fuel consumption and driveability show that distributed electric powertrains can offer two very interesting advantages. They can contribute to fuel saving by effectively hybridizing the whole vehicle combination. Additionally they allow to propel longer and heavier long haul vehicles in a safe manner, due to the additional drive axles. These additional drive axles are only present, when also the additional trailer is attached to the pulling unit. Thus, the concept provides an inherent adaptation of propulsion power to the loading capacity. Therefore, the vehicle combination can be configured to suit the current transport mission's needs.

The driving stability of such vehicle combinations with driven axles in the dolly and the trailer is investigated in the project by multi-body simulations providing insight into potentially dangerous situations. The findings will then be incorporated in the truck's Global Energy and Torque Management System, which distributes the driver's torque demand between the different powertrains to minimize fuel consumption, but under the boundary condition of driving stability, ensuring both safe and efficient driving.

The fuel consumption simulations show that fuel saving of 5% up to 17% can be achieved with the additional electric powertrains. The optimal configuration of EMG and battery vary over the different drive cycles, vehicle configuration and loading condition. Real word measurements at the end of the project will show the actual fuel savings achieved with the demonstrator. However, a fuel saving potential of up to 17% would already be a significant share of the project's overall target of improving transport efficiency by up to 33%, which also includes aerodynamic measures and smart loading units.

The next steps in the AEROFLEX project are the development of the driven dolly and the energy management strategy. Functional safety plays a key role during this process, because public road testing is envisaged in the last phase of the project, to gain real world measurements of the resulting fuel consumption.

As a specific technical objective, the AEROFLEX project is also drafting recommendations for revising standards and legislative frameworks. Currently, the AEMPT cannot be homologated easily, because powertrains in trailers and dollies are not supported by the legal framework. However, as the concept is very promising, changing the corresponding the legal framework should be considered, defining boundary conditions under which such distributed powertrain concepts can be operated in future long haul trucks.

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 769658.

Implementation of Powertrain control for economic, low real driving emissions and fuel consumption

Measures for Fuel consumption reduction in Long Haul traffic

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1. Abstract

In the transport sector, the reduction of real driving emissions and fuel consumption of heavy duty (HD) road haulage is one of the main societal challenges. Fuel efficiency and emissions reduction interact with each other and vary with the specific vehicle application, operating conditions and mission. The introduction of EU regulations (e.g. Euro VI) is a baseline in test environment conditions, while a clear need exist to have real driving efficiency (fuel consumption and emission) measurements to promote the introduction of innovative solutions for fuel consumption and emission reductions.

The overall objective was the development of new means of predictive and comprehensive powertrain control in an optimal way, exploiting to the full potential of the individual systems for each vehicle application and mission.

Targeted impact is to successfully market a new generation of optimally controlled Heavy Duty Vehicles in 2020 and beyond that are proved fuel efficient and compliant with Euro VI emissions limits under real driving conditions and attractive from a Total Cost of Ownership (TCO) perspective. For society as a whole, this leads to lower transport-related CO_2 emissions, improved (urban) air quality and lower noise levels.

The IMPERIUM [1] concept relies on control strategy improvements around the following four technical clusters: (a) predictive management for a global powertrain and vehicle supervisor, (b) engine control, (c) waste heat recovery, and (d) hybridization.

This contribution presents an overview on the outcomes of the EU-funded 3-year research program IMPERIUM [2] and therefore gives a glance on upcoming technologies for CO_2 reduction in commercial vehicle transport.

2. Introduction and objectives

Control strategy improvements in the main technical clusters follow two improvement strategies. The first improvement approach targets existing control strategies. This will mostly rely on migration from direct control strategies to model-based control strategies as well as on integration of existing strategies. The model-based control strategy approach relies on a mathematical model of the physics of parts of the system (e.g. combustion), which is running in real time on the computing platform and can provide more accurate information of the current state of the system. Furthermore, a mathematical (sub) system description is the base to use predictive control strategies. The integration of different control enables tighter synchronization between the (highly dependent) systems and, therefore, improved performance.
The second improvement approach targets the introduction of extended and predictive input data. This additional data will provide predictive information of the vehicle mission and environment situation, therefore enabling predictive strategies that are able to correctly control the systems according to events that will occur with high probability in the short-term future. Examples are the identification of hills or traffic jams and the resulting tailoring of the control strategies up to activation or deactivation of specific auxiliaries according to this information.

2.1. Objectives

The overall objective of the IMPERIUM project is to develop new means of *predictive and comprehensive powertrain control* in an optimal way, exploiting to the full potential of the individual systems for each vehicle application and mission.

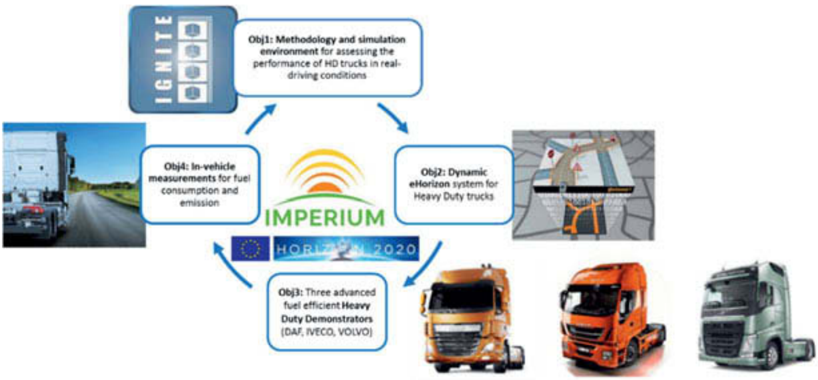

Fig. 1: The IMPERIUM Approach [3]

The main innovations and targeted key results are (see Fig. 1):

- Objective 1: Development of a methodology and simulation environment for assessing the performance of HD trucks in real-driving conditions
- Objective 2: Development of Dynamic eHorizon system for Heavy Duty trucks
- Objective 3: Three advanced fuel-efficient demonstrators (DAF, IVECO, VOLVO), each integrating eHorizon and providing different approaches of Vehicle Control Units and powertrain configurations
- Objective 4: Analysis and validation of the project outcomes by means of in-vehicle fuel consumption and emissions measurements integrated into the proposed simulation environment

2.2. Concept

The IMPERIUM concept (see Fig. 2) comprises four major elements to address the objectives:

- Assessment of the performance and fuel consumption of heavy-duty trucks under real driving conditions
- Predictive eHorizon and mission-based learning
- Optimised and integrated on board control, i.e. the global powertrain and vehicle supervisor
- New and improved powertrain hardware components and systems.

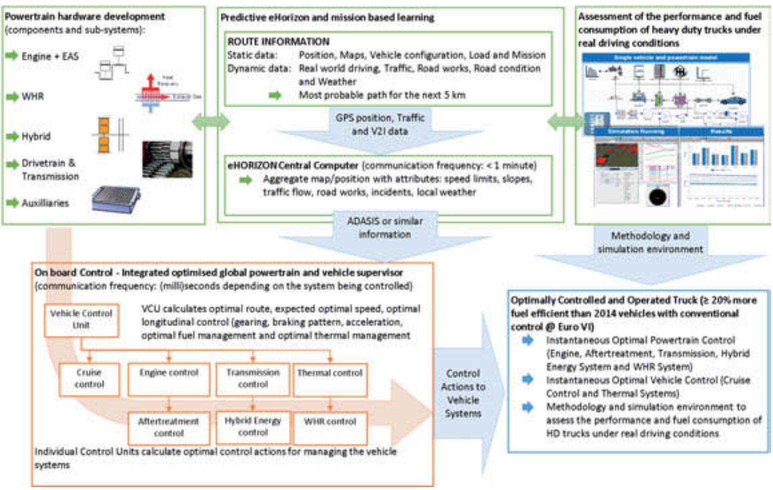

Fig. 2: Overall concept of the project, the major elements and targeted outcome

3. Prediction of the future velocity profile

3.1. Definition of desired and available road parameters

The target of this task was to identify further road attributes on top of the slope information already used today which would be of value for predictive powertrain control. The starting point for this analysis was to search for use cases in which look ahead information could be used to reduce fuel consumption. The use cases would lead the road attribute which are required to realize them.

Numerous static attributes are already available as part of the ADASIS V2 protocol already used in state-of-the-art solutions. Many of the attributes therein are simply not used to date. The following list provides a simplified excerpt of available attributes:

- Age of Data
- Vehicle velocity
- Heading relative to path
- Position probability
- Position confidence
- MAP available flag
- GPS available flag
- Off-road flag
- Functional road importance class
- Road segment shape (e.g. freeway, roundabout, ramp,…)
- Effective Speed limits
- Variable Speed Signs
- Alternative Speed Limits
- Number of Lanes
- Tunnel, Bridge, Divided road
- Urban Area flag
- Complex Intersection
- Geometry (Longitude; Latitude)
- Curvature
- Route Number Type
- Slopes
- Road Conditions (paved/unpaved)

As much as we hope that the traffic on Europe's highways is free of congestion, the reality is different. Road works, accidents, weather and erratic driver behaviour can lead to severe congestion. Fig. 3 below shows the historic traffic flow data over 24 hours for the journey between Stuttgart and Cologne. Each congestion (red in Fig. 3) is an obstacle.

Traffic flow data providers such as INRIX and HERE provide data for most roads in Europe. Provides. The parameters from INRIX are:

- Parameter of INRIX
- Current road speed
- Free flow road speed
- Historical road speed
- Predicted road speed
- Level of congestion

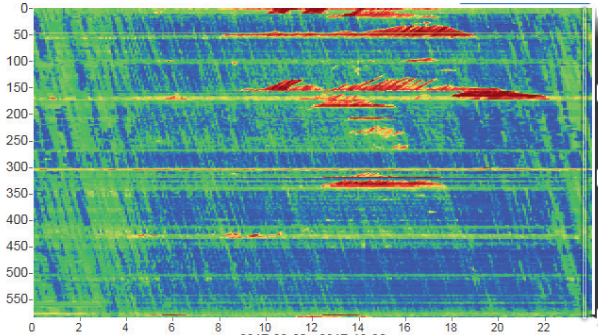

Fig. 3: Historic traffic flow data (x axis time of day, y axis position on route: Source INRIX)

3.2. System architecture for connected and/or dynamic eHorizon platform

The starting point for the definition of a generic system architecture of a connected eHorizon solution shown in Fig. 4.

This generic architecture offers all possible options for collecting data from and providing static road attributes and dynamic traffic flow data to vehicles.

A positive aspect of this approach is that privacy issues are addressed. There´s no need to provide the vehicle position to the backend, privacy is guaranteed by design. Furthermore state-of-the-art authentication / authorization mechanisms and encryption (SSL/TLS) is applied to all communication channels between the vehicle and the backend.

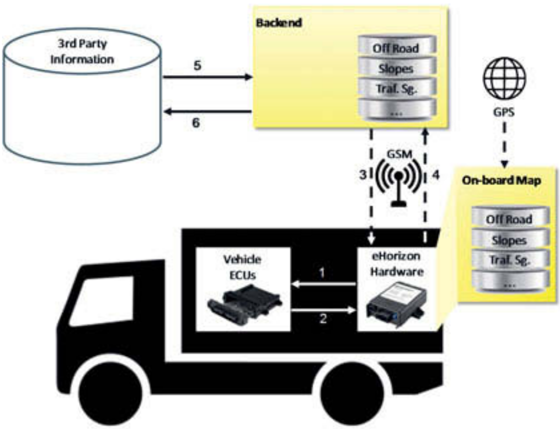

Fig. 4: Generic system architecture of a connected eHorizon solution

The results of the traffic flow processing for all road segments of the covered region are prepared in the backend. Messages for the current traffic flow are delivered to and stored in the vehicle gateway part of the backend. The vehicles subscribe for a certain geographic area. The current traffic flow status is delivered in map tile format to the in-vehicle units and updated every two minutes. Further details have already been published in [4]. The eHorizon prototype solution is installed and validated on the demo-trucks the OEM partners.

4. Optimization and energy management

4.1. Control concept

The IMPERIUM project aims to reduce the fuel consumption of the demonstrator vehicles through improvements in the way in which the vehicles are controlled. Ultimately, reduced fuel consumption is achieved through reducing the energy usage expended in performing a given mission. We describe the high-level supervisory strategy responsible for energy management an Energy Management Supervisor (EMS). The EMS strategy is responsible for defining the overall velocity and power profile and for coordination the utilisation of the various vehicle subsystems.

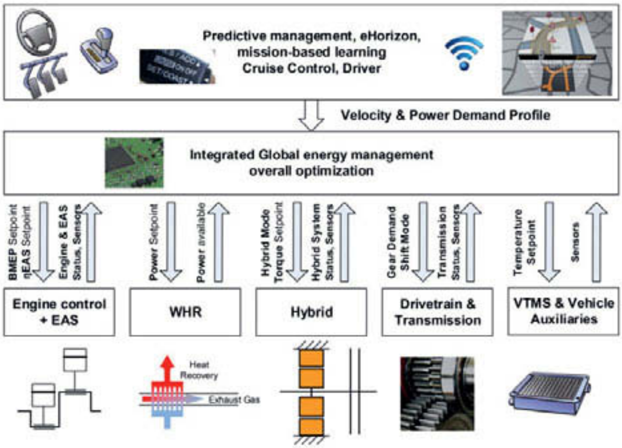

Fig. 5: IMPERIUM integrated control concept [2]

4.2. Energy Management Supervisor

Many Energy Management Supervisor strategies operate based on past and current data alone, with no knowledge of the future. Strategies such as the Equivalent Consumption Minimization Strategy [1] applied in parallel hybrid vehicle torque-split optimisation takes this form. These strategies find a locally optimum solution to an energy management problem.

However, it has been shown that if accurate preview information about the probable future inputs can be added, the performance of EMS strategies can be improved [2]. Such strategies are described as predictive-EMS and their performance may approach a globally optimum solution.

A range of techniques have been explored to solve the globally-optimum predictive EMS problem. These include Dynamic Programming (DP) [3], [4], [5], analytical optimisation with Pontryagin's Minimum Principle (PMP) [6], [7], Quadratic Programming (QP) and Second Order Cone Programming (SoCP) [8], and Trust Region [9] among others. The use of Genetic Algorithms is another approach that shows promise. Each technique has benefits and drawbacks that affect their suitability for real-time implementation, discussions on which can be seen in the references.

When there are multiple degrees of freedom in a problem, optimisations may involve making some trade-off. For example, a truck's fuel consumption, in terms of litres per kilometre, will be lower at lower speed due to the aerodynamic drag. Therefore, if only energy usage is considered the optimal strategy may be to drive very slowly. However, in reality, the time taken to complete a mission is an additional cost and so must also be considered as a factor in the optimisation. This trade-off is illustrated in Fig. 6, where an optimal strategy balances the transport energy demand and the travel time. Where large variations in time occur, an equivalence factor must be applied to compare results.

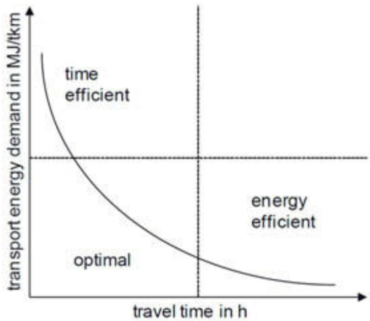

Fig. 6: Transport energy demand versus time [17]

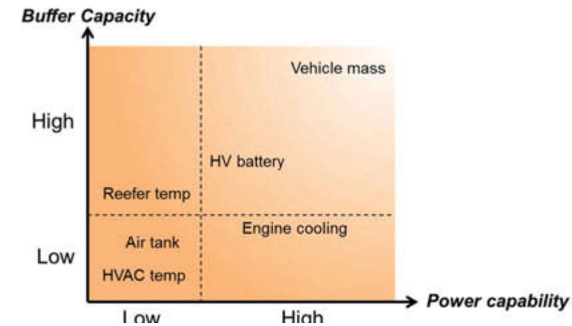

Fig. 7: Power and energy storage of vehicle systems. [18]

A truck's primary source of energy comes from diesel fuel, or electricity from the grid in the case of a BEV or plug-in hybrid vehicle. The truck contains systems that act as energy buffers, which store and release energy in a variety of forms over the course of a mission. By optimising the operating regimes of these energy buffers, the overall energy utilisation of the vehicle may be minimised.

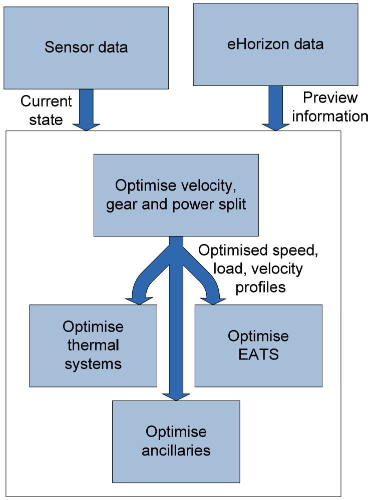

Fig. 8: Cascade of optimisation

Fig. 7 maps some of the energy stores on a long-haul truck against both power capability and energy buffer capacity. When selecting parameters for use in a global optimisation problem both these dimensions should be considered, as it is generally not well conditioned to optimise both large and small scales together. Instead, the optimisation problems can be considered as a cascade of problems, see Fig. 8. For example, optimisation of the vehicle mass buffer may be performed first, resulting in a velocity and power demand. Subsequent optimisation problems solving the power split, optimal gear selection, ancillary utilisation and so forth are then performed based on the output of the first optimisation.

4.1. Global powertrain and vehicle supervisor with hybrid drive

For hybrids the battery SoC is included in the optimization, also adding constraints on minimum and maximum allowed SoC, minimum terminal battery SoC and electric motor power. A functional overview of the Energy Management strategy is shown in Fig. 9.

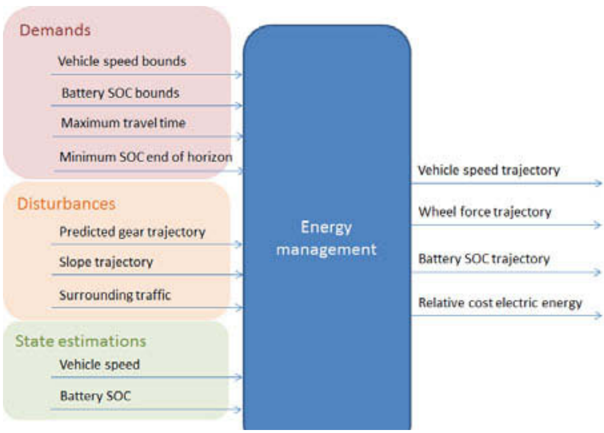

Fig. 9: Energy Management control structure with main inputs and outputs

The states used in the optimization formulation are vehicle kinetic energy, stored battery energy and travel time. Optimization control signals are resulting forces on the wheels from engine, brakes and electric machine respectively. The power losses for engine, electric motor and battery are modelled using quadratic approximations.

The optimization cost function main term is the fuel consumption, but additional terms for penalizing braking as well as energy throughput for the battery is included to avoid unnecessary wear.

4.2. Power Management Strategy

The power management is formulated as a dynamic c programming problem. It finds the optimal selected gear trajectory, given constraints on maximum engine torque.

For hybrids, power mode and torque split between combustion engine and electric motor are also included in the optimization, adding constraints on electric motor power. For this setup, also the capability regarding minimum engine torque from the Vehicle Motion Management software composition with respect to emission fulfilment is considered. A functional overview of the Power Management strategy is shown in Fig. 10.

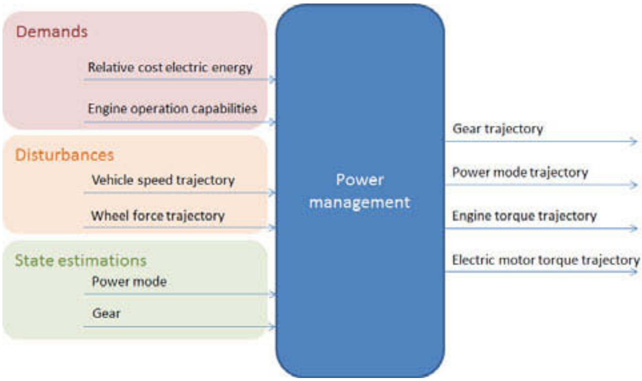

Fig. 10: Power Management control structure with main inputs and outputs

Optimization states are gear selection, power mode (electric, hybrid), and control signals are requested gear and power mode. Power split between engine and electric motor is calculated using the battery energy co-state trajectory from the Energy Management functionality.

The optimization cost function main term is the fuel consumption, but also a term for penalizing gear shifting is included to avoid poor drivability.

Optimal control trajectories for engine speed and torque for the prediction horizon are obtained in the Power Management functionality using the optimized gear selection and power mode strategies. The speed and torque trajectories are provided as predictive information to the integrated engine and exhaust aftertreatment controller. In that functionality the information enables predictively coordinating engine and exhaust aftertreatment control to minimize total consumption (fuel and urea), while fulfilling emission demands.

4.3. Optimisation on Powertrain level

One possibility to overcome this issue is to break the complex optimization problem into several smaller optimization problems (sub problems) for e.g. different system levels, components, etc. These sub problems can be solved fast, with acceptable accuracy. Note that this approach relies on the assumption, that the solutions of all sub problems can be realized in parallel, and that they lead to a solution, which is reasonably close to the global optimum. Therefore, the key lies in the identification and formulation of appropriate smaller problems, that fulfil above-mentioned assumption. Looking at the overall System Structure (seeFig. 11) gives valuable insights in how the formulation of the sub problems may look like. It is shown that all relevant powertrain components, such as Engine, After Treatment System, Transmission, Battery and Electric Motor have a direct connection to the Powertrain Controller. Additionally, the Velocity Optimizer exchanges the predicted load profile with the Powertrain Controller. In other words, in the Powertrain controller all relevant information related to the overall optimization problem is available.

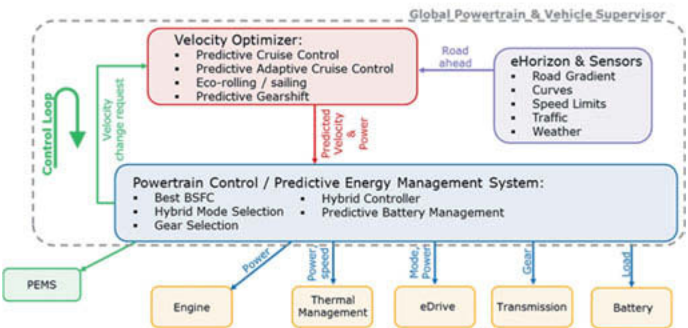

Fig. 11: Global powertrain and vehicle supervisor structure

As stated above, solving the overall optimization problem directly and in real time is currently not possible with known state of the art methods. Therefore, the idea is that the Powertrain Controller fulfils two main tasks:

- Coordination of all information exchange between powertrain components and the velocity optimizer. The predictions are tailored to the needs of each component, and components can use the predictions to compute optimal operation strategies for themselves. An “efficiency factor” or “cost” is assigned to each strategy, giving an indication about the loss of efficiency.
- Collection and evaluation of all optimal and alternative operation strategies that the components and the velocity optimizer provide. The best overall strategy is selected based on a cost function. Information exchange between the components is updated according to the selected strategy.

4.4. Model Predictive Engine & EAS Control

The main task of the Model Predictive Engine Controls (MPEC) within the EMSC is the provision of cost factors for a set of possible engine load points (engine torque/speed) for the pre-selection of the gear level and or powertrain strategy (e.g. E-Motor /ICE torque split or load point shift) by the Powertrain Supervisor (PS). Secondly the optimized request values for Engine and EAS Control are determined. These is the request for exhaust after treatment system (EAS) heat up, the desired DOC upstream temperature and the limiting value for tailpipe NOx. Additionally, the gear information, torques & speeds are received from the Predictive Gearshift Module. For at least two predicted possible torque/speed pairs the corresponding engine and exhaust after treatment optimizer calculates the corresponding cost functions. The main trade-offs for the engine/EAS that need to be considered and optimized towards lowest operation costs which keeping compliant with emission limits are:

- NO_X/Total Fuel Consumption (Diesel & AdBlue) trade off;
- Thermal management EAS: Engine Out NO_X versus engine out temperature (SCR efficiency = f(SCR temperature))
- Cooling actuator power versus Engine BSFC = f(intake manifold temperature and EGR temperature)
- Thermal management/Coolant circuit engine: Power/Temperature engine coolant circuit versus engine fuel consumption and engine out NO_X

The NO_X/Soot trade-off is considered as not critical for fuel consumption in the considered application.

4.5. Thermal System

The predictive cooling circuit control aims to reduce the energy consumed by the auxiliaries in the cooling system. Namely following actuators are controlled in course of a predictive control strategy:

- Engine coolant pump
- Grill shutters
- Fan

The grill shutter control allows to reduce the cooling air flow through the A/C condenser, the charge air cooler and the radiator to decrease the aerodynamic drag of the vehicle. Therefore, the cooling air flow control must consider air flow demands from the engine and after treatment system, the A/C system and the engine cooling system. The predictive grill shutter control enables a faster engine warm-up, may prevent unwanted fan activation for predicted load steps and reduce aerodynamic drag at situations with moderate or low engine loads and high driving speeds.

The fan is used to increase the cooling air flow in case of insufficient flow from vehicle velocity (ram air effect). Predictive fan control allows to reduce the overall fan energy consumption by avoiding high fan speed requests that are causing a rapid increase in fan power consumption.

The predictive cooling circuit control considers as input predicted vehicle velocity, engines speed, engine load and possible gears over time from the velocity optimizer and returns velocity change requests over time.

5. Simulation and Validation

5.1. Vehicle modelling

A schematic overview of the full vehicle model is presented in Fig. 12. Acceleration and deceleration control inputs are generated by a driver / cruise controller model, based on a desired road speed. These

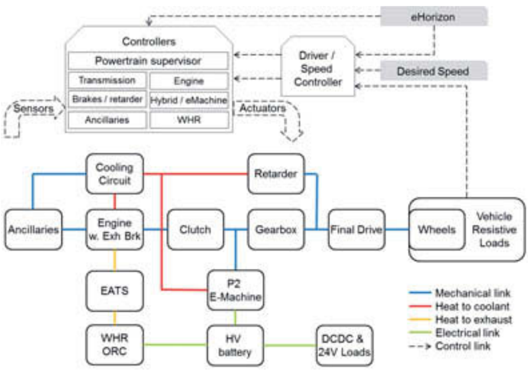

Fig. 12: Schematic representation of the reference vehicle model

control signals are used by a powertrain supervisor to calculate the required torque delivery at the wheels. The supervisor then co-ordinates the vehicle subsystems to deliver the torque and maintain other functions, such as cooling, exhaust aftertreatment, waste heat recovery and state of charge management. Torque is transmitted between the powertrain and the wheels through gearbox and driveline models, considering efficiencies and inertias. A vehicle resistive loading model, consisting of aerodynamic, rolling resistance and gravitational forces, is then accelerated by a force generated through torque at the wheels. The loop is then closed by the speed controller sensing the updated vehicle speed. Predictive control is added by providing eHorizon data which can be used both to modify the vehicle velocity in the speed controller and to subsequently modify the co-ordination of the powertrain and ancillaries once the target velocity is determined.

5.2. Traffic and environment modelling

In real-world driving, the behaviour of the vehicle depends of factors outside of the vehicle boundary. These factors may include changes in the environment, the road that the vehicle is driving on, or the traffic situation the vehicle meets. We can include these factors in an extended simulation environment, as illustrated in Fig. 13. This extended environment includes all the physical and control models described above and adds an environmental model, a road network model and a traffic micro-simulation model via co-simulation.

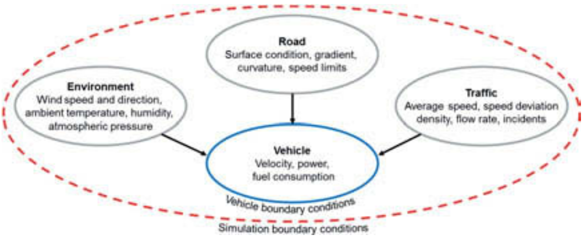

Fig. 13: External factors influencing the vehicle in the real-world

The environment model includes configuration parameters for wind speed and direction, as well as sea-level atmospheric conditions in terms of pressure, temperature and humidity. These are then processed, by way of a standard atmospheric model [10], to give the atmospheric conditions at the vehicle's instantaneous elevation. These calculated environmental conditions are then applied as inputs at each simulation time step.

A virtual road network is defined as set of nodes in a 3-dimensional space, connected by edges. Nodes can be considered as analogous with road junctions and edges with roads. Each edge may consist of one or more lanes. The edges have parameters associated with them, such as speed limits and lane restrictions. Edges may be straight or have a predefined curvature in 3-dimensions, allowing for bends and elevation profiles (road gradients) to be embedded in the network. A simple example network is illustrated in Fig. 14.

It is possible to generate virtual road networks using map data and gradient data

Such a synthetic network was used based on the European Automobile Manufacturers' Association (ACEA) Long-Haul drive cycle und updated by the highway part of the VECTO cycle. The Long-Haul mission is of relevance since it has been utilised in past European collaborative research programmes and, as such, it provides an agreed basis for assessing long haul heavy-duty vehicle performance.

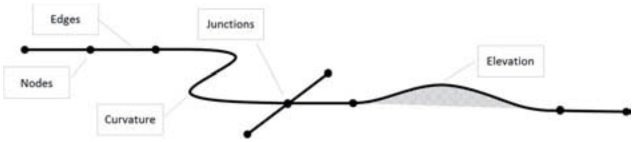

Fig. 14: Example of a virtual road network

Finally, traffic is added to the virtual road network by means of traffic micro-simulation, which employs agent-based modelling to produce naturalistic traffic flow patterns. Each vehicle in the simulation obeys a set of rules that govern the vehicle and driver’s behaviour with respect to the other vehicles in the simulation. As each vehicle interacts with the surrounding vehicles, complex traffic flow patterns emerge, such as congestion and traffic jams. The SUMO (Simulation of Urban Mobility) [11] simulation engine and TraCI4Matlab [12] are used in the results presented here.

5.3. Addition of eHorizon to simulation

To investigate the impact of predictive EMS strategies on fuel consumption in real-world conditions the optimisation algorithms should be evaluated in-the-loop within the extended modelling environment. eHorizon data as described in chapter 3 can be treated as an input to the vehicle model. However, the eHorizon data used in the simulation must be generated by some means. The solution deployed here is to use the traffic micro-simulation engine described above along with a software component designed to emulate the properties of the dynamic eHorizon back-end.

5.4. Validation approach

At current project stage an intermediate validation status is available. The simulation environment was used as a validation environment, with individual simulation models for each vehicle (System Under Test). The simulation models for the Systems Under Test are carefully tracked back to measurement results, either with component measurements or by vehicle measurements.

The VECTO CO_2 Long-Haul cycle definition is used as a reference cycle. The Long-Haul cycle is further enriched by simulated traffic interacting with the driving truck. This enriched cycle is defined as the 'IMPERIUM Long-Haul' cycle. The VECTO simulation tool is not used, as it does not yet include the ability to simulate traffic. The VECTO Reference Loading condition 'LH-RL' is used in all cases. This corresponds to a payload mass of 19300kg and a trailer mass of 7500kg.

For each truck, a different combination of technology advances has been included to reach the intermediate status.

Table 1: Truck improvements in intermediate stage

Vehicle	Downsized engine	Engine improvement	Hybridization	Vehicle drag reduction	Control improvements
Truck 1	Engine displacement from 13 to 11 l	small	P2	no	Hybrid only
Truck 2	no	strong	P1	yes	Hybrid only
Truck 3	no	no	No	no	Predictive, with dynamic eHorizon

When simulated under traffic conditions on the IMPERIUM Long Haul cycle, the fuel consumption reduction reached by the intermediate Version 1.0 models incorporating the listed technologies ranges between 5.1 % and 6.6 %. These results are shown in Fig. 15: Relative Fuel Consumption and the improvements in intermediate state with and without trafficFig. 15.

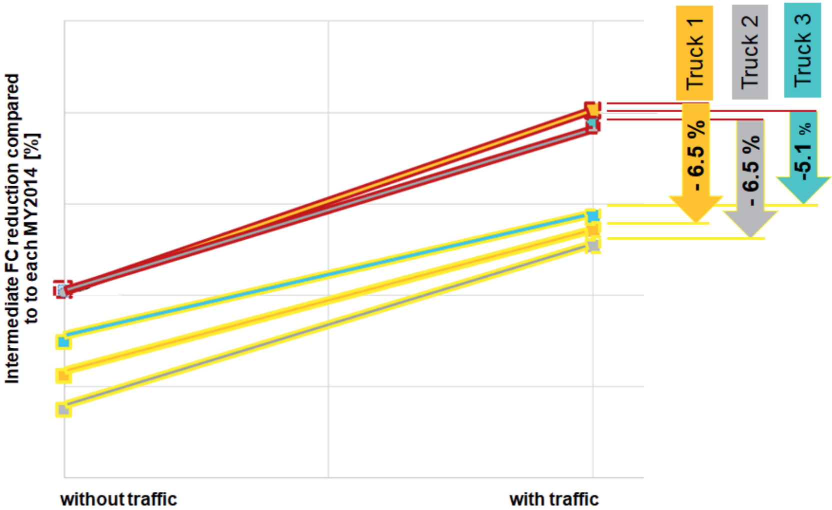

Fig. 15: Relative Fuel Consumption and the improvements in intermediate state with and without traffic

As simulated traffic is included, interactions between the vehicle under test and the traffic will influence the fuel consumption result. Therefore, the statistical nature of the results must be considered. When considering the findings and the corresponding explanations below, a typical interval size for the '95% prediction interval' of +/- 1.2% should be considered when judging the numbers.

It can be concluded that:

- Fuel consumption increases by circa 10% under the studied 'real traffic' conditions.
- Strong improvements in reducing engine and vehicle losses, as applied in the first step on truck 1, leads to circa 6.5 % fuel consumption reduction. These are not strongly correlated to the traffic situation.
- The full hybrid technology applied on truck 2, leads to a fuel consumption reduction of 4.6% in free-flowing traffic and similar reductions of 6.6% when the traffic increases.
- The changes in vehicle control considering upcoming road inclinations and the dynamic electronic horizon data stream on truck 3 leads to reductions in fuel consumption by up to 5.1 %, particularly in case of increased traffic.

6. Summary and Conclusion

This work presents measures for fuel consumption reduction with a target of -20% compared to model - year 2014 vehicle. The concept foresees the separation of three main layers in the control strategy. The top level for vehicle control is enhanced by the use of dynamic eHorizon information for best use of energy. The upgrade of online traffic and road information for energy consumption is a main enabler for vehicle velocity optimisation strategy. This system is implemented on all 3 demonstrator trucks.

The middle layer presents a global powertrain optimisation with respect to power, propulsion, thermal system and pollutant emissions. The outcome are globally optimised set values for the powertrain elements like internal combustion engine, transmission, thermal system, waste heat recovery, battery and emotor.

Finally the use of predictive information in the traditional powertrain domain, especially the combustion system enables further improvements.

The dependency on traffic directly leads to the problem of non-reproducible validation measurements on real roads. Therefore a simulation – based validation strategy is developed. The simulation elements of the trucks are validated on various platforms like HiL, engine testbed and demonstrator trucks. Next the question of “representable traffic conditions” was solved by the analysis of European traffic routes and transfer of typical traffic scenarios on the VECTO CO_2 Long-Haul cycle. The simulation platform enables interaction of the ego-vehicle with defined traffic scenarios for validation.

Within the project the validation phase is currently on-going, therefore intermediate results were given in this paper.

7. Acknowledgement

The research leading to these results has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement n° 713783 (IMPERIUM) and from the Swiss State Secretariat for Education, Research and Innovation (SERI) under contract n°16.0063 for the Swiss consortium members.

The project results as well as the content of this paper are a cooperation of the consortium consisting of the following partners under the lead of AVL.

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Increasing transport efficiency through digitalisation of trailers

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Abstract

The demographic change as well as the increasing Internet trade and the ecological change of values will present logistics with manifold challenges in the coming years. Digitalisation as a major technological trend with a global impact on the entire industry provides a solution of how additional logistics traffic in urban areas can be avoided by increasing trailer transport efficiency. Great potential for improvement arises e.g. by reducing empty trips of trailers and the optimisation of their load capacity. Due to the digitalisation of trailers, logistics processes can be optimised, different material and goods flows can be bundled in real time and made more efficient, which ultimately leads to CO_2 savings. A customer-benefit assessment of various trailer digitalisation products using certain digitalisation characteristics of logistics for evaluation provides an overview of their effectiveness in increasing transport efficiency. It turns out that the trailer digitalisation products “Smart Capacity Management” and “Smart Track & Trace” have the greatest potential to improve transport efficiency.

1. Introduction

Over the next years digitalisation will be a significant technological trend with global impact across industries. In particular, the digitalisation of road transport of goods is an important instrument for achieving a reliable and sustainable transport system of the future and the delivery of goods [8]. Digitalisation alone offers the immense opportunity to reduce logistics emissions by up to 10 to 12% by 2025 [4] and to contribute to the decarbonisation of the global economy.

For logistics, this means the mass adoption of intelligent and connected digital technologies and applications (e.g. mobile, cloud, sensors, data analysis, machine learning, blockchain, IoT) and the improvement of vertical and horizontal integration between supply chain partners [12].

This will likely lead to a radical shift in business thinking and implementation of business processes in logistics that require a new business paradigm toward a connected, smart, highly efficient and sustainable digital logistics ecosystem that is fully transparent to all stakeholders involved [12]. This has far-reaching implications for suppliers of raw materials, components and parts, for the transporters of these supplies and finished goods as well as for customers requiring fulfilment [7]. An important key element in the logistics chain is the linking of separate activities. As transport accounts for a significant part of the logistics costs, digitalisation can provide a continuous data flow along the value chain, which leads to increased transparency of the transport systems and thus enormously improves the efficiency of the logistics system.

The transformation of the logistics value chain into a sustainable digital logistics ecosystem forces companies in the logistics and commercial vehicle industry to react quickly to changing market requirements. This requires the development of innovative solutions in order to increase efficiency and reduce costs in the face of increasing competitive pressure and uncertainty.

2. Digitalisation in logistics

2.1 Digital logistics ecosystem

Digitalisation means basically capturing an analog signal and converting it into digital form for the purpose of generating a digital representation that can be electronically stored or processed [1]. Digitalisation makes information and communication available anywhere, anytime, within any context, and for any user using any device and type of access [12]. The digitalised trailer thus becomes an elementary link for the transmission of data from upstream and downstream processes in the value chain.

The better information and transactions are collected and processed, the more systems are equipped with a certain level of intelligence and the more these systems communicate with each other via interconnections, the higher the degree of digitalisation of a network, e.g. an entire supply chain or a single logistics process [12]. Digitalisation disrupts the logistics processes in whole or in part [8], but could also create an intrinsic value for industry and society [12].

Building a logistics network with digital technologies would provide a new level of flexibility and responsiveness that will allow companies to compete more effectively to provide customers with the most efficient and transparent service delivery [7].

Businesses can use analytics technologies (such as hyper connectivity, supercomputing, big data) to analyse comprehensive logistics data using complex algorithms while saving money, increasing margins, and being more cost-effective and environmentally friendly [12].

The digital logistics ecosystem is based on four key factors [14]:

- ❐ Technology
- ❐ Process
- ❐ Organisation
- ❐ Knowledge

Critical to the success of digital logistics strategies is the Integration of technology and applications with good knowledge management across organisations and business processes [12].
The digitalisation of logistics, particular relevant for trailers is based on five characteristics [12]:

- ❐ cooperation
- ❐ connectivity
- ❐ adaptiveness
- ❐ integration
- ❐ autonomous control

For trailers as part of the logistic process, a broad range of digital technologies such as mobile, cloud, sensors, augmented reality, data analysis needs to be implemented in order to enable integrated planning and execution systems, logistics transparency, autonomous logistics and automated systems, and advanced analytics [7].
The scope of digital logistics which is relevant for trailer can be described by the five characteristics as mentioned above. Available technologies, which can be allocated to these characteristics, offer significant benefits in managing, scheduling and synchronizing freight and logistics operations.

Some of these technologies offer following features:
Real-time, full transparency across the supply chain, visibility and efficiency for transport chains and logistics centres, big data analytics optimisation, cloud-computing intelligence regardless of device or location, open intelligent user interface / software design for horizontal and vertical collaboration, low management complexity through decentralised, autonomous decision-making, reducing errors in complex processes and enabling a rich customer experience through augmented reality solutions (e.g. wearable computing), better automation through human-machine interaction and more [12]. In the context of this study, five specific

Krone- trailer digitalisation products were selected, which essentially have the abovementioned properties:

- Smart Scan
- Smart Track & Trace
- Smart Capacity Management
- Smart Tyre Monitoring
- Smart Trailer Check

Furthermore, these digital technologies / products enable companies to respond to disruptions in the supply chain in good time, to adjust changes in logistics processes, and even predict potential risks by modelling the system with a what-if scenario analysis [12].

The digitalisation of the entire process for planning, procurement, production, delivery and return will further improve logistics processes, optimize work processes and reduce throughput times [12]. Depending on the digitalised equipment, the connected trailer plays a decisive role in this context.

Fig. 1 shows a digital logistics ecosystem that takes into account digitalised trailers and explains how digitalisation affects logistics from a customer benefit perspective.

This considers an affordable system that works efficiently, offers collaborative solutions and a mix of modes of transport, and supports the local economy.

As well, it reduces greenhouse gas emissions, pollution and waste, minimizing the consumption of non-renewable energy sources and using technologies that reuse and recycle the components [12].

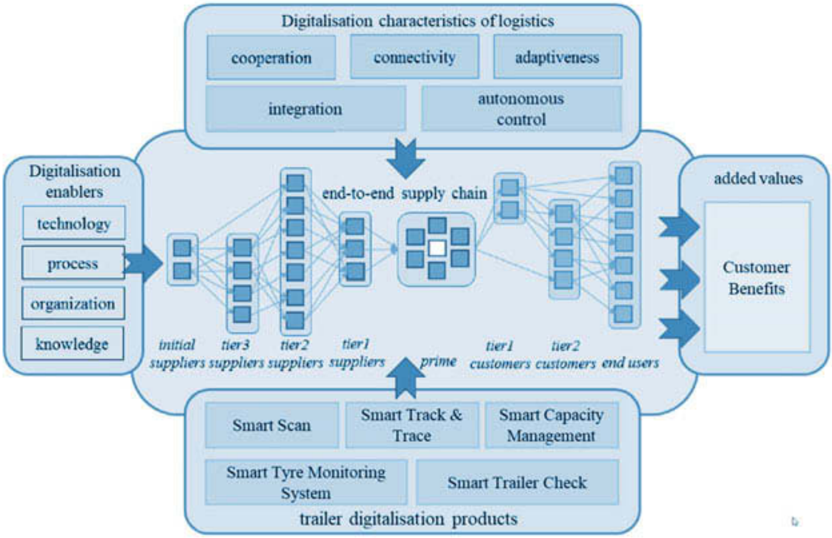

Fig. 1: Digital logistics ecosystem relevant for trailer
(derived from Yasanur Kayikci, ScienceDirect Procedia Manufacturing, 2018) [12]

2.2. Digitalisation characteristics of logistics

The digitalisation characteristics of logistics which are relevant for trailers can be described as follows:

Cooperation: Cooperative measures (e.g. shared transport capacity) through digitalisation can improve the efficiency and reliability of the logistics industry [4].
Virtual service providers, such as freight exchanges and digital freight forwarders, enable companies (or partners) to form strategic alliances that enable the sharing of their physical facilities to use logistics services outside of their own operations [5].
This requires an interorganisational exchange of information and data integration as well as an architecture to support virtual logistics clusters for which the digitalisation of the trailer is a prerequisite [12].

Connectivity “refers to the ability of a technology to act as an interface to other digital resources on the network, or to accept a connection from another resource” [6]. Digitalisation via connectivity enables vertical integration from supplier to customer. Horizontal integration can also be achieved between other competitors and other business partners along the supply chain to ensure end-to-end visibility [12].

Data-generating connected trailers, supercomputing, and real-time big-data analytics enable shipping companies to meet supply and demand for underused transportation facilities. In 2018, 25% of trailers in Germany were on empty trips, and 50-70% did not fully use their full cargo capacity. Thanks to digitalised trailers, the logistics system can be made smarter and productivity can be increased by transparent processes to prevent errors and unplanned interruptions.

Adaptiveness: Digitalisation offers an open, dynamic and adaptive system where components and their relations can change over time and be impacted by out-of-system events [12]. The system of networked digital resources is both adaptive (system that can be changed by an external actor, e.g., via a graphical user interface) and self-adaptive (system that changes in response to perceived changes in the environment, e.g. User input or changes in the internal composition of the system) [6]. For instance, smart trailers are adaptable to different sensors to track and trace and systems to make loading capacity visible and control the condition of the trailer.

Integration refers to the ability of a system to connect, integrate, monetize and share data, devices, systems and processes in the digital economy in near or in real time [13]. Various computer systems, devices, and software applications are physically or functionally linked together to control the entire logistics flow [12]. The data generated in the trailer are transmitted by telematics to a cloud, analysed accordingly, evaluated and forwarded to the portal of the shipping company or other digital service platforms, allowing communication between back-end systems of organizations [12]. This enables interactions between logistics subsystems and creates added value [12]. In fact, traditional data centres and enterprise services are seamlessly connected with cloud, mobile, and other application programming interface (API) digital ecosystems [13]. Digitalised global logistics platforms like freight exchanges are conFig.d with this system logic to interconnect all users (e.g., shippers, logistics services) to maintain a real-time operating environment [12]. These platforms consolidate demand from multiple shippers, streamline the end-to-end logistics planning process, and based on the warehouse location and targeted delivery location, suggesting suitable modes of transport [4].

Autonomous control: Digitalisation enables decentralized, autonomous decision-making by acting independently and without outside control [12].

Thanks to machine-learning technologies or big-data analysis of the trailer's operating data, it is possible to make predictions about specific logistical processes and wear characteristics of the trailer.

Every day, many real-time events can be recorded and analysed by sensors, satellites, radar, video cameras and smartphones [2].

In logistics applications, the algorithm tracks the real-time movements of shipments and calculates their estimated time of arrival, taking into account the effects of weather conditions, port congestion and natural disasters [12]. However, this is only possible if the trailers can provide appropriate digital information on the location, load condition, wear behaviour, etc..

2.3 Digitalisation of trailers

Since the trailer is a central link in the logistics process of the value chain, five different technical solutions for the digitalisation of Krone-trailers are described below and evaluated regarding their effects on digitalisation characterises of logistics as well as customer benefits.

2.3.1 Smart Scan

Smart Scan (product name of Krone) provides dispatchers and drivers with real-time information on how much available cargo space a trailer still has and where exactly there is room left in the cargo hold, see Fig. 2. For this purpose, a camera is attached to one of the rear corner posts in the trailer and calibrated to ensure the greatest possible reliability. The camera produces digital 2D-images around the clock. Using an algorithm, the photos can be evaluated so that it becomes clear which areas are loaded and which ones are free. The distribution is visualized in the Telematics Portal with green and red areas and evaluated in terms of the number of available pallet spaces. The dispatcher receives information about where there is still room and the trailer can receive more cargo. This information can be included in the planning of routes and loading orders and additional orders can be accepted. This system contributes significantly to the increase of transport efficiency when connected to Smart Capacity Management, as the utilization of the loading area can be optimized and empty trips avoided.

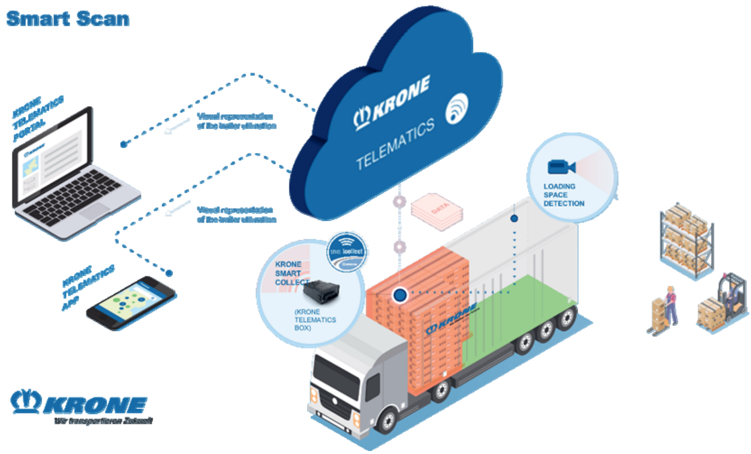

Fig. 2: Smart Scan

2.3.2 Smart Track & Trace

Smart Track & Trace (product name of Krone) is a carrier detection system that monitors the entire supply chain, including storage space in warehouses, see Fig. 3. Beacons (Radio Beacons) mounted on the carriers collect data such as the amount of goods, the weight, the shocks to which the load is exposed, and the position and data of the beacon. Through the communication with the Telematics Portal a complete tracking of the shipment is possible, which can be used by both the shipping company and the forwarder. In combination with Smart Capacity Management, Smart Track & Trace offers much more than just a report on freight transport, as it can also provide additional information about the remaining available charging capacity in order to increase capacity utilization.

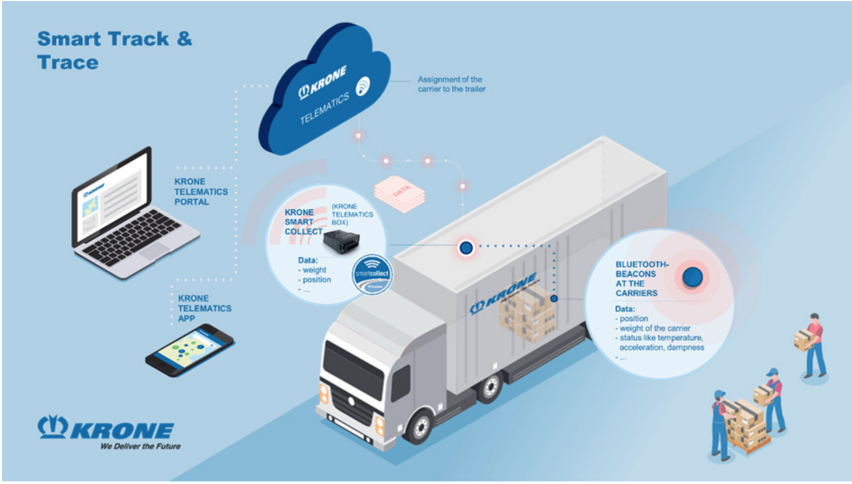

Fig. 3: Smart Track & Trace

2.3.3 Smart Capacity Management

Smart Capacity Management (product name of Krone) describes an information exchange platform with a connection to a freight exchange, which functions like an intelligent electronic postman who receives data digitally from an actor involved in a transport, such as the sender, and then digitally forwards it to the transporter and the recipient of the goods [13], see Fig. 4. The data transfer works but also in the other direction [13]. If the transporter enters the pick-up or delivery date or the recipient enters the weight after weighing, this data will be re-transmitted to the respective other operators [13]. Smart Capacity Management uses the trailer's digitally recorded data from the EBS (Electronic Braking System), Smart Scan and Smart Track & Trace systems in order to determine the available cargo load and area, the quantity and location of goods booked for the carrier, and matches that knowledge with the freight and order pools on the freight exchanges.

The freight exchange then receives the provider information and provides the dispatcher with further cargo transport suggestions in the Telematics Portal according to the "either-or-principle".

Cargo transport data is transmitted in real time. This means that the parties involved in a shipment already receive delivery note data in their ERP system while the truck is still driving, regardless of who created the delivery note and where. This brings significant productivity gains by eliminating multiple surveys and correcting one and the same transport data, as well as saving time and money. Smart Capacity Management increases the transport efficiency and consequently the capacity utilization of the trailer as well it reduces the number of empty trips.

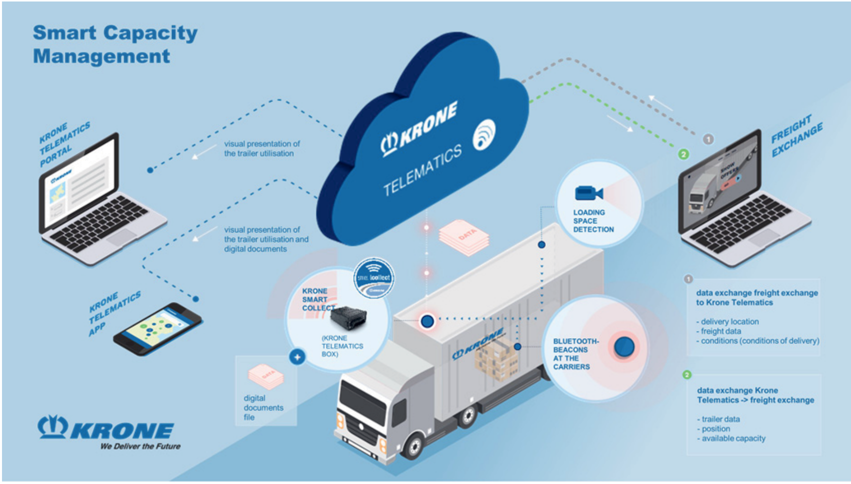

Fig. 4: Smart Capacity Management

2.3.4 Smart Tyre Monitoring

The Smart Tyre Monitoring (product name of Krone) uses two sensors per axle which are mounted on the tyre valve of the rim, see Fig. 5. Tyre pressure and temperature are individually measured for all tyres and transmitted to an electronic control unit which is connected to the trailer telematics unit. The data is transmitted to the cloud in real time via the trailer telematics unit. Both driver and fleet manager are informed about the tyre conditions. In case of a pressure or temperature deviation, the system will send an alarm via the cloud to the Telematics Portal.

Smart Trailer Tyre Monitoring helps to avoid breakdowns, which always lead to downtimes of the trailer and reduces transport capacity for the transport company. By monitoring tyre pressure and temperature, tyre wear and CO_2 consumption can also be reduced.

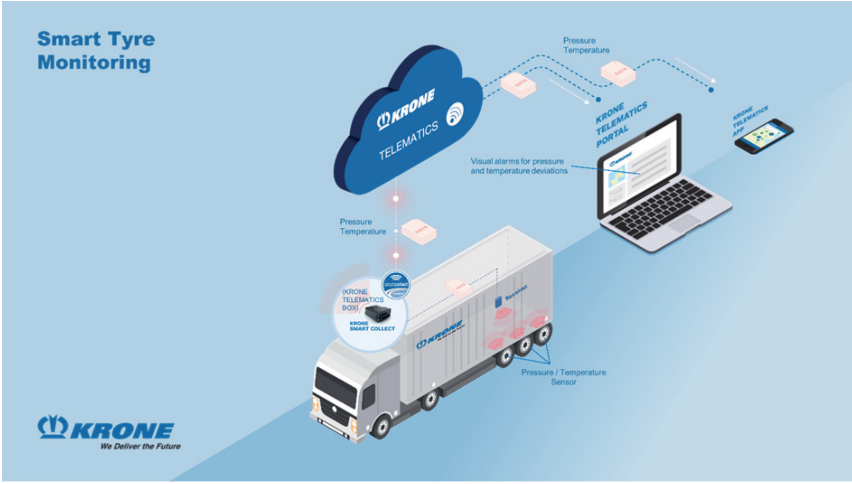

Fig. 5: Smart Tyre Monitoring

2.3.5 Smart Trailer Check

Smart Trailer Check (product name of Krone) enables the digitally supported visual inspection of the trailer via a mobile app, see Fig. 6. The driver records the actual condition of the trailer on the basis of a digital checklist which is individually tailored to the respective trailer. The software also automatically queries data from systems such as the Smart Tyre Monitoring System. The results of the individual test points are then automatically compared with the nominal conditions and evaluated before departure of the trailer. The driver then receives a recommendation as to whether he is allowed to put the trailer into operation or not. This information is then stored digitally and forwarded by telematics to the cloud and made available in the Telematics Portal as a test report for retrieval. The fleet manager thus always has the complete overview of the fleet and can initiate measures if necessary, for example planning a workshop visit. Also, the driver can retrieve the results of his digitalised visual inspection on his smartphone or tablet when needed (e.g. police control). With the Smart Trailer Check, damage to the vehicle and signs of wear can be detected at an early stage, thus increasing the traffic safety of the vehicle.

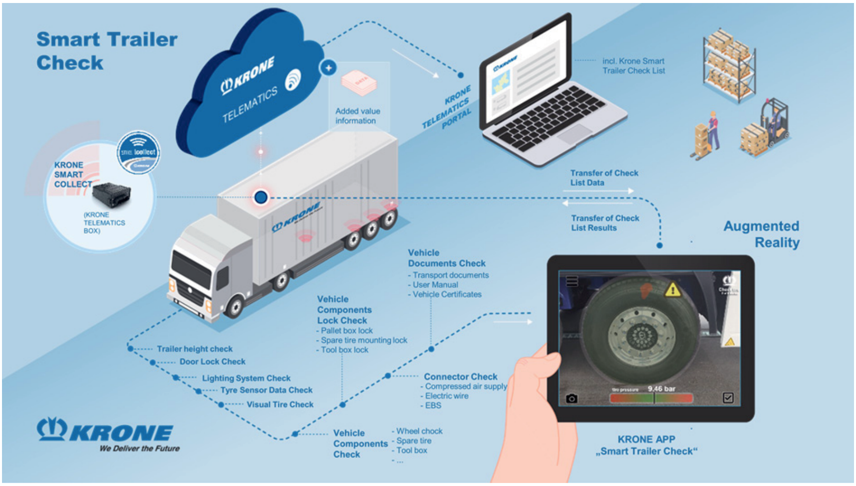

Fig. 6: Smart Trailer Check

2.4 Trailer digitalisation products and transport efficiency

The evaluation of potentials for increasing the transport efficiency of individual trailer digitalisation products was carried out as part of a case study for FMCG companies. In order to compare various potentials for increasing the efficiency of transport / customer benefits, a two-stage approach was chosen. This approach is based on a case study of Yasanur Kayikci who examined the sustainability impact of digitalisation in logistics [12].

In the first step, several customer benefits relevant to the case study were identified and qualitatively evaluated for their relevance to the various digitalisation characteristics of logistics as described above, see table 1.

Table 1: Effects of digitalisation characteristics of logistics on customer benefits (derived from Yasanur Kayikci, ScienceDirect Procedia Manufacturing, 2018) [12]

Added value	Description	Coorporation	Connectivity	Adaptiveness	Integration	Autonomous Control	Total
Logistic costs	Changes in logistics cost savings in terms of transport, warehousing, inventory carrying and administration costs [21] [23] [18] [14] [9]	3	3	2	3	1	12
Delivery time	Changes in delivery improvements, cycle time, lead time [21] [23] [18] [14] [9]	3	2	2	2	3	12
Transport delay	Changes in amount of delayed shipment [21] [14] [9]	3	3	0	3	3	12
Loss / damage	Changes in amount of lost and/or damaged goods from damage, theft and accidents [21]	3	2	0	3	1	9
Frequency of service	Changes in utilization rate (load factor), frequent intervals [23] [15]	2	2	1	1	3	9
Forecast accuracy	Changes in demand uncertainties [23] [14]	3	3	2	1	3	12
Reliability	Changes in logistics quality in terms of transport, inventory and warehousing e.g. perfect order, scheduled time deliveries [21] [23] [18] [14] [9]	3	1	1	3	3	11
Flexibility	Changes in planning conditions e.g. percentage of non-programmed shipments executed without undue delay [21] [14] [9]	3	3	2	1	3	12
Transport volume	Changes in total transported freight volume [21]	2	3	2	2	2	11
Resource efficiency	Non-renewable resources consumption in use of vehicles and transport facilities [21] [18] [15]	3	2	1	2	2	10
Process emissions	Changes in fuel consumption, CO2 and other greenhouse emissions [21] [18] [15] [9]	2	2	3	3	3	13

3 = high / excellent, 2 = moderate, 1 = less/poor, 0 = no relevance

In the second step, the same approach was chosen for the evaluation of the individual digitalisation products in terms of their relevance to the digitalisation characteristics of logistics, see table 2.

Table 2: Effects of trailer digitalisation products on digitalisation characteristics of logistics (derived from Yasanur Kayikci, ScienceDirect Procedia Manufacturing, 2018) [12]

Digitalisation Product	Description	Coorporation	Connectivity	Adaptiveness	Integration	Autonomous Control	Total
Smart Scan	Camera system with algorithm for availably cargo space	1	3	2	2	3	11
Smart Track & Trace	Beacon for track & trace load carriers	2	3	3	3	3	14
Smart Capacity Management	Information exchange platform connecting trailer telematics with freight exchange	3	3	3	3	3	15
Smart Tyre Monitoring System	Sensor system for measuring tyre pressure and temperature	1	2	3	3	3	12
Smart Trailer Check	Digital Check list implemented as Mobile App	2	3	3	2	2	12

3 = high / excellent, 2 = moderate, 1 = less/poor, 0 = no relevance

This study assumes that the greatest potential for increasing transport efficiency / customer benefits can be achieved if many of the individual digitalisation characteristics of logistics with regard to customer benefits and digitalisation products are evaluated with a high degree of relevance. After adding up the individual scores depending on the customer's benefit and the digitalisation products, the results were multiplied together and displayed in in table 3.

Table 3: Effects of trailer digitalisation products on customer benefits
(derived from Yasanur Kayikci, ScienceDirect Procedia Manufacturing, 2018) [12]

Added value / customer benefits	Description	Smart Scan	Smart Track & Trace	Smart Capacity Management	Smart Tyre Monitoring System	Smart Trailer Check
Logistic costs	Changes in logistics cost savings in terms of transport, warehousing, inventory carrying and administration costs [21] [23] [18] [14] [9]	132	168	180	144	144
Delivery time	Changes in delivery improvements, cycle time, lead time [21] [23] [18] [14] [9]	132	168	180	144	144
Transport delay	Changes in amount of delayed shipment [21] [14] [9]	132	168	180	144	144
Loss / damage	Changes in amount of lost and/or damaged goods from damage, theft and accidents [21]	99	126	135	108	108
Frequency of service	Changes in utilization rate (load factor), frequent intervals [23] [15]	99	126	135	108	108
Forecast accuracy	Changes in demand uncertainties [23] [14]	132	168	180	144	144
Reliability	Changes in logistics quality in terms of transport, inventory and warehousing e.g. perfect order, scheduled time deliveries [21] [23] [18] [14] [9]	121	154	165	132	132
Flexibility	Changes in planning conditions e.g. percentage of non-programmed shipments executed without undue delay [21] [14] [9]	132	168	180	144	144
Transport volume	Changes in total transported freight volume [21]	121	154	165	132	132
Resource efficiency	Non-renewable resources consumption in use of vehicles and transport facilities [21] [18] [15]	110	140	150	120	120
Process emissions	Changes in fuel consumption, CO2 and other greenhouse emissions [21] [18] [15] [9]	143	182	195	156	156

Potential to increase customer benefits / transport efficiency	less	moderate	high / excellent
	90-119	120-149	150-180

The evaluation shows that the digital product "Smart Capacity Management" has the greatest potential for increasing transport efficiency in logistics, followed by Smart Track & Trace. This seems logical, as this product meets most digitalisation requirements in terms of logistics characteristics and generates the greatest customer benefit. However, it should be noted that the Smart Track & Trace and Smart Scan products are prerequisites for implementing Smart Capacity Management in the trailer in order to generate the necessary data for the freight exchange. In comparison to the various digitalisation products, Smart Scan achieves the lowest scores in terms of customer benefit on the basis of the overall logistics characteristics. This seems to be plausible since smart Scan can be classified as a partial solution of the smart capacity management and can only exploit the full potential in conjunction with the higher-level system. The products Smart Tyre Monitoring System and Smart Trailer Check were rated slightly lower than the Smart Capacity Management and Smart Track & Trace products, as they indirectly contribute to increasing transport efficiency. Essentially, this is about reducing breakdowns or damage and wear that may affect the driving suitability and availability of the trailer.

In general, all products make a significant contribution to reducing CO_2 emissions, whether by optimizing trailer utilisation, reducing empty trips or maintaining tyre pressure.

3. Conclusion

Although this type of evaluation of trailer digitalisation products in regard to increase of transport efficiency is only one possible approach, it turns out that integrative platform solutions such as Smart Capacity Management offer the greatest customer benefit due to their cross-functional effects in the logistics chain.

However, digital platform solutions also face the greatest challenges in their implementation, as they have far-reaching effects on internal infrastructures of logistics companies in conjunction with critical success factors such as technology, process, organization and knowledge. In view of the challenges facing demographic change, changing customer behaviour and environmental conditions, the digitalisation of trailers can contribute to technical solutions that ensure a consistent flow of data along the value chain, thereby increasing the efficiency of the entire value chain and reducing CO_2 emissions.

4. References

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helyOS – Highly Efficient Online Yard Operating System

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Abstract

The paper introduces a new control centre software approach for gated areas, called helyOS. This software is currently developed in different research projects. Its first-time application is the fully automated, electrically driven AutoTruck. After a general introduction of the application domain the paper describes the AutoTruck vehicle, the architecture as well as capabilities and features of helyOS and introduces an exemplary user interface for distribution centres.

Introduction

The Highly Efficient Online Yard Operating System (helyOS) is developed by the Fraunhofer Institute for Transportation and Infrastructure Systems IVI in the project “AutoTruck”, which is funded by the German Federal Ministry for Economic Affairs and Energy (BMWi). The AutoTruck-project consortium, which consists of industrial and research partners and an end user, develops a delivery truck for automated driving in distribution centres. However, the vehicle shall also be homologated for driving with a driver on public roads. The use case is, that the driver parks the truck at a designated point or the parking area, when entering the distribution centre, see Fig. 1. After the driver has left the vehicle, it will drive autonomously on the distribution centre area e.g. to loading docks or charging stations. When the vehicle has finished its tasks, it drives back to the parking area again, where the driver can enter it and leave the distribution centre. The project website [1] provides a short video of the concept.

The authors envision automated driving of trucks on restricted areas like distribution centres as a good migration path towards autonomous driving. Such systems are already known, but the automated vehicles drive only in the restricted areas. The new concept of AutoTruck is the usage of the vehicle both with conventional driving on public roads and automated driving in restricted areas. For automated driving the sensors will be used, which are already installed or are anticipated to be installed in future trucks for advanced driver assistance systems.

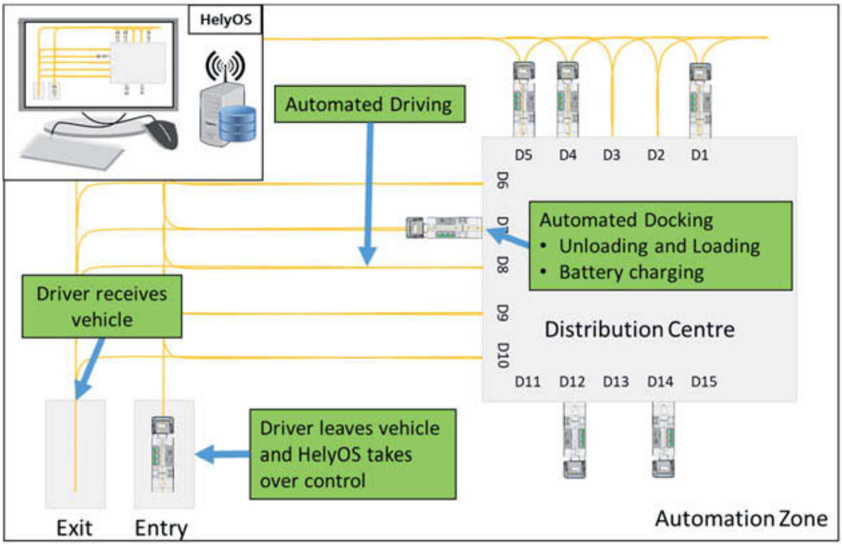

Fig. 1: Schematic functional overview of the Automation Zone controlled by helyOS

The challenges regarding safety and homologation are significantly lower in gated and fenced areas. The main reasons are that the area is well known and can be adapted to autonomous driving vehicles e.g. by marking driving zones. Furthermore, people within the area can be instructed in order to prevent risky behaviour and trouble makers. This allows an easier first step into automation before moving towards automated driving on public roads. It also gives the opportunity to gain experience with the necessary technology in real world scenarios.

One of the important tasks within the AutoTruck-project is to develop a control centre based on modern web technologies to make it available on various platforms and accessible either on premise via a local network or globally via the internet. This *Highly Efficient Online Yard Operating System* (short: helyOS) enables the operator of a yard to assign missions to autonomous vehicles. Within the project the automated driving to a loading/unloading dock will be demonstrated. Beyond that, more complex tasks like moving swap bodies or semi-trailers will be supported in future.

In the following sections this publication describes the vehicle, which is used within the AutoTruck-project. Afterwards the helyOS infrastructure and the helyOS user interface are described, which allow the operator of a distribution centre to control fleets of automated vehicles on its premises.

The Vehicle

Fig. 2 shows the AutoTruck testing vehicle, which is built up in collaboration with the project partners Orten, Wabco and Götting and additional suppliers. Despite the newly installed sensor-, actuator-, and control technologies the truck shall still be homologated for normal operation on public roads. The project partners focused on technologies that are expected to be available in future serial trucks. Hence, the yard automation concept of the AutoTruck-project will be applicable to those trucks.

Fig. 2: The AutoTruck testing vehicle

Fig. 3 shows an overview of the functional components. Orten installed an electric powertrain into the truck supporting drive-by-wire and allowing for easier and smoother control in longitudinal direction. For lateral control an electric steering system is installed, which enables steer-by-wire. With these two technologies the truck can be manoeuvred completely by an electric control unit (ECU).

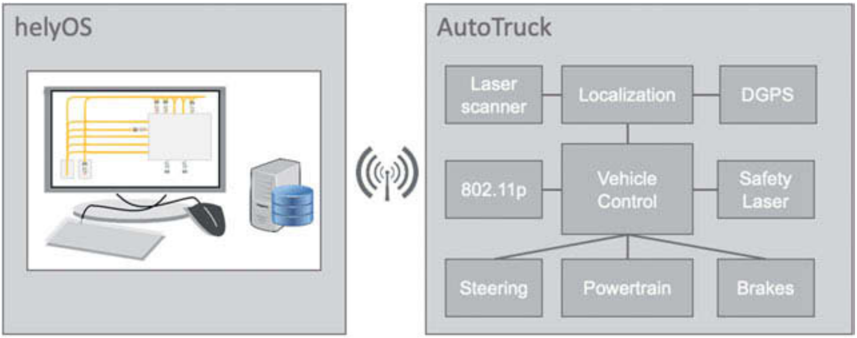

Fig. 3: Structure of the functional components within the AutoTruck

In addition to electrical braking, Wabco provides its expertise to add an additional safety layer by using the conventional brakes in critical situation. Furthermore, they provide the communication between the truck and helyOS. This communication is based on the IEEE 802.11p standard.

The localization system uses three technologies to measure the position of the truck in real-time with high accuracy and availability. For a global reference a Differential GPS (DGPS) and a scan matching method are used. The scan matching is based on a digital map and a continuously updated laser scan “finger print” of the truck’s surroundings. Both measurements are combined with a calculated odometry position in a fusion system by Götting KG. The resulting position is used for lateral and longitudinal control of the vehicle.

Two additional laser scanners, one at the front, another at the back, are the core of the safety system. These scanners recognize obstacles like people with a safety integrity level sufficient for autonomous operation of vehicles in non-public areas.

Fraunhofer IVI is responsible for the transmission of the data between the helyOS infrastructure and the truck via the communication device provided by Wabco, and also the underlying vehicle control. The connection between the functional blocks in the truck uses a variety of interfaces. Besides CAN, another important technology is the Robotic Operating System (ROS), see [2]. When used appropriately, ROS enables a flexible and fast development approach. Different functions can be developed in separate nodes, which are then interconnected via standard interfaces defined by ROS or proprietary ROS-based interfaces.

helyOS Architecture

helyOS is designed as a web application. In general, it consists of a backend and a frontend. The separation of backend and frontend enables many degrees of freedom regarding the usage and application fields of helyOS. The following paragraphs describe the system's components shown in Fig. 4.

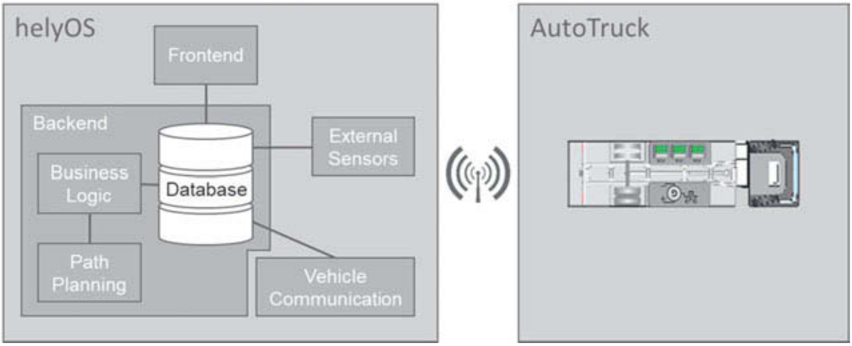

Fig. 4: Structure of the functional components in the helyOS infrastructure

The *Frontend* (user interface) presents the current situation on the yard to the operator based on a digital map including the live positions of the automated vehicles. The user interface is interactive such that the operator can access vehicle status data in real-time and can control the automated vehicles by scheduling missions. The frontend uses widely adopted web-technologies and runs on virtually every mobile or desktop device (tablet, laptop computer, smartphone) providing a modern browser.

The *Backend* can be installed either on premise or in an internet cloud. It provides the main computation power and a database and implements the business logic for different use-cases. Since the backend is responsible for all expensive calculations, the requirements for the frontend hardware are quite small.

The *Central Database* is a key component of the backend. It saves all information about missions, vehicle status and operator interactions enabling a detailed tracking and statistical evaluations of the performed missions. It is also used for synchronizing and data exchange between frontend, business logic and the automated vehicles.

The *Business Logic* is responsible for decomposing operator tasks into elementary actions. For example, the task unload and load the AutoTruck at a certain gate is broken down into the sequence drive to the given gate, dock at the gate, wait until the unloading/loading process is finished, drive to the parking area and stop at a parking spot. While processing the elementary actions the business logic supervises the status and informs the operator via the frontend. Furthermore, it is responsible for creating the elementary actions according to the operator task. It e.g. calls the path planning module to get feasible routes to reach a certain destination based on the digital map of the yard and also incorporates a scheduling algorithm for the driving action in order to avoid collisions with other automated vehicles on the yard. Since the positions of all automated vehicles on the yard and their current and future missions are available in the business logic, newly planned driving actions take this information into account. Finally, all elementary actions are compiled into a mission description and sent to the vehicle, which is responsible to perform the mission safely. Due to latencies in the wireless communication, helyOS does not steer, propel or brake the vehicles directly. These actions are performed by the vehicle itself, as described in the previous section.

The module *Path Planning* is used by the business logic to plan feasible routes if the operator task requires a driving action. Since helyOS shall support a flexible yard operation without defining fixed routes, the path planning incorporates the TruckTrix-Algorithm developed by Fraunhofer IVI, see [3]. This algorithm is able to calculate if and how a given vehicle can drive to a desired position given that the vehicle has certain constraints like e.g. maximum steering angels and a non-holonomic kinematic structure. Therefore, TruckTrix uses a digital map that defines driving areas and obstacles. Due to the short calculation times, the path planning process can react on temporary obstacles like swap bodies and containers that are not part of the fixed infrastructure. Hence, TruckTrix also provides feasible paths if the obstacle situation on the yard changes. Moving obstacles are currently not considered during path planning.

The *Vehicle Communication* module selects the scheduled elementary actions from the database and sends them just in time via a ROS-network to the corresponding vehicle. This component also provides a communication channel for live data received from the vehicle. This includes but is not limited to vehicle positions, current velocity, traction battery state of charge and many other status information. All this information is written to the database and synchronized with the frontend. Another key-responsibility of the vehicle communication module are the check-in and check-out procedures for vehicles on the yard. During the check-in the vehicle provides its own kinematic structure and capabilities to the backend. This is required by the path planning procedures to enable the calculation of feasible and collision free routes. In the other direction the vehicle receives a digital map of the yard for self-localization purposes using e.g. laser scan-matching methods.

helyOS provides also an interface to *External Sensors* mounted to the infrastructure of the yard. This interface is a key feature for operating autonomous vehicles safely especially in mixed traffic. These external sensors can observe a certain area like a blind spot or a loading/unloading gate and report any objects or obstacles to the business logic, which includes them in the digital map of the yard. Beyond that, automated vehicles receive obstacle and object information in order to ensure a safe and reliable operation without slowing down unnecessarily. Another use-case is to measure and publish the distance of a vehicle approaching a gate from the infrastructure instead of the vehicle itself.

The vision for helyOS is to develop a flexible operating system for yards that interacts with the hardware (vehicles and external sensors), performs standard tasks like scheduling and observing actions, path planning, managing resources and creating a live map. Based on that fundamental basement, use-case specific applications can be developed significantly faster. helyOS encapsulates basic tasks and provides general services like path planning and scheduling of actions based on available resources and the current status of the yard. Fig. 5 gives an overview for this operating system approach.

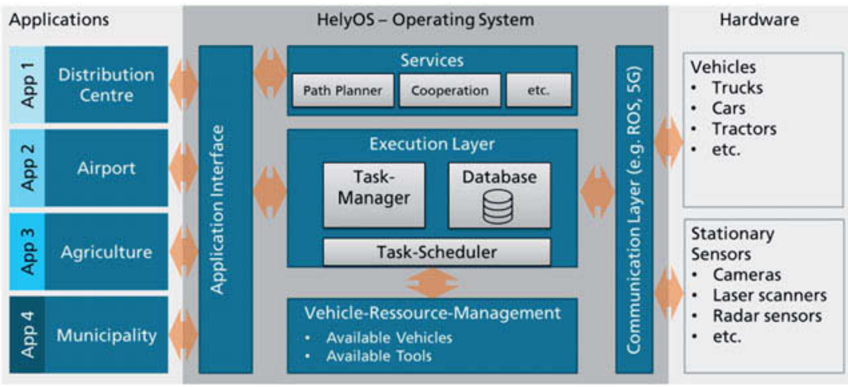

Fig. 5: helyOS as operating system for different applications of automated vehicle fleets

helyOS User Interface

The operator interacts with the autonomous vehicles using a graphical user interface – the frontend. Within the helyOS context this is a web-application that runs in widely spread internet browser applications like Firefox, Safari and Google Chrome enabling a great flexibility with respect to the underlaying hardware. Any desktop or laptop computer as well as tablets and mobile phones can be used in principle. However, bigger screens improve the user experience significantly. Depending on the server location of the backend, the frontend hardware requires either a connection to the internet or to a local network.

Fig. 6 shows a screenshot of the main page. As a key component, it displays a digital map of the yard showing the current situation including autonomous vehicles and, if available, other objects recognized by external sensors. Hence, the operator has a live-view of the proceedings.

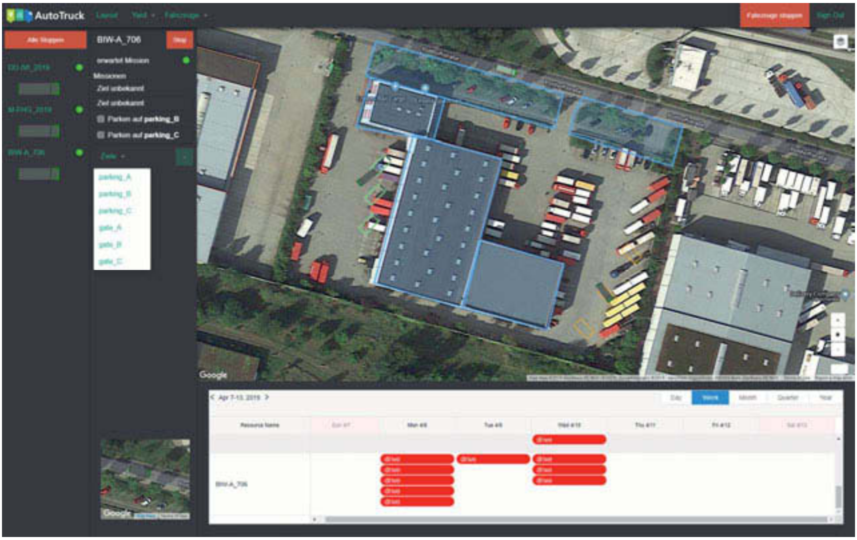

Fig. 6: Screenshot of the helyOS-UI for AutoTruck Project

The map is a 3D digital representation of the yard which can optionally be combined with Google Earth images. All key positions in the yard like loading/unloading gates and parking spots are marked with interactive boxes. The image of each autonomous vehicle is interactive, too. The operator can assign missions to those vehicles by simply clicking a vehicle in the map and selecting an interactive box. The box itself knows in which direction the vehicle shall approach and stop. Hence, moving an autonomous vehicle from an arbitrary position to a key position requires three clicks including the confirmation. All remaining steps like path planning and coordinating the mission with other automated vehicles is done by helyOS in the background.

Due to the fast path planning provided by the system, all currently present static obstacles (trailers, swap bodies, containers, other parking vehicles etc.) are considered. The calculated route is part of the mission data set and can be displayed in the map as well.

The left-hand pane lists the registered vehicles. If a vehicle is selected in this list, detailed mission information is presented in a pane next to it. This includes a mission description and further live-data like e.g. current velocity, state of charge and operational status information provided by the vehicle itself. Furthermore, a mini-map displays the corresponding map section.

For scheduling tasks conveniently, the frontend contains a calendar view at the bottom. It shows missions a certain vehicle currently performs, has performed in the past and will perform in future. A click on the read bar gives further information about the mission including precise starting times and estimated or measured end times.

In addition to the main page, the frontend-backend-architecture provides a great freedom to add sub-pages or even change the look and feel completely. The fundamental technologies especially in the backend remain the same. In general, only the frontend needs to be adapted to the specific use-cases.

Summary and Outlook

The helyOS control centre software utilizes the capabilities of automated vehicles to create an added value for customers. A single operator is able to control and monitor many automated vehicles at once. Due to the used web technologies this can even be done remotely via the internet.

The application fields have a wide range from distribution centres, yards of production sites, airfields and harbours to agriculture. The basic idea is to generalize common tasks like communication, mission management etc. in the context of automation of mobile machines and provide an application interface for apps that are tailored to different application fields. In order to support the application development, helyOS provides several services like path planning for complex vehicles and a scheduler that coordinates the movements of many automated vehicles at once.

Currently, the system is in development. A first technological break-through demonstration is planned within the AutoTruck project in the second half of 2019 together with the end user Emons. In future, helyOS will be improved step by step in terms of architecture, functionality, availability and safety within research projects and/or in cooperation with industry partners.

References

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Current results from the fuel saving project "20-20-20"

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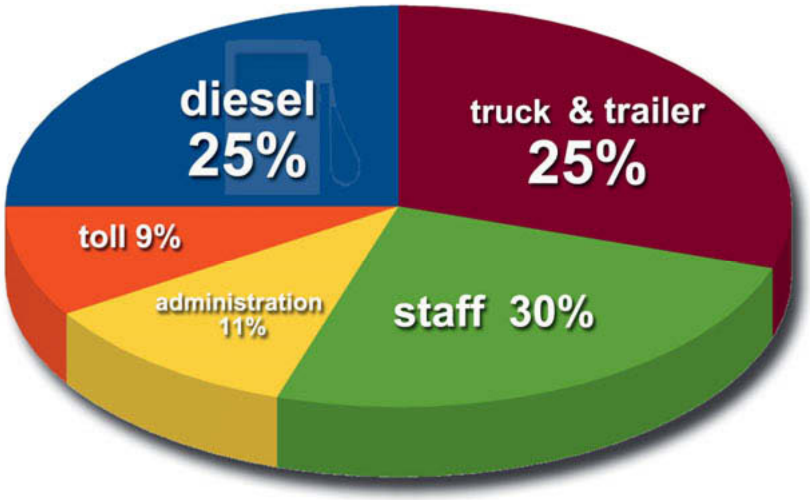
Int. Spedition Bartkowiak GmbH, Hildesheim

1. The remaining liters to the destination

2. Interdisciplinary considerations on the fuel-saving potential

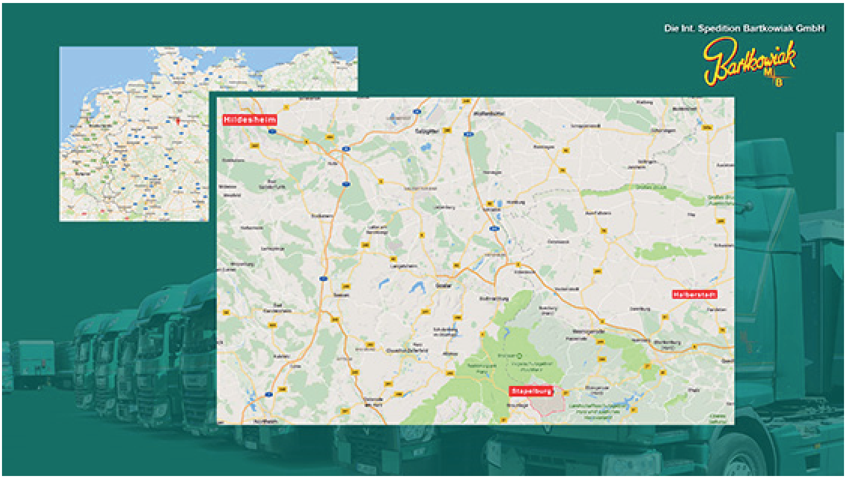
3. CONCLUSION - 31 million kilometers evaluated

Projekt: 20-20-20 (Start of the project in 2008/2009)



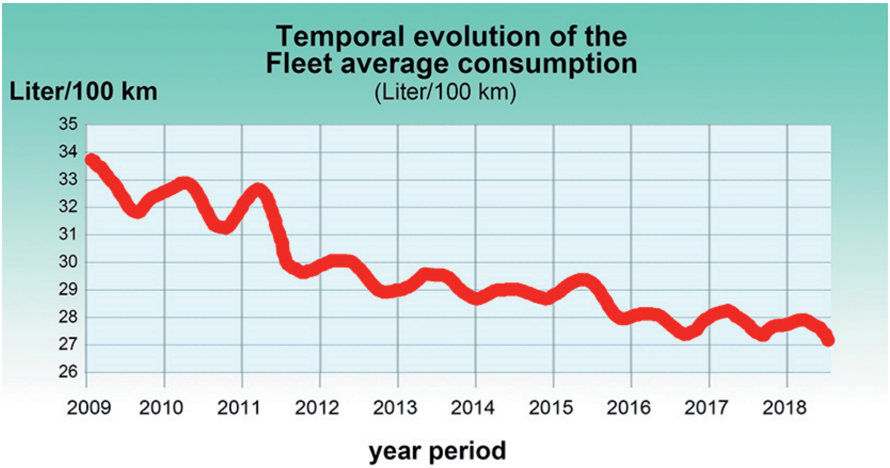
TCO, (Total Cost of Ownership)

Introduction - presentation of the forwarding company

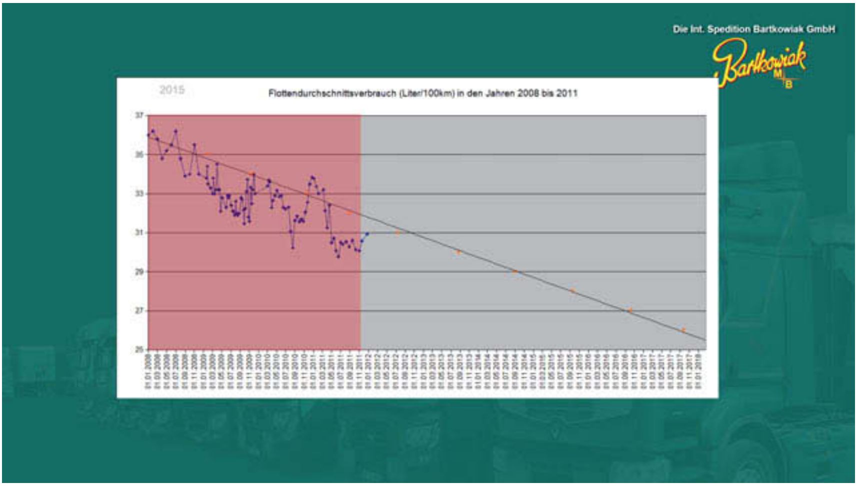


- How do we manage a fleet of 32-38 trucks to reduce the average fuel consumption from about 35.5 liters / 100 km to 20 liters / 100 km?

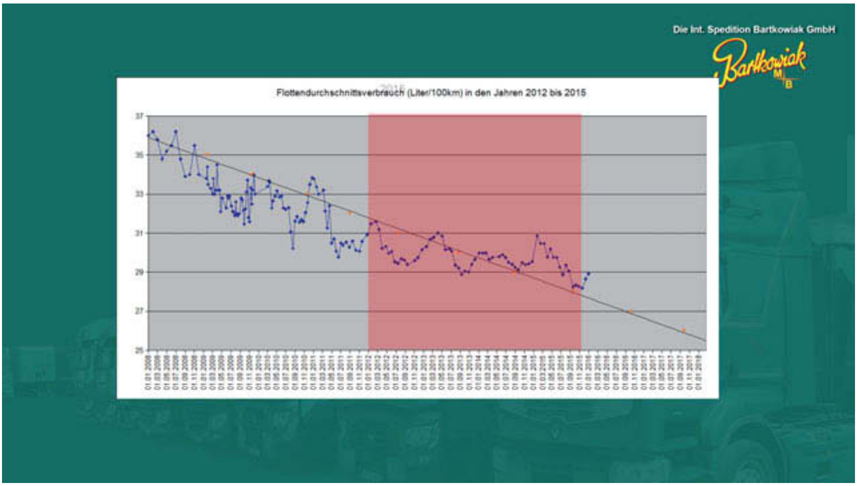
An analytical review from the field:



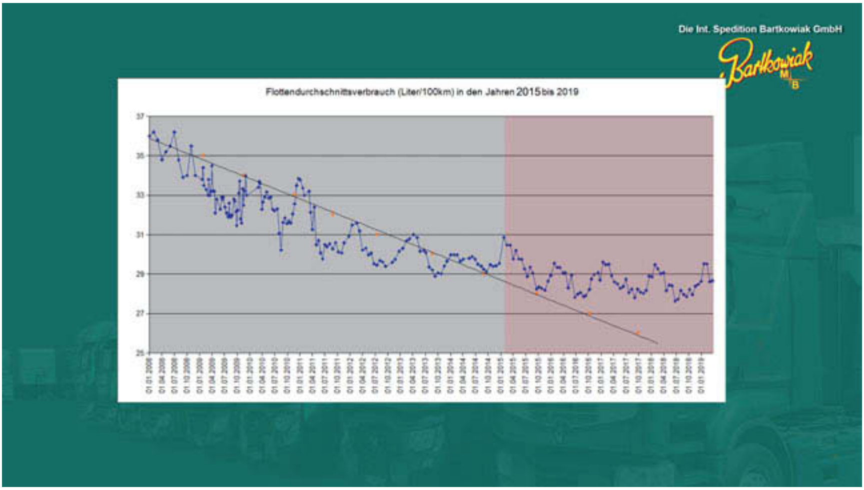
Accounting for our fleet average consumption over the past 10 years



2008 - 2011



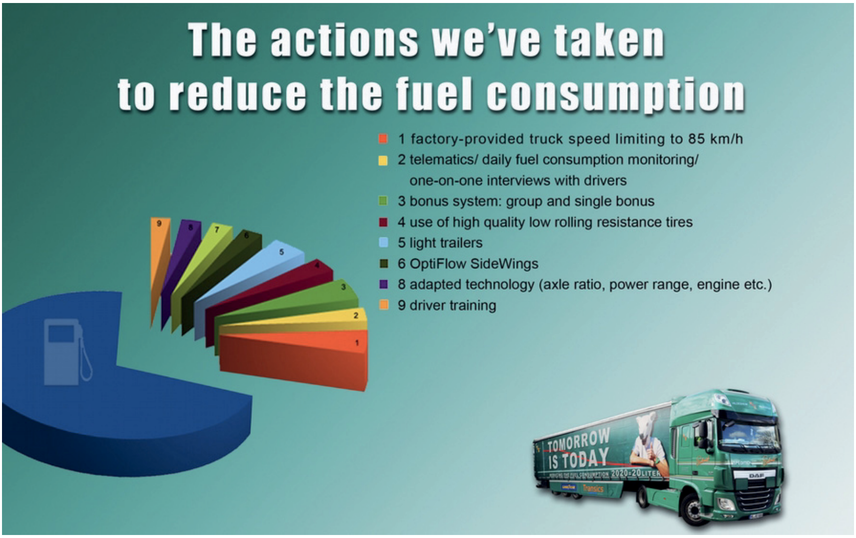
2012 – 1015


Die Int. Spedition Bartkowiak GmbH
Flottendurchschnittsverbrauch (Liter/100km) in den Jahren 2015 bis 2019
37
35
33
31
29
27
25

2015 – 2019

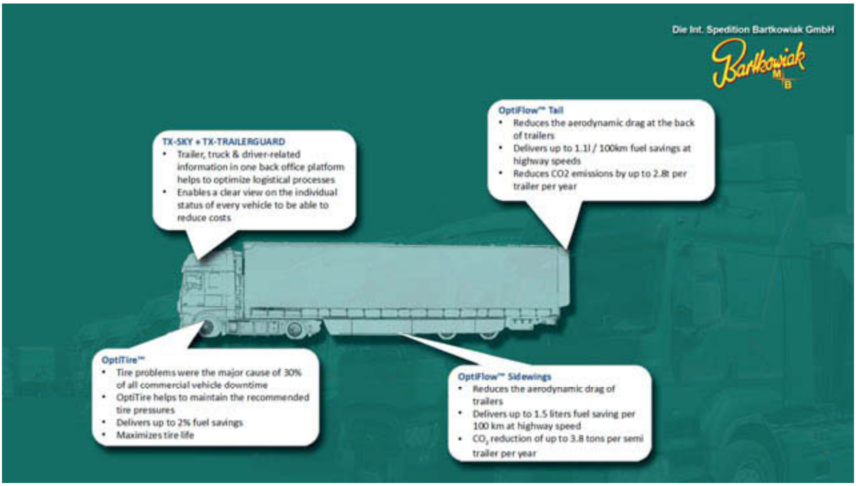

Die Int. Spedition Bartkowiak GmbH
Truck comparison

- Where do we stand and what else needs to be done so that the project can be completed successfully



The entire 9-point plan was implemented between the two Truck + Trailer


Die Int. Spedition Bartkowiak GmbH
Bartkowiak
4
3
2
1


Die Int. Spedition Bartkowiak GmbH
Bartkowiak
TX-SKY + TX-TRAILERGUARD
• Trailer, truck & driver-related information in one back office platform helps to optimize logistical processes
• Enables a clear view on the individual status of every vehicle to be able to reduce costs
OptiFlow™ Tail
• Reduces the aerodynamic drag at the back of trailers
• Delivers up to 1.1l / 100km fuel savings at highway speeds
• Reduces CO2 emissions by up to 2.8t per trailer per year
OptiTire™
• Tire problems were the major cause of 30% of all commercial vehicle downtime
• OptiTire helps to maintain the recommended tire pressures
• Delivers up to 2% fuel savings
• Maximizes tire life
OptiFlow™ Sidewings
• Reduces the aerodynamic drag of trailers
• Delivers up to 1.5 liters fuel saving per 100 km at highway speed
• CO_2 reduction of up to 3.8 tons per semi trailer per year

1. The remaining liters to the destination

the idea 20-20-20

Every year we wanted to lower the average by 1 liter / 100km. That is 12 years = 12 liters; So in 2020, the average consumption of our fleet would be 23.5 liters / 100 km.

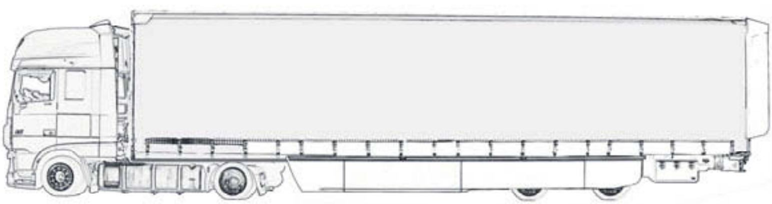
With the help of modern drive technologies, like e-mobility, hybrid technology, etc. then the last 3.5 liters to 20 liters in average consumption to create: therefore "20-20-20"

How do we manage the remaining x liters?

Brief presentation of the fuel-efficient concept based on our "9-point plan" with current results until the end of May 2019

- Book excerpts: End of the day? Not with us! A forwarding company becomes a savings lab.
- Recent results / confirmation of the measures (new GOODYEAR tire test and the incredible consumption of our experienced employee, Hendrik Stalder (see book, page 64/65).)
  He proves that we at least 10% of this savings (of absolutely 22.5%!) to owe the aerodynamic parts of the trailer.
  Fuel saving champion: We regularly issue the most fuel-efficient truck and give it the title "fuel-saving champion". In 2017 it was z. A DAF XF 440 FT. 2018 a Renault T. Outlook for 2019 ...
- Are the two-axle semi-trailers from Berger more economical or ecological than normal three-axle semi-trailers? A reflection from practice.

2. Interdisciplinary considerations on the fuel-saving potential



- **Truck-Energy-Balancing ------ one try**
- **What will become of the third axle** (Break-Disk-Wear)**?; E-Drive**
- **Electrical-Driving**
- **Brake-Energy-Recovery**
- **What further parts can save energy by changing them?**
- If there is going to be a change of the truck's and trailer's main frame, what would be the exact costs and its benefit?
- How exactly has a legislative change to look like in order to integrate useful aerodynamic parts into the truck/trailer?
- How can the OEMs contribute?

- When will the truck manufacturers change the propulsion?
- How can the tyre manufacturers contribute in the next years?
- How is the trailer of the future going to look like?
- How is the suppliers' contribution going to look like?

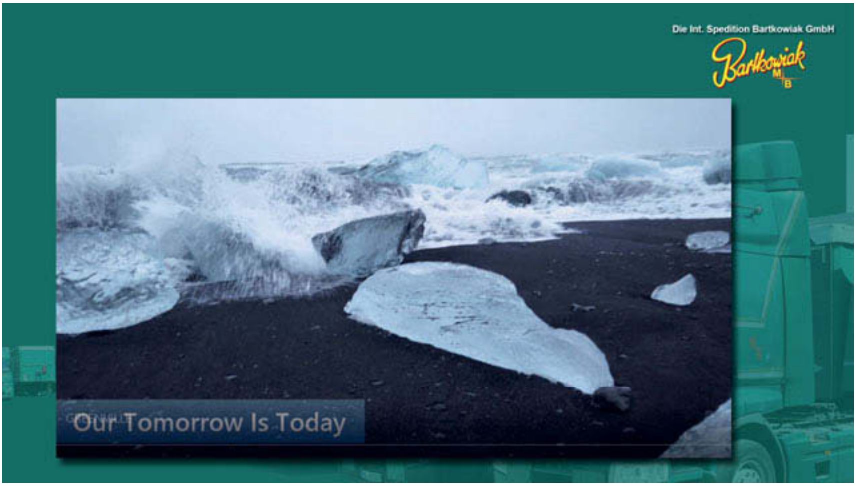
We engage these matters to already plan the strategical purchase of trucks and trailers. In this process, the law maker must not be forgotten (e. g. the tax on CO2 emissions).

3. CONCLUSION - 31 million kilometers evaluated

- What could we achieve?

  Over the last years we have seen that the average fuel consumption can be reduced by 1 litre / 100 km every year, provided that one has the right ideas. Taking this formula for granted it must be possible to reduce the average fuel consumption to 20 litres / 100 km. Since the last litres won't be the easiest ones though it's difficult to predict an exact target period.

Short closing film "Our tomorrow is today"



- Possibility to answer questions

Automotive and
Traffic Systems Technology

ISBN 978-3-18-092350-5

Source: © Milano Medien GmbH