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# Commercial Vehicles 2017

## Truck, Bus, Van, Trailer

# VDI-Berichte 2298

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# Preface

The Commercial Vehicle Industry is facing significant challenges in this era of increasing needs for transport of people and goods. The society is changing rapidly, where more people are living in urbanization areas and demanding more smart and sustainable solutions: silent, clean, safe, connected and efficient. Transport of people and goods is the live-blood of our economy, fulfilling the needs to let people travel to places for work, leisure, healthcare, and others, and transporting products and half-products, distributed on short distance or transported over long haul, to industrial areas to add value and distribute them to end users, households or the individual consumers.

Making use of new technology, like digitalisation and electrification, the Commercial Vehicle Industry improves their products and services in an increasing tempo. Our customers are using the vehicles in a complex environment, making use of sophisticated planning tools, being connected and integrating all kinds of relevant information to serve the end users and perform better than their competition. It is this environment that stretches requirements and urges for differentiating solutions.

New and stricter global legislations on emissions, safety and vehicle masses and dimensions will lead to new solutions to be integrated in vehicle platforms. Modularization and standardization could make significant difference in coverage of the global market requirements and the efforts of the Industry to serve specific customer wishes. The vehicles are increasingly sophisticated and make use of a large amount of functional systems, which need to be integrated and having an overall architecture aiming at energy efficiency and low costs.

Automated and connected vehicles can contribute to lower total cost of ownership over the life cycle of the commercial vehicles, which is a decisive criteria for end-users. How the driver will perceive his future task is another area of investigation, where smart interfacing concepts support safe and efficient use of such vehicles.

The programme committee of the VDI-Congress “Commercial Vehicles” invites all commercial vehicle architects and specialists to contribute to a lively event by sharing their experiences, results and views. The Congress will cover the 6 categories as mentioned below, amongst others Transport Solutions of the Future, Vehicle Architectures, Automation, De-

Carbonization, Connectivity and Product Industrialization. By means of sending in an abstract of your paper and lecture, you will get the chance to get in contact with an international audience of experts in the field of Commercial Vehicles. We look forward your subjects for presentation and discussion.

On behalf of the programme committee.

**Loek van Seeters**
DAF Trucks NV

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# E-Mobility for City Bus and Coach Applications – An integrated System Approach from ZF

Dr.-Ing. Dipl.-Wirt.-Ing. **Jochen Witzig**, Dr.-Ing. **Andreas Grossl**, M.Eng**. Matthias Wenger**, ZF Friedrichshafen AG, Friedrichshafen

**Abstract**

Based on a general strategy for the electrification of commercial vehicles, ZF derived a product portfolio for future drivetrains including both full electric drivetrains as well as hybrid electric drivetrains based on existing conventional transmission systems. Considering this strategy, the following paper describes in detail the two products for full electrified driving for medium and heavy bus and truck applications, the electrical portal axle AVE130 and the currently developed new central drive. The AVE130 is an optimal solution for low floor buses including both solo and articulated buses enabling on the one hand an independent and innovative interior concept and vehicle architecture of low floor buses, because the complete drivetrain is integrated into the wheel hubs of the driving axle. Furthermore, due to this, the overall weight of the drivetrain is outstanding. Complementary to this already in series production available product, ZF develops currently the central drive solution for both low floor and low entry buses (solo and articulated) and distribution trucks. The consideration of the complete drivetrain from e-motor down to the wheels offers the possibility to ensure an overall very good efficiency which is one of the key topics for E-Mobility vehicles as efficiency is directly linked to range with a given set of batteries. This is ensured in the central drive by the combination of a high speed e-motor and a reduction gear stage. The possibility to combine the central drive with standard axles (both direct and portal axles) ensures not only a high drivetrain reliability and a very good system efficiency, but also the possibility to consider a platform strategy between conventional and full electric bus applications. The central drive but also the AVE130 in a modified structure can be applied for both bus and truck applications. Both products are available as a component, but also as a system including power electronics and drive control unit.

**Strategic drivers of electrification of bus and coach applications**

Global megatrends have a significant impact on the drivetrain concepts of the future. Beside of sustainable handling of available resources, continuous growth of population and its concentration in urban metropolitan areas, the reduction of global and local emission of $CO_2$, $NO_x$ and further polluting emissions such as respirable dust and noise is one of the key challenges and targets in future commercial vehicle developments.

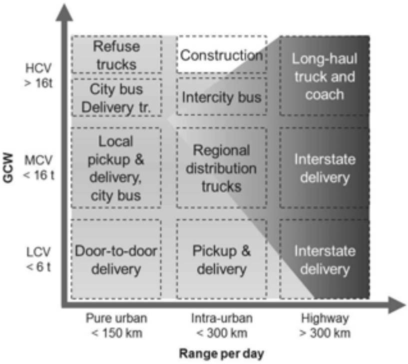


Fig. 1: Clustering of different commercial vehicle applications regarding vehicle weight and daily mileage (light gray = BEV, dark grey = HEV) [1]

In order to answer to these trends and challenges, ZF has set up a general strategy regarding electrification for commercial vehicles, which includes fully electric solutions as well as hybridization of conventional transmission systems. The decision whether a full electric or a hybrid solution is the preferred choice mainly depends on two factors: the vehicle weight and the range per day. This relationship is illustrated in Fig. **1**, where different commercial vehicle applications are clustered accordingly.

Based on this clustering, a battery electrical vehicle (BEV) is the preferred solution in case of a limited and regular daily mileage, predictable battery charging and mainly city operation. In contrast to this, hybrid electrical vehicles (HEV) are seen in applications which are distinguished by high daily mileage, high vehicle weight and fuel consumption as well as highway application. While in certain use cases

A vehicle of BEV type will already be more cost-effective than a HEV within a few years and today's hybrid solutions in these use cases should consequently only be seen as an interim solution, there are others that will require a hybrid for quite some time. . The reason for this statement is that a BEV does not constitute a sensible proposition for long-distance transportation due to the large amount of capacity that needs to be installed. However one crucial requirement for these HEV is to ensure local emission free driving in the inner city area. This fits in with government's objectives of reducing local emissions in urban areas. It still remains to be seen when technologies with game-changer potential will be adopted universally (e.g. fuel cell, overhead line) and until then ZF's electrification strategy is based on these interrelationships: Battery vehicle for all urban vehicles with limited daily mileage, and hybrid for all long-distance transportation applications.

A more detailed description of general drivers for electrification and the derived ZF strategy regarding electrification is shown in the paper “Electrification in Commercial Vehicles - Megatrends and Solutions - Electrical Central Drive for LCV and TraXon Hybrid for Heavy Duty” [1].

Out of these investigations, ZF derived the product portfolio regarding electrification of commercial vehicles as shown in Fig. **2**. From left to right, both the vehicle weight as well as the daily mileage are increased and ZF’s solutions are shown accordingly.

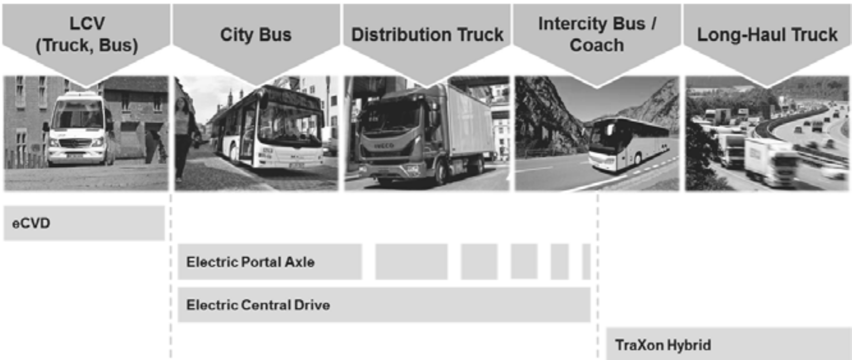


Fig. 2: Products from ZF implementing consequently the strategy regarding BEV and HEV applications

Following this strategy, especially in city bus applications, a clear orientation towards BEV will be seen in future – and can already be seen today. Cities like Köln or Eindhoven have already started to implement BEV in their public transportation systems and many have committed to do so in the near future. Furthermore, worldwide tenders from public transportation agencies call out for only considering full electric solutions starting from 2020 onwards. China as one of the global leaders regarding E-Mobility has already seen a huge increase in electric vehicle production in the last years. All in all, extrapolations predict in the next 10 years more than 250.000 commercial vehicles with alternative driveline concepts.

ZF accommodates this situation with an integrated strategy for both city bus and coach applications. In this strategy, beside the consideration of different bus types, also the different application areas and routes are incorporated in order to provide the optimal solution to the public transportation agencies. One other guiding principle during the development for ZF is the overall system efficiency, including e-motor, power electronics, mechanical parts as well as the axle.

**AVE 130 – Electrical portal axle especially for low floor city buses**

The AVE130, an electrical portal axle, available both as component (only axle) or system including power electronics and drive control unit. In Fig. **3**, the AVE 130 is shown.

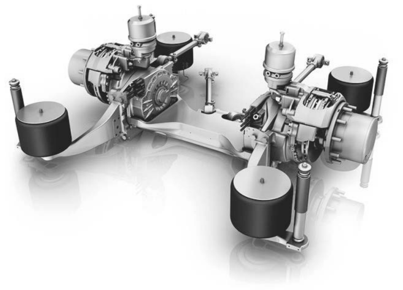

Fig. 3: Electrical Portal Axle AVE 130 from ZF

Due to the very compact design – in fact, the complete drivetrain is included into the wheel heads of the axle, one of the main advantages of the axle is the high independency regarding the interior design and vehicle architecture of the bus. Especially for all battery electric vehicle solutions from ZF, one main focus during the development is put on the overall system efficiency. In consequence of this together with the necessity of a very short driveline in order to enable full low floor capability, a combination of a high speed running ASM motor in combination with a two gear steps was chosen. The asynchronous motor is water cooled, however, in order to have an evenly distributed temperature profile in the motor which is also beneficial for the efficiency, and a reduced bearing temperature, a special internal air circulation was designed using advanced simulation methods considering the dynamic air flow. Considering all these aspects, the overall temperature profile is well under control for all application scenarios, whereas the heat development of the brake discs have been also considered in the overall design of the wheel heads. Directly connected to the high speed ASM motor, a patent power split gear stage, followed by a planetary gear stage are attached. These enable the AVE on the one hand the full low floor capability as well as a performance of approx.. 11.000 Nm torque at each wheel, in total approx. 22.000 Nm tractive torque. This high power driveline pushes even full loaded articulated city buses gradeabilities of up to 15% with a sufficient acceleration and driving performance. The compact design offers beside of the described advantages regarding vehicle interior design also a benchmark weight / power ratio which is very important especially for electric driven vehicles, where weight reduction is equal to range extension. The weight of the AVE130 axle is just about 200kg higher compared to the weight of a conventional low floor axle AV133.

Another important potential of the AVE 130 is the easy application of the driving axle in an articulated bus at the middle axle position, which means as a puller axle for articulated buses. This driveline concept offers in comparison to the standard pusher concept advantages regarding vehicle dynamics (the rear part of the bus is pulled similar to a trailer) and also regarding cost advantages as the joint between front and rear bus can be designed much more easily.

In order to reduce the effort for service for the public transportation agencies maintaining both conventional and full electrical vehicles, a consequent common part concept was implemented. Due to this, parts like disc brakes, brake discs, air springs, shocks or wheel bearings are identical between conventional and electrical axles from ZF.

To summarize, the AVE130 electric portal axle is the optimal solution for solo and articulated low floor buses offering the possibility of innovative new interior vehicle design and vehicle architecture and – especially for articulated buses, provides the possibility of installing a puller set up meaning having the driven axle at the middle axle position which brings advantages regarding driving dynamics and cost of the joint between front and rear bus.

Beside of the application in buses, there are also investigations ongoing to derive an accordant electrical axle to be installed in future distribution trucks.

The AVE130 is already available as component, by end of 2017 also as a system supply including also power electronics and drive control unit.

**Central Drive – Full electrical solution for low entry and low floor buses and coaches**

As an ideal complementary solution to the described electric portal axle AVE130, ZF is currently developing a central drive system to be applied in low floor buses (solo and articulated), but as well in low entry buses and commuter buses, see Fig. **4**. Additionally, also the requirements from heavy distribution trucks are already considered in the development phase to enable the installation and application of the central drive in distribution trucks. ZF targets to have SOP for the central drive middle of 2019.

Fig. 4: Electrical Central Drive from ZF

The central drive consist of a high speed e-motor and – in the basic design – of an integrated planetary gear set to combine the benefits regarding efficiency and weight of a high speed running e-motor and the high performance torque characteristic leading to traction torques at the driving wheels of approx. 25.000 Nm in total depending on the used axle ratio.

The design and the dimensioning of the central drive from ZF considers especially the possibility for bus manufacturers to set up a platform strategy between conventional and electric buses, at least from drivetrain point of view. This means that both the assembly position as well as the connection to the drive shaft is the same as for the EcoLife, which is the conventional automatic transmission system from ZF. Simply saying, from a drivetrain perspective, it is possible to remove the combustion engine and the transmission and replace it with the central drive from ZF keeping the rest of the drivetrain as it is. Of course, other topics such as auxiliaries, battery installation etc. needs to be considered separately.

By considering the optimal layout of the complete drivetrain starting from e-motor and ending at the axles and wheels, it is possible to design a benchmark product regarding both weight – compared to central motor solutions of competitors – and regarding system efficiency including e-motor, power electronics and mechanical efficiency of accordant components.

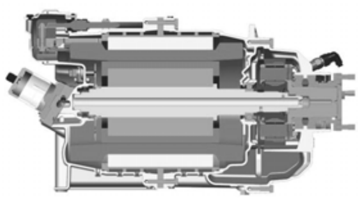

Fig. 5: Modular Concept of Central Drive

The modular concept of the central drive from ZF is based on the requirement to consider already now future requirements from different electrified vehicle families. The modular design consequently enables the variation of the length of the e-motor as well as the usage of a fixed reduction gear module and a power shiftable module to combine high vehicle speed and high gradeability, especially for distribution trucks, commuter buses and articulated buses. The modular concept is shown in Fig. **5**.

ZF develops in parallel two e-motor technologies to be applied in the same housing, an induction machine and a permanent synchronous motor. Reason for developing both systems is that depending of the drive cycle of the vehicle, but also depending on the topics like fleet strategy of the public transportation agencies or logistic companies, number of variants, costs, temperature profiles or needed effort for safety concepts, both motor technologies have their advantages. The currently developed ASM motor shows very high efficiency values not only in high but also in medium rpm areas, reached by several design measures.

One further important aspect during the development of ZF Central Drive is the consequent consideration of standard axle ratios already known from conventional drivetrains. From ZF`s point of view, this is important due to two aspects. On the one side, the usage of already in service of heavy city bus applications proven components increases the overall system reliability. Competitor solutions sometimes have to use unfavourable axle ratios in order to achieve the needed vehicle speed and gradeability depending on the speed range of the e-motor. These axle ratios could have difficulties regarding lifetime requirements especially in heavy city bus applications as well as achieving the needed efficiency. On the other side, the standard axles in for both city and intercity buses have been improved in the last years regarding the efficiency characteristics. By using these axles, the overall efficiency characteristic of the drivetrain using the central drive from ZF, is very competitive, and this is valid for both ASM and PSM motor technology.

Same as for AVE130, the central drive will be available both as component and as system including power electronics and drive control unit.

**Summary and outlook**

Based on an overall strategy for electrification of commercial vehicles, ZF derives a portfolio of different products serving both full electrical vehicles such as LCV, mini buses, low floor and low entry buses and articulated buses as well as distribution trucks, but also long haul trucks and coaches with hybrid electrical systems.

Especially for city bus applications, ZF offers the electrical portal axle AVE130 as a series product. By integrating the complete drivetrain into the two wheel hubs, this axle offers on the one side new possibilities regarding design of the vehicle interior as well as weight advantages, on the other side, the AVE130 enables especially in articulated buses the puller concept, meaning the driving axle is the middle axle. This is beneficial for both driving dynamics and cost savings due to the less complex joint between front and rear bus.

Complementary to this, the new ZF central drive is currently under development and targets for SOP middle of 2019. The central drive can be applied to both low entry and low floor buses (solo and articulated), but also to distribution trucks and commuter buses. This is possible due to the possibility to combine the electrical central drive with standard axles (low floor and direct axles) already known from conventional drivetrains. This possibility offers both a reliable total drivetrain system as well as a system with a high overall system efficiency. The modular design of the central drive brings high flexibility regarding variation of power of the e-motor and performance, but also the possibility to attach a power shiftable module to serve high vehicle speed and high gradeability requirements. In order to have the best suitable drivetrain depending on the drive cycle, ZF offers both an ASM and a PSM e-motor for central drive.

Both AVE130 and central drive from ZF is available as component supply, but also as system supply including power electronics and drive control unit.

With both products AVE130 and central drive, but also considering the other products from ZF in development (hybrid systems as well as electrical solutions for LCV and midi buses), ZF supports a sustainable commercial vehicle fleet for a high variance of future applications.

## Reference

[1] "Electrification in Commercial Vehicles - Megatrends and Solutions - Electrical Central Drive for LCV and TraXon Hybrid for Heavy Duty", M. Dietrich, M. Kohler, Dr.-Ing. F.-D. Speck, Paper zur Tagung „Getriebe in Nutzfahrzeugen", 2017

# Electrification in Commercial Vehicles

## Megatrends and Solutions – Electric Drives for Light and Medium Commercial Vehicles and TraXon Hybrid for Heavy Duty

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**Abstract**

The use of hybrid and electric drives in commercial vehicles allows for a significant reduction in fuel consumption and emissions. This means that this technology can make a major contribution to reaching CO2 reduction targets. At the moment, a trend in inner-city delivery traffic can be seen that all-electric vehicles are being used due to falling battery costs. We can also expect cities to impose local access restrictions on diesel vehicles to meet particulate and noise emission limits. Taking everything into account, the vehicle system's total cost of ownership is nevertheless of high importance and therefore it is desirable to generate cost-effective solutions.

Through its e-mobility strategy for commercial vehicles, ZF has cost-effective solutions for all vehicle segments from all-electric delivery commercial vehicles to long-distance traffic, where the combustion engine will remain indispensable for many years to come. This paper provides an overview of market trends, motivation and suitable solutions for the truck segment as well as the current status of developments.

**Drivers of Electrification**

The electrification of commercial vehicles has emerged clearly as a trend on its own over the past few years. Electrification is, however, not an end in itself, but helps meet various needs. Emissions reduction and total cost of ownership are the key drivers in this case.

With emissions reduction it makes sense to differentiate between CO2 reduction and the reduction of other emissions on account of the different mechanisms involved. CO2 is in itself a non-poisonous gas that does not affect human health. It is the detrimental impact on the climate which makes the reduction of CO2 emissions a key driver. In this respect, the focus is on the global consideration of CO2 emissions, with the issue of where the CO2 is emitted of minor importance. The situation is different with the other emissions, such as NOx, particulates or even noise. Here, the local reduction of emissions is often also desirable, particularly in urban areas where pollution levels are already high.

Governments are firmly committed to reducing CO2 emissions. In the EU, for instance, the target is to reduce overall greenhouse gas emissions by at least 40% through 2030, taking 1990 as the base year. This of course has an impact on the auto industry. CO2 legislation is already in place for passenger cars, with ambitious targets that will drive technological development in the industry for years to come. Such regulations are only now emerging for commercial vehicles. Starting with a monitoring phase from 2018 where buyers will be given information on CO2 emissions of vehicle combinations to increase market transparency, initial limit values are expected from 2021; these values are also likely to be ambitious.
Electrification can contribute to achieving these limit values. However, electrification ultimately constitutes just one of many solutions, some of which compete with each other when it comes to CO2 abatement costs. That is why it is also crucial in the case of electrification to offer cost-effective solutions. The reduction of CO2 emissions always also entails a proportional reduction in fuel consumption and, in turn, running costs for the operator; the extra costs of the systems used must, however, pay off within an acceptable time frame. This applies in particular so long as CO2 legislation is not so stringent that, without such systems, the limit values can no longer be achieved.
The reduction of other emissions has no positive impact on fuel consumption, and so there are no direct savings with operating costs. The reduction of these emissions is driven by government, particularly by municipal authorities given the importance of local emissions. The introduction of low-emission zones, driving bans and city tolls are just some of the tools used here. As such, increasing numbers of vehicle operators in inner-city transportation are pursuing a strategy of converting their fleets to electric vehicles, with local emissions virtually reduced to zero in the process. *Fig.* **1**shows the various described drivers.

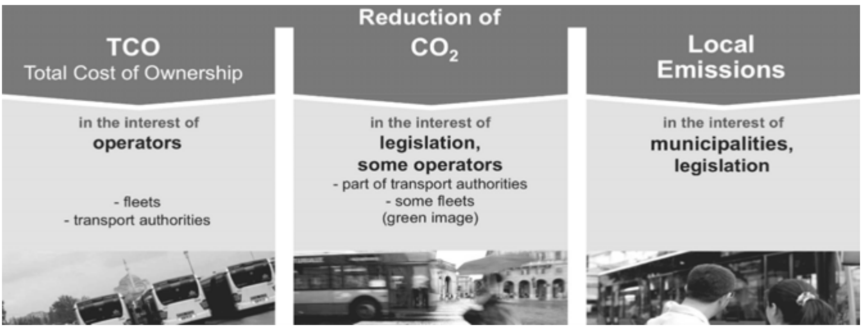


Fig. 1: Market Drivers for Electrification

## ZF's Electrification Strategy

There are a host of different vehicle classes for commercial vehicles; unlike passenger cars, specific vehicles are developed for specific use cases. This is beneficial for electrification as it allows the electrification solution to be tailored more optimally to a specific application, without having to offer every solution in every vehicle class.

Consequently, the dimensioning of a battery, for instance, for an electric passenger car is problematic. While most users' daily mileage is below 50 km, the same vehicle may nonetheless also be used occasionally for longer journeys, with users even driving their car on vacation. Therefore the battery in an electric passenger car is substantially oversized for most days of the year; you actually only use the installed capacity on a handful of days. For commercial vehicles by contrast, there are many applications where the vehicles clock up a similar number of kilometers every day, without other journeys that fall outside the norm. Tailoring the battery size to these applications allows you to make much better use of the costly battery component. This means that an electric vehicle proves much more cost-effective in certain commercial vehicle applications than in the passenger car.

So it makes sense with commercial vehicle applications not just to differentiate by weight, but by daily mileage too. This is illustrated in *Fig.* **2**. The lower the daily mileage of a vehicle, the more suitable it is as an electric vehicle. In ZF's view, for certain use cases an electric vehicle will already be more cost-effective than a hybrid vehicle within a few years. The hybrid should therefore only be seen in these vehicle classes as an interim solution on the way to the electric vehicle. This fits in with government's objectives of reducing local emissions in urban areas.

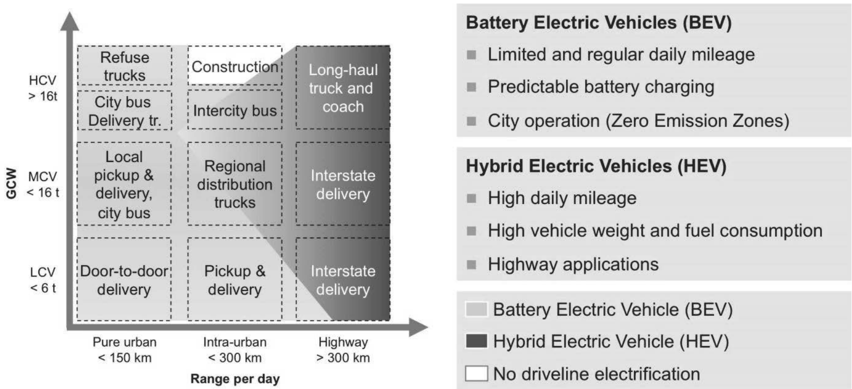


Fig. 2: Areas of Electrification

By contrast, a battery vehicle does not constitute a sensible proposition for long-distance transportation due to the large amount of capacity that needs to be installed. It still remains to be seen when technologies with game-changer potential will be adopted universally (e.g. fuel cell, overhead line). As such, the internal combustion engine will still be a firm fixture in this usage area for some time to come and the hybrid the mode of choice when it comes to electrification. The challenge lies in making this hybrid as cost-effective as possible so that it also pays off for the operator. It is also apparent that customers also want to make use of the limited electric range of their vehicles wherever a powerful electric drive is already on-board thanks to the hybrid; be it for electric driving on the first or last kilometers of a journey, at depots or in factory workshops and warehouses.

ZF's electrification strategy is based on these interrelationships: Battery vehicle for all urban vehicles with limited daily mileage, and hybrid for all long-distance transportation applications (Figure 2). This gives rise to the various products for trucks and buses.

**Derivation of Electric Drives from Passenger Car Applications**

Since ZF also develops electric drives for passenger cars, it would seem logical to use these in commercial vehicle applications wherever possible. In this way you can benefit from the far higher volumes from the passenger car and provide a commercial vehicle drive at a very attractive price point. Several drives are available in various performance classes.

One example is the eVD2 electric drive, which develops up to 150 kW of power (*Fig.* **3**). This drive features a high-revving concept where the electric motor reaches a speed of 13,000 rpm. This makes for a compact design of the electric motor and cuts costs. The requisite ratio of 9.6:1 is achieved by means of a two-stage transmission; more than one gear is not required. Asynchronous technology is used as the motor technology. The drive is designed as an axle drive, i.e. it includes the differential from which the wheels can be driven directly. Electric motor, transmission and differential are installed in a single housing and, together with the power electronics, form a compact unit weighing just 113 kg in total. The innovative design is rounded off by an integral overall cooling concept, which includes both power electronics and the electric motor and also cools the electric motor's rotor.

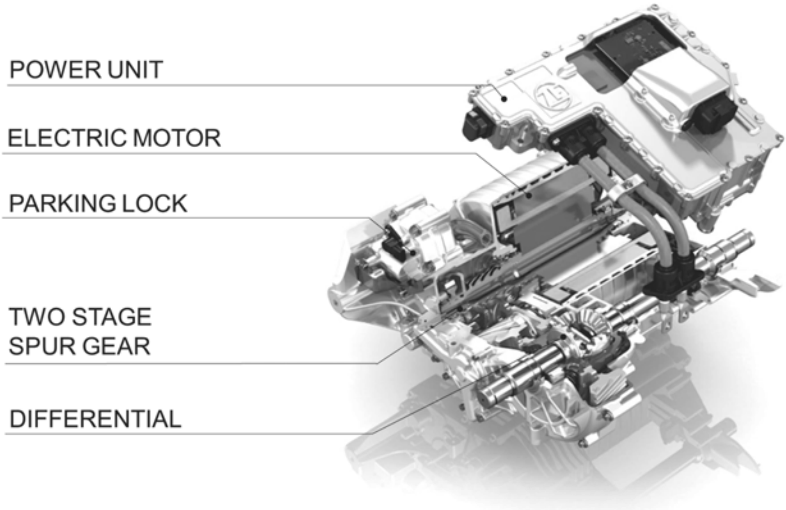


Fig. 3: Electric Axle Drive, main Components [1]

In addition to the 150 kW class, market demand also exists for electric drives below and above this class. In response, ZF is also developing under the name eVD3 a modular axle drive platform to support the entire range, from subcompact and mid-size cars to premium vehicles (*Fig.* **4**). Synchronous or asynchronous technology is used for the electric motor, depending on the variant. For commercial vehicles the high variant is particularly important since other applications can be developed with it above and beyond eVD2. This variant offers power of up to 250 kW; the engine speed is increased to 18,000 rpm. This drive is also very compact and weighs just 130 kg.

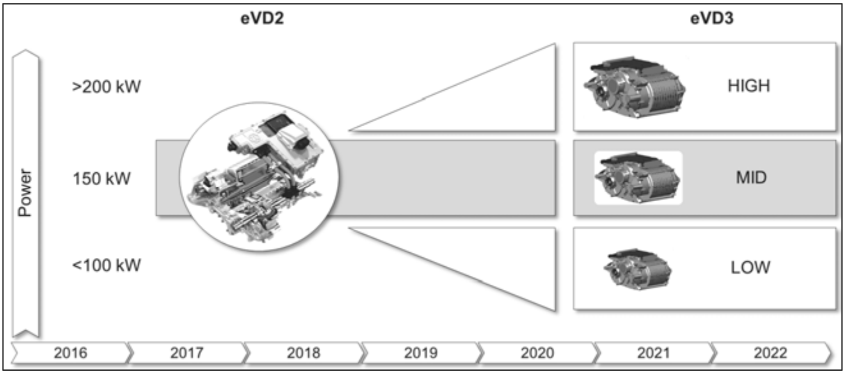


Fig. 4: Outlook Electric Vehicle Drive (eVD) Development [1]

To capitalize on the passenger car's economies of scale, the electrical components need to be adopted wherever possible with no modifications for the commercial vehicle variants. The mechanical components must, however, be adapted in any case with regard to ratios, packaging and mounting points. This applies especially if the drive is designed to be used in conjunction with a rigid axle as a central drive since the differential is no longer required in the drive unit in this case. When adapting the mechanical components, you can then factor in commercial vehicle-specific requirements from the outset.

The desire to adopt electrical components unmodified from the passenger car begs the question of the application limits in commercial vehicles. In the first instance, torque and power requirements need to be analyzed, which are the result of slope and speed requirements. Yet, this is insufficient in itself and paints an overly optimistic picture. It is also important to consider the thermal load on the electrical components, which is produced with typical commercial vehicle drive profiles and use cases. These drive profiles and use cases must not, on the one hand, cause the permissible limit values in the components to be exceeded, while, on the other hand, thermal temperature rises also impair the service life. Therefore, any analysis of the application limits must also ensure in particular that the required service lives in the commercial vehicle applications can be achieved.

The application limits are determined at ZF in a combined simulation process whereby component loads are calculated from the drive profiles, before temperature and damage simulations are conducted for the individual components. Ideally the models should be aligned with real world data in advance. As soon as the unit is available as hardware, application limits can also be determined or confirmed experimentally.

These analyses demonstrate that a drive derived from the eVD2 cannot be used for truck applications (7.5 t and higher). As such, the range of applications is restricted to light commercial vehicles. ZF will present both axle drives and central drives in this segment in order, on the one hand, to serve vehicles with front-wheel drive and, on the other hand, rear-wheel-drive vehicles with a rigid axle.

The electric drives for trucks are based on eVD3. As such, it is possible to serve at least the current 7.5 t and 12 t vehicles; it may also be possible to increase the application limits here further. The focus with these vehicles will be on the central drive variant. Other ZF products are available for heavier-duty vehicles; these products are developed specifically for commercial vehicles, such as the electric central drive [2].

This gives rise to the product portfolio for trucks illustrated in *Fig.* **5** where commercial vehicle-specific solutions and solutions derived from the passenger car complement each other

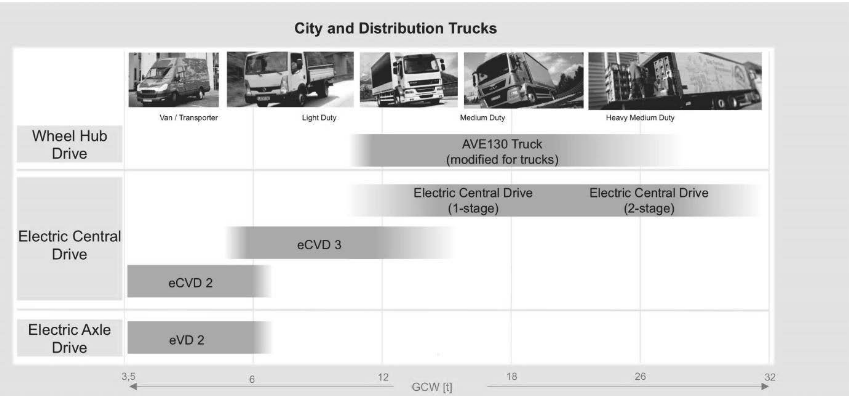


Fig. 5: Product Options for City and Distribution Trucks

**Heavy Duty Hybrid**

As indicated, hybrid drivetrains will be the mode of choice when it comes to electrification of heavy duty applications. The first applications will be shown in urban areas where early adopters can benefit from the use of hybrid vehicles in niche applications. The use of a hybridized tractor allows the delivery of a maximum payload at night. At the same time, the vehicle does not have any restrictions with regard to the range and can also carry out long distances without transship the load on smaller (full electric) vehicles. A typical use case is the supply of supermarkets in inner cities, in particular as soon as municipalities prohibit the use of diesel-driven trucks at night or even in the inner city area due to the setting noise emissions.

From the described use case, the requirement "e-drive – last mile delivery" can be derived correspondingly to the hybrid system. It should be noted that the required distance is not to be understood literally, but rather distances of up to 15 km in purely electric mode are to be covered. In addition to the reduction of noise emissions, the operation of the last mile in the purely electrical mode also enables the avoidance of local emissions in the urban environment. This becomes particularly relevant as soon as municipalities implement temporary or even full-scale entry restrictions for diesel vehicles. In such scenarios, it cannot be ruled out that despite the considerable additional costs for hybrid drives already in this early phase, a positive business case is already emerging.

It remains to be noted that hybrid vehicles in the Heavy Duty segment will only outgrow the niche market if there is a significant market penetration for long haul applications. Main drivers for rising penetration rates of new technologies in this very attractive segment are either legislative obligations or a proven TCO benefit with reasonable amortization periods, which means within 2-3 years at maximum. In terms of legislative stimulus, it can be expected that the first step of binding CO2 limits in EU may be achieved without hybrid drivelines.

Prospects to reach reasonable TCO amortization periods for hybrids in long haulage applications exist. Looking into the TCO calculation of a hybrid vehicle, the main cost drivers are batteries and the hybrid transmission including inverter and electric motor. Battery prices have decreased considerably over the past years and this will continue. The main driver here is the electrification of passenger cars with OEMs having ambitious price targets and huge battery production capabilities being installed to produce cost-effectively and deliver scale effects. Regarding the other electric components, cost reductions are also possible with increasing numbers. Today there is a bit of a chicken-or-egg problem where numbers are simply too small to produce cost-attractive components.

The respective cost savings, on the other hand, are determined by the yearly mileage, fuel costs and the fuel efficiency of the hybrid system. In terms of fuel efficiency, ZF has conducted elaborate measurements that show reduction potentials of ~7% in average compared to diesel vehicles [3] [4]. The exact amount of saving depends not only on installed power of the e-motor and battery capacity, but also heavily on topography and traffic density. Therefore, it will be a key success factor for logistic companies to pick suitable routes mainly to leverage the full potential of hybrid drivetrains.

Having all the relevant figures in mind, it is quite easy to calculate the market price that needs to be achieved to reach reasonable amortization periods. With falling battery prices it is just a matter of time when the turning point will occur. Battery price forecasts at ZF show that it should be possible to reach an amortization period of 2 years in 2025, even with a rather conservative battery price scenario. That means that the technology would be attractive to end users without taking legislative obligations into account.

Regardless of the influence of battery prices, it is the challenge for ZF to come up with smart solutions that are cost-effective while fulfilling main requirements like pure electric driving for early adopters and attractive fuel economy figures. Therefore ZF has investigated various e-motor technologies for hybrid solutions to fulfil this market needs.

In general, the advantages of permanent-magnet synchronous motors (PSM) are a compact design with high efficiency. Especially in the lower speed range of the e-motor the PSM has a higher efficiency than other technologies. However, the product cost is higher through the use of high quality magnetic materials. Another penalty is the drag loss that every PSM e-motor comes with. In recent years, several PSM solutions have been the focus of market attention. As an outlook and taking mass production into account, low-cost e-motors can be a decisive competitive advantage. In this case, the asynchronous e-motor (ASM) technology could be a key to success as it no more needs expensive high quality magnetic materials. Compared to the PSM technology it has efficiency disadvantages in lower and higher efficiency in upper speed range. Also the ASM design does not come with any drag losses as the PSM does.

ZF's heavy hybrid solution is based on the TraXon transmission, a state of the art AMT and a highly integrated e-motor solution (*Fig.* **6**). The cooling of the hybrid system is integrated in the TraXon transmission oil cooling.

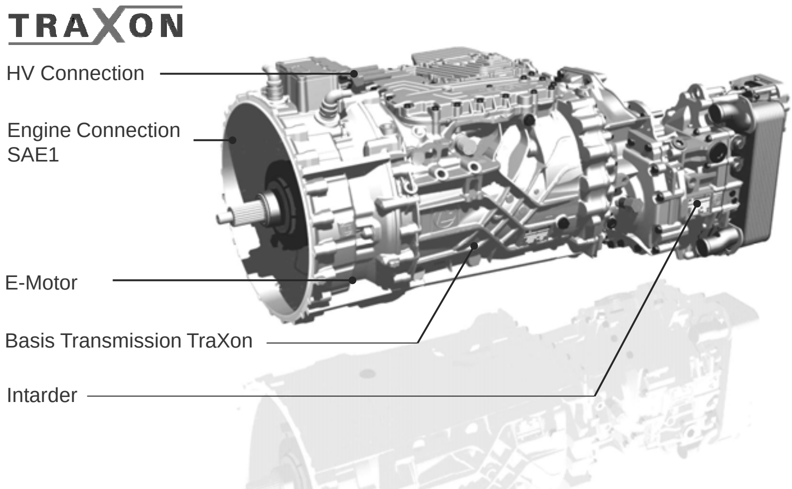


Fig. 6: ZF Heavy Duty TraXon Hybrid

The hybrid control unit (HCU) provides operational and strategically functions with a high level of flexibility to meet several customer demands and to adapt to various applications. Also the torque rating of the hybrid system with 1200 Nm related to the transmission input shaft is a statement on its own.

ZF's heavy hybrid solution based on the TraXon transmission provides the needed versatility as required by the drivers for electrification and should be available for early adopters in 2018.

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# Mensch-Maschine-Interface der Zukunft: Innovative Lösungen für die Nutzfahrzeuginstrumentierung

# Human Machine Interface of the future: Innovative solutions for commercial vehicle's instrumentation

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**Kurzfassung**

Klassische Instrumentierungen mit analogen Anzeigen werden zunehmend durch digitale, frei programmierbare Displays ersetzt. Der Fortschritt im Consumer Bereich bei Tablets und Smartphones, die Anforderungen nach „Safety, Economy and Networking“ macht auch im automotiven Nutzfahrzeugbereich nicht halt. Der Fahrer erwartet eine klare, verständliche Information in Echtzeit, aber keine Nachrichtenflut. Continental hat Konzeptlösungen erarbeitet, die zu einer schnellen und qualitativ hochwertigen Grafik-Implementierung führen - vom ersten Designentwurf bis zur Anzeige im Nutzfahrzeug.

Der Interaktion von Instrumentierung und Fahrer, der Abstimmung mit weiteren Anzeigeeinheiten für Telematik, Kamerasysteme, Spiegelersatz und Infotainment kommt weitere Bedeutung zu. Einheitliche und aufeinander abgestimmte Lösungen sind in Zukunft angefragt. Fahrerassistenzsysteme, teilweise mit Objekterkennung und Einsatz von Fahrer-Monitorsystemen sind weitere Bausteine zum Human-Machine-Interface (Mensch-Maschine-Schnittstelle) des automatisierten Fahrens.

Um Kunden und Fahrern neue Lösungen, Systeme und Konzepte erlebbar präsentieren zu können, gibt es den Continental Innovations-LKW. Hier lassen sich neben dem frei programmierbaren Kombiinstrument, der digitale Spiegelersatz, Umfelderkennung, Abbiegeassistenz, Fahrermonitoring und andere Innovationen erfahren.

**Abstract**

Instrumentation containing classical pointer gauges will be increasingly replaced by digital, freely programmable clusters. Trends set by consumer products like tablets and smartphones, as well as requirements for “Safety, Economy and Networking” will drive the automotive commercial vehicle market in future. The driver expects a clearly understandable representation of information in real time, and no information overload. Continental provides

solutions leading to a fast and high-quality implementation of a graphical user interface: a design idea, a first draft which leads to an implementation into the commercial vehicle.

Interaction between instrumentation and driver, including seamless adjustment with further displaying units for telematics, mirror replacement, infotainment and camera systems is of importance. A holistic and fully integrated Human Machine Interface is the key to next generation instrumentation. Advanced driver assistance functions, combined with object detection and driver monitoring systems are further modules towards a Human Machine Interface for highly automated driving.

The new technical solutions are demonstrated in the Continental Innovation Truck. Customers and drivers can experience the Freely Programmable Cluster FPC, mirror replacement by digital cameras, turn assist, surround view and driver monitoring systems and other innovations installed.

## Introduction

Continental is one of the worldwide leading suppliers for automotive products and solutions focusing on the following four automotive megatrends (shown in Fig. 1):

- Safe and accident-free driving
- Information management inside the vehicle and beyond
- Preserving environment and resources
- Affordable vehicles to provide global mobility.

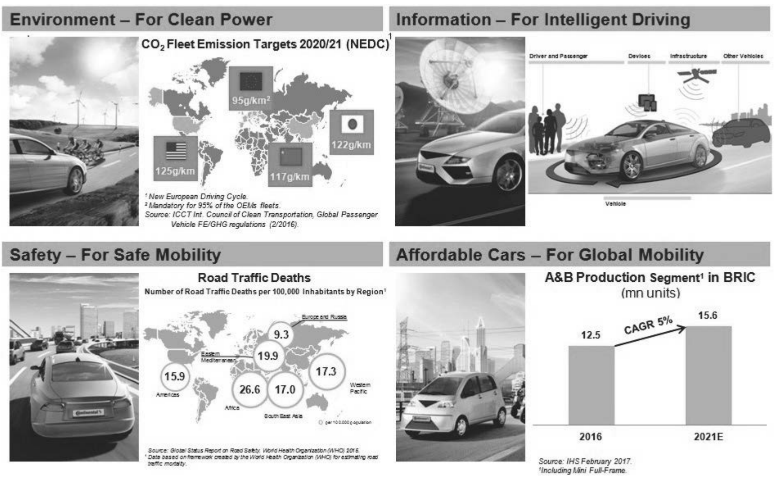


Fig. 1: Megatrends in the automotive industry

Additionally, connectivity, digitalization and servitization are important drivers which have to be considered as part of a future solution.

Continental is offering intelligent technologies and products for the mobility of people and goods worldwide. As a market leader for automotive instrumentation and solutions in passenger cars Continentals business unit Commercial Vehicles & Aftermarket drives activities for trucks, buses, agricultural vehicles, construction machines, two-wheeler and marine.
This article illustrates solutions for the next generation of instrumentation with focus on trucks and buses and gives an outlook on future ideas for highly automated driving.

**Current market situation**

Currently the majority of trucks are using so called hybrid clusters, a combination of pointer-gauges, display(s) and telltale lights. The main display is centrally positioned either in horizontal (landscape) or vertical (portrait) orientation. Colored TFT-displays or monochrome displays in segmented, dot-matrix or mono-TFT-technology can be found inside. Usually transmissive displays are used, this is a mature technology which requires a backlight to serve as light source.

Instrumentation for commercial vehicles differs between the markets because of different vehicle classes with different functionality. Light duty trucks, being regionally on duty, need budget-priced products, medium and heavy duty trucks with superior tasks and functionality tend to use high-grade products.

The European market is characterized by hybrid clusters with 4” up to 7” colored TFT-displays, partly with additional monochrome displays, telltale lights and with two up to six pointer-gauges.
The North-American market currently uses hybrid clusters up to 5” colored TFT-displays, additionally small segmented displays, many telltale lights and several gauges, partly mounted inside the instrument cluster but also outside in the dashboard.
The South-American market follows the European truck market with its vehicles and instruments or adapts to the market-specific requirements.
Asian markets show differences between the Indian, Chinese and on the other hand Korean and Japanese markets. The first named often use simple clusters with monochrome displays in a simple vehicle architecture. Beyond that, the last named use instruments with color TFT-displays up to 7”.

Buses show all types of instrumentation from panels with single gauges up to freely programmable clusters. They distinguish from city buses, following a determined route and using standard equipment, and coaches mostly offering luxury equipment. Nevertheless, it has been noticed that the Chinese manufacturers are aiming to increase their market share in the European commercial vehicles market. Therefore, high-end equipment and electronics are being utilized.

Beside the hybrid clusters several secondary monitors can be found in the center console (B-panel area) such as in passenger cars. They provide navigation information, radio stations and music information, fleet management data etc. From passenger cars known head-up displays showing a virtual picture in front of the vehicle are not visible in the commercial vehicle market yet - except some aftermarket solutions mainly for coaches. One reason is the not suitable geometry of the cabin with a steep mounted windscreen. Alternative combiner solutions are not seen as the optimal solution.

**Current trends in instrumentation**

The automotive Human-Machine-Interface HMI is dominated by trends in the consumer market:

After smartphones replaced the pushbutton telephones and TVs are using increasing display-sizes such display-oriented products and the related interaction concepts found their way into all types of vehicles. Urgently needed are intuitive and safely operable Human-Machine-Interfaces, minimizing driver’s distraction, with the possibility to integrate mobile devices. The development of an understandable, easy to use, affordable and safe solution challenges designers and vehicle manufacturers [1].

Hybrid clusters in passenger cars are increasingly replaced by freely programmable clusters. The usual display size is 12.3” in the format 8:3, starting with a resolution of 1280 x 480 pixel. Nowadays displays of 1440 x 540 or 1920 x 720 pixel are supporting the trend towards higher resolutions and color depths, better contrast values, improved brightness and wider viewing angles plus anti-glare and/or anti-reflection coating. As well, optical bonding technologies are being increasingly used to reduce light diffraction and improve readability under bright environments.

Increasing functional density in trucks and buses causes an increasing amount of information to be displayed to the driver considering his driving situation without distracting him.

Current truck instrument clusters will increasingly be replaced by FPCs in next vehicles generation. The advantage of FPCs lies in the flexibility of information representation: from the vehicle, its surroundings, from driver assistance systems or other safety related information, but also infotainment and camera related content can be displayed situationally.
The display components used in passenger cars are reused for commercial vehicles, which benefit from attractive prices despite of their lower production volumes. As a result of different cabins, dashboards and seating geometry of trucks compared to passenger cars larger displays might be introduced. Expected can be sizes of 14” and larger. Considering functional safety aspects the further usage of telltale lights in FPCs are recommendable.

The design of the Graphical User Interface (GUI) orientates to the unique concept “Simplify Your Drive” [2] – maximum information flexibility for vehicle manufacturer and drivers depending on the market, brand, vehicle and driving mode, when only the needed information is shown on the FPC and the center console display.
Camera systems showing the rear view behind the vehicle or a 360° surround view or digital cameras replacing the external wing mirrors require suitable display devices and solutions. FPCs can lower system cost by removing additional camera monitors and displaying the content situationally.

**Freely Programmable Cluster for commercial vehicles**
When using FPCs the arrangement of where to place the pointer gauges, displays and telltale lights are becoming less significant. On the other hand which information shall be shown on a FPC when and in which way on is becoming more important.
Variant management is done basically via configuration and parametrization of the software depending on the vehicle’s functionality, the engine variants, the markets and further specifications. Functional safety requirements according to ISO 26262-4 are currently considered up to level ASIL-B.

Mechanically challenging are the stress-free mounting of the display component and an optimized thermal management to dissipate heat. Nicely shaped input devices, e.g. for trip reset, might be needed and even if the FPC is switched off it should be integrated aesthetically pleasing into the dashboard.

The FPC electronic concept is an embedded system with suitable graphical computing performance leading to a two-controller solution:

- a vehicle controller serving interfaces like CAN (FD), LIN, inputs/outputs, .. doing calculations and providing the signals for controlling the graphics, executable on the real-time operating system OSEK
- a graphics controller for calculation, rendering and presentation of graphics on the display, executable on LINUX for automotive applications.

Both controllers must communicate with each other and are placed on a dedicated multilayer controller-board. Both controllers are available in different variants, offering different performance and communication interfaces. Multi-core options are also available to ensure a scalable combination from lower-end to high-end applications. The controller-boards are tested and qualified. To ensure scalability and exchangeability the best suitable controller-board for the application will be chosen. The main-board containing the other electronics, the power supply, telltale lights, interfaces will be performed according to the project-specific requirements, the outline and the available installation space.

The FPC software concept has to consider the cold-start behavior, during which a fast boot time is always required. A suitable download possibility for large data volumes, primarily caused by graphical data is needed to reduce the download times. Real-time calculation and presentation of dynamic graphic objects like virtual rotating pointers to indicate speed or RPM leads to layer concepts which considers different frame rates.
Depending on the used graphic controller and its graphic engine 3D models can be rendered or graphic objects in 2D or a more 2.5D spatial shape can be shown on the display.
The vehicle manufacturer is able to implement and show on demand different modes and themes and can provide exchangeable designs over lifetime depending on the market requirements. Over lifetime the FPC offers a higher flexibility through easy and fast changing GUIs, driven by new functionality, new markets or legal requirements. Personalization by the driver and configuration of the shown information is possible. Over-the-air OTA software updates will drive this flexibility without the need to visit the garage. This surely saves time and enhances efficiency.

The software application is developed by the use of a graphical oriented software-toolchain, which is easy to learn and use. For developing the software logic executable on the vehicle controller optionally Matlab (by Mathworks) or a Programmable logic control can be chosen.
The graphics are developed by using commercially available graphics software for computers. These graphics are implemented by a special software for development of an embedded

automotive GUI. A successful software development of a FPC requires a new process and close collaboration between the graphic designer, creating the graphics, and the technical artist, who is in charge of the GUI implementation into the embedded system and the software application engineer, responsible for development of the logical software modules (Fig. 2).

Widgets are specific software modules, developed for a dedicated controller and help to control menus and graphical objects efficiently in the application.

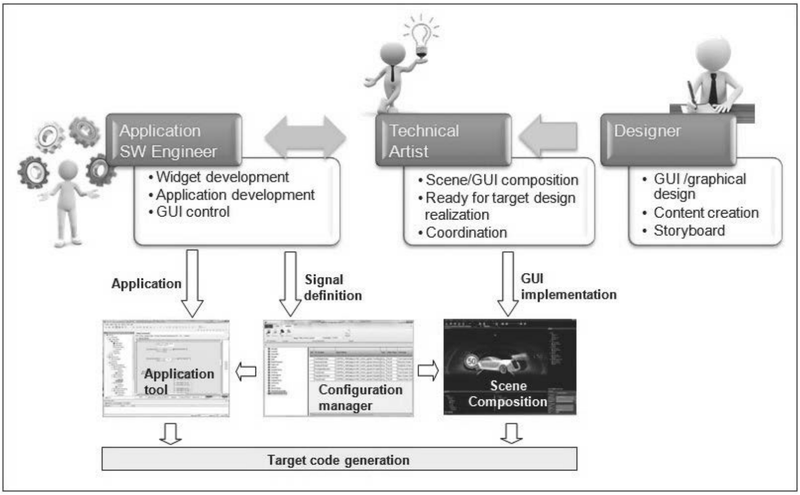


Fig. 2: Software Development Process

The manufacturer can choose one out of four different cooperation models with the supplier based on his software capabilities and strategy:

- Supplier delivers only hardware (the product), the full software development is in responsibility of the OEM
- Supplier delivers hardware and software up to an Application Programming Interface API, all further software development is in responsibility of the OEM
- Supplier delivers hardware and a compatible software toolchain with that the OEM develops his application software and GUI. The toolchain fits to the functionality of the hardware and provides after configuration all signals needed in the application and as well in the specific graphics software

- Supplier delivers a fully developed product based on customer requirement specification.

A typical concept of a freely programmable cluster for commercial vehicles using a 12.3“ TFT-display is shown in Fig. 3: all available information on CAN are processed, status of inputs are read, outputs are set, camera pictures can be shown, activation of buttons are recognized, loudspeaker and telltale lights are activated when needed.
Additionally, information from the vehicle, from streaming services or from radio, infotainment system, tachograph or telematic unit can be displayed in the direct view of the driver.

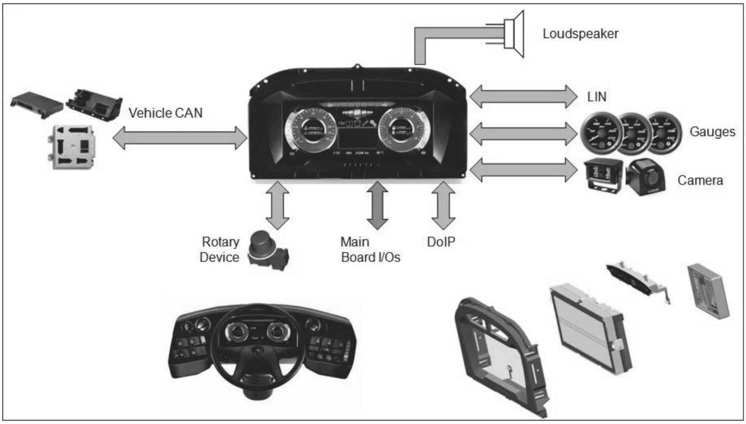


Fig. 3: Example of a FPC

**Trends and new ideas**

Amount and display sizes are increasing. Buttons and switches in the middle of the dashboard, the center console, are replaced by touch-areas and -displays. For the time being they are combined with turn-push actuators and speech control. This multimodal approach can be found in many passenger cars, and increasingly in trucks to minimize the level of distraction compared to single operating systems [3].
Touch functionality can be combined with haptic feedback and multiple finger-detection as known from smartphones. Gesture recognition is another Human-Machine-Interface functionality to activate defined use cases like taking or rejecting a call. Connectivity of mobile devices, mobile phones or tablets, with the transport company or bus tour operator, connec-

tion to cloud-server or social media will be present in future and probably influence the logistic process.

The Human-Machine-Interface HMI is not limited to single operating products, but can be seen as a holistic, cross-systemic approach, in which hardware- and software components have to adapt dynamically to preferences and needs of the driver, the driving situation and the surroundings of a vehicle. A holistic Human-Machine-Interface is the appropriate answer which leads to a safe and intuitive driving experience also in commercial vehicles.

**Concept study: Holistic Human-Machine-Interface**

A concept study conducted by Continental [4] started with an intensive interview and observation of 21 test persons consisting of truck drivers, truck manufacturers and fleet managers. The research led to four questions and three driver models:

- The four questions deal with (1) the pleasure of driving. (2) how to keep the driver busy in different driving situations. (3) defines new benefits for the driver and (4) is proposing confidence-building measures when it comes to highly automated driving.
- The three driver types are shown in Fig. 4: the enthusiastic, the balanced and the (typical) driver.

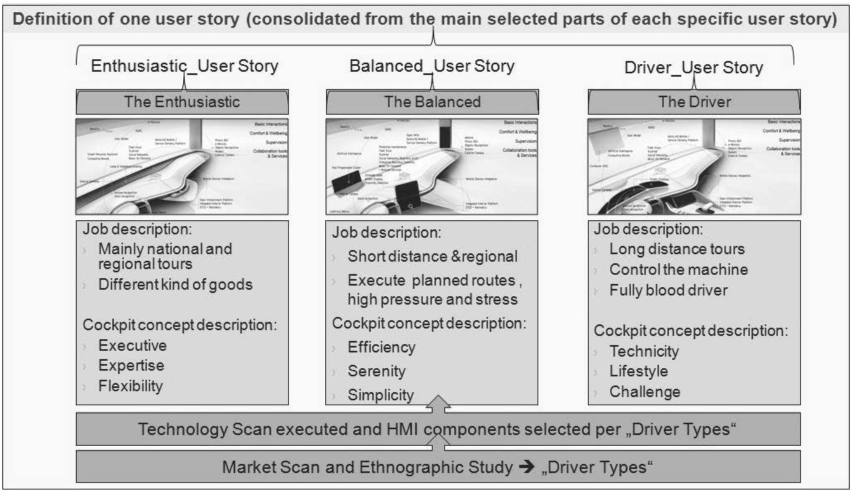


Fig. 4: Definition of driver types and user stories for a holistic Human-Machine-Interface

A consistent holistic Human-Machine-Interface was designed keeping the different driver types, different driving situations and also highly automated driving scenes in mind (Fig. 5).

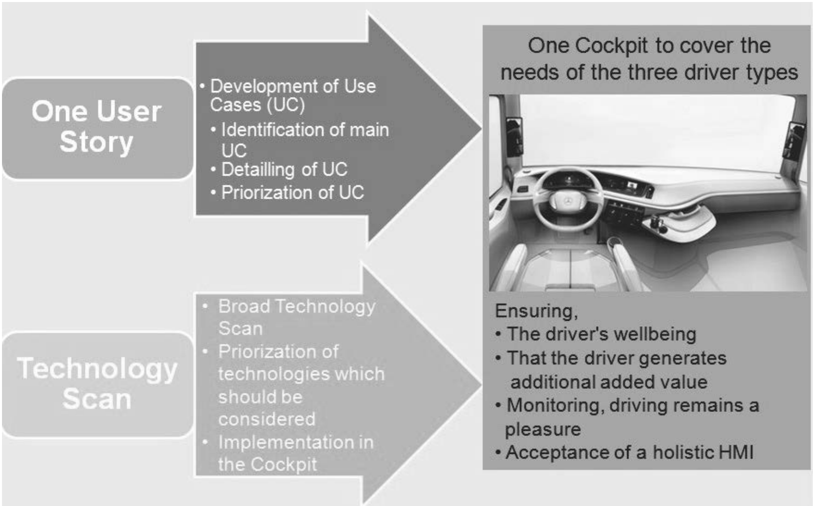


Fig. 5: A holistic Human-Machine-Interface

The concept study was presented to truck manufacturers, resulting in a positive feedback. Therefore the on-going development will be continued in this direction.

**Solution for a Holistic Human-Machine-Interface**

A solution for a holistic Human-Machine-Interface will influence today's vehicle architecture and will merge separate devices together. An independent operating FPC and an infotainment head-unit will merge into a central HMI-ECU which controls two or more monitors or display areas. The head-unit has all computational power, leaving monitors as unintelligent display units.

Cost minimization can be achieved on system level but not on module level. Furthermore weight saving and a maximized freedom in design and flexibility of functions and their allocation promote this solution (Fig. 6).

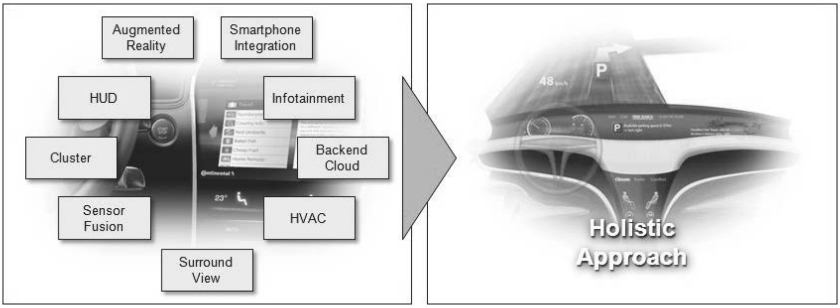


Fig. 6: Motivation for a holistic Human-Machine-Interface

Finding an optimized solution for the combination of a safe embedded system, a trusted system, an open system and a HMI system in one head-unit is challenging: the safe and embedded system represents the FPC, the trusted system the integration of third party software, for example body builder functions, and the open system includes the infotainment functionality. The underlying software architecture is based on a hypervisor technology. Virtual machines each representing one of the former explained functions allow a flexible representation of information on several monitors. Connectivity, integration of mobile devices, telematic functionality, data from truck or bus body builder or third party modules can be combined and displayed in an innovative and intelligent way.
Fig. 7 shows the system solution of the new system set-up.

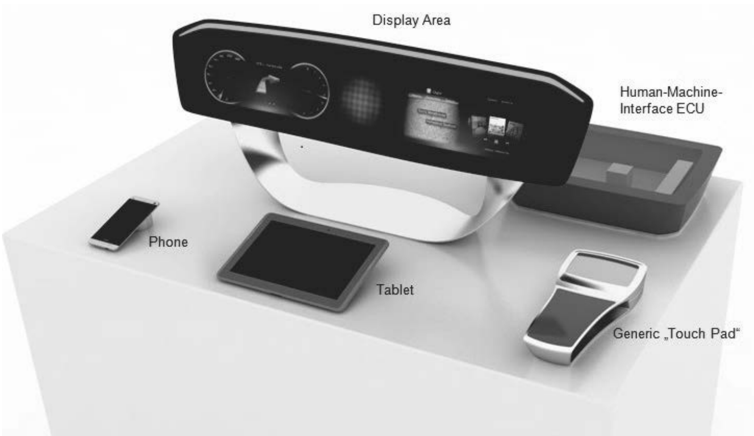


Fig. 7: System solution for a holistic Human-Machine-Interface

**Highly Automated Driving**

On the way to highly automated driving a lot of questions arise to which answers have to be found and given: How to involve and inform the driver as good as possible? Especially for highly automated driving the driver needs to know about the status of the vehicle, the behavior of the systems, how the vehicle reacts to comprehensively trust and accept it (Fig. 8).
A well-designed Human-Machine-Interface can help to build trust in the vehicle with such systems provided that the vehicle behaves as the driver expects.

By taking over the driving task to highly automated driving it needs to be clarified to which extent the driver has to stay fit and concentrated. Or vice versa: how to keep him busy during that period? The blocking or activation of functions related to the driving modus – manually or highly automated – can help to use the time beneficially. Supposed that logistic and organizational tasks can be done by the driver during the highly automated driving phase. This can contain the day's schedule, some documentations and further office work, for example preparation of delivery notes and invoices.


Fig. 8: Highly Automated Driving

Highly automated driving and the possible execution of new tasks by the driver require new display areas, for example a virtual display on the windscreen (Fig. 9).

Fig. 9: Windscreen display

Head-up displays and OLED (Organic LED) foils are a first step into this direction. The information can be placed clearly readable in the driver's primary field of vision. Especially highly automated driving information are optimally positioned on the windscreen because the driver can recognize it in context with the peripherals.

In [5] is stated that distraction is the reason for about 20% of truck accidents and microsleep causes about 50% of accidents on long-haul drives. In this case the human-machine interface has to detect a reduced attention of the driver and if necessary has to get back driver's attention to the driving task. Cameras are used to supervise the interior and to determine the condition of the driver. This can be done with Driver Monitoring Systems (DMS) which identify head pose, eye opening, eye gaze and face biometry (Fig. 10). These attributes are important to be detected and interpreted during the highly automated driving phase.
Face biometry is another precondition to identify the driver for personalization of the user interface or for other adjustments in the vehicle.

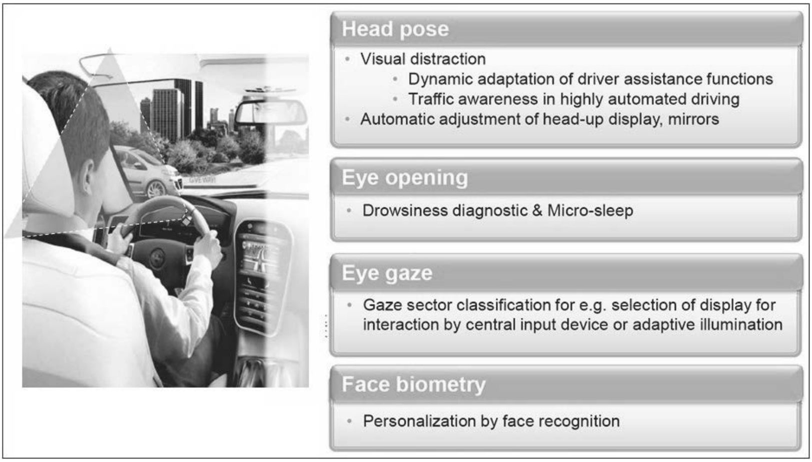


Fig. 10: Driver Monitoring System (DMS)

By detecting head pose and eye gaze information needs only to be displayed if the driver is looking consciously on the display. An urgent alert should be shown on the display that is nearest to the driver's field of vision. Additionally, an illuminated light bar installed on the dashboard can guide back driver's attention to the important information displayed or the important situation on the road [6]. This system is called Halo.

Continental equips DMS already in passenger cars, the first request for trucks of the next generation is on the table.

The development of highly automated driving solutions has started by applying all these innovative technologies.

## Conclusion

The automotive world is in a huge transformation phase: digitalization, connectivity and servitization are gaining importance. Large displays, virtual displays, intuitive and innovative interaction concepts and highly automated driving will lead to new system solutions with the objective to relieve the driver from his driving task and later on to fully take it over. Transparency and predictability of such systems increase driver's trust and acceptance in it. This is an importance factor for a successful introduction of those technologies. As described in this article the implementation of a holistic Human-Machine-Interface for trucks and buses considering multimodal aspects will be the future solution for highly automated driving.

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# ZF Innovation Truck 2016

## Advanced Driver Assistance Systems are increasing safety and usability

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**Abstract**

Advanced Driver Assistance Systems (ADAS) enable commercial vehicles to SEE, THINK and ACT. The development can be strongly supported by transferring knowledge about these systems from passenger cars. The Innovation Truck 2016 demonstrates the potential of these systems to increase operating efficiency by increasing safety and relief of the driver. The truck autonomously evades the end of a traffic jam, stays in the lane and maneuvers on the work yard.
This article describes the components used: the hybrid drivetrain TraXon Hybrid, the active steering system ReAX, and the camera and radar. Furthermore the technical implementation and the expected benefits and applications are discussed, in particular the highway application with Highway Driving Assist, Evasive Maneuver Assist and the work yard application with Safe Range.

**Motivation for ADAS in commercial vehicles**

The growing parcel market and the ever-increasing shift of freight flows onto the road forces logistics to demand new solutions along the entire supply chain, to meet increasing demand or cost pressure. The expectation of both online customers and highly networked industry supply chains is that everything is delivered just-in-time. This leads not only to blocked roads, but also to substantial safety hazards. Automation of unpleasant and monotonous driving situations in combination with intelligent goods and traffic control could not only relieve the driver but also make traffic safer and more efficient. Even for commercial vehicles, the main focus of automated driving is safety.

And not without a reason: Germany alone has 400 severe rear end collisions with trucks per year. Over 90 percent of all accidents are caused by human failure and of that 30 percent are caused by distraction (cell phone, navigation …). So therefore automated driving is mainly pushed by safety from a societal and legislative point of view. The mandatory introduction of automated emergency braking systems for trucks has already started application and the steps till 2018 will further increase the benefits. But it will take a long time till a sufficient market penetration is achieved.

But there are other reasons for automated driving of commercial vehicles besides safety. The biggest reasons are the total cost of ownership (TCO) and the lack of qualified drivers. Nevertheless, a noticeable improvement on the cost side will only be achieved at SAE-Level 4 (fully automated). According to studies the net driving time will then increase from 90 hours per week and vehicle today to 144 hours per week. This leads to a high pressure to quickly increase the level of automation for commercial vehicles.

Platooning appeals directly to decreasing the total cost of ownership by improving fuel efficiency of commercial vehicles traveling in a tight formation. Depending upon spacing aerodynamic drag can be reduced by approximately 40% in trailing vehicles, less in leading vehicles. Decreased spacing requires increasingly sophisticated V2V communication and control systems. At typical highway speeds aerodynamic drag is responsible for roughly half the fuel consumption on ideal flat highways. To achieve anything close to this kind of savings on undulating highways, the control systems must have predictive knowledge of road grade. [5]

Although total cost of ownership provides particular value creation for commercial vehicles the challenges for autonomous commercial vehicles are similar to the ones for automated passenger cars. Not all ethical questions for autonomous driving are answered in the marketplace. The society needs to start the discourse whether the increased overall safety in traffic through autonomous driving is worth the potential risks from a small number of accidents from new failure modes. And in addition appropriate operating conditions must be created. The conditions vary from an infrastructure that is highly networked and prepared for autonomous driving to acceptance by drivers and fleet owners as well as data security.

From a technological point of view autonomous driving is already possible. The stage of maturity of the systems will further increase as they gradually take over driving in certain situations. The development requires further actions to improve the robustness and safety of autonomous driving in all driving situations. That’s especially true for commercial vehicles and their characteristic differences to passenger cars.

The 2016 innovation prototypes were developed paying special attention to the central principles of safety, efficiency and autonomous driving. Thus, the vision of zero fatalities in traffic ("Vision Zero") plays an important role in the ZF Innovation Truck and its functions: One result is the Evasive Maneuver Assist (EMA) developed together with WABCO. This system automatically steers tractor trailer combinations around hazardous areas safely while decreasing vehicle speed, helping prevent rear-end collisions. The Highway Driving Assist (HDA) is another assist system which actively keeps the vehicle in the lane and at an appropriate, safe distance from the vehicle in front. The ZF Innovation Truck also takes safety to a new level in the depot by automatically maneuvering into the specified loading dock, preventing accidents and downtime caused by maneuvering.

**Purpose of Innovation Vehicles for ZF**

ZF Friedrichshafen AG's strategic claim is to be the global innovation and technology leader in the areas of driveline and chassis technology as well as active and passive safety technology. This applies to all the ZF Group's fields of application - from the passenger car to specialty vehicles. For some years, ZF has visualized this claim in the form of innovation prototypes. In these concept vehicles, that are always the center of attention of ZF's IAA presentation, the technology company bundles exemplary solutions for future mobility and presents them to the industry. Due to the cooperation of different ZF departments - in particular the Corporate Advanced Engineering Department and ZF divisions responsible for the product - these innovation prototypes are also considered as lighthouse projects within the ZF Group.

The innovation prototype of 2013, for instance, focused on electro-mobility and lightweight design [1]. At the IAA Commercial Vehicle Show in 2014, ZF presented a long truck-trailer combination that could be maneuvered locally without any emissions thanks to its hybrid system and whose complex trailer connected via two articulation joints could also be easily remote-controlled from the outside using a tablet [2]. In 2015, the focus was once again on subcompact cars: the presented "Advanced Urban Vehicle" (AUV) was equipped by ZF with innovative front axle kinematics as well as various advanced driver assistance systems. Apart from autonomous parking even in the narrowest parking spaces, the purely electrically driven vehicle could also use data from the cloud making the vehicle particularly efficient and safe. The AUV was also the first joint development project of the extended ZF Group which integrated the formerly independent U.S. company TRW Automotive in May 2015 [3].

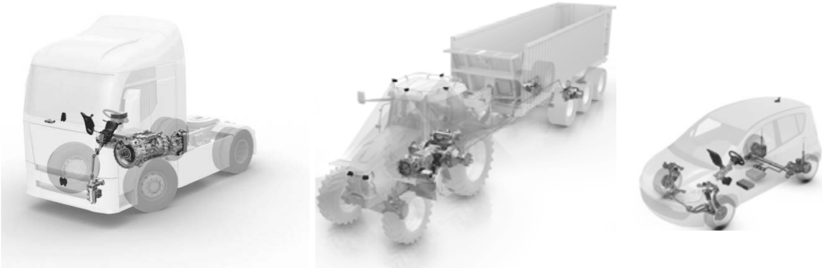

Fig. 1: ZF Innovation Truck 2016, Innovation Tractor 2016 and Advanced Urban Vehicle

For 2016, ZF's objective was to transfer its competence in the area of advanced driver assistance systems, with which ZF can serve the megatrend "autonomous driving," to commercial vehicles and off-road machinery. The 2016 innovation prototypes should visualize how ZF takes ideas, systems and competences from the passenger car and adapts them to the special demands of commercial vehicles. At the same time, it should prove ZF's new claim to make all vehicles see, think and act in the future by connecting sensors, control units and mechatronic systems. Thus, two innovation prototypes were created for 2016: on the one hand a truck (Innovation Truck 2016) that does not only contain new, automated driving and maneuvering functions for the depot but also integrates attractive safety assistance systems for driving on the highway; and on the other hand an agricultural tractor (Innovation Tractor 2016) that can increase the efficiency of an agricultural business by an electric drive and the automatic hitching of trailers and implements.

### Architecture of the ZF Innovation Truck 2016

The Innovation Truck 2016 is a 2-axle semi-tractor with a semi-trailer. The base vehicle was changed over to ZF components for the drivetrain, the steering system, the sensors, the ADAS control units and the V2X-communication. Table 1 gives an overview over the specification of some of the systems attached to the Innovation Truck 2016.

Fig. 2: Systems Overview

Table 1: Specification Innovation Truck 2016

| | |
|---|---|
| Diesel engine | |
| Power | 340 kW at 1500-1900 U/min |
| Torque | 2300 Nm at 1000-1400 U/min |
| ZF Hybrid Module | |
| Power | 120 kW at 650 V |
| Torque | 1000 Nm |

| | |
|---|---|
| TraXon Hybrid | |
| Type | 12 Gear AMT Gearbox + Intarder |
| Capability | Directdrive with 2800 Nm max. torque |
| ReAX-G | |
| Type | Single integrated electrohydraulic active steering system |
| Torque | > 50 Nm |
| Features | Torque / position control mode, pull compensation (e.g. for crosswinds or road crowns), adjustable effort for the driver |
| AC1000 | |
| Type | 77GHz scalable radar |
| Distance | Up to 200 m |
| Features | Adaptive cruise control (ACC) and automatic emergency braking (AEB) |
| S-Cam3 | |
| Type | Stereo front camera |
| Field of view | horizontal 52° and vertical 39° |
| Features | Automated emergency braking (AEB), adaptive cruise control (ACC) for highway conditions, lane centering, advanced traffic sign recognition and more |
| Openmatics Bachbox | |
| Type | Telematics system with wireless LAN interface and GPS |

The TraXon Hybrid combines the compact automatic basic transmission with a hybrid module: The clutch bell housing contains an electric motor with a power of 120 kW and a torque of 1 000 Nm. It is connected to the combustion engine with an SAE1 connector. Additionally, for gear changes of the TraXon transmission, a dry clutch is fitted in the hybrid module. This configuration allows the use of all hybrid functions: from braking power recuperation through engine switch-off at a standstill (start-stop function) to combustion engine boosting, to purely electric maneuvering. The high voltage battery of this parallel hybrid system packs a power of 9 kWh, so one battery charge is sufficient for several electric maneuvering operations. ZF tests have shown that this already mature hybrid system has the potential to reduce the fuel consumption of even heavy trucks by some 5 percent.

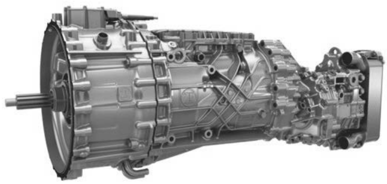

Fig. 3: Hybrid System TraXon Hybrid

The electrohydraulic active steering system ReAX-G is a single integrated unit that contains the motor, ECU, gearbox, and torque sensor. The integrated design offers both technical and commercial advantages including improved electromagnetic interference (EMI) performance, and reduced installation times. A J1939 CANbus interface permits the ECU to communicate with other similarly equipped intra-vehicular systems. The ReAX-G system provides a specific torque derived from sensor measurements which improves vehicle control. [4] This improves high speed lane keeping while reducing the work required of the driver to steer the vehicle. In normal operation speed-dependent on-center stiffness and off-center efforts are varied by specifying the breakpoint positions at the ends of the on-center, transition, and off-center zones. Fig. 4 shows an example of hand wheel torque varying as a function of hand wheel position and ground speed.

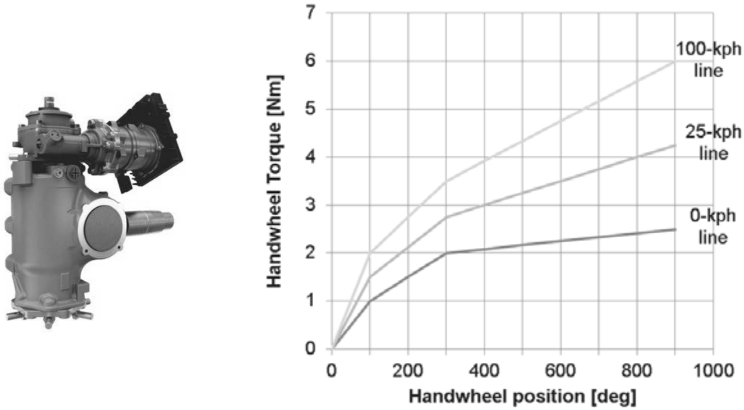


Fig. 4: Active steering system ReAX-G with torque description diagram

The 77GHz midrange radar AC1000 and the front camera S-Cam3 are both sensors for the area in front of the vehicle. One of the features of the AC1000 is the dual operation mode, which automatically adapts the field of view of the radar based on the vehicle speed. On higher speeds for example on highways, the radar is in ACC mode and is able to detect objects up to 200m. At lower speeds the radar switches to AEBS City mode, where the forward looking distance is reduced to gain a wider opening angle. The AC1000 is therefore suitable to meet Euro NCAP requirements and features like radar based ACC or AEB. The camera S-Cam3 is a front camera for passenger cars with a field of view of 52° horizontal and 39° vertical. The S-Cam3 features camera based AEB and ACC for highway conditions as well as several object detection features like lane detection for LKA. The data of both sensors are fused.

Fig. 5: Radar AC1000 (left) and camera S-Cam3 (right)

**Description of SAE Level 2 functionalities: Highway Driving Assist, Evasive Maneuver Assist & Safe Range**

The Highway Driving Assist (HDA) consists of two functionalities, the Adaptive Cruise Control (ACC) and the Lane Keeping Assist (LKA). The Adaptive Cruise Control detects vehicles and obstacles ahead by fusion information from camera and radar. The driver-selected speed is maintained as long as distance to the leading vehicle is safe. In order to prevent unsafe distances the speed is adapted, even to standstill. The Lane Keeping Assist detects lane borders with the aid of the camera. Upon deviation the controller calculates the necessary steering angle to hold the vehicle in the lane. The controller demands are being translated into actual vehicle movement by the ReAX active steering system. The simultaneous control of torque and angle gives the driver a good feeling.

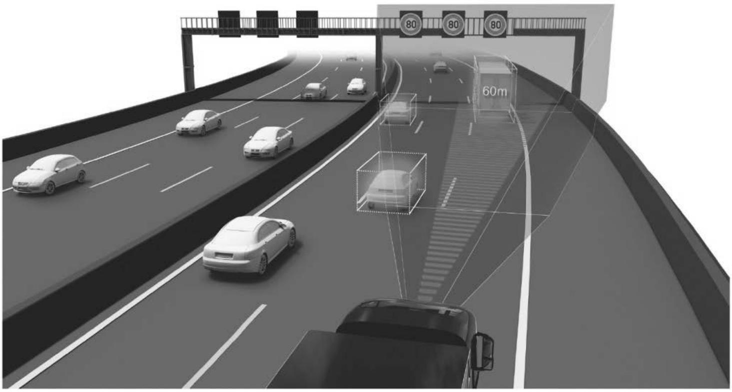


Fig. 6: Highway Driving Assist

The Evasive Maneuver Assist is a collision avoidance system and an extension of the advanced emergency braking (AEB). If the needed braking distance is too long and a collision could not be avoided by the AEB, the driver can initiate an evasive maneuver either to the left or to the right. The function then calculates the trajectory for a single lane change and controls the lateral movement with the active steering system ReAX. The function supports the driver to avoid an offset crash due to insufficient steering or rollover due to excessive steering.

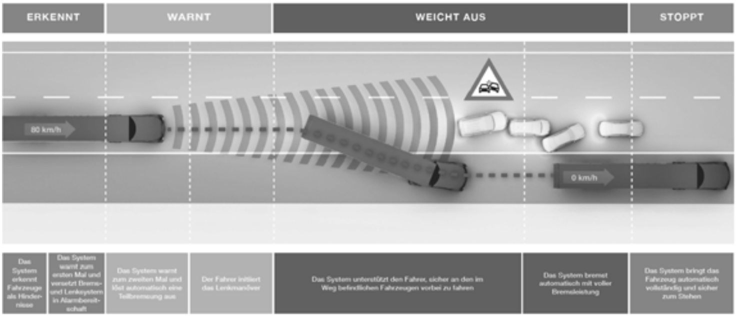


Fig. 7: Evasive Maneuver Assist

The Safe Range functionality is the next step beyond the tablet maneuvering presented in 2014. The loading ramp is equipped with sensors to detect the position of the truck. A controller calculates the path from the actual truck position to the loading ramp and commands the truck via a wireless local area network (WLAN). The lateral and longitudinal movement of the vehicle results by means of the active steering system ReAX and the TraXon Hybrid drivetrain. All that’s left for the operator to do is to start the maneuver. Safety during maneuvering is enhanced by the “Pedestrian Detection” function. Persons that are located between the truck and the loading ramp are detected by cameras. In case of detection the truck stops automatically.

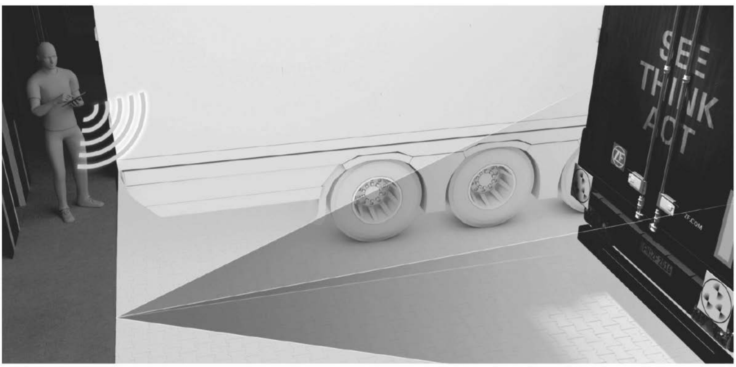


Fig. 8: Safe Range

**Summary**

Technologies that ZF has already developed for passenger cars offer enormous potential when they are transferred to other application areas like commercial vehicles or autonomously driving off-road machinery. This way, commercial vehicles can become even safer and more efficient. To do so, ZF uses competences in sensors, control electronics and mechatronic systems to make vehicles see, think and act. This was implemented in an exemplary manner in the innovation prototypes of 2016 - the Innovation Tractor and Innovation Truck. Both vehicles feature the SafeRange function which enables maneuvering using the tablet or even completely automated hitching or maneuvering at the loading bay. Thanks to an electric wheel head in the trailer, the tractor also has an ideal traction management. In the Innovation Truck, ZF applied the Highway Driving Assist function which combines an automated lane keeping assist system with automatic distance control and counteracts distance errors including too close tailgating. The Evasive Maneuver Assist (EMA) function is an intelligent assisted emergency steering control system.
These two functions by ZF Friedrichshafen AG bring active assistance systems for commercial vehicles to the next level, clearly exceeding the current safety standard in this area: Both systems, Evasive Maneuver Assist (EMA) and Highway Driving Assist (HDA), use sophisticated sensors as their "eyes" in combination with the high-performance control units' intelligence and the electrified mechanics' competence.

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[5] Alam, A., Besselink, B., Turri, V., Martensson, J., and Johansson, K.H., "Heavy-Duty Vehicle Plantooning for Sustainable Freight Transport," IEEE Control Systems, December 2015.

# Mercedes Benz Future Bus – First partly automated city bus with CityPilot

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**Abstract**

Megacities, traffic gridlock, environmental problems – the hot topics are the same on every continent. Under these circumstances, people's need for mobility to attend work and school and take recreation, cannot be met by private transport alone. Daimler as a mobility provider has a number of possible solutions. A major one is a range of buses, especially when used as a complete, individually coordinated transport system for urban environments. What urban public transport will look like in the future is shown by the semi-automated city bus with CityPilot – it operates even more safely, efficiently and comfortably than conventional buses. The CityPilot is based on different sensor concepts including stereo cameras, short and long range radar sensors and even GPS. Sensor fusion supports a reliable situation analysis which enables the semi-autonomous driving. Additionally networking with the traffic lights is used the cope crossings. Mercedes-Benz is showing this spectacular technology on an equally spectacular technology platform, the Mercedes-Benz Future Bus with CityPilot. Together they set a milestone, both in the history of the bus and on the way to autonomous and accident-free driving.

## 1. Introduction

### The requirements on an autonomously driving city bus

BRT lines are ideal for autonomous driving. Always the same route on a separate line or track, a clearly defined timetable, defined and identical actions at bus stops: regular service city buses on BRT lines (BRT = Bus Rapid Transit) are ideal for autonomous driving. Both in the truck and passenger car sectors, Mercedes-Benz is the leader in taking steps on the way towards autonomous driving. Transferring this comprehensive know-how to the regular city service bus sector is therefore logical. Bus operation is however subject to certain special circumstances – this is why the technology cannot simply be adopted from other vehicle systems, but must rather be developed further in the important aspects and where necessary also supplemented regarding the specific operating conditions. This applies to typical traffic situations such as traffic lights and pedestrian recognition, vehicles ahead in the same lane, passing through tunnels, negotiating junctions controlled by traffic lights, stopping and departing from bus stops and automatic opening and closing of passenger doors.

The bus rapid transit line 300 through Amsterdam is the longest one in Europe (c.f. figure 1) and it connects the airport Schiphol with the city of Haarlem. The route profile of Airport Line 300 is demanding: the bends are sometimes very tight, and the oncoming traffic lane is not physically separated. It is separated from the regular traffic on nearly 20 kilometers. The route also has 22 traffic lights, three tunnels and includes high speeds of up to 70 km/h. The longest tunnel has a length of 1,7 kilometers where no GPS signal is available at all. The eleven bus stops are raised, allowing passengers to enter the buses conveniently at ground level.

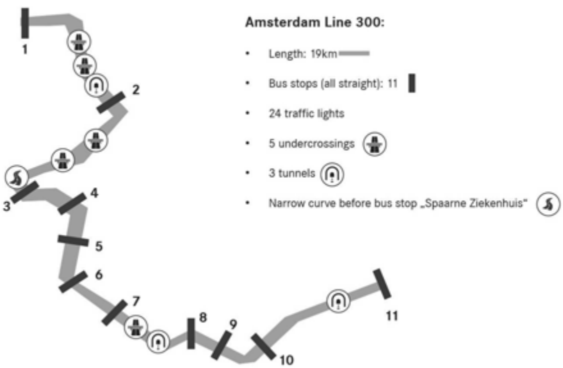


Fig. 1: Amsterdam line 300

**The next milestone in autonomous driving**

Ten cameras in different systems with a wide range of purposes, long and short-range radar systems, fusion of the resulting data and reconciliation with stored values, networking with traffic light systems and an automatic braking system – these are the technical requirements of the Mercedes-Benz Future Bus with CityPilot for semi-automated driving on BRT routes. The CityPilot is another milestone reached by Mercedes-Benz on the road to autonomous driving. The CityPilot is based on the Highway Pilot of the Mercedes-Benz Actros, however it exceeds the latter's capabilities to meet the needs of its specific area of operation: new functions include traffic light recognition, pedestrian recognition, centimetric precision when halting at bus stops and the ability to drive semi-autonomously in tunnels. In this way the bus becomes one with its environment not only with its design, but also with the technology it uses to move along its line and communicate with its surroundings.

## 2. The City Pilot - a highly specialized and unique technical feature

The specific operating conditions for a city bus therefore require equally specific technical equipment for autonomous driving – the cost and effort required for monitoring the road and the surroundings is very high. Mercedes-Benz can however fall back on extensive experience with the Future Truck [1]. This includes features such as long-range radar with a range of up to 200 m, electrically actuated steering and the mirrorcams instead of exterior mirrors. With the data of the long-range radar sensor obstacles on the track are recognized and if braking is necessary the CityPilot always brakes in a smooth way with respect to the standing passengers inside.

Also familiar is the lane-tracking camera, which is used for the Lane Keeping Assist system in other Mercedes-Benz buses and trucks. A further lane-tracking camera is used as an additional safeguard.

### Specific sensor setup is necessary

There are no less than four short-range radar sensors – two in the front section and two at the front corners – to cover distances from 50 centimetres to ten metres ahead of the bus. Two stereo cameras with a range of up to 50 metres allow 3D vision and recognition of obstacles and pedestrians. They are housed in a console at the lower edge of the windscreen. The technology is within the swept area of the windscreen wiper and defroster, but outside the driver's direct field of view. The stereo cameras are used for pedestrian recognition and the visual recognition of the traffic lights.

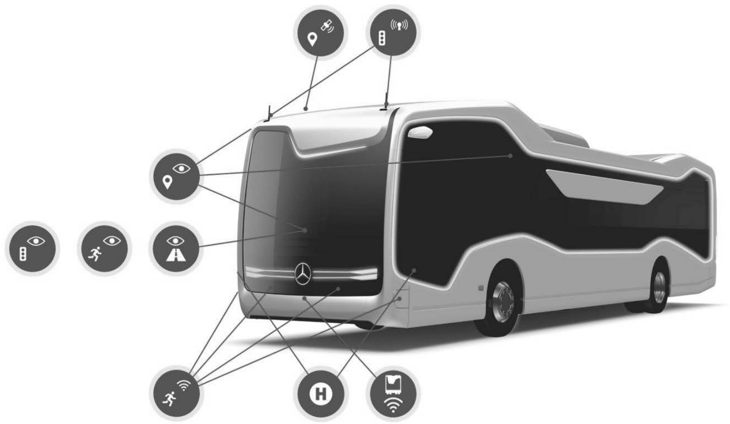

Fig. 2: Sensor setup of the Future Bus

Precise positioning of the Mercedes-Benz Future Bus is ensured by the satellite supported location system GPS, the lane-tracking cameras and four cameras for global visual location. These cameras are installed at front axle level high up on the sides, monitoring the surroundings and comparing them with images pre-stored in memory. Their purpose is to ensure exact positioning, and they are guided by waypoints. They operate to an accuracy of eight centimetres and are also used in illuminated tunnels. Such cameras were first used three years ago, for the autonomous journey of a Mercedes-Benz S-Class on the Bertha-Benz Memorial Route [2]. Two further close-range cameras are directed vertically downwards at the front sides. These recognise the pattern of the asphalt road surface like a fingerprint, and likewise compare this continuously with previously stored images of the route. And finally there are three cameras recording the journey. They record both the movements of the bus and the actions of the driver.

**Sensor fusion realizes reliable environment perception**

In this way a complex process of sensor fusion creates a precise picture of the local environment, with the exact position of the bus in its immediate surroundings. This means that it moves along its lane with centimetric precision. More precisely than a driver could ever hope to achieve manually in day-to-day operation.

The information of the traffic lights is very important for the CityPilot on the BRT track in Amsterdam. Therefore two independent systems are used as a redundancy. First the CityPilot is able to recognise the status of the light thanks to its sophisticated camera system. This traffic light recognition uses the same camera as the pedestrian recognition does. A machine vision algorithm searches for traffic lights permanently and then determines the current status.

Second networking technical data with the traffic light infrastructure along the route ensures early recognition of each traffic light status, thus allowing a predictive, consistent and as a result more fuel-efficient driving style than is possible by conventional means. This is called V2I, Vehicle to Infrastructure. It works by WLAN to a distance of around 300 m in urban areas.

This redundancy is important due scenarios where one traffic light is for example hidden behind a road sign. It is easily overlooked with the naked eye, and a challenge for the bus's camera systems, but for V2I such handicaps present no problem. The fast and reliable WLAN connection avoids the need for any visual contact. Data transmission takes place with WLAN technology via the standardised ITS-G5 frequency band at 5.9 gigahertz (standard IEEE 802.11p, [3]).

The result is a new dimension in the efficiency of the bus as a means of transport, thanks to networking with its environment: the bus covers its entire route semi-automatically, without the driver having to operate the accelerator or brake, or even the passenger door controls – an enormous relief in regular service operation. Strictly speaking, the Mercedes-Benz Future Bus operates at level two of the five defined levels [4] on the way to autonomous driving – semi-automation with lane-keeping function, longitudinal guidance, acceleration and braking by assistance systems.

## 3. Semi-automated driving– how the CityPilot works in practice

### Airport Line 300 in Amsterdam

The "Schalkwijk Centrum" bus stop on Airport Line 300 between the town of Haarlem and metropolitan Amsterdam. Schalkwijk is the largest district of Haarlem, with around 30 000 inhabitants. Airport Line 300 links Haarlem to Schiphol airport, with an extension to Amsterdam. This popular line is used by around 125 000 passengers each day, and the buses arrive and leave at intervals of a few minutes. Airport Line 300 is Western Europe's longest BRT line (BRT = Bus Rapid Transit). Long stretches of its route are on bridges or in tunnels. In towns and built-up areas the buses are usually at ground level, and the route includes road junctions. This is a challenge with respect to autonomous driving.

**The CityPilot in real world scenario**

The bus driver presses a blue key on the left-hand window sill console to activate the CityPilot. Prerequisite: The drivers feet must leave the accelerator or brake pedal, and the steering wheel must be released, as any driver activity overrides the CityPilot – the driver always retains final control, and is able to intervene. The content of the display has now changed (c.f. figure 3). The lettering "Pilot" becomes visible, and the speedometer – previously shown as an instrument segment and digitally – is reduced to a digital display. A special traffic light operates ahead of the bus: two red spots next to each other on the BRT line mean Stop, and two white spots one above the other mean Go. The light changes to white, and the bus gently moves off into the middle of its lane as if guided by an unseen hand. Standing passengers have no need to worry, as this bus always drives defensively in the interests of its occupants.

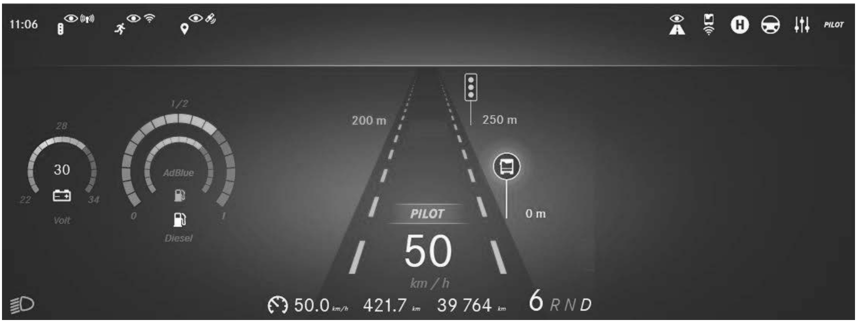


Fig. 3: HMI of the Future Bus with CityPilot

The next traffic light is showing red, and the bus tells its driver the distance at an early stage. The lights change just before the bus comes to a stop, so it promptly accelerates completely automatically and drives across the junction without stopping. Another red traffic light – safely and gently, the bus applies its brakes automatically and comes to a stop. A number of pedestrians hurry across the road while the light is changing. The bus waits, lets them pass and only moves off when the road is clear.

**Safe driving at 70 km/h without steering**

On leaving a built-up area the CityPilot accelerates the bus to the permitted 70 km/h. The maximum speed is pre-programmed, and the driver's hands remain off the wheel even at this speed. When there is oncoming traffic in the form of manually controlled buses, the driver's hands briefly move to the steering wheel to intervene if necessary, as required by the regulations.

**Automated procedure at bus stops**

The bus approaches every bus stop smoothly without driver action and then stops just alongside the raised kerb. The approach to a bus stop is quite challenging for every driver: if they drive precisely towards it, the distance from the kerb is perfect. If the bus comes too close the tyres will scrape the kerb, which is why city bus tyres have reinforced walls. If the gap is too large, passengers have difficulty in getting in and out. The CityPilot always complies with the regulations, keeping the right distance from the kerbs along its route. The procedure at bus stops is also automated: when the bus has stopped it automatically engages its frequent-stop brake and opens the doors. A photoelectric barrier tells it whether passengers are getting in. The doors are closed when all are on board. A countdown then runs in the driver's display, and the bus moves off after exactly five seconds.

**The CityPilot distinguishes between objects on the road and next to it**

To the camera and radar technology, it must appear that the bus is moving directly towards road signs or other obstacles when taking a bend. But this is no problem: the bus is moving in a so-called "hose" and will not react to objects next to the road surface - it can distinguish between an obstacle on the road and an obstacle next to the road.

**Vehicle to Infrastructure (V2I) – the CityPilot communicates with traffic light systems**

And a special feature that makes the advantages of connectivity obvious: the bus and the traffic lights communicate with each other. The traffic light tells the bus what colour it is showing, while the bus reports its approach and adjusts its speed to the predictable colour change. It can initiate a priority change to ensure a "green light" along the route. It is not always automatically given priority, however, because if another bus has just passed through or cross-traffic has just been given the "green" light, an immediate change would lead to a traffic jam. So the bus and the traffic light flexibly adapt their actions thanks to their communication, allowing the best possible traffic flow.

**The challenge of negotiating tunnels: Guidance by cameras alone**

The bus covers the stretch up to the final stop in De Hoek on a raised carriageway once again, with Schiphol airport already visible in the background. The bus approaches it through a 1.7 kilometre long tunnel – semi-automatically, with no GPS signal, guided only by its camera systems. On the way it passes below part of the airport. At the "Schiphol Handelskade" stop it emerges above ground again – the end of a fascinating 19 km long, semi-automated journey into the future of the city bus. Now it is the driver's turn to take control.

## 4. Testing

After the implementation of the individual systems (bus stop approach, traffic light communication, etc.) the first test drives where used to test these individual systems separately. By increasing maturity of the individual systems the interaction of the systems was implemented as a next step because the CityPilot is based on reliable systems and a reliable interaction. Another goal of the testing activities was the coverage of the relevant situation on the BRT line. The main question was: Is the CityPilot able to manage all real world scenarios which occur on the BRT line in Amsterdam. And there happened some scenarios while testing no one expected in the first project phase: e.g. mowing machines or ducks on the track.

Nevertheless intensive tests have verified safety and practical relevance. The development engineers have intensively tested the CityPilot both in test vehicles based on the Citaro and in the Mercedes-Benz Future Bus, including numerous test journeys on selected routes in closed-off areas. The world premiere in the Netherlands, on Airport Line 300 between Amsterdam and Haarlem, was also preceded by intensive tests. Even today, the bus is in public operation following an exemption from the state transport authority in Stuttgart according to Section 70 of the German vehicle licensing regulations, based on an expert report by TÜV Rhineland. It is allowed to operate on public roads despite deviating from the normal technical and service specifications.

## 5. Benefits

**Fuel-savings and a smoothly flowing driving style thanks to networking**

Traffic lights en route are no obstacle to the bus with CityPilot, as it knows the traffic lights on its line. Being networked with the traffic light, the bus can influence its status and obtain 'green lights' all the way. If the wireless connection to the traffic light is interrupted, the bus uses visual recognition. Conversely, the traffic light communicates with the bus and tells it when it is about to change. The bus then automatically adjusts its speed to the situation. The result is a highly efficient and smooth driving style. It noticeably reduces fuel consumption and therefore CO2 emissions, saves wear and tear and is also very passenger-friendly by virtue of the smooth ride.

**Automatic braking when encountering obstacles and pedestrians on the road**

Thanks to its radar and camera technology, the Mercedes-Benz Future Bus with CityPilot is able to recognise obstacles and pedestrians. It can identify pedestrians crossing its lane, for example. In such a case, the bus automatically initiates braking action. Additional function: at the end of a stop it does not accelerate away from the bus stop if pedestrians are crossing its path.

There is no automatic emergency braking function, out of consideration for standing passengers and those seated without a seat belt. If necessary, the driver can however take control of the vehicle at any time and take emergency braking action. The driver anyway has full responsibility at all times.

**Benefits for operators: reduced costs, increased availability**

The continually gentle and moderate style of driving benefits not only passengers, but operators and the environment, too. Fuel consumption and CO2 emissions drop, the strain on the engine and other major assemblies is reduced, resulting in prolonged service lives - and the same goes for the tyres. All these factors add up to long-term reductions in costs and increase the availability of the buses.

## 4. Summary and Conclusion

The main goal of the FutureBus with CityPilot was a concrete outlook to the city bus of the future. And the project has shown that the automation even in urban areas is possible. With the demonstration on line 300 in Amsterdam a real world scenario was mastered.

The benefits are a smooth, efficient ride which is comfortable for the passengers and even for the driver whose task changed from driving to supervising. Also the safety for the passengers, the driver and even for other road users is increased. The benefits for the operator are a reduced fuel consumption and lower CO2 emissions. Additionally the automated bus stop approach system avoids damages of the tires.

With the Mercedes Benz FutureBus not only these technologies where demonstrated. The interior and exterior design of a next decade's city bus was realized as well. With the symbioses of technology and design the best possible outlook to the city bus of the future is given.

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# New system architectures for commercial vehicles to support complex functions for autonomous driving

## Sensor set-up for redundant 360°-coverage of the environment

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**Abstract**

Complex driving situations require quick and responsible reactions. Innovative assistance functions support the drivers to stay in control of complex situations in order to arrive safely and relaxed at their destination.

The assistance functions will evolve from support functions (Emergency Brake Assist (EBA), Adaptive Cruise Control (ACC), Lane Departure Warning (LDW)) already used today to advanced functionalities supporting autonomous driving.

Today, a Heavy Duty Truck (HDT) in Europe contains at least one Long Lange Radar (LRR) and one camera looking in front of the vehicle supporting the legally required emergency braking and lane departure warning. Future functions like automated yard parking, highway pilot, overtake assistant, right turn assist and automated cruising chauffeur require additional viewing directions of the sensors until finally a 360° coverage around the vehicle is reached. To realize autonomous functions the sensing probability and reliability has to be improved further. This will be achieved by new high-performance sensors and redundant sensing with different technologies.

Radar sensors and cameras will be further improved for enhanced viewing distance and better spacial resolution. Furthermore new LIDAR-technologies will be introduced to have a 3$^{rd}$ independent sensor technology for critical functions. In addition, the increasing automation requires the vehicle architecture to be adopted and optimized. This results in a cost optimized sensor placement and redundancy required for functions with a SAE level3 or higher.

**Radar sensors**

Due to existing legislations in Europe, a Long Range Radar is used in every newly registered heavy duty truck to support emergency braking and ACC. These functions can be realized by a high performance radar sensor alone or with a radar-camera combination which uses a fusion of the detected objects to get a higher confidence on the environmental situation. Due to the fact that a camera is mandatory for Lane Departure Warning (a radar cannot detect the lines on the road), the cost adder for an enhanced camera performance supporting object detection needed for EBA and ACC is comparable low. So far the radar sensors take the lead for EBA and ACC as cameras have limited performance in bad/dark weather conditions. The mandatory requirements for EBA on moving and stationary objects don´t push radar technology to its limits and a cost optimized entry version of a radar sensor can be used. Requirements allowing crash mitigation also on stationary objects from a vehicle speed of 85km/h requires premium technology. For this scenario a radar sensor with a much higher detection distance and a narrower radar beam is needed to get a reliable detection and classification of non co-operative targets.

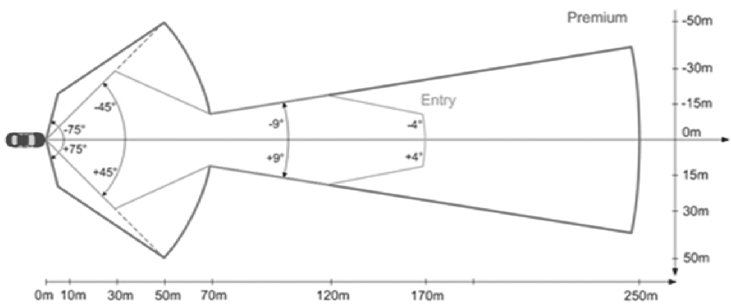



Fig. 1: Comparison of the field of view for two radar sensors
- green: fulfilling the legal requirements
- red: crash mitigation on standing object from a speed of 85km/h, much better support of ACC (cut-in of overtaking vehicles) and ACC-stop&go

Currently available radar sensors can be further differentiated by their operation frequencies (26,5GHz or 77GHz). The more complex 77GHz technology gives a per se better object resolution in space and speed. In addition, by using the micro-doppler effect 77GHz radar sen-

sors support the detection of vulnerable traffic participants (pedestrians and bicycles) allowing for additional safety functions.
So called short range radar sensors (SRR) have been and still are used for side looking functions (blind spot detection,..). So far the volumes are low in the truck market. These short range radar sensors (SRR) are optimized for a larger viewing angle to allow object detection close to the vehicle, but are limited in viewing distance to max. 100m. First generations of SRR used 26,5GHz

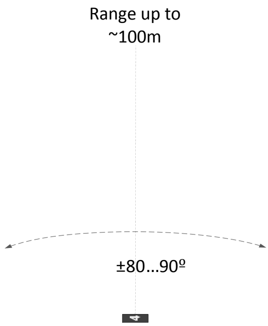



Fig. 2: Typical field of view for a short rage radar (SRR), supporting Blind Spot Detection, Lane Chance Assist, and in case of 77GHz also Right Turn Assist (pedestrian and bicycle detection)

Due to expected legislation for a Right Turn Assist to significantly reduce the number of severe accidents with pedestrians and cyclist in case of right turning vehicles at a junction, the 77GHz radar technology was also introduced for SRR-sensors and will become the technology of choice for these short range sensors.
For upcoming truck architectures the challenge is to optimize the radar sensor technologies and positions for an optimum coverage of the environment and reducing unavoidable blind spots to a minimum.

**Cameras**

Camera technology using a simple object detection was introduced in trucks to warn distracted truck drivers, in case they risked leaving their lane and causing severe accidents. The lane departure warning function gives an optical and acoustical warning to the driver if there is a risk of an unintended overriding of the lane markings on the road. The LDW-function became mandatory together with the EBA introduction.

Having already a mandatory intelligent camera in the vehicle for LDW, additional functionality can be realized with relatively low additional cost. The required electronics is already available from passenger cars and therefore functions like traffic sign recognition, intelligent head lamp control,... were also adopted for truck application. The forward looking object detection of vehicles in front enables improvements in functions like EBA and ACC by means of a fusion of the camera and radar data.

Another upcoming camera application which allows a further reduction in operational costs is the replacement of the bulky mirrors which contribute up to 3% to the fuel consumption by using small camera heads.

Fig. 3: Comparison of a digital mirror system with the view of a conventional truck mirror

The first step will be the introduction as an independent mirror replacement system, but the cameras will be integrated into a 360°-camera coverage over time, which allows a surround-view around the vehicle. The long range cameras of the mirror system will then also support overtake functionality and the wide angle cameras will support the turn assist functions.

To support these features, complex algorithms have to be developed and implemented. In Fig.04 an example for an algorithm to support the right turn assist is shown. In future system the additional information will be used to further improve radar based systems by object fusion.

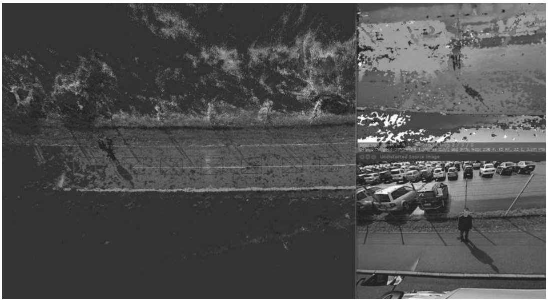


Fig. 4: Example of pedestrian recognition by optical algorithms to support the right turn assist

Driven by needs from the passenger car market the resolution of automotive cameras is increasing steadily and the semiconductor supplies already have 8Mpix-imager on their roadmaps. An optimized camera set-up can be derived based on these roadmaps and assumptions on the development of available computing power for optical object detections algorithms.

This camera set-up, analog to the radar sensor set-up, will cover 360° around the vehicle, is cost optimized and fits into the overall system architecture to allow for the needed reliability and probability of the object detection for the required driving functions.

## LIDAR

The 3rd independent sensor technology LIDAR (Light Detection And Ranging) combines the properties of Radar (time of flight measurement) with a possible optical imaging method.

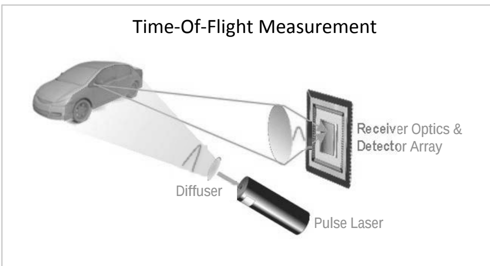



Fig. 5: Schematic description of a 3D Flash LIDAR system. The environment is exposed by a laser through a diffuser. The reflected laser light is detected (intensity, time of flight) by a semiconductor imager.

In the past a laser beam scanned the environment point by point, which was relatively time consuming and restricts the applications. Future systems will illuminate the area of interest by an infrared laser flash and detect the reflected light by intensity and time of flight with a semiconductor detection array.

Major advantages of the new flash-lidar technology are:

- No moving parts – solid state
- Scalable fields of view and range
- High angular separation (precision 2D)
- Contiguous pixels – no gaps
- High vertical resolution compared to Radar
- Co-registered Range & Intensity
- No motion blur

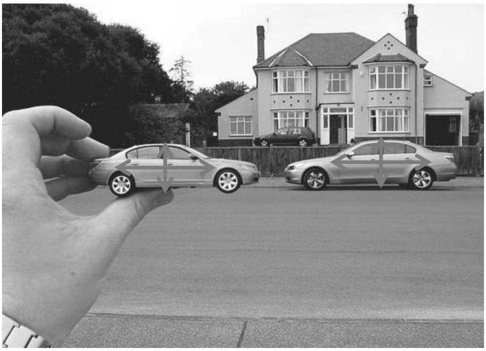


Fig. 6: Optical picture of two cars. With a mono camera and object detection it is difficult to correctly detect the scenario. With the additional time of flight measurement of a Lidar-sensor the scenario is clearly recognized.

LIDAR will be the 3rd sensor technology which is required to achieve the quality for modeling the environment for complex autonomous driving functions.

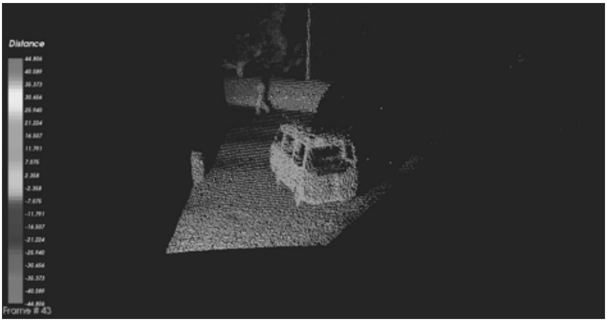



Fig. 7: Result of a Flash-Lidar measurement. Intensity of the reflected laser light is shown. By color coding also the distance measurement is given very accurately.

**Generic sensor architecture for SAE level2 and level3 functions**

To define a generic sensor architecture for autonomous driving the targeted functions and use cases have to be analysed in detail. This analysis will lead to requirements regarding object detection quality and probability which then defines a minimum sensor set-up for each function. Combining the requirements from all targeted functions will then lead to the sensor architecture of the vehicle.

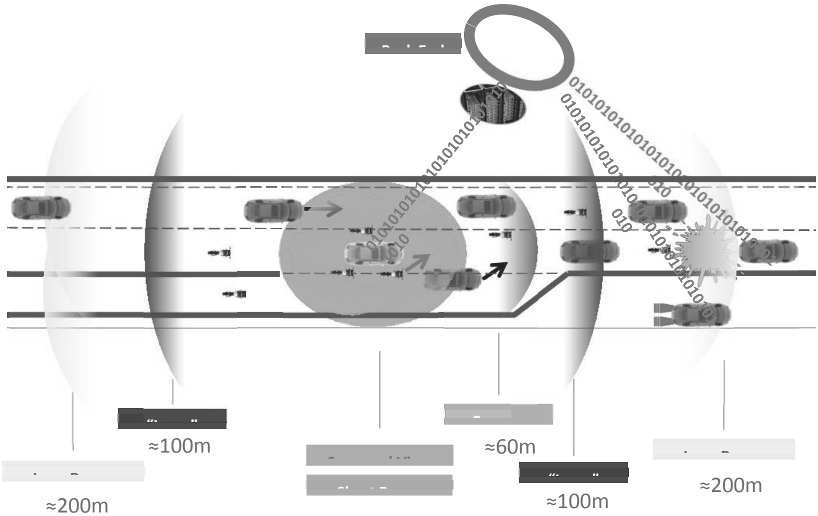



Fig. 8: Example of a generic sensor set-up consisting of a redundant 360° sensing of the environment by Radar and Camera, supported by LIDAR and V2X-communication

With a complete sensor set the vehicle environment will be scanned with a redundant 360°-coverage through radar sensors and cameras and supported by LIDAR-sensors. In addition the vehicle will be connected to a back-end to get additional information on road condition and changing traffic situations. Furthermore V2V-communication will be established to support a fast exchange of information between traffic participants (for example needed to support emergency braking within a platoon)

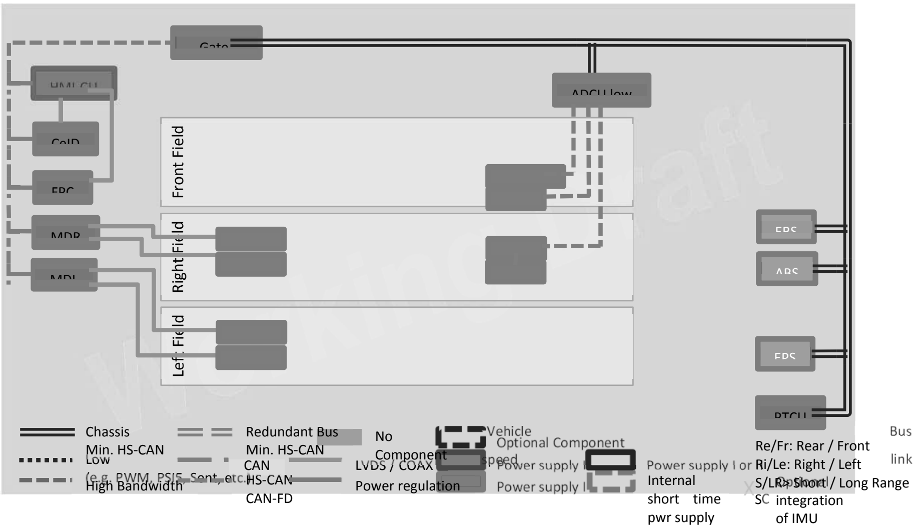



Fig. 9: Todays vehicle architecture supporting EBA, ACC, RTA, LDW, ILA, TSR and mirror replacement

Starting from todays vehicle architecture shown in Fig.09 with one long range radar sensor and one camera looking in front of the vehicle and two short range radar sensors looking to the side we developed a generic architecture by adding sensors according to the functions roadmap. The advanced architecture shown in Fig.10 will then support the cruising chauffeur (SAE level3).

For level3 functions redundancy of the power supply is required, allowing the vehicle to come to a standstill through a minimum risk maneuver. In this architecture the level2 components act as a fallback level to support driving a save maneuver. Redundancy in braking and steering is also an intrinsic requirement to level3 functions.

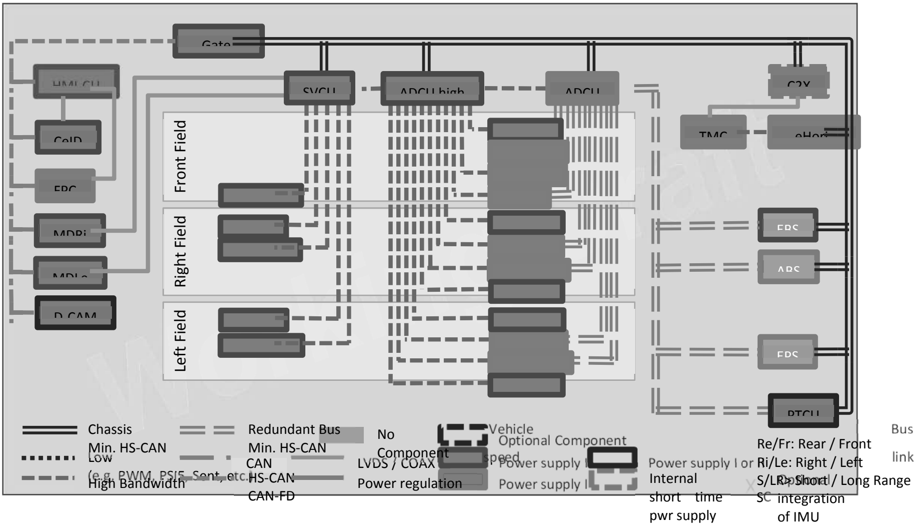



Fig. 10: Future architecture for a redundant 360° sensor coverage of the vehicle to allow for SAE level3 functions

**360°-view: Challenges of ADAS-sensors in the trailer**

One major challenge towards autonomous driving is to get the rear view in the required 360°-coverage of the environment in tractor-trailer vehicle combinations. Here, the trailer partially blocks the view of the sensors mounted on the tractor. Cameras and radars can be positioned and designed in a way, that they look along the side of the tractor/trailer combination, but a blind spot behind the trailer always remains.

For radar sensors the implementation into the trailer can be straight forward. Two Long Range Radar Sensors looking backwards and mounted on the rear corners of the trailer would allow for the required coverage. The connection of the sensors via daisy chain together with a first fusion inside one sensor will reduce the number of relevant objects and thereby the amount of data transferred to the tractor to a minimum. A basic version of such a system can be realized even with the limited bandwidth of todays tractor-trailer communication. Increasing this bandwidth with a new communication standard would allow the transmission of the needed information from individual radar sensors.

The integration of a backward looking camera into the trailer will be more com}plex. Sending the image information to the tractor requires high bandwidth communication. Due to the required flexibility in combining a tractor with different trailers a wireless standard has to be used, allowing an easy coupling between the camera and the main computing unit. Furthermore the optimum opening angle of the camera optics and mounting position has to be investigated in more detail to allow for example wide angle coverage for yard maneuvering close to the back of the trailer and a long distance coverage of quickly approaching vehicles from the back during highway operation.
Due to the different innovation cycles in tractors and trailers we assume that there will be special trailers approved for different driving functions. The tractor will adjust the supported functionality dependent of the capabilities of the trailer.

**Summary**

What started as “simple” assistance functions will grow into some of the most important new components in future commercial vehicles. The calculable benefits that automated driving can bring, will significantly drive improvements of current sensor technology, fusion and architecture. A wave of fascinating developments can be expected between now and 2025.

# From the automated vehicle to platooning
## – a look into the future

Dr. **Christian Ballarin**, Daimler AG, Stuttgart

### AUTONOMOUS TRUCKS

Autonomous vehicles have been racking up the miles for some time now on company grounds, off of public roads. In these closed-off areas, trucks ─ either partially or fully automated ─ can be used to transport containers, bulk goods or hazardous materials, for example. In 2001 two Mercedes-Benz trucks already took over internal transport operations at a company based in Ulm, Germany. Guided by transponders, the trucks travel a predefined route between the warehouse and plant at a speed of 5 km/h.

Autonomous trucks are also nothing new when it comes to specialized applications in protected areas such as container ports. These trucks have not been allowed to operate on public roadways, however. It is exactly in this context, though, that the truck can once again prove to be the better option when configured for autonomous operation. After all, on roads that have no intersections ─ such as freeways ─ trucks almost always drive at a constant speed without exceeding the maximum speed limit. With its physically separated lanes and the absence of pedestrians, cyclists and slow-moving vehicles, freeways offer the optimal platform on which to automate truck driving.

### AUTONOMOUS DRIVING @ Daimler Trucks

In May 2015 the Freightliner Inspiration Truck started with a spectacular debut in the USA on the way to becoming the first autonomous truck used on public roads. The truck became the first truck in the world to be issued a road permit by a government authority (the permit was issued in Nevada). The technology embedded in this vehicle is grounded in the Highway Pilot System, which was officially introduced in a Mercedes-Benz truck already in July 2014 on a cordoned off section of freeway in Germany.

Shortly thereafter, in the fall of 2015, a Mercedes-Benz Actros outfitted with the Highway Pilot System was registered as a test vehicle that could be legally operated on public roads in partially automated mode only. This means that the vehicle automatically maintains its own lane, speed and distance to the vehicle ahead; the driver is, however, required to permanently monitor operation and be in a position to manually resume full control of the vehicle at any given moment.

The Highway Pilot automatically detects its own system limitations. Before these limitations are reached, the system will prompt the driver in good time to take over control of the vehicle. The Highway Pilot does not replace the driver, but instead assists and relieves him by assuming control on monotonous sections of road and stop-and-go traffic in traffic jams. The driver has full control of the truck at all times during automated driving and must manually resume control of the vehicle in difficult or tricky situations.

**PLATOONING**

The next stage of autonomous driving has also "hit the road" for testing and is termed Highway Pilot Connect. This system leverages the networking between vehicles in a convoy ─ referred to as a "platoon" in this context ─ to realize further benefits. The overarching objective is to use less road space, improve safety and reduce fuel consumption. To this end, two or more trucks utilize direct data communication to form a platoon with a distance of 15 meters between the vehicles. This short gap minimizes aerodynamic drag to considerably reduce fuel consumption and emissions by an average of up to 7 percent for all of the vehicles traveling in the platoon.

As such, a platoon comprising three vehicles requires only about half of the road space compared to the same number of vehicles traveling separately at the legally mandated minimum distance of 50 meters. These vehicles are interconnected in a highly dynamic and flexible manner. At any time, trucks can exit the platoon as new, compatibly equipped trucks join it. Passenger cars can even "cut through" the platoon to take the next exit without disrupting the formation. The trucks behind the lead truck also do not simply trail "blindly". As every member of the platoon (including the lead vehicle) is equipped with the Highway Pilot system, the formation basically comprises a series of automated trucks that come together for a certain period of time to maximize their own efficiency as well as that of road hauling in a greater context. For example, networked, partially automated vehicle operation makes it possible to level out changes or fluctuations in speed throughout the platoon to minimize peak fuel consumption.

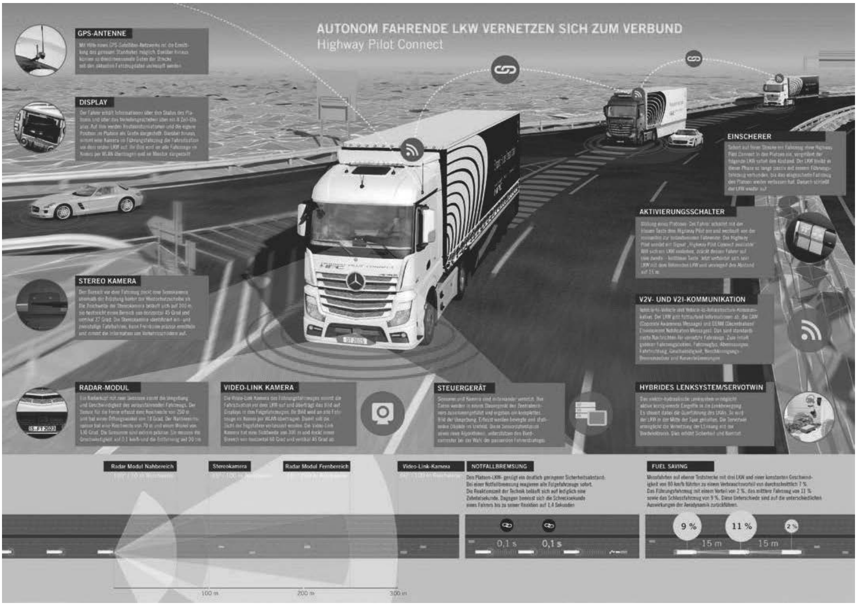



Fig. 1: Highway Pilot Connect (© Daimler AG)

**Connectivity**

Thanks to connectivity, all vehicles immediately respond to unforeseen events: If a truck needs to brake, for example, all trailing vehicles also automatically brake. The response time of the trailing vehicles is a mere tenth of a second – a fraction of the driver's perception time that can take up to 1.4 seconds. At a speed of 80 km/h, the platoon vehicle travels just 2.2 meters before braking occurs at all trailing vehicles. Driving manually, this distance would be approximately 30 meters. This means that the shortened distance between vehicles of 15 meters still provides adequate safety for emergency braking.

Connectivity also enables every member of the platoon to be informed of the driving situation of the entire formation at all times. A camera in the lead vehicle records the driving situation in front of the truck and transfers a live stream to monitors in the trailing vehicles. All members of the platoon can also view their own position in the platoon on the monitor at any time as well as track those of the other vehicles on a digital map.

Daimler Trucks can already demonstrate these numerous platooning functions with Highway Pilot Connect on the road and in traffic. The best example of this is a journey from Stuttgart to Rotterdam of over 700 km as part of the European Platooning Challenge, an event of the

Presidency of the Council of the European Union organized together with the Dutch Ministry of Transport. For the first time, networking has made it possible to link autonomously driving trucks as all vehicles respond in a precise and intelligent manner to the vehicle ahead.

Fig. 2: Platooning with Highway Pilot Connect (© Daimler AG)

**V2X COMMUNICATION**

The same networking technology also enables intelligent interaction among additional road users and the traffic infrastructure as well as incorporates applications that sustainably improve safety in road traffic. Consistent networking of road users and the traffic infrastructure will yield the breakthrough. When "V2X" messages are sent by a particular vehicle to all other (relevant) road users, communicating every vehicle movement and breakdown, unforeseen events will be all but a thing of the past.

Today's traffic jams, which can surprise drivers directly behind a hilltop or bend, will be just as predictable as sudden cross traffic and impending right of way violations, and heavy showers and even walls of fog will no longer be a threat. The truck can then "see around corners" and the driver is warned in good time so that braking can occur in an emergency. Digital maps not only "see" hills, but also curve radii and speed limits and lift off the throttle in ample time. High-performance camera systems detect the direction of movement of pedestrians and cyclists and provide the driver assistance system with additional, valuable information to avoid a collision.

In V2X communication, trucks not only exchange data, but also relay it to a data center. For example, this can be data on detected variable speed limits or current traffic light statuses. Data that vehicles report multiple times is validated in the data center and converted to recommendations and instructions. Every traffic sign and freeway overhead signpost can serve as a basis for sending and receiving information while maintaining stringent data security requirements.

## SAFETY

Redundancy in sensor systems and fail-safe components such as the steering and brakes ensures an extremely high safety standard. If the minimum requirements for the system are not met due to bad weather or missing lane markers, for example, the Highway Pilot outputs acoustic and visual signals to the driver so he can resume manual control. The driver is given ample time to accept active driving again. If the driver does not respond, the truck will automatically brake itself down to a safe stop.

## OUTLOOK

Today, Daimler Trucks can already demonstrate the many platooning functions of the Highway Pilot Connect system on the road and in traffic. Continuing to further develop assistance systems for trucks will always be a high priority; automation is a key component in this context and makes an important contribution to achieving higher levels of safety, efficiency and connectivity in goods transport on the road.

Unabridged version (German only): www.springerprofessional.de/ATZextra

# Future $CO_2$ legislation and innovations to reduce TCO – using Continental Innovation Truck as an example

## Evaluation of Photovoltaic System and Coasting Technology

M. Eng. **Tobias Huber**, Dipl. Ing. (FH) **Thomas Grossner**, Continental, Regensburg

**Abstrakt**

Nutzfahrzeug Märkte sind hauptsächlich getrieben über die Gesamtbetriebskosten (= Total Cost of Ownership - TCO). Technische Fortschritte um die Sicherheit, die Effizienz und den Komfort zu erhöhen, als auch Maßnahmen, um die Instandhaltungskosten zu reduzieren spielen auch eine wichtige Rolle. In Zukunft werden aber auch $CO_2$ Ziele mit Handlungsplänen in den einzelnen Zielmärkten definiert: zum Beispiel werden die $CO_2$ Grenzwerte für Nutzfahrzeuge in den Vereinigten Staaten um 25 % bis 2027 reduziert werden. Die EU Kommission hat bereits auch $CO_2$ Grenzwerte für 2030 angekündigt. Mit diesen gesetzlichen Initiativen werden $CO_2$ Emissionen ein zusätzlicher Treiber für zukünftige Entwicklungen bei Nutzfahrzeugen. Neue Technologieansätze zielen auf weitere Verbesserungen des Verbrennungsmotors, Hybridisierung, Verringerung der Fahrwiderstände, oder Energierückgewinnungssystemen; diese werden helfen, zukünftige $CO_2$ Grenzwerte einzuhalten. In diesem Berichte wird auf eine Form der Energienutzbarmachung eingegangen: die Photovoltaikanwendung, die das Bordnetz und die Batterieladefunktion während der Fahrt und auch im Hotel Modus unterstützt.

In einem weiteren Teil wird berichtet von Untersuchungen von Continental über das Potential von "predictive eco coasting" basierend auf Echtzeit Informationen vom dynamischen eHorizon, mit dem Ziel die Kraftstoffkosten und damit TCO zu reduzieren. Nimmt man an, dass eine Konstantfahrt auf der Autobahn nur durch 2 Staus unterbrochen wird, spart man mit "predictive eco coasting" bis zu einem Prozent Kraftstoff ein, verglichen mit der herkömmlichen Verzögerung über die mechanische Bremse.

Der Continental Innovation Truck ist ein Demonstrator der bereits eine Vielzahl von innovativen Technologien zeigt. Ein Photovoltaik Lösung wurde bereits 2016 integriert. Das "predictive eco coasting" wird in 2017 umgesetzt.

**Abstract**

Commercial Vehicle (CV) markets are mainly driven by Total Cost of Ownership (TCO). Technical progress to improve safety, efficiency and comfort, as well as measures to reduce the maintenance costs play an important role, too. In the future, $CO_2$ targets and reduction roadmaps will be defined for the individual focus markets: for example $CO_2$ targets for trucks in the United States will be reduced by 25 % until 2027. The EU Commission has also defined $CO_2$ limits for 2030. With these legislation initiatives, strict $CO_2$ limits will become an additional driver for the future development of CVs. New technology approaches with focus on Internal Combustion Engine (ICE) improvements, hybridization, lowering the driving resistances or improving energy harvesting technologies will help to meet future $CO_2$ emission regulations. The first focus in this paper is in the field of energy harvesting, particularly photovoltaic enabled powernet support and battery charging function during driving but also during hotel mode.

In a second focus Continental also evaluates the potential of predictive eco coasting in combination with real-time dynamic eHorizon information in order to further reduce TCO. Assuming only two traffic jams on the highway and with predictive eco coasting decelerations instead of mechanical braking, up to 1 % fuel consumption can be saved within a whole day's trip.

The Continental Innovation Truck is a demonstrator which incorporates numerous innovative technologies. A photovoltaic solution has already been integrated. The predictive eco coasting solution will be integrated in 2017.

## 1. Motivation – Strong legislative pressure from the European Union and the United States

<u>EU-Market:</u> Less than two degrees – this is the upper limit for global warming the world community agreed to in November 2015. The EU has now defined associated goals for each of its member states. Moreover, for the first time the $CO_2$ emissions of trucks and buses will be restricted.

Since many years, $CO_2$ emission limits for passenger cars and light duty vehicles have been legally determined. From 2021 onwards, the EU set a more severe target of 95 g $CO_2$/km for the passenger car fleet in average. Additionally, the new 'Worldwide harmonized Light duty Test Procedure' (WLTP) and Real Driving Emissions (RDE) will be introduced to ensure homologation tests which reflect real driving oriented behavior.

Although, heavy-duty vehicles (HDVs) only represent 4 % of the on-road fleet in the European Union, they are responsible for around 30 % of on-road $CO_2$ emissions [1]. Unlike other countries such as the United States, China, Japan and Canada, the European Union currently has no fuel efficiency standards that limit truck $CO_2$ emissions [2].
Since 2014, the EURO VI standard regulates emission limits for heavy duty vehicles for CO, HC, $NO_x$ and PM, but not for $CO_2$. In July 2016, the European Commission announced that it will accelerate work on $CO_2$ regulations for trucks and coaches to fight against climate change. Initially a new evaluation method via computer simulation tool will be able to estimate fuel consumption before thresholds will be defined. Besides, looking ahead to 2030, the EU Commission will contribute to a more transparent and competitive market and to the adoption of the most energy-efficient technologies [3].

<u>US-Market:</u> In 2016 the U.S. Environmental Protection Agency (EPA) and the National Highway Traffic Safety Administration (NHTSA) released the final regulations for heavy-duty vehicle fuel-efficiency and greenhouse gas standards. The new standards, which will take effect in 2018 and run through 2027, represent Phase 2 which seeks to improve fuel efficiency and reduce carbon emissions from trucks and buses.
The structure of the Phase 2 regulation is similar to Phase 1, with regulatory standards for tractors, commercial pickups and vans, vocational vehicles and engines used in tractors and vocational vehicles. In addition, the Phase 2 regulation incorporates one new major category: trailers. The regulatory targets for Phase 2 are shown in the Fig. 1 below It also include impacts of the Phase 1 regulation. Combined, the Phase 1 and 2 standards will improve the fuel efficiency of commercial vehicles between roughly 25 % and 50 % compared to a 2010 baseline – for long-haul trucks the $CO_2$ reduction target till 2027 is 25 %. The Phase 2 regulations continues to drive the development and deployment of fuel efficiency technologies. The estimated payback time for tractor-trailers, heavy-duty pickup trucks, and vocational vehicles amounts to two, three, and four years, respectively [4].

Officially the focus of Phase 2 is looking beyond off-the-shelf technology – also with potential inclusion of trailers. SAE International has technologies like driver coaching features, friction reduction & improve lube, speed limiters, automated manual transmission, automatic engine shutdown, automatic tire pressure control, hybrid technologies, improved aerodynamics, low rolling resistance tires and stop/start system in mind [5].

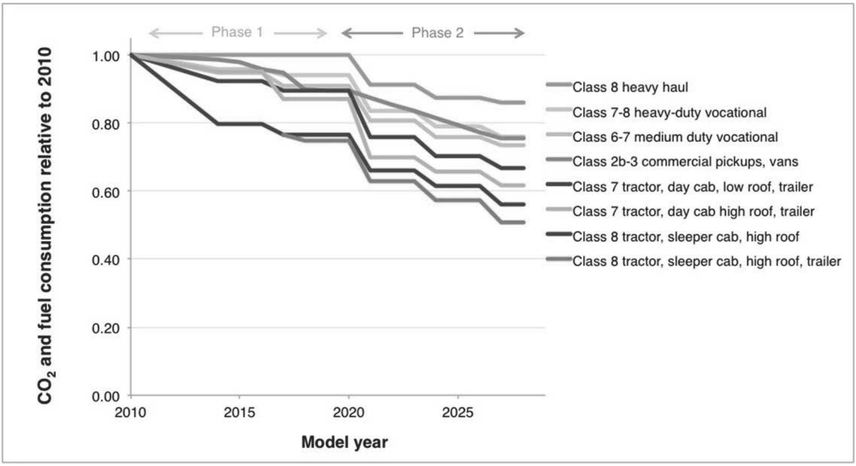



Fig. 1: US final $CO_2$ and fuel consumption rulemaking for heavy-duty vehicle fuel-efficiency and greenhouse gas standards from 2010 till 2027

In addition to the $CO_2$ regulations, many US states and local authorities have implemented driving situations and down time (= Anti-Idling). These strict regulations have already in the past and will continue to drive new technology developments, E/E architecture and environment adaption discussions [6]. Many fleets have reported significantly reduced idling with the use of telematics/GPS systems, which provide fleet managers with data about vehicle location and engine status, including idling behavior. These data allow managers to identify idling patterns and determine which measures for idling time reduction could be applied for idling time reduction. Other technologies such as cabin insulation, window glazing and reflective paint, may reduce a stationary vehicle's energy requirements. Passive measures, such as parking in the shade in summer or facing south in winter, may also reduce power needs [7]. Additional potential can be provided from a Photovoltaic System (PV), which could support the air conditioning system in hotel mode to keep the driver's cabin comfortable.

## 2. Photovoltaic (PV) Application on Truck

Continental has integrated a solar panels system on the roof and wind deflector of the driver's cabin of the Continental "Innovation Truck". This demo application includes a set of 90 silicon solar cells that have been installed over two separate carriers with a flexible carrier substrate. The solution delivers a nominal power of around 280 W (p). The silicon solar cells are implemented in a plastic plate-plate composite to demonstrate a high flexibility and low-weight application. The usage of standard silicon cells shows price advantages through worldwide optimized production processes, good availability and certificated quality definitions. The entire application has been constructed in a way that the existing truck shape was replicated. In addition, the existing antenna concept had been adapted and directly been integrated in the PV module.

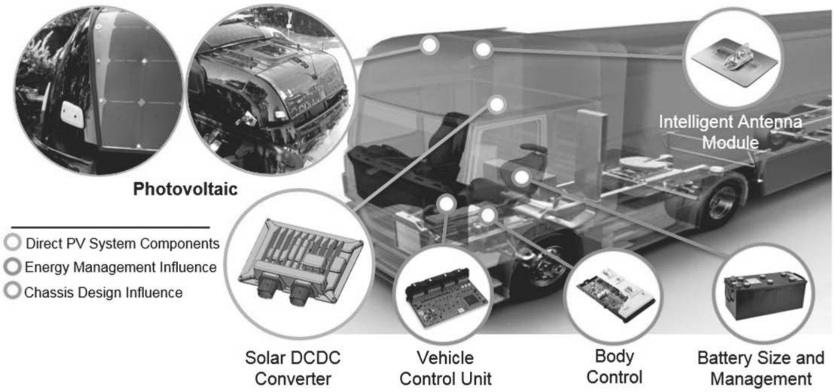



Fig. 2: Photovoltaic system connected to the series vehicle architecture via Solar DCDC Converter which improves vehicle energy management

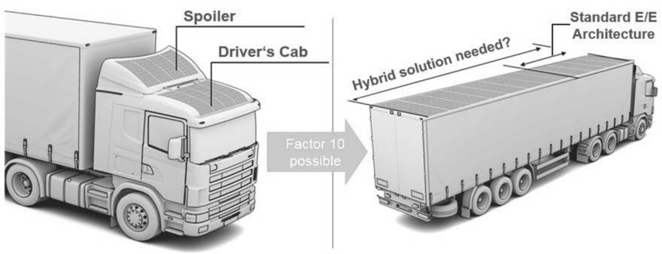
Depending on the sun radiation, the truck can cover parts of its onboard energy demand or, optionally, charge the battery unit. Besides the integration of the PV panel, the focus of the demonstration lies on the intelligent connection with the battery system via a 24 V solar-DCDC converter. The DCDC converter system includes a step-up/step-Down conversion and a LIN communication for simple diagnostic features as well as energy balance reporting. The Continental DCDC converter system charges batteries from 6 V to maximum battery voltage with conversion efficiency higher than 94%. The maximum charge voltage is defined between 12 V and 32 V for the 24 V powernet system. The DCDC converter can also operate when the truck system is off (e.g. in hotel mode).

Figure 3 shows that PV technology development is still ongoing with focus to become more efficient, less expensive and enables lighter module configurations. At the moment, standard modules can be purchased with approximately 18 % cell efficiency. By 2021, the efficiency should be at a level of about 21 % and until 2025 to around 30 % due to innovative technology approaches - e.g. new tandem technology cells. This increased efficiency will allow in spite of confined space conditions on the driver's cabin area to provide more overall performance. Given this and the assumption that 3.5 m² is available for PV modules it will be possible to install up to 1000 W (p).

According to defined scenarios, it can be expected that such a solar application reduces the overall fuel consumption by more than 1 % - depending on use case and sun radiation intensity in the focus markets.

Beside the Continental demonstration in the Innovation Truck, a further solution could be to cover the top of the trailer with PV modules. For this use case an area of up to 25 m² is possible. With the aforementioned efficiencies up to 4.5 kW (p) would be possible in 2017 and over 7.0 kW (p) in 2025. This energy could be used in a hybridized powertrain (e.g. via 48 V Mild Hybrid System) where it could be used for eBoost by supporting the ICE or eDriving effects.

Picture




| | | |
|---|---|---|
| **Space** | **1 m²** (Spoiler) up to **3,5 m²** (Spoiler+Cab) | up to **25 m²** |
| **Peak Power*** | › up to **600 W (2016)**<br>› up to **1000 W (2025)** | › up to **4500 W (2016)**<br>› up to **7700 W (2025)** |
| **E/E Architecture** | with Standard System possible | (Mild) Hybrid System recommended |
| **Influence of Driving Strategy** | No big influence | Possible Influence:<br>**eBoost Power support possible** |
| **Influence of Still Stand Energy Consumption** | **Yes – support of APU possible** | **Yes – support of APU possible** |
| **Power Support for Cooling Transporter** | Very limited | **Larger energy shares can be covered by PV** |

* According Cell Supplier Roadmap; **APU** = Auxiliary Power Unit; **PV** = Photovoltaic

Fig. 3: PV application at truck and trailer – specification for 2017 and 2025 in combination with possible influences

According to our scenario calculations, the European Union, Brazil and China will be the first markets in which there could be a Return-of-Invest (ROI) for such a solution. With certain oil price assumptions and solar power scenarios, the payback time will be less than three years in the future through cost reduction during driving and also in hotel mode. The US market could also become interesting if further $CO_2$ limitations come into force

Interesting advantages of a PV system are listed below:

- **Reduce Generator Mode:** Reduce fuel consumption by generation of electrical power during driving. Additionally an increase of alternator lifetime is possible.
- **Comfortable Living:** PV applications reduce the need to plug in when parked - adjust to anti-idling laws. Especially during hot summer days the PV system supports the air conditioning system in hotel mode to keep the driver's cabin comfortable.
- **Auxiliary Power Unit (APU) / Electrical Power Unit (EPU) Maintenance:** Reduce run-time of APU motor to maintain battery charge. Reduces usage based APU maintenance cost. The PV system is also ideal for vehicles that lose battery charge when powered off over a long period and for vehicles with air conditioning, lighting, monitoring equipment or other auxiliary systems which run on battery.
- **Battery Charging and Balancing:** It is a major challenge for truckers to maintain adequate charge and overall health of batteries powering the truck's main engine and auxiliary systems. Generally, current deep-cycle battery life is expected to last 2 to 3 years, although this depends heavily on the conditions of the low volt battery that is used. The replacement of truck batteries will, as a matter of course, depend on application conditions. So the whole PV System in combination with the Energy Management can regulate via Solar DCDC Converter the state of charge of battery, which maintains the health and extends the battery life.
- **Complete Anti-Idling System:** PV provides an independent and renewable power source. Solar constantly tops up battery bank and enable an advanced system; also for the Anti-idling regulation in US.

## 3. eHorizon with Intelligent Usage of Static and Dynamic Information

As already mentioned, today's main driver for more fuel efficient long-haul trucks can be seen in the reduction of the Total Cost of Ownership (TCO) for the vehicle owner, not in regulatory pressure. It is commonly presumed that fuel costs account for up to one third of the yearly total cost of ownership for a long-haul truck in Europe. That's why even small improvements in fuel efficiency can be profitable, assuming the amortization time is less than 2-3 years.

OEMs are continuously working on improving combustion engine efficiency, aerodynamics and/or rolling resistance, with remarkable results. Besides all hardware improvements, the driving behavior also has significant influence on the fuel consumption of a truck. This chapter aims to increase the awareness for the positive fuel consumption impact of a predictive operating strategy in conjunction with the coasting driving mode, something which is already proven for passenger cars [8]. The use of data from the surrounding environment allows for proactive actions instead of a purely reactive control system.

The dynamic electronic horizon - also called dynamic eHorizon - supplements the environmental sensor technology of the vehicle with additional information [8]. It does not only enlarge the virtual field of view beyond the range of onboard sensors, but also goes beyond the visual range of the driver. To provide real-time information, the dynamic eHorizon uses crowd sourced data from other vehicles as well as further data sources via internet. Besides real-time updates of the maps, also dynamic traffic information such as traffic jams, accidents, stop-and-go traffic, slow moving traffic, icy roads or traffic light phases can now be provided on top of traditional static information. In this way, the dynamic eHorizon enables numerous new functions that improve efficiency, comfort and safety. In the context of fuel saving, the dynamic road and traffic information will enable a very fuel efficient driving mode, the predictive eco coasting.

Predictive driving strategies which have already been introduced in series vehicles [9] [10] use static map information in order to enable efficiency improvements. The static eHorizon positions the vehicle on a digital map. An algorithm calculates the most probable path (MPP). A database in the unit provides the road attributes along the MPP. These attributes are subsequently transferred to various control units in the vehicle which automatically adapt the vehicle behavior to the forthcoming road attributes. One example is the speed adaptation before and after a slope. In this case the vehicle accelerates ahead of a slope in order to use the momentum within the slope and thus minimize the gear shifting operations. Prior to a downhill incline, the vehicle speed will be slightly reduced in order to use the potential energy of the vehicle during driving downhill to regain this speed but without or reduced use of primary energy. These driving functionalities save fuel and increase comfort and safety at the same time since strong braking can be avoided. With this function, the fuel consumption can be reduced by up to 3 % [10].

The evolution from the static to the dynamic eHorizon, which is schematically illustrated in Figure 4, forms the basis for additional energy saving potential.

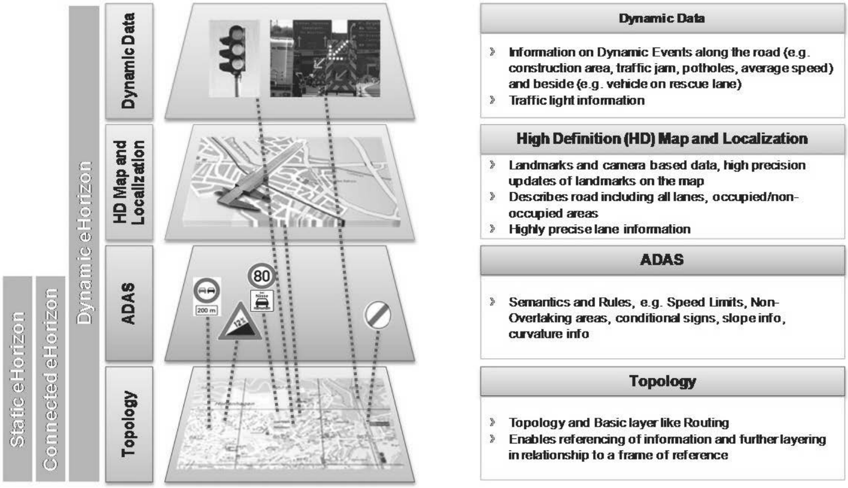


Fig. 4: Evolution from the static to the dynamic eHorizon

### 3.1 Predictive Eco Coasting with Usage of the Dynamic eHorizon Information

As the powertrains of long-haul trucks are usually not (yet) hybridized, it is not possible to recuperate excessive kinetic energy with a generator into electrical energy. This would allow the storage and later usage of the energy for other purposes. However, purely Internal Combustion Engine (ICE) driven trucks can also profit from kinetic energy via predictive eco coasting.

Coasting is the most efficient way to recuperate kinetic energy as it has no conversion losses. Only the drag forces of the vehicle (aerodynamics and rolling resistance) reduce the maximum kinetic energy recuperation potential; but these forces would also be present in the hybrid system.

The dominating use case for long-haul trucks is the more or less constant driving behavior on highways or wide country roads. Nevertheless, there are many situations that force the truck driver to slow down, e.g. traffic jams, road works, stop-and-go traffic, severe weather conditions, highway exits, urban areas, etc..

In order to quantify the maximum fuel saving potential of predictive eco coasting based on dynamic eHorizon information, Continental together with AVL List GmbH defined four main driving scenarios which represent the above mentioned initial disturbances that require the truck to slow down. In the following, for all four driving scenarios the fuel consumption differences between a predictive eco coasting driving mode, a prospective driving mode and a worst-case (aggressive) driving mode were simulated. Basis for the simulation was a typical European semitrailer unit (max. 40 t). Three different vehicle weights (maximum load, middle load, empty) were considered. All simulations were performed on a flat route (without slopes) to show the additional benefit beyond today's static eHorizon solution. “AVL Cruise” was used as the simulation environment.

Fig. 5 describes driving scenario 1 "deceleration until close to standstill from 85 km/h" which simulates a traffic jam on a highway.

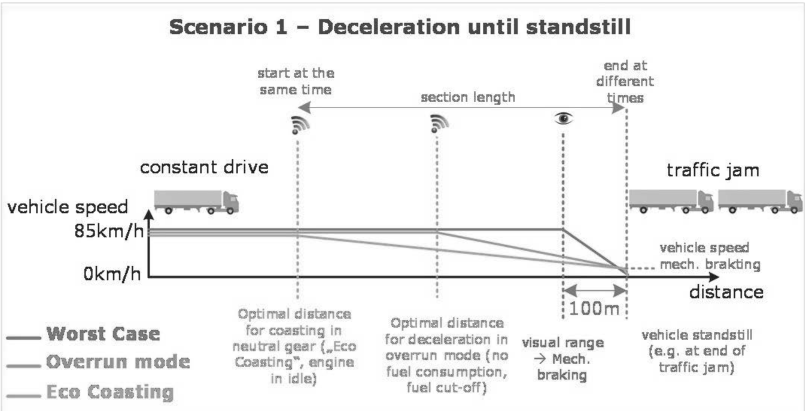



Fig. 5: Schematic description of driving scenario 1 "Deceleration until standstill from 85 km/h”

Our assumption of a worst case reference is characterized by keeping a speed of 85 km/h until coming close to the disturbing event. 100 meters prior to the end of the traffic jam the driver mechanically brakes to force the truck to standstill.

In the best case driving mode the truck receives dynamic eHorizon information including the position of the tail end of the upcoming traffic jam. Using the functionalities of the connected Energy Management (cEM) [8] [11], the ideal distance (timing) for switching into the coasting mode can be calculated on the basis of the vehicle driving resistances which mainly depend on the vehicle weight, the aerodynamic drag, the rolling resistance of the tires as well as the topography of the road ahead, e.g. up- or downhill slopes. During the coasting event, the combustion engine is continuously running at idle speed ("idle coasting").

In the prospective driving mode the truck decelerates with the combustion engine drag forces in the overrun mode with fuel cut-off functionality until the truck almost stands still. Also in this case dynamic eHorizon information and the cEM functionalities are used to determine the optimal timing for the switch into the overrun mode.

Even though it would technically be possible to also apply engine-off coasting with an additional fuel consumption benefit, this approach needs to be further worked on to ensure the availability of all safety and comfort functions during the engine-off phase. Therefore, engine-off coasting will not be considered here.

It is obvious that the deceleration distance for idle coasting is the largest one and is thus used to compare fuel consumption and the required time for all three driving modes ("section length"). The movement of the traffic jam tail end during the longer coasting time is neglected for the sake of simplicity. In a similar approximation, the fact that the worst-case and prospective vehicles will stand longer in the traffic jams in idle mode is also neglected

At the end of the decelerations either by coasting or by overrun the vehicle will be stopped through mechanical braking as soon as the speed of 3 km/h is reached. This is a realistic approach which simplified the definition of the simulation runs.

Fig. 6 shows the simulation results of driving scenario 1 "Deceleration until standstill from 85 km/h" in absolute and relative values. Besides the consumed fuel for the different driving modes, the deceleration distances and the needed times are also compared even if the time differences play a minor role in the case of traffic jams.

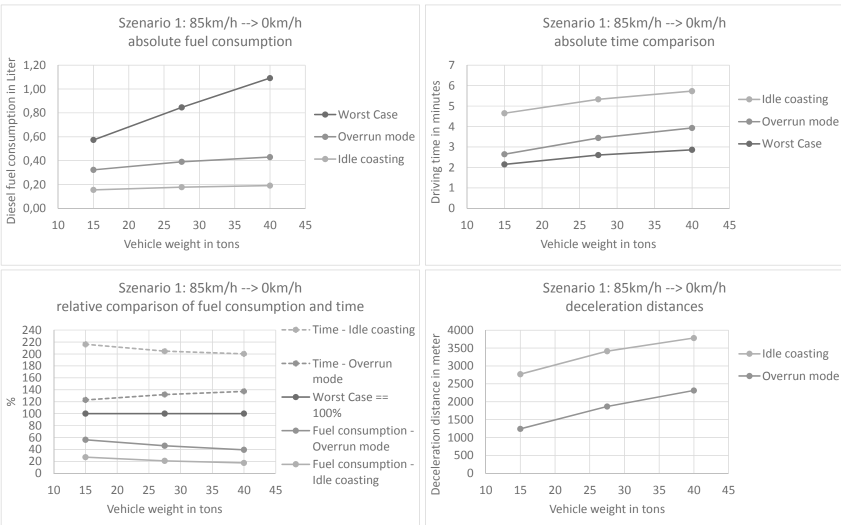


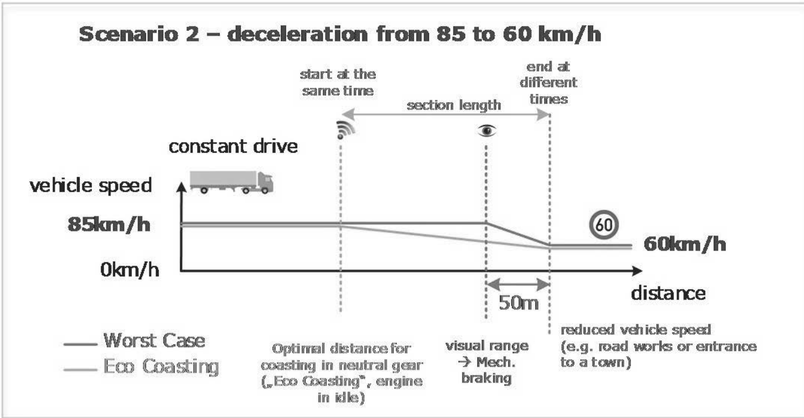

Fig. 6: Simulation results of driving scenario 1 "Deceleration until standstill from 85 km/h”

The simulation of the scenario "Deceleration to standstill from 85 km/h" shows that referred to the deceleration distance of the coasting, predictive eco coasting saves a weight dependent absolute fuel amount of 0.4 to 0.9 liter Diesel per event compared to the worst-case driver. Deceleration in overrun mode (fuel cut-off, but shorter deceleration distances) shows lower fuel saving potential compared to the predictive eco coasting mode. Depending on the weight, 0.25 to 0.65 liter Diesel can be saved in comparison to the worst-case driving mode. In relative numbers the differences are even more impressive: a 40 t truck using predictive eco coasting can save up to 82 % of the fuel amount consumed by a worst-case driver in a hurry, while with overrun mode the savings reach up to 61 % for this single event.

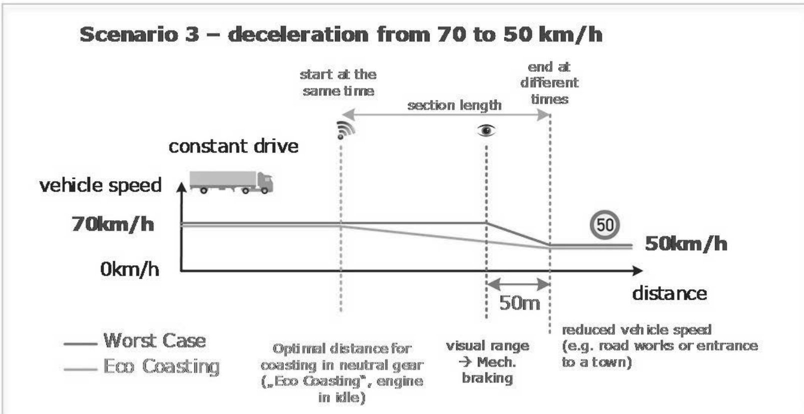
The coasting distance (gearbox in neutral position) can amount to nearly 3.8 km (40 t, starting at 85 km/h to nearly standstill), while in overrun mode (engine drag force of the combustion engine is effective) 2.3 km deceleration distance will be reached. The deceleration distance in the worst-case driving mode is by definition exactly 100 meters long.
The time to complete the reference coasting distance varies among the three driving modes. The worst-case driver of course completes the reference distance most rapidly as he drives the longest period at initial speed.
In comparison, the deceleration time of predictive eco coasting is twice as long. The deceleration time for the overrun mode lies between the worst-case and the coasting, but closer to the worst-case (depending on the weight 20 % to 40 % more).
As already mentioned, deceleration times are less important in the case of traffic jams, as the truck has to stop anyway. So, neglecting the rearward extension of the traffic jam during the waiting time of the worst-case and prospective drivers, with coasting effectively no time is lost.

Similar reflections as for driving scenario 1 were also made for the driving scenarios 2 to 4. In the following, the scenarios 2 to 4 are explained briefly in the schematics definitions.

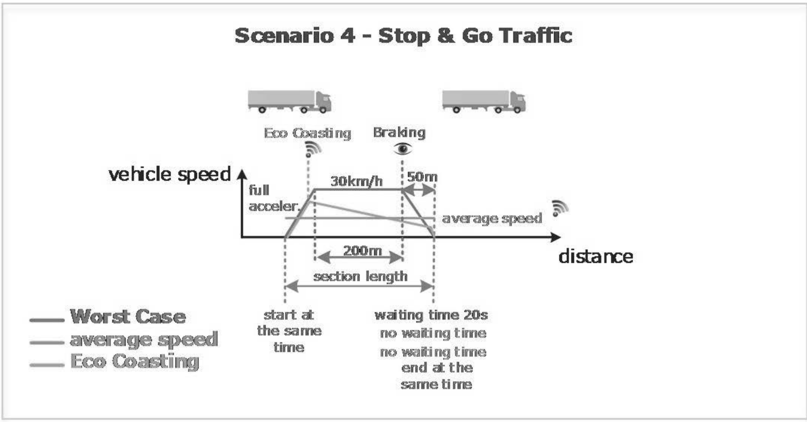
The following figure 7 shows the driving scenario 2 "deceleration from 85 km/h to 60 km/h" which simulates road works on the highway or slow moving traffic:




Following figure 8 illustrates driving scenario 3 "deceleration from 70 km/h to 50 km/h" which simulates driving on an extra urban road with the approach to a city:



The following figure 9 shows driving scenario 4 "stop-and-go traffic" within a traffic jam:




All four driving scenarios were analyzed in the same way as the described in driving scenario 1.

Table 1 shows the summary of the simulation results in absolute values of all four evaluated driving scenarios with their relevant parameters, the fuel consumptions, the coasting distances and the times needed for a worst-case and a prospective driving mode, and with eco coasting. Table 2 shows the same results in relative values.

Table 1: Summary of the simulation results in absolute values with consumed fuel and needed time at different driving scenarios for a worst-case and a prospective driver, and with predictive eco coasting.

| | Weight | Section Length | consumed fuel [ml] | | | needed time for sector length [s] | | |
|---|---|---|---|---|---|---|---|---|
| | [t] | [m] | worst case | prospective | idle coasting | worst case | prospective | idle coasting |
| Scenario 1 | 15 | 2770 | 574 | 323 | 155 | 129 | 159 | 279 |
| 85 -> 0 km/h | 27,5 | 3415 | 846 | 390 | 178 | 156 | 207 | 320 |
| | 40 | 3780 | 1091 | 430 | 191 | 172 | 236 | 344 |
| Scenario 2 | 15 | 1007 | 202 | not simul. | 28 | 43 | not simul. | 51 |
| 85 -> 60 km/h | 27,5 | 1385 | 337 | not simul. | 39 | 59 | not simul. | 70 |
| | 40 | 1617 | 460 | not simul. | 45 | 69 | not simul. | 81 |
| Scenario 3 | 15 | 827 | 135 | not simul. | 28 | 43 | not simul. | 50 |
| 70 -> 50 km/h | 27,5 | 1076 | 221 | not simul. | 34 | 56 | not simul. | 65 |
| | 40 | 1217 | 302 | not simul. | 41 | 63 | not simul. | 73 |
| Scenario 4 | 15 | 290 | 120 | 89 | 70 | 71 | 71 | 71 |
| Stop & Go | 27,5 | 300 | 161 | 103 | 90 | 72 | 72 | 72 |
| | 40 | 310 | 204 | 118 | 111 | 74 | 74 | 74 |

Table 2: Summary of the simulation results in relative values with consumed fuel and needed time at different driving scenarios for a worst-case and a prospective driver, and with predictive eco coasting.

| | Weight | Section Length | consumed fuel [%] | | | needed time for sector length [%] | | |
|---|---|---|---|---|---|---|---|---|
| | [t] | [m] | worst case | prospective | idle coasting | worst case | prospective | idle coasting |
| Scenario 1 | 15 | 2770 | 100 | 56 | 27 | 100 | 123 | 216 |
| 85 -> 0 km/h | 27,5 | 3415 | 100 | 46 | 21 | 100 | 133 | 205 |
| | 40 | 3780 | 100 | 39 | 18 | 100 | 137 | 200 |
| Scenario 2 | 15 | 1007 | 100 | not simul. | 14 | 100 | not simul. | 119 |
| 85 -> 60 km/h | 27,5 | 1385 | 100 | not simul. | 12 | 100 | not simul. | 119 |
| | 40 | 1617 | 100 | not simul. | 10 | 100 | not simul. | 117 |
| Scenario 3 | 15 | 827 | 100 | not simul. | 21 | 100 | not simul. | 116 |
| 70 -> 50 km/h | 27,5 | 1076 | 100 | not simul. | 15 | 100 | not simul. | 116 |
| | 40 | 1217 | 100 | not simul. | 14 | 100 | not simul. | 116 |
| Scenario 4 | 15 | 290 | 100 | 74 | 58 | 100 | 100 | 100 |
| Stop & Go | 27,5 | 300 | 100 | 64 | 56 | 100 | 100 | 100 |
| | 40 | 310 | 100 | 58 | 54 | 100 | 100 | 100 |

Summarizing the main aspects of all simulation results, the following can be stated:

- In all driving scenarios, significant fuel consumption potentials can be achieved by using intelligent environmental and traffic information coming from the dynamic eHorizon. The absolute fuel consumption potentials increase with rising payload.
- During deceleration from 85 km/h down to standstill (e.g. ahead of a traffic jam), predictive eco coasting can save 0.4 to 0.9 liter Diesel per event (scenario 1) depending on the payload. To achieve this result, the predictive eco coasting mode is started at the optimal distance prior to the event.
- The distances in the predictive eco coasting mode (gearbox in neutral position, ICE in idle) can amount to nearly 4 km (40 t, 85 km/h). The deceleration in the overrun mode (no fuel consumption but lower deceleration distances) shows a lower fuel consumption benefits than the eco coasting mode.
- Intelligent decelerations to other speeds (e.g. 70 km/h to 50 km/h ahead to the entrance of a village) show fuel consumption benefits of 80 % to 90 % with an additional time demand of only 10 % to 20 % (scenario 2).
- The evaluation of driving within stop and go traffic with intelligent motion from standstill to standstill (scenario 4) shows a possible fuel consumption reduction of 42 % to 46 % for the predictive eco coasting. It is worth mentioning that coasting shows higher fuel saving potentials than driving through the traffic jam with constant mean speed (figure 9).

### 3.2 Statistic Events for Typical Eco Coasting

In order to determine the benefit of the abovementioned results on the total cost of ownership an estimation must be made how often long-haul trucks could encounter predictive eco coasting opportunities. The simulated scenario 1 "deceleration from 85 km/h to standstill" represents a traffic jam on a highway. How often will a long-haul truck get into a traffic jam?
Since many years the German automotive club ADAC publishes the yearly traffic jam report for German highways [12]. For example in 2016, about 694.000 traffic jams were registered, with a total length of 1.378.000 km which translates into an average traffic jam length of about 2 km, and an accumulated traffic jam duration of about 419.000 hours which means that the average duration of a traffic jam amounts to 0.6 hours (36 minutes). Based on Germany's 12949 highway kilometers it can be estimated that on average over the complete year, day and night times, working days and weekends, and over all federal states, a long-haul truck will encounter approximately 2.2 traffic jams per day (based on 600 km trip length). Special data from the ADAC show that during the day between 6 am to 7 pm significantly more traffic jams will arise than during the night hours. So it is obvious that the probability to meet a traffic jam is also higher during the daytimes. For the evaluated time frame from 6 am to 7 pm each truck would meet about five traffic jams per working day on average. With these high traffic jam numbers it also has to be considered that the truck will execute less kilometers driving distance and therefore the probability to meet a traffic jam will be lower again.
Nevertheless, it is clear that traffic jams on highways are recurring events where a 40 t truck has a fuel saving potential of 0.9 liter Diesel per event through predictive eco coasting.

Analyzing the highway part of a random drive of a long-haul truck on German highways of around 1500 km, 51 deceleration events occurred which started from a speed of more than 80 km/h. By providing real-time traffic information from the dynamic eHorizon, fuel savings by predictive eco coasting should have been possible on many of those deceleration events.

Following enumeration of deceleration events, for which we do not claim completeness, will occur more or less regularly during a typical truck driver's working day. In many of those cases it could be possible to coast at least a part of the maximal possible coasting length:

- Traffic jams on highways
- Road works on the highways can force the truck to reduce its speed (e.g. from 85 km/h to 60 km/h)
- Stop and go traffic

- Latest after 4.5 hours driving and at the end of the day, the trucker has to make a break, e.g. on a rest area besides or outside of the highway. In those cases the truck has to come to standstill anyway whereof a big portion of the deceleration could be performed by rolling-out
- The truck is close to the end of its highway travel and has to slow down at the next exit
- Driving on a country road with upcoming speed limits, e.g. at junctions, traffic circles or town signs announcing a village (e.g. from 70 km/h to 50 km/h).
- Reaching the target where the truck has to stop anyway to unload the freight.
- Deceleration before reaching severe weather or road conditions.

Summarizing all examples it can be stated that there are a lot of possible events which make a deceleration of the truck necessary. In several cases fuel could be saved by applying predictive eco coasting.

The two following simple examples should give a hint about the fuel saving potential of predictive eco coasting.
Assuming that a fully loaded truck will drive 600 km on a typical work day with a fuel consumption of 30 L/100 km, and assuming that only two traffic jams on the highway will allow predictive eco coasting, and neglecting all other possible deceleration events, then the fuel consumption benefit will be 1 %.

Assuming realistic numbers of predictive eco coasting events, the daily fuel and cost savings as well as the lost time can be estimated (see Fig. 10). Additionally, the numbers can be extrapolated to several years (see Fig. 11):

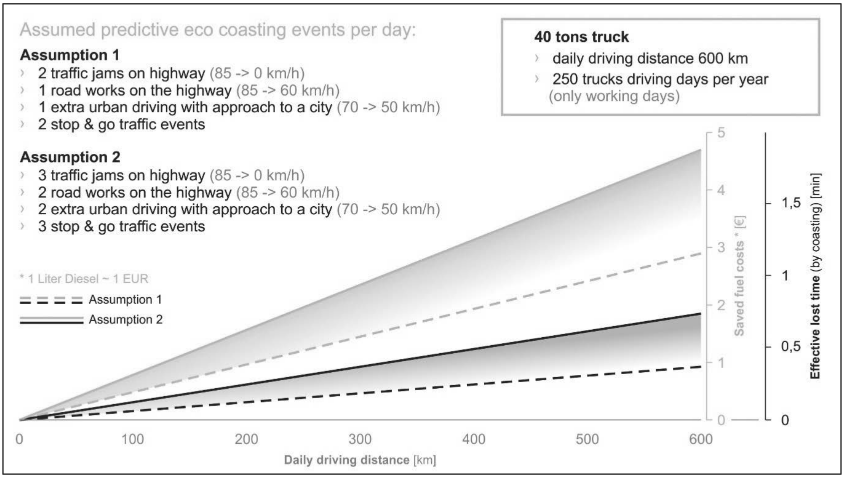



Fig.10: Assuming realistic numbers of predictive eco coasting events, the daily fuel and cost savings as well as the effective lost time can be estimated.

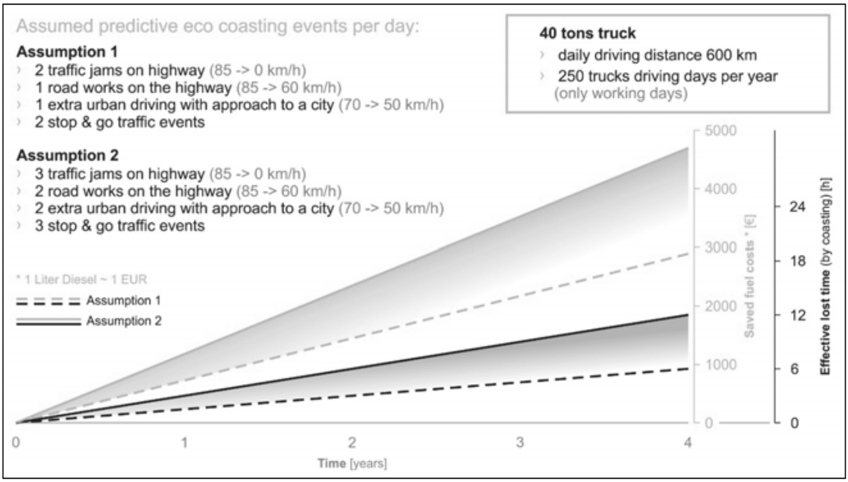



Fig.11: Assuming realistic numbers of predictive eco coasting events per day, the fuel and cost savings as well as the effective lost time can be extrapolated to a longer time. Over the years appreciable cost savings can be reached.

Having said that any absolute saving number is obviously coupled to number and type of events and thus can deviate significantly from the aforementioned. At this point we point out once again that these numbers are simulation results. These can differ from real behavior due to differences between the ideal and real world. But the opportunities which have been revealed clearly indicate that this technology has the potential to offer significant fuel and $CO_2$ savings.
The real fuel consumption benefits will be assessed within the IMPERIUM project [13] of the public-private partnership European Green Vehicles Initiative (EGVI). One aim of the IMPERIUM project is to implement the predictive eco coasting technology in a truck and to verify the fuel consumption benefits.

Additionally, for safety reasons it makes sense to approach an obstacle or a target in a controlled way by coasting instead of driving much longer with the maximum allowed speed. In many cases, rear-end collisions could be avoided if the driver is warned by the dynamic eHorizon information and by early speed reduction.

### 3.3 Acceptance of the Driver and of the Following Traffic

The dynamic eHorizon delivers early real-time environment and traffic flow information for the route ahead. Sometimes it can happen that even the driver is not able to see the event even if the truck already decelerates by changing to the predictive eco coasting mode in order to save fuel. This is a new unusual driving behavior of the truck which needs explanations for the concerned actors; these are the drivers themselves and the following traffic.

For the driver acceptance it is essential that predictive eco coasting will only start if an event which makes a deceleration necessary is really present. For building up trust the system needs a very high hit ratio. What is more disappointing than rolling out on the highway if the traffic jam does not (anymore) exist. If this happened several times the driver would switch off this functionality.

Generally the driver should be informed how far ahead and which event will trigger coasting (traffic jam, speed limit, etc.). Maybe the driver is also interested in the lost time caused by the coasting which is, as already mentioned, effectively equal to zero in the case of traffic jams or only a few seconds in the case of speed limits. It may also be interesting for the driver to be able to set the maximum distance at which coasting is triggered, e.g. 2000 m, 3000 m, etc. This way control is given back to the driver.

The information should be provided to the driver either on his standard display or a separate HMI, or even more safe and comfortable directly on the wind screen via a head up display (example in Fig. 12).


Fig. 12: Desirable HMI information for the driver during predictive eco coasting events. Here: via head up display information on the windscreen via head-up display.

The driver of the direct follower, often also a truck, will probably not realize the beginning of the coasting phase because the speed decrease will be very slow. In many cases the adaptive cruise control of the following truck will keep the spacing constant. Sooner or later the driver will have a look forward in order to understand why the truck ahead slows down more and more. In the case that he does not see an obstacle, he would normally start to overtake. He cannot know that e.g. two kilometers ahead a traffic jam will also force him to slow down to standstill. Therefore, the subsequent driver should be informed about the potential behavior or disturbance ahead. In Fig. 13 a proposal for the information of the subsequent traffic is shown in form of the pictogram of the official road sign for moving in queues. It could be mounted e.g. between bumper bar and cargo area. Additionally, the sign could be set into a blinking mode in order to draw more attention to the sign.

In future the reason for the deceleration could also be transferred directly to the head-up display of the following truck via vehicle to vehicle communication.


Fig. 13: Possible marking of the truck to inform the subsequent traffic. Right: during normal driving. Left: warning during eco coasting. Additionally, the sign could be set into a blinking mode in order to draw more attention to the sign.

## 4. New Truck Structures – New Possibilities

New $CO_2$ regulations will be a driving force going forward. They will lead to new technology approaches, new E/E architecture structures opening the door for advanced driving strategies

The next generation of trucks might have integrated hybrid systems based on 48 V or High Voltage (HV) which enable eCreaping (electrical parking), eDriving, engine-off strategies (stop/start and engine-off coasting) and recovery of braking energy. This energy can be used for auxiliary units or to support the combustion engine. In urban surroundings, there will be a trend towards fully electric trucks.

The forthcoming extension of the cabin length brings new opportunities. The future cabin will be modified for improved aerodynamics and safety and therefore there could also have more space available for photovoltaic – see figure 14 [14].

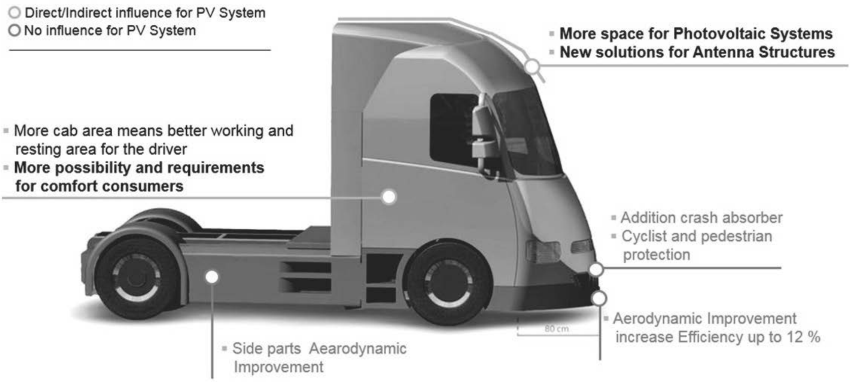



Fig. 14: EU modification of the chassis design after 2020 – advantages for Photovoltaic System integration and $CO_2$ reductions based on improved aerodynamics (Basic picture: eurotransport.de)

## 5. Continental Innovation Truck – Technologies for Future Improvements

Since 2015 Continental has implemented next generation features in our second InnovationTruck which is used to present next generation of safe and green transport mobility. The focus is to apply innovative systems and to show advanced integration into the vehicle network.

Systems and components like free Programmable Cluster, Wing-Mirror Replacement, Blind Spot Detection, Combiner Head-Up Display or On Board Weighing are implemented to demonstrate relevant use cases.

## 6. Conclusion

Interaction of different disciplines into one overall truck application is needed to reach the next level of $CO_2$ regulation in US and EU but also to reduce TCO. Today's truck owners are clearly TCO driven, so the primary focus is on fuel reduction: every 1 % fuel reduction means about 500 € cost reduction per year for a long haul truck (40 t in EU). New technology approaches have a payback time focus of 2 to 3 years (or earlier). In the future truck OEMs (and fleet owners) will also be $CO_2$ driven based on $CO_2$ regulation in the United States (start in 2010 a fuel reduction by 25 % needed in real driving till 2027); in the EU clear regulation will start at least in 2030. To enable further $CO_2$ reduction, new technologies such as hybridization, aerodynamics, ICE improvement or energy harvesting must be introduced.
Continental evaluated a photovoltaic system approach and predictive eco coasting based on advanced information from dynamic eHorizon. With further improvements in the price/performance ratio of solar cells, this technology can become viable and therefore important. Besides the total cost of ownership, the reliability of the truck system must be guaranteed. PV can help to reduce maintenance costs and times (e.g. battery system change).

In order to quantify the maximum fuel saving potential of predictive eco coasting based on dynamic eHorizon information, Continental simulated five different driving scenarios which require a truck to slow down. The fuel consumption differences between a predictive eco coasting mode, a prospective driving mode and a worst-case (aggressive) driving mode were evaluated. In all driving scenarios the fuel consumption of the predictive eco coasting mode was lowest. Compared to an aggressive driving mode, up to 90 % fuel can be saved within the coasting distance. Presuming only two traffic jams on the highway with predictive eco coasting decelerations instead of mechanical braking, up to 1 % fuel consumption can be saved within a whole day's trip.

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# Energy Management for Future Commercial Vehicles

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**Abstract**

Heavy duty vehicle road transport produces a significant share of CO2 emissions. Beside efficient engines and trucks, the use of bio-fuels and the electrification of the drivetrain are possibilities to reduce these emissions. For long haul heavy duty transport the saving potential from today's hybrid systems is not satisfactory. Full electrification fails due to size of needed battery. But progress in battery technology is promising. In some years it should be possible to install much more battery capacity in the vehicle than today.

To start with, this report compares the diesel consumption of a modern heavy duty truck to the hypothetical energy consumption of a lossless transport from south to north of Germany. This leads to the dimensioning for a balanced hybrid with maximum potential for recuperation. Simulation results show the energy balance during the trip, considering the driving losses and electrical losses.

Based on the encouraging results of the hybrid solution, the full electrical use case is evaluated for different battery capacity and charging options. Quick charging, battery exchange and overhead contact line are discussed regarding necessary charging stops during the trip.

Beside the energy management system in the truck, this report takes a look on the necessary energy management for the truck on infrastructure level. Requirements are derived for both management systems and for their interaction.

## 1. Motivation and Scope

Heavy duty transport has a significant share in greenhouse gas emissions. For Europe about 25% of total greenhouse gas emissions are produced by the transportation sector. About 5% of all CO2 emissions in Europe are related to heavy duty vehicle (HDV) transport. [1]

Within the last years, combustion engines became more efficient. NOx and particle emissions have been reduced to a very low level by filters and exhaust aftertreatment systems. CO2 emission keeps on a perceptible level as it is closely linked to fuel consumption. [1]

The targets for the future are focussing on CO2 reduction. One way is a vehicle with optimized fuel efficiency. Best case the vehicle is powered by bio fuels, resulting in a CO2 neutral well to wheel balance. Alternatively the vehicle can be powered electrically with energy from wind, solar energy or tidal power. Of cause a hybrid vehicle can also be a solution. This is reflected by the policy of the European Commission (EC) on “2050 low-carbon economy” for the transport sector in the following way :

Transport

Emissions from transport could be reduced to more than **60%** below 1990 levels by 2050.

In the short term, most progress can be found in petrol and diesel engines that could still be made more **fuel-efficient**.

In the mid- to long-term, plug-in **hybrid and electric cars** will allow for steeper emissions reductions.

**Biofuels** will be increasingly used in aviation and road haulage, as not all heavy goods vehicles will run on electricity in future.

Fig. 1: EC policy for low carbon economy in transport sector. (Source: [2])

Especially for heavy duty commercial vehicles it is not obvious, which solutions become feasible with future emerging technologies. The resulting scenario is probably somewhere between a highly efficient combustion engine and a full electric vehicle. But not only the vehicle itself, but also the related infrastructure has to be discussed. Finally the investments and total cost of ownership for all involved parties shall be reasonable.

The motivation for this elaboration is the thrill of a chase for possible future technical and logistic solutions for heavy duty transport. The solutions are based on expected technological progress. Challenges to be faced are identified within the discussion of the solutions.

## 2. Efficiency of Diesel Powered Heavy Duty Truck

The efficiency of heavy duty trucks has steadily been improved during the last three decades. Looking to the past 10 years, the diesel consumption of an Euro V vehicle on a trip between south and north of Germany was at 35l/100km in 2008 [3]. In 2011 the consumption was decreased to 33l/100km on that trip due to modern, more efficient diesel engines.
Today a consumption of 30l/100km seems realistic, when the vehicle is equipped with

- modern aerodynamics
- low friction powertrain
- tires with low rolling resistance, supported by a tire pressure monitoring system
- GPS based predictive eco cruise control
- and an onboard computer and a fleet management which provides economy recommendations to a trained driver.

Related to the engine, the increase in efficiency around 2011 means that the efficiency (mechanical power from chemical power) increased from about 44% to about 47% (mean values via trip north/south Germany). Nevertheless the efficiency of the engine itself will probably never cross 50% due to physical limits. This means that in any case only 50% of the chemical energy put into the vehicle at start of the trip will be converted to mechanical energy. The rest is lost in heat.
A waste heat recovery (WHR) system may return a certain share of the heat to useable power. But the absolute savings from the WHR system decrease with higher efficiency of the vehicle. Potential for amortisation is limited. It surely makes sense to find a way to reduce the diesel put into the vehicle by supplying the vehicle with other kind of energy pre trip and during the trip.

Within the next section the optimal heavy duty hybrid vehicle for the trip from south to north of Germany is dimensioned. This hybrid differs from today’s hybrid solutions by additional energy storage capacity and adapted power characteristics for motor/generator. The hybrid in long haul use case relies on mixed topology.

In a later section the full electric vehicle will be dimensioned. This approach will also be evaluated for the challenging track from south to north through Germany. Basically the results can also be used for estimation of the energy balance on flat topology.

## 3. The Balanced Hybrid Solution

### 3.1 Energy Balance on a Track trough Germany with Lossless Vehicle Approach

Principally the energy for the transportation task to bring a load from e.g. Stuttgart to Hamburg would be balanced, if the transporter would move on a friction less slider, in a vacuum tube. A catapult in Stuttgart would have to shoot the vehicle away with the necessary energy of 36kWh to reach the highest point of the trip with 80km/h. The start speed of the vehicle would be 290km/h. In Hamburg the vehicle arrives with 378 km/h because of the additional height difference. The return catapult in Hamburg would store 61kWh, prepared to shoot back another 40t to Stuttgart.

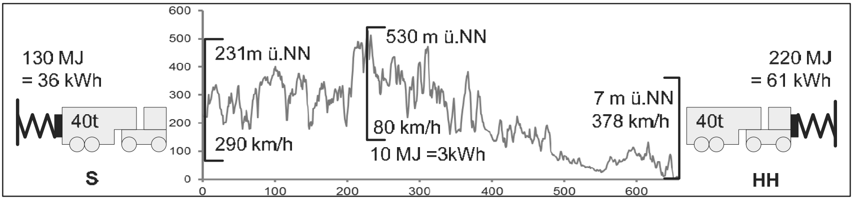



Fig. 2: HDV on a lossless roller coaster way from south to north of Germany and vice versa

This thought experiment is purely based on conversion between kinetic and potential energy. But the energy stored in the moving mass of the vehicle may also be stored in an electrical battery. A storage capacity of 61kWh (lossless) should be sufficient to drive the track from south to north as well as back from north to south. A 100kWh battery (lossless) would be operated between 20% and 81% SOC.

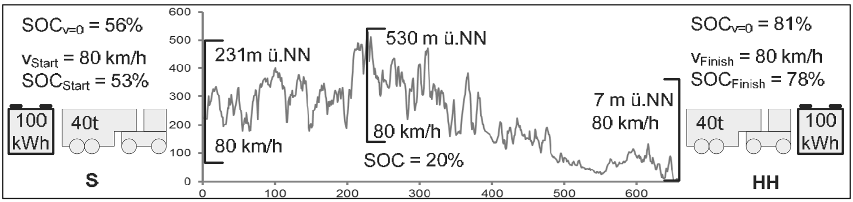



Fig. 3: Potential energy buffered by a vehicle battery with capacity of 100kWh

The lossless vehicle could travel principally at 80 km/h constantly. But now the power for climbing a hill or for recuperating downhill is quite large. To climb a 5,8% ramp (3,3° inclination) with a 40t friction-less vehicle, the drive would have to deliver 500kW, raising to about 700kW at 8%, which is maximum slope at A7 in Germany. Theoretically for 10% inclination, 870 kW power is required.

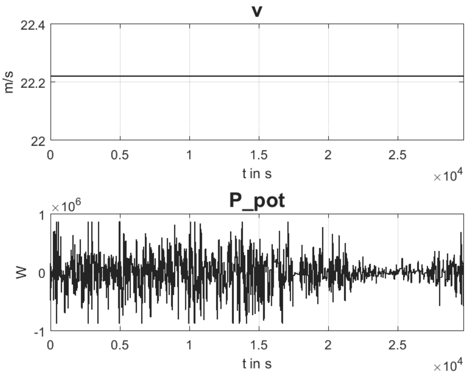



Fig. 4: Power (P_pot), resulting from variation in potential energy with constant speed (v).

Consequently the speed of the vehicle has to be adapted to match to the maxima for drive power, respectively for recuperation. For climbing up the hill, the speed will be reduced by physics to the speed matching to maximum drive power. So with 500kW drive power, the vehicle may still climb the 5,8% hill with 80km/h but for 8% the speed will fall to 57 km/h and for 10% to 46km/h.

The same speed values are valid as limits for downhill driving. When entering the slope at a speed above these limits, it would not be possible to limit the speed to the allowed maximum by recuperation. As the ideal hybrid shall not waste any energy by friction braking or by using an additional retarder, the speed has to be reduced before entering the downhill slope.

This results in first basic requirements to the energy management system of the vehicle :

- The energy management of the vehicle has to take care that kinetic energy is recuperated first, before going downhill.
- The speed has to be tuned to a level that downhill at any downhill location the recuperation potential will not be exceeded.
- The energy management system has to have precise forward looking information about topology of the track as well as on the own potential for recuperation. It has to compute a prognosis on total energy balance.

Now, with variable speed, the power for acceleration and deceleration has to be added to the balance. Driving uphill, kinetic energy is directly converted to potential energy without exchange via battery. For downhill slope, first the kinetic energy from speed reduction and secondly the energy from changing the potential will be stored to battery. Only about 2kWh (7,2MJ) battery capacity has to be available to buffer the energy for acceleration and from deceleration during the trip from south to north of Germany.

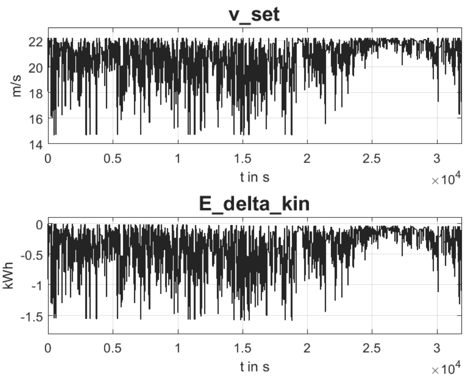



Fig. 5: Kinetic energy (E_delta_kin) to be buffered by battery
if power (P_pot) is limited to 500kW by limitation of speed (v_set)

### 3.2 Consideration of Losses and Configuration of the Balanced Hybrid Vehicle

Based on the results from paragraph above, the vehicle in a first step could be configured as follows : The vehicle is equipped with an electric motor/generator power of 500kW. A battery with 100kWh capacity is installed. The battery will store recuperated energy and contributes to the vehicle propulsion for acceleration and for gaining potential energy.

Assuming related progress in efficiency for battery charging and discharging, for power conversion by power electronics and for the electric motor respectively generator, the overall efficiency for transferring battery energy to traction is assumed to 90%. The same value is assumed for charging by recuperation.

Not considered yet but unfortunately unavoidable in real world is the power to cope with friction and aerodynamic resistance. For a fully loaded heavy duty truck traveling with 80km/h, this power is about 80kW. The power could be supplied by diesel engine, running in a con-

stant working-point. Of cause other power sources are possible like CNG engine or turbine. All variation in speed and potential energy is supported by the electrical system.
To avoid mechanical gears, the mechanical power source should drive a 80kW generator, for supplying drive power or loading the battery. Alternatively the power may directly be provided electrically by a fuel cell. Consequently the power of the e-motor increases to 580kW.

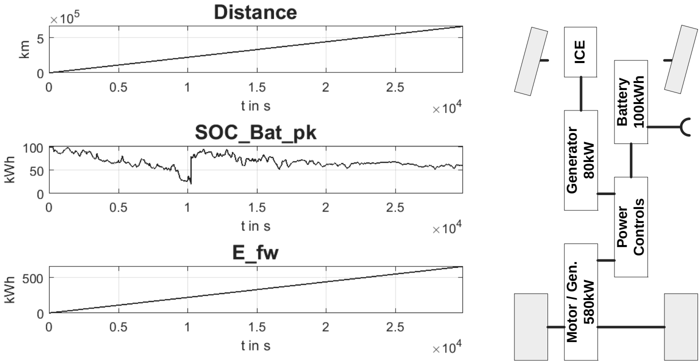



Fig. 6: Energy balance and power architecture of hybrid with 100kWh supporting battery. Charging battery to 80% after 3h travel is sufficient for the remaining distance.

Starting with a fully charged battery in Stuttgart and accepting one time quick recharge on the trip, the solution seems feasible and represents a balanced hybrid solution.
Still available electrical energy at destination can principally be subtracted from the mechanical energy provided by the diesel engine (E_fw), as the electrical energy could have been used for torque support.

- Dependent on the SOC of the battery and dependent on the desired energy which shall electrically be available at destination of the trip, the energy management system can decide on further electrical support for the combustion engine.

Regarding the simulation results shown in Fig. 6, an accumulated energy of 660kWh results from the constant driving losses. 40kWh excess energy from the supporting battery could be subtracted from the 660kWh. The resulting 620kWh mechanical energy would lead to a diesel consumption of about 22l/100km. So compared to pure combustion vehicle with 30l/100km the CO2 reduction is significant. Honestly the 180kWh charged electrical energy adds to the overall costs. Overall energy costs are expected to be reduced by about 5000€/year (at 200000km travel per year).

## 4. From Balanced Hybrid to Full Electric Approach

The balanced hybrid is dimensioned to deliver up to 500kW drive power from battery and to charge the battery with same power. This results in challenging high peak current for the 100kWh battery. Even at 800V voltage level, the current reaches 625A which means a current of “5C” for the battery. Regarding the battery lifetime and battery losses, the capacity should be higher.

Today a battery capacity of about 200kWh can realistically be integrated in an European truck, towing a semi-trailer. Assumed the battery capacity will double every ten years, the battery capacity of 450 kWh seems realistic for 2030. This capacity would result in an acceptable charge/discharge current of “1,1C”.

This battery capacity is now very close to the needs for travelling long distance in pure electric drive. To check this approach, the vehicle configuration is changed :

A battery of 450kWh is installed. This battery now includes the capacity to buffer variations in potential and kinetic energy as well as to deliver the 80kW constant drive power. No additional engine, turbine or fuel cell is installed. The assumed efficiency for the electrical system will stay at 90%.

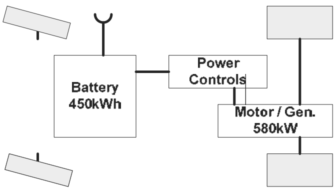
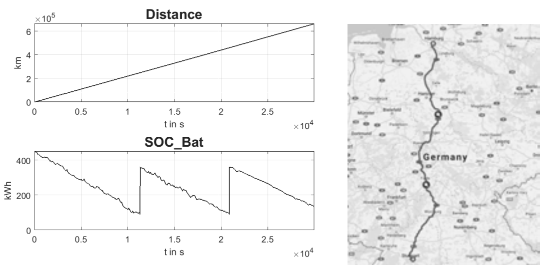



Fig. 7: Power architecture of full electric vehicle

## 5. Discussion of Simulation Results for the Electric Vehicle




(Source : google maps)

Fig. 8: Energy balance and needed charging stops for the electric vehicle (450kWh battery)

The result of the simulation for the full electric vehicle shows that the 450kWh battery would have to be recharged with 270kWh twice during the trip from Stuttgart to Hamburg. First re-charge is necessary after about 3 hours. Next recharge is necessary about another 2,5 hours later. (Fig. 8)

Unfortunately the driver and his boss cannot accept two stops. On a trip with active driving time below 9 hours, only one rest period of 45 minutes is mandatory after 4,5 hours.
A second stop may be acceptable if it lasts only a few minutes, e.g. by exchanging the bat-tery.

To have only one stop on the trip, the battery would have to be increased to 600kWh. This may be a realistic capacity after 2035. But now the energy to be charged to the battery at the stop increases to 360kWh, with higher requirements to the charging infrastructure.

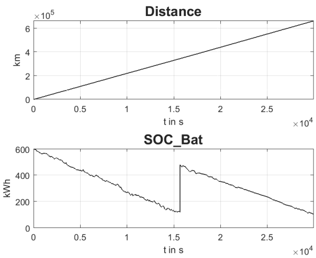
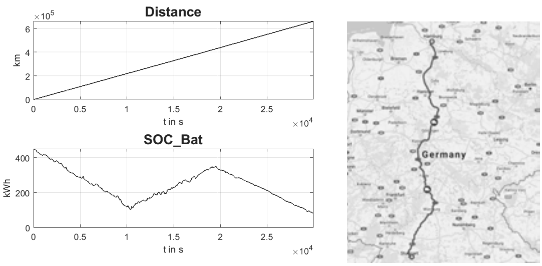



Fig. 9: Energy balance and needed charging stops for the electric vehicle (600kWh battery)

Alternatively to charging stations, battery exchange or higher battery capacity, an overhead contact line could enable a “charging while driving” solution.




(Source : google maps)

Fig.10: Energy balance for charging while driving via overhead power line (450kWh battery)

The line would supply 220kW along 200km for 80kW drive power plus in average 140 kW for charging the batteries. With this approach the battery energy capacity can now be reduced back to 450kWh. Beside the overhead charging no other charging is necessary during the trip. The driver is completely independent from singular charging stations and can have a break anywhere.

The total energy consumption for the full electric vehicle is 840kWh. The diesel truck with 30l/100km would consume 200l for the same trip. Calculated with assumed costs for today of 23ct/kWh for electricity and a diesel price of 1,05€, both would result in total costs of 210€. In 2030 the fleet owner would only change to electrification for long haul if electricity gets cheaper and/or diesel gets more expensive.

## 6. Different Charging Options and Resulting Requirements to Infrastructure

### 6.1 Quick Charging

The 100kWh battery of the balanced hybrid has to be charged just once with 60kWh. This should be possible in 30 minutes and raises moderate requirements to infrastructure.
The full electric vehicle would have to be recharged twice with 270 kWh (60% of 450 kWh) respectively once with 360 kWh (60% of 600 kWh).
The energy refill of 270kWh lasts about 45 minutes on a 350kW high power charging station.
But in future many electric trucks are on the way. For the service station it is a challenge to provide enough energy. If 10 trucks would have to be recharged, this leads to the same energy per hour, as the domestic home of a small family consumes in one year. The needed power of about 3-4MW matches to the power of an on-shore windmill. Assumed that 100 or more trucks per hour would have to be recharged, then a complete wind park would have to be installed around the station.
The truck driver cannot accept that all quick charge points on the station are occupied when he arrives. Already at the start of the trip the driver needs the reliable information that he can recharge his vehicle reliable in time at necessary charging stops.

- All electric vehicles as well as the energy supplying infrastructure have to be linked by a comprehensive energy management network.
- The energy management has to optimise the entire energy supply and distribution. Main criteria for optimization are the changes in available energy during the day and the number of vehicles which need to be charged at a certain location and time.

- The energy management has to integrate the individual planning for the trip. It has to give the driver the reliable information, when to start the trip and when to charge at which station.

### 6.2 Battery Exchange

For the large battery capacity of a long haul electric vehicle, battery exchange seems not to be realistic for the whole capacity. The battery cells are probably highly integrated and distributed over the vehicle. Not all of them can be made accessible from outside.

On the other hand battery exchange may have potential for quick energy refill for the balanced hybrid truck, alternatively to quick charging. It could also be a back-up solution for full electric vehicles. At least a part of the battery can be exchanged in case all energy dispensers are occupied or the service station has a lack of energy supply. For emergency refill on the road an exchange system may become mandatory. Standardisation of batteries and matching vehicle interfaces would be unavoidable.

- The comprehensive energy management network has to integrate possibilities for battery exchange and has to interact with the related deposit systems.

### 6.3 Overhead Contact Line

The overhead contact line could be a solution for different challenges. The vehicle gets the energy for driving as well as for parallel charging of the batteries. The driver keeps the comfort as with combustion engine: no fuelling stops on the trip. Energy supply is distributed over a long distance, avoiding hotspots in supply. The energy may be provided by several distributors, segment by segment. Within one segment an exchange of energy between uphill and downhill driving vehicles is possible.

- For billing purposes the energy management of the vehicle has to send accurate information about sourced energy to the energy management of the infrastructure at the end of each segment.
- The energy management of the vehicle has to control the power distribution inside the vehicle e.g. parallel battery loading from recuperation and overhead line, propulsion by motor with parallel loading of battery or parallel motor supply from overhead wire and battery.
- The energy management of the vehicle together with the energy management of the infrastructure can decide on delivering energy back to infrastructure. Nevertheless it has to be ensured that at the end of the overhead wire the battery has the required state of charge.

## 8. Summary, Conclusion and Outlook

With the balanced hybrid solution, it is possible to limit the diesel consumption of a heavy duty truck on the motorway from south to north of Germany to 22l/100km. The vehicle has to start with a fully charged battery of 100kWh, which has to be recharged one time during the trip. The energy management in the vehicle has to integrate a speed management to limit the power for propulsion and recuperation.

Prerequisite for the balanced hybrid is considerable progress in battery technology. The energy density has to be increased for installation of the hybrid battery in parallel to the engine. The power density as well as efficiency and durability for higher currents have to be increased to handle the power of up to 500kW.

Larger battery capacity would enable long distance driving. The high charging power puts great demands on the infrastructure for quick charging. Battery exchange as an alternative seems not feasible for entire battery but may become necessary for a part of battery.

A promising solution seems to be "charging while driving" via overhead contact line. No explicit charging stop between Stuttgart and Hamburg is needed for a vehicle with a 450kWh battery, if a 200km segment of the motorway is electrified.

A comprehensive energy management on infrastructure level has to ensure that enough energy is available to supply all trucks on the way with energy in time. This energy management has to interact with the internal energy management of the vehicle.

With confidence in technology the electrified heavy duty transport could be feasible beyond 2030. But regarding investments and operational costs, electrification will only have a chance against bio-fuels if the price for electricity decreases significantly in relation to price of the fuels.

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# The NEOPLAN Tourliner – leading the way in $CO_2$ reduction through aerodynamically optimised design

## Optimised consumption with consideration to various vehicle requirements

Dipl.-Designer **Stephan Schönherr**, Dipl.-Ing. **Stephan Kopp**,
Dipl.-Ing**. Marius Hellmold**, MAN Truck & Bus AG, Munich

**Abstract**

In order to significantly reduce the vehicle's consumption, a lot of attention was paid to its streamlined design. The goal was to also use aerodynamics to influence and significantly reduce the consumption. During the design phase, each detail was therefore looked at closely in order to determine how to implement the NEOPLAN design criteria, specific vehicle design and detailed design in a way that optimises the cW value. Through optimisation loops, we found a target-oriented design with calculated solution approaches and implemented this meticulously in the area at the front of the bus, the front roof dome, the mirrors, the air-conditioning system cladding, the wheel arch panels, wheel trim, entire rear panel, as well as areas in the underbody. The results were then examined on a scale model in a wind tunnel and confirmed through test drives of initial vehicles.

The cW value was reduced by over 20% in comparison to the first Tourliner (2002), from 0.46 (good at that time) to 0.36 now. The vehicle therefore achieves overall fuel savings of 10% in comparison to the predecessor bus, reducing consumption to an average of approx. 20 litres per 100 km.

This represents a high degree of innovation, as the improved consumption is in a standard, entry-level vehicle of the NEOPLAN brand.

The standard Tourliner not only has a more attractive acquisition cost – it is also designed to reduce consumption. More for people and the environment!

This is illustrated through images, graphics and short films.

**Zusammenfassung**

Um den Verbrauch des Fahrzeugs signifikant zu reduzieren, wurde sehr auf die strömungsgünstige Gestaltung das Fahrzeugs geachtet. Ziel war es, auch durch die Aerodynamik die Verbrauchsreduzierung maßgeblich zu beeinflussen und deutlich zu senken. In der Designfindung wurde deshalb an jedem Detail genau geprüft, wie Design Criteria NEOPLAN, spezi-

fische Fahrzeuggestaltung und die Detailausführung cW-Wert-optimiert ausgeführt wird. Im Bereich der Busfront, der Bugdachkuppel, der Spiegel, Klimaanlagenverkleidung, Radlaufverkleidungen, nebst Radzierblenden und der gesamten Heckmaske, so wie Bereichen im Unterboden wurde durch optimierende Schleifen eine zielführendes Design mit berechneten Lösungsansätze gefunden und akribisch umgesetzt. Abschließend wurden die Ergebnisse mit einem Maßstabmodel im Windkanal überprüft und durch Testfahrten der ersten Fahrzeuge bestätigt.
Der cW-Wert konnte vom ersten Tourliner (2002) von dem damals guten Werten von 0,46 auf nun 0,36 über 20% verringert werden. Insgesamt erreicht das Fahrzeug damit eine Einsparung an Treibstoff um 10% im Vergleich zum Vorgänger-Bus auf durchschnittlich ca. 20 Liter/km.
Der Innovationsgrad ist hoch, da es hier um die Verbrauchsverbesserungen eines Standard- und Einstiegsfahrzeug in die Markenwelt von NEOPLAN handelt.
Standard ist mit dem Tourliner nicht nur günstiger in der Anschaffung, sondern auch verbrauchsreduzierend gestaltet! Mehr für Mensch und Umwelt!
Mittels Bildern, Grafiken und kurzen Filmen wird dies Thema veranschaulicht.

**MAN Truck & Bus AG welcomes a new, very efficient member to the family with the NEOPLAN Tourliner**

The new NEOPLAN Tourliner is a true all-rounder and creates the opportunity to break into the premium segment of coaches. The key advantages for the customer are:

- Aerodynamic value improved by more than 20%. Fuel consumption reduced by 10%.
- Coach from the standard segment with the typical, highly appealing NEOPLAN design including the new ring-shaped LED daytime driving lights
- Flat floor enables flexible design of the interior for various uses
- The new MAN D2676 LOH engine with optimised driveline and new MAN EfficientCruise with EfficientRoll significantly reduce consumption.
- Maximum safety thanks to numerous safety systems and compliance with directive ECE R66.02 on the strength of superstructures
- Modular design: From the end of 2017, the coach will be available in four different lengths with two or three axles

Design and family affiliation of the new NEOPLAN Tourliner

It only takes one look to see that the new NEOPLAN Tourliner is part of the NEOPLAN family. The front dome, which has been incorporated dynamically into the roof, the distinctive typical NEOPLAN rockers on the sides, the panel on the roof running into a comet-tail-shaped panel of the air-conditioning system, the striking headlights, and the familiar, multi award-winning sharp cut design make it clear: here comes a real NEOPLAN. This vehicle is ideal for anyone looking to add a coach from the standard segment to their existing fleet, whilst retaining a uniform appearance.


Fig. 1: The new NEOPLAN Tourliner

Just by taking a look at the "face" of the bus, you will notice a design feature found in all NEOPLAN coaches since the IAA 2016: the newly designed headlights with daytime driving lights. The previous silver background has been replaced by black to give a more modern look. In addition to this are the LED daytime driving lights, which are designed as a ring of lights around the low-beam headlights. This design is familiar to sports cars, and underlines the dynamic expression of the NEOPLAN Tourliner just like in the other NEOPLAN coaches.

Fig. 2: The NEOPLAN family with new Tourliner

**Sophisticated design elements for passengers and drivers**

The colour of the interior has been completely revised to provide passengers with a great deal of light and space, which is added to by the "floating" design of the luggage racks. The new colour concept uses strong contrasts of grey and beige tones to create an ambience of class. The use of LED lamps for the interior lighting and on the new service sets opens up new possibilities in terms of light design. The service sets also offer greater comfort thanks to draught-free ventilation with individually adjustable air vents. The aeration and ventilation concept has been completely revised for an improved interior climate.

The level floor gives the operator plenty of scope to configure this truly universal vehicle in order to best suit its specific intended purpose. Furthermore, passengers can get to their seats and the luggage racks more easily thanks to the raised aisle. A lifting platform is also available for long-distance travel in both the left and right-hand drive variants, with the option of pushing together up to six rows of seats on rails to create space for up to two wheelchairs.
Drivers in the new NEOPLAN Tourliner will find a driver's workplace with optimised ergonomics. The side control panel has been revised and now has improved storage options, with spaces adapted to accommodate commonly used items such as an A4 map or a large drinks bottle. Furthermore, the switches have been rearranged to achieve greater user ergonomics. The new generation of the Multi infotainment system 7" display is now available to provide entertainment on journeys. All in all, the driver's workplace impresses with its special value and production quality.


Fig. 3: The driver's workplace

Fig. 4: The passenger area

**Economy and efficiency through aerodynamic exterior design and a completely revised driveline**

This bus impresses in both appearance and efficiency. The new exterior design has improved aerodynamic values once again by more than 20% in comparison to the predecessor model. The cW value of the new NEOPLAN Tourliner is just 0.36, which is comparable to that of a modern middle-class van. A great deal of effort has gone into the development of the complex aerodynamics and flow optimisation of the Tourliner. A heavy focus was also placed on the optimisation potential, preliminary investigations and current condition analysis of the predecessor vehicle. The identified potential for improvement was used to create a work catalogue of the body parts to be optimised. When designing, implementing and transferring the NEOPLAN design criteria to the vehicle package of the new Tourliner, each and every external area of the vehicle is optimised to improve aerodynamics. Many details on the bus exterior can contribute to this. For example, the new exterior mirrors, which have better wind resistance as well as a better view. Also, the front panel with the relevant areas of the front-end corners, the lower front spoiler edge, the corner radii of the windscreen and the associated rain channels integrated in the A-pillars, as well as the front roof dome at the top with the connected air-conditioning system, which is integrated on the roof in a smooth and appealing manner. Equally important are all of the components installed on the roof. The aim here is to achieve flush surfaces and reduce protrusions from air conditioning system blowers, roof hatches and attachment parts. In trying to achieve perfect aerodynamics, there is also a focus on the side walls with the underpressure areas, air inlets, cooling air gills, window pane joints, doors, wheel arch flaps, wheel housings, wheel trim and luggage flaps. The rear section and rear panel are also a major influencing factor in the aerodynamics of any bus or coach. It is here that a significant share of the aerodynamics optimisation can be achieved. Great care has been taken in the design of the rear panel with corresponding upper spoiler break-away edge, lateral truncated rear end and lower bumper spoiler edge, and the surfaces, light edges, component separation points, joints between cladding parts and surface transitions have been shaped accordingly.

Here, the exterior components are implemented in small steps and optimisation loops. Once the initial design CAS data has been created, this is checked using a cW value calculation program. The resulting improvement potential then flows into the revision loop, and is implemented while still maintaining the balance between compliance with the technical vehicle specifications and dimensions, the vehicle package, the typical NEOPLAN design criteria and the best possible aerodynamics. The final 3D design Strak data represents the maximum possible flow optimisation of the vehicle exterior.

MAN Truck & Bus AG has gone to great lengths and drawn on all its expertise to determine and validate the final result of the flow-optimised outer shell of the new NEOPLAN Tourliner, as well as precisely identify the cW value of the vehicle. This has involved tests in the wind tunnel with a large scale model, driving tests on accompanying test routes, and motorway journeys with initial vehicles to obtain real data. The various results from computer-based calculations, the flow test in the wind tunnel and the results from the real driving tests are then compared with one another. The impressive cW value of the NEOPLAN Tourliner is no coincidence, and is confirmed by these results.

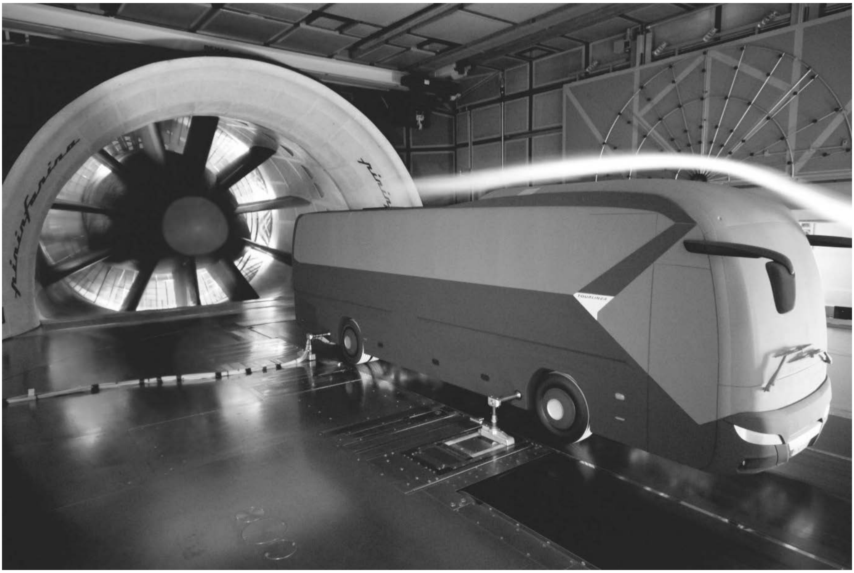


Fig. 5: The aerodynamic and flow-optimised exterior of the NEOPLAN Tourliner

Today, optimised aerodynamics alone are not enough. From a technical point of view, the D2676 LOH engine also offers improved performance and torque, featuring an optimised driveline that allows for fuel savings of up to 10%. The long axle ratio of i=2.73 and the optimised shifting strategy contribute to this, among other factors. Also available are the new generation of MAN EfficientCruise, and for the first time in coaches, the MAN EfficientRoll freewheel function. This "coasting" function delivers added efficiency even on slightly downhill gradients by automatically switching the gearbox to neutral position "N" and allowing the bus to roll with the lowest possible driveline friction loss.

**Improved active and passive safety and service of the NEOPLAN Tourliner**

The NEOPLAN Tourliner also leads the way when it comes to safety. The MAN AttentionGuard is now available for the first time. The aim of this assistance system is to detect reduced attention levels of the driver and provide a warning if necessary. It uses the data from the LGS (Lane Guard System) for this, as well as other data. If the MAN AttentionGuard detects a lack of attentiveness, it provides the driver with a visual, acoustic and haptic warning, however does not actively intervene in the driving activity. As for all NEOPLAN coaches, there is a whole range of assistance systems available for the new NEOPLAN Tourliner, including the EBA advanced emergency braking system, the ACC Adaptive Cruise Control and the TPM tire pressure monitoring system. Vehicle availability is improved thanks to the new service interval calculator, which monitors and anticipates maintenance appointments and component wear.

The reinforced framework structure contributes to passive safety, and as of 2017 complies with the applicable directive ECE R66.02 on the strength of superstructures. For this, the framework needs to withstand 50% more upheaval energy, which MAN has achieved through the patented tube-in-tube technology and the use of high-strength steels. The new NEOPLAN Tourliner also has two extremely stable roll-over bars in the area of the B-pillar and at the rear.

# Energy Efficient Standstill Air Conditioning for Trucks
## Energieeffiziente Standklimatisierung für LKW

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**Kurzfassung**

Die Anzahl und die Dauer der Pausen sind für den Fernverkehr gesetzlich festgelegt. In den Pausen wird bei sommerlichen Umgebungsbedingungen vom Fahrer oftmals der Verbrennungsmotor weiterbetrieben, um mittels der Klimaanlage das Fahrerhaus zu kühlen. Allerdings führt dies zu einem zusätzlichen Kraftstoffverbrauch, CO2-Emissionen, Lärmbelästigung und erhöhten Betriebskosten.

Aus diesem Grund wird bei IAV derzeit eine Standklimaanlage auf Basis eines Zeolith/Wasser-Adsorptionskreislaufes entwickelt. Mit Hilfe dieses Systems kann die Temperierung der Fahrerkabine während der Pausenzeiten ohne zusätzliche Antriebsenergie und somit ohne CO2-Emissionen sichergestellt werden. Nach der Pause wird das System mittels der Abgaswärme des Verbrennungsmotors wieder regeneriert.

Zur Simulation und zur Auslegung dieser Anlage wurde ein detailliertes physikalisches Modell für den gesamten Adsorptionskreislauf entwickelt. Die Ermittlung der erforderlichen Kälteleistung für die Fahrerkabine erfolgte mit Hilfe eines Fahrgastzellenmodells. Unter Zuhilfenahme dieser Modelle wurde die gesamte Anlage konzeptioniert und dimensioniert. Im vorliegenden Beitrag wird zunächst das Funktionsprinzip des Zeolith/Wasser-Adsorptionskreislaufes beschrieben. Anschließend werden die entwickelten Simulationsmodelle vorgestellt, wobei auch auf die physikalischen Grundlagen der Anlage eingegangen wird. In einem weiteren Schritt folgt die Präsentation der Ergebnisse. Abschließend soll ein Ausblick auf die Integration des Systems in das Fahrzeug gegeben werden.

**Abstract**

Legal European regulations for the transportation sector specify the duration of rest periods for truck drivers on tour. To cool the cabin during breaks in hot seasons, truck drivers often run the engine. However, this leads to additional fuel consumption and noise pollution. For this reason, IAV develops an innovative standstill air conditioning system powered by a zeolite/water adsorption heat pump. With this system it is possible to ensure the cabin air condi-

tioning during rest periods without any additional power demand and consequently without fuel consumption. After the rest period, the system is regenerated during the drive using the waste heat of exhaust gas from the internal combustion engine. To design this system, a detailed physical simulation model was developed. This contribution introduces the functional principle of the system, first. Afterwards, the simulation models and the results are presented. Finally, an outlook for the vehicle integration is given.

## 1. Introduction

In Europe, laws regulate the legal driving time as well as the required rest periods for truck drivers. The compliance with these laws is subject to strict controls.

Ensuring a comfortable cabin temperature during the compulsory rest periods is currently a huge challenge in the development process of trucks. For cold environmental conditions, an auxiliary heating system can be used. However, under summery weather conditions the drivers often run the internal combustion engine to drive the air conditioning compressor. This leads to additional fuel consumption and $CO_2$-emissions, higher operating costs as well as noise pollution.

In the last years several concepts for standstill air conditioning systems operating independent from the internal combustion engine have been presented.

Some of these concepts are based on a separate refrigeration cycle in an integrated system on the cabin roof. Other concepts use the existing refrigerating cycle. However, with both systems the compressor is driven by an electric motor during the rest periods. The required electrical power is taken from the battery, which needs to be charged during the drive. This leads to additional fuel consumption and $CO_2$-emissions.

Another concept is based on a cold storage system containing a phase change material. The storage is charged using the standard air conditioning system while driving. With the stored cold, the air conditioning can be ensured during the standstill. Compared with the above mentioned concepts this system doesn’t require an air conditioning compressor in the rest periods. This is an advantage regarding noise and efficiency. However, during the drive additional refrigerating capacity is required to recharge the cold storage. As a result the fuel consumption and $CO_2$-emissions increase.

To avoid the above mentioned disadvantages, IAV develops a standstill air conditioning system based on a zeolite/water adsorption circuit. With this system the standstill air conditioning of the cabin can be realized without any additional input power and consequently without noise pollution and $CO_2$-emissions. The most significant advantage is, that this system can be charged during the drive by using the exhaust gas waste heat of the internal combustion engine. Thus, no additional fuel consumption occurs.

In order to simulate and design this system a detailed physical based simulation model for the whole adsorption system was build up. With this model all components as well as the complete circuit were developed. Currently, a first demonstrator is investigated in the lab. In a next step, the system will be integrated in a truck and evaluated under real conditions.

In the following, the design and functioning principle of the zeolite/water adsorption circuit, the physical basics and the simulation models will be described. Afterwards the simulation results are presented and discussed. Finally, an outlook for the vehicle integration as well as the next steps is given.

## 2. Design and Functioning

The adsorption material zeolite 13X is used for storing the cold in the zeolite/water adsorption circuit. This material has a high water adsorption rate of up to 30 % of its dry mass. Dry zeolite has a very strong attractive effect to water molecules. The circuit consists of a water reservoir, an evaporator, a condenser and the zeolite material (Fig. 1). The system is evacuated from air.

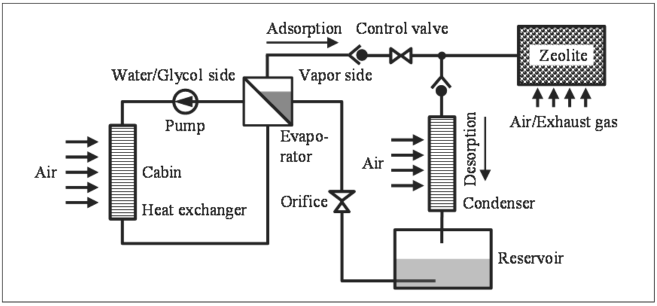


Fig. 1: Zeolite/Water adsorption circuit

### 2.1 Cooling Mode

During rest periods, the internal combustion engine of the truck is switched off. At the beginning of the break, the zeolite is in a dry state. Due to the vacuum in the system the water vaporizes in the evaporator. When the control valve is opened, the zeolite adsorbs the water steam (Fig. 1). For a continuous process, the vaporized water is refilled from the reservoir. The evaporation process requires heat, which leads to a cooling down of the water in the evaporator. The evaporator is coupled with a water/glycol circuit. Thus, the water/glycol mixture is cooled down in the evaporator and flows through a heat exchanger which is integrated in the cabin. In this heat exchanger the water/glycol mixture adsorbs heat from the air, which is cooled down and led into the truck cabin. This air ensures a comfortable cabin climate.

### 2.2 Charging Mode

The system can operate in the cooling mode as long as the zeolite is not saturated. When the zeolite is saturated it has to be regenerated. The adsorbed water in the zeolite will be desorbed by means of heat. This process happens during the drive using the exhaust gas waste heat of the internal combustion engine. For the desorption process a zeolite temperature of 180 °C is required. The exhaust gas temperature of one at IAV available truck, on which this project is based, is between 200 °C and 400 °C. The mean value in a representative driving cycle is 280 °C, which is enough for the desorption process.
The desorbed water steam flows through a condenser, cooled by the ambient air. In the condenser the steam is liquefied. The water is stored in the reservoir.

## 3. Simulation Models

To design the described standstill air conditioning system, several simulation models were used. The required refrigerating capacity was determined with a cabin model. Furthermore a detailed physical based simulation model for the zeolite/water adsorption circuit was developed, which makes it possible to design the components as well as the whole system. With this model it is possible to ensure that the system meets the required refrigerating capacity and the available space.
The models for the cabin and the zeolite/water adsorption circuit will be described in the following.

### 3.1 Simulation Model for the Cabin

The cabin model (Fig. 2) is based on the approach presented in [1]. For the mathematical simulation of the thermal processes in the compartment all elements are described as three-dimensional polygons. The model considers all heat transfer mechanisms:

- convection
- long wave heat radiation
- heat conduction

Generally, all components of the cabin can exchange heat by radiation. However, a part of emitted heat radiation may not reach the receiver surface. This is expressed by so-called view factors. An analytical calculation of these factors is mostly impossible. Additionally, it is complicated by elements between the corresponding surfaces interrupting the radiation exchange. For these reasons, all cabin elements are meshed in the model and the view factors are calculated numerically.

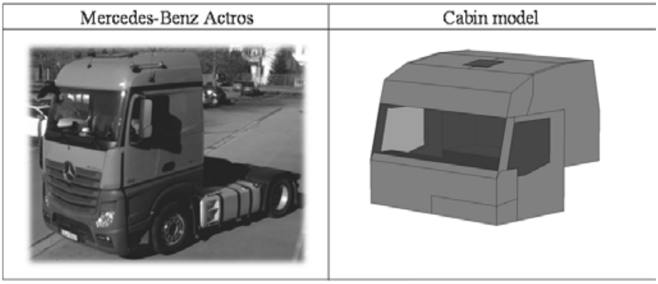


Fig. 2: At IAV available truck and cabin model

Moreover, the model considers the solar radiation, which has a high influence on the thermal behavior of the cabin. Hereby, the shadowing effects due to other cabin elements are also taken into account.

In addition the model includes a thermal passenger model. This considers the metabolic rate, the convection, the long wave heat radiation, the solar radiation, the transpiration and the breathing of the driver. Finally, this passenger model calculates the so-called predicted-mean-vote index (PMV-index), which evaluates the thermal comfort of the passenger.

### 3.2 Model for the Zeolite/Water Adsorption Circuit

In order to design the zeolite/water adsorption circuit, a physical based model was developed for a transient simulation of the processes in the system. This model consists of different sub models for the components which are based on energy and mass balances. For the zeolite storage a model was developed which describes the micro and macro diffusion of the water steam.

These models will be briefly introduced in the following.

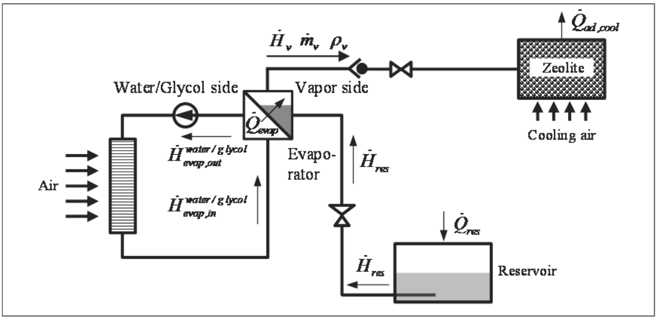


Fig. 3: Enthalpy and heat flow rates for the adsorption process

For the water reservoir, the mass and energy balances are given as follows:

$$\frac{dm_{res}}{dt} = -\dot{m}_v \quad (1)$$

$$\frac{dU_{res}}{dt} = \dot{Q}_{res} - \dot{H}_{res} \quad (2)$$

where:

$\dot{m}_v$ water vapor mass flow rate from the evaporator to the zeolite

$m_{res}$ water mass in the reservoir

$U_{res}$ internal energy of the water in the reservoir

$\dot{H}_{res}$ enthalpy flow rate at the reservoir outlet

$\dot{Q}_{res}$ heat flow rate to the reservoir

For the orifice an isenthalpic expansion is assumed. Consequently, the enthalpies at the orifice inlet and outlet are identical.

For the evaporator, the energy balances for the vapor side and the water/glycol side are coupled by the heat flow rate $\dot{Q}_{evap}$. The energy balances for the vapor side and the water/glycol side in the evaporator are given by:

$$\frac{dU_{evap}^{water/glycol}}{dt} = \dot{H}_{evap,in}^{water/glycol} - \dot{H}_{evap,out}^{water/glycol} - \dot{Q}_{evap} \tag{3}$$

$$\frac{dU_{evap}^{vapor}}{dt} = \dot{H}_{res} - \dot{H}_{v} + \dot{Q}_{evap} \tag{4}$$

where:

$U_{evap}^{water/glycol}$, $U_{evap}^{vapor}$ internal energy of the water/glycol and the vapor

$\dot{H}_{evap,in}^{water/glycol}$, $\dot{H}_{evap,out}^{water/glycol}$ enthalpy flow rates at the evaporator inlet and outlet

$\dot{H}_{res}$ enthalpy flow rate from the reservoir to the evaporator inlet (vapor side)

$\dot{H}_{v}$ enthalpy flow rate from the evaporator outlet to the zeolite (vapor side)

$\dot{Q}_{evap}$ heat flow rate from the water/glycol side to the vapor side

The masses are assumed to be constant.

The control valve between the evaporator and the zeolite storage was modeled with a simple approach (Eq. 5). In the simulation model the vapor mass flow rate and therefore the refrigerating capacity is controlled by varying the diameter $d_{tube}$ of the connection tube between the evaporator and the zeolite storage. The pressure drop in the tube is defined by:

$$\Delta p = \lambda \cdot \frac{L_{tube}}{d_{tube}^{5}} \cdot \frac{8 \cdot \dot{m}_{v}^{2}}{\rho_{v} \cdot \pi^{2}} \tag{5}$$

where:

$\lambda$ pressure loss coefficient

$L_{tube}$ tube length

$d_{tube}$ tube diameter

$\rho_{v}$ vapor density

For the zeolite storage the following mass and energy balances are applied:

$$\frac{dm_{ad}}{dt} = \dot{m}_v \qquad (6)$$

$$\frac{dU_{ad}}{dt} = \dot{H}_v + \Delta\dot{H}_{ad} - \dot{Q}_{ad,cool} \qquad (7)$$

where:

$m_{ad}$ adsorbed water mass

$U_{ad}$ total internal energy of the zeolite storage

$\Delta\dot{H}_{ad}$ adsorption enthalpy flow rate (Eq. 8)

$\dot{Q}_{ad,cool}$ heat flow rate due to the cooling

The adsorption enthalpy flow rate in Eq. 7 is given by:

$$\Delta\dot{H}_{ad} = \dot{m}_v \cdot \left(\Delta h_c + \Delta h_b\right) \qquad (8)$$

where:

$\Delta h_b$ specific bonding enthalpy (Eq. 9)

$\Delta h_c$ condensation enthalpy of water (Eq. 10)

The release of bonding energy during the adsorption process leads to a heat up of the zeolite. To avoid overheating, the zeolite storage needs to be cooled ($\dot{Q}_{ad,cool}$ in Eq. 7).

The specific bonding enthalpy can be calculated with:

$$\Delta h_b = A \cdot \left(1 + \frac{\beta \cdot T_{ad}}{n} \cdot \left(\frac{E}{A}\right)^n\right) \qquad (9)$$

where:

$A$, $E$ material parameters

$T_{ad}$ adsorb temperature

$\beta$ thermal expansion coefficient

$n$ characteristic constant

The condensation enthalpy of water is:

$$\Delta h_c = h_g - h_f \qquad (10)$$

where:

$h_g$ gaseous enthalpy of water

$h_f$ fluid enthalpy of water

The water load of the zeolite filling can be described with the following equation:

$$x = \frac{m_{ad}}{m_z} \qquad (11)$$

where:

$m_{ad}$ adsorbed water mass

$m_z$ zeolite mass

It follows:

$$\dot{m}_{ad} = \dot{m}_v = m_z \cdot \frac{dx}{dt} \qquad (12)$$

The water load x can be calculated with the linear-driving-force-approach [2]. That means that the derivative of the water load is proportional to the difference between the current water load and the water load equilibrium. The derivative of the water load is given by:

$$\frac{dx}{dt} = k \cdot \left( x_{eq} - x \right) \qquad (13)$$

where:

$x_{eq}$ water load equilibrium (Eq. 14)

$k$ proportional coefficient (Eq. 15)

$x$ current water load

For the water load equilibrium the Dubinin-Astakhov equation [3] is used:

$$x_{eq} = \hat{x} \cdot e^{-K_{ad} \cdot \left( \frac{T_{ad}}{T_s} - 1 \right)^n} \quad (14)$$

where:

$\hat{x}$ maximum water load at ambient conditions

$K_{ad}$, $n$ characteristic constants

$T_{ad}$ adsorb temperature

$T_s$ saturation temperature of water

The coefficient k in Eq. 13 is given by [4]:

$$k = \frac{15 \cdot D_{eff}}{\left(0.5 \cdot d_p\right)^2} \quad (15)$$

where:

$D_{eff}$ effective diffusivity of water molecules in the zeolite filling

$d_p$ diameter of the zeolite particles

The effective diffusivity of water molecules in the zeolite filling depends on the inner structure of the zeolite particles and can be calculated with [4]:

$$D_{eff} = \frac{D_c}{\mu} \cdot \frac{1}{1+\alpha} \quad (16)$$

where:

$D_c$ combined diffusivity (Eq. 17)

$\mu$, $\alpha$ form factors

The combined diffusivity is [4]:

$$D_c = \left( \frac{1}{D_f} + \frac{1}{D_m} \right)^{-1} \tag{17}$$

where:

$D_f$ diffusivity of flow through the zeolite filling

$D_m$ diffusivity of the water molecules migration into the zeolite particles.

## 4. Results

By means of the cabin model (chapter 3.1) the required refrigerating capacity was determined for different environmental conditions. The investigations were done for different global positions. Hereby, the days with the highest ambient temperature and the highest solar radiation were selected from appropriate weather data.

For the simulations it was assumed, that the cabin is cooled down during the drive with the conventional air conditioning system. Consequently, the cabin is already pre-conditioned at the beginning of the rest break. Moreover, it was defined that the curtains are closed and the truck is faced to the sun while parking.

With these boundary conditions the highest required refrigerating capacity occurs in the afternoon. At this time the ambient temperature as well as the solar radiation is significantly lower than at noon. However, this is overcompensated by the steeper incidence angle between the solar radiation and the windscreen. This leads to a higher solar transmission coefficient of the glass and consequently to a higher solar heat flow rate into the cabin.

The required refrigerating capacities are shown in Tab. 1 for different exemplary global positions. The set cabin temperature was defined for a predicted-mean-vote-index (PMV) of zero, which represents an optimal thermal comfort for the driver.

The highest refrigerating capacity of 2.9 kW is required for the environmental conditions of Berlin. In Gibraltar the diffuse solar radiation is even higher than in Berlin, however, the required refrigerating capacity is lower. This is caused by the more southern and more western global position of Gibraltar and the higher incidence angle of the sun. This leads to a lower solar heat flow rate through the windscreen.

Tab. 1: Required refrigerating capacity for different ambient conditions

| Location | Berlin, GER | Gibraltar, UK | Rome, IT |
|---|---|---|---|
| Day | 21 | 21 | 19 |
| Month | 7 | 7 | 8 |
| Time of the day | 4:00 pm | 4:00 pm | 4:00 pm |
| Ambient temperature [°C] | 34.4 | 34.3 | 38.1 |
| Relative humidity of the ambient air [%] | 41 | 45 | 40 |
| Diffuse solar radiation [W/m²] | 206 | 259 | 68 |
| Direct solar radiation [W/m²] | 494 | 494 | 106 |
| Direction of the truck (clockwise from north) [°] | 270 | 270 | 270 |
| Volumetric flow rate [m³/h] | 460 | 460 | 280 |
| Recirculated air rate [-] | 0.8 | 0.8 | 0.8 |
| Set cabin temperature [°C] (PMV=0) | 19 | 20 | 21 |
| **Required refrigerating capacity [kW]** | **2.9** | **2.7** | **1.9** |

Based on these results the maximum required refrigerating capacity was defined to 2.9 kW. This capacity has to be ensured by the zeolite/water adsorption circuit for the compulsory rest period of 45 minutes.

During the night the ambient temperature as well as the solar radiation are always lower. This leads to a reduction in required refrigerating capacity. Therefore it can be assumed, that the system is able to ensure an air conditioning for several hours overnight (cf. Fig. 8).

For a simple manufacturing, the zeolite storage was designed as a system of hollow cylinders (Fig. 4). The inner tube is vapor permeable. The zeolite filling is between the inner and the outer tube. During the adsorption process, the vapor flows from a manifold into the tubes. For the desorption process, the exhaust gas is directed through the space between the tubes to the environment.

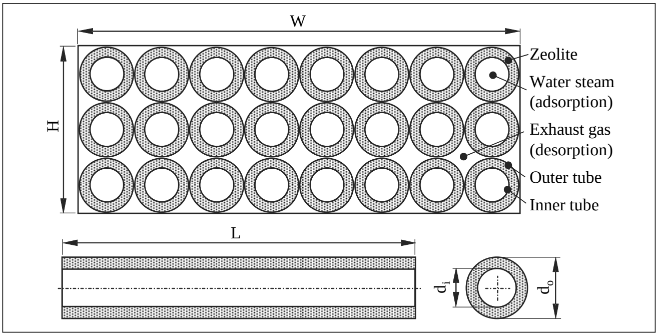


Fig. 4: Zeolite storage (simplified)

In Fig. 5 the zeolite temperature and the maximum water load are shown depending on the diameter of the outer tube. The diameter of the inner tube was exemplary defined to 12 mm. For the zeolite filling an initial water load of 5 % was assumed. The curves in Fig. 5 are valid for the whole system with specific outer dimensions (cf. Tab. 2)

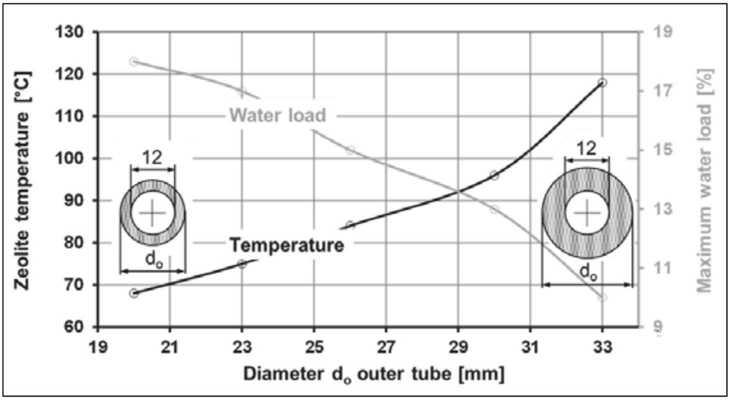


Fig. 5: Zeolite temperature and water load depending on the diameter of the outer tube

With an increased outer tube diameter the number of tubes includable in the specified installation space, decreases. As a result the total outer surface is also reduced. In addition, the thickness of the zeolite filling between the outer and the inner tube increases. Both effects lead to poor cooling conditions. Consequently, the maximum water load and thus the achievable refrigerating capacity decreases.

For a high refrigerating capacity a huge number of tubes with a small outer diameter would be worthwhile. However this leads to a very high manufacturing effort. For this reason, a compromise had to be reached and therefore the outer tube diameter was defined to 30 mm.
In a further step the influence of the inner tube diameter was investigated. Fig. 6 shows the maximum operating time of the system as well as the zeolite temperature for different diameters of the inner tube. The diameter of the outer tube was set to 30 mm. The operating time is based on a constant refrigerating capacity of 2.9 kW (cf. Tab. 1).

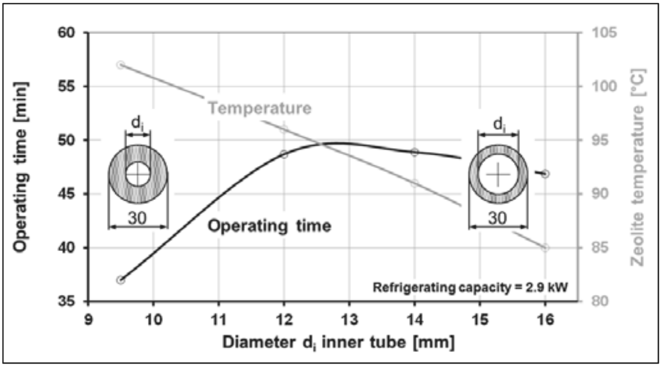


Fig. 6: Operating time and zeolite temperature depending on the diameter of the inner tube

The maximum operating time of about 50 min can be achieved for inner tube diameters between 12.5 mm and 13 mm. With a smaller inner tube diameter the zeolite mass increases, which actually leads to a higher operating time. However, this is overcompensated by the higher thickness of the zeolite filling and the resulting poor cooling conditions. This leads to a higher zeolite temperature and a reduced maximum water load. Therefore the operating time decreases with an inner tube diameter below 12.5 mm. For diameters above 13 mm the zeolite temperature decreases although the lower zeolite mass reduces the operating time.
Apart from the operation time, criteria like the manufacturing effort and the costs also had to be considered. Hence not the variant with the highest achievable operating time was chosen. Additionally, in this project the main focus was on ensuring the functioning of a first prototype. The reduction of the mass and the installation space are tasks for further steps. The final parameters of the demonstrator system are summarized in Tab. 2.

Tab. 2. Parameters of the system

| Parameter | Value |
|---|---|
| Diameter inner tube [mm] | 12.7 |
| Diameter outer tube [mm] | 30 |
| Number of tubes [-] | 104 |
| Zeolite mass [kg] | 56 |
| Length [mm] | 1500 |
| Width [mm] | 800 |
| Height [mm] | 120 |

Fig. 7 shows the refrigerating capacity, the air inlet temperature into the cabin and the water/glycol inlet temperature depending on time. The volumetric air flow rate into the cabin was defined to 460 m³/h. It was assumed, that the cabin as well as the water/glycol circuit is preconditioned using the conventional air conditioning system during the drive. The investigations were based on the environmental conditions of Berlin (cf. Tab. 1).

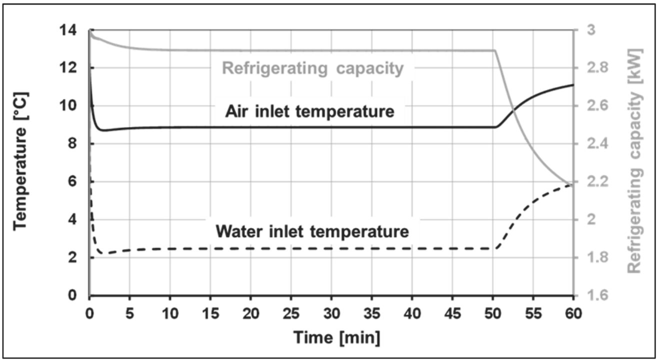


Fig. 7: Refrigerating capacity, air and water/glycol inlet temperature depending on the time

With the designed standstill air conditioning system it is possible to achieve a constant refrigerating capacity of 2.9 kW for 50 min. With an air inlet temperature of 9 °C and the above mentioned air flow rate a cabin temperature of 19 °C can be ensured. After 50 min the refrigerating capacity is significantly reduced because of the increasing saturation of the zeolite. This leads to a temperature increase of the inflowing air.

Fig. 8 shows the maximum operating time depending on the refrigerating capacity. The curve is not linear, because a reduced refrigerating capacity leads to a lower zeolite temperature. This causes a higher maximum water load and consequently a higher operation time.

As already described, the refrigerating capacity of 2.9 kW can be ensured for 50 min. For an overnight rest period of 8 h, the achievable refrigerating capacity is 500 W.

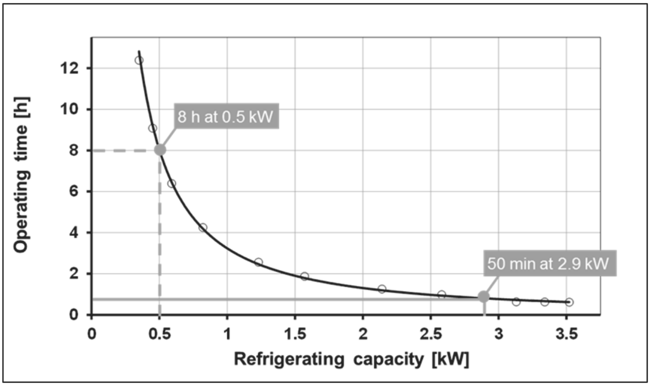


Fig. 8: Operating time depending on the refrigerating capacity

**5. Conclusion and Outlook**

Laws regulate the driving time and the rest periods for truck drivers. To achieve a comfortable cabin temperature during the compulsory breaks in the summer, several concepts for standstill air conditioning systems were already presented, which work independent from the internal combustion engine.

Some of these concepts are based on a separate refrigeration cycle powered by the battery. Another concept uses a cold storage, which is charged with the conventional air conditioning system during the drive. Due to the need of recharging, both concepts lead to additional fuel consumption and $CO_2$-emissions during the drive.

IAV develops a standstill air conditioning system based on a zeolite/water adsorption circuit. This system operates without any additional input energy, noise pollution and $CO_2$-emission. The charging is realized by the exhaust gas waste heat of the internal combustion engine without any additional fuel consumption.

To simulate the processes in the whole system, a detailed physical based model was developed. With this model a standstill air conditioning system was designed, which fulfils the defined criteria regarding the installation space, manufacturing costs and refrigerating capacity. The refrigerating capacity of 2.9 kW can be ensured for 50 min, which is enough to achieve a comfortable cabin temperature under hot summery conditions. For an overnight break of 8 h a refrigerating capacity of 500 W can be realized.

Currently, one single zeolite tube integrated in the system is tested in the lab. The next step will be the integration of the whole system in a truck and an evaluation under real conditions.

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# Monitoring the fresh-air flow rate for energy-efficient bus ventilation

## By monitoring of relative humidity and $CO_2$-concentration

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**Abstract**

City busses and coaches are typically ventilated with high fresh air rates without monitoring of air quality according to recommendations and requirements of associations of public transport companies. The air quality of cabin air regarding humidity and CO2-concentration depends however on the number of passengers. Hence the air quality of the ambient air could be monitored and air conditioning units could be switched on re-circulation air, which is called here “monitored fresh air rate”. Average occupancy of city busses is 30 %. This means the cabin will be ventilated with a surplus of about 70 % of the required fresh air. This causes a high energy consumption which could be saved. The aim of this work is the monitoring of the cabin air quality with the help of sensors and development of appropriate control algorithms that could reduce energy consumption without any impairment of safety, comfort, stress and health.

### 1 Current situation

The air quality in busses influences passenger comfort and health conditions. Fur-thermore, air quality also affects safety aspects such as fogging of wind shield and increased driver’s stress at uncomfortable conditions.

Therefore high air exchange rates are recommended or requested for cabin air by VDV (Association of German Transport Companies) [2] for city busses, with 15 m³/h per passenger, and by GBK (Quality Association of Bus Comfort) [3], with a 75-times per hour air exchange for parked coaches for quality levels 3-5.

Based on these overall requirements current ventilation of busses is carried out independently of the number of passengers, assuming instead full occupancy. The number of transported passengers varies very widely in the course of the day, with average occupancy of 30 % in city busses. This means, in most times energy is wasted with heating and cooling fresh air that actually is not needed to desired temperatures.

## 2 Motivation and objectives

Increased requests of customers to reduce fuel consumption and also the European commission's communication COM(2014) 285 “Strategy for reducing Heavy-Duty Vehicles' fuel consumption and CO2-emissions” [4] make it necessary to develop solutions for commercial vehicles with reduced fuel consumption and thus reduced CO2-emissions.

Besides optimization of the primary power train, fuel consumption reduction of the secondary consumers is getting increasingly attractive. Here aggregates for heating and air conditioning of passenger compartments are the largest secondary consumers.

There are different known concepts to improve the cooling and heating perfor-mance. Reducing the fresh air rate in to the vehicle cabin depending on the number of passengers (and hence the air quality) is a possibility with a performance improve-ment high potential.

The actual thermal load by external and internal effects can be controlled also by re-circulating air, if the quality of cabin air is controlled simultaneously.

City busses are particular interesting for energy efficient ventilation because their occupancy widely varies between 0-100 % throughout the day, and with an average occupancy of about 30 % included rush hours. Besides different level of occupancy, door opening phases can are influencing cabin air conditions significantly. Moreover, external conditions can change very quickly due to mobility of the bus, and these can influence cabin air conditions. Energy efficiency of city busses is besides environ-mental aspects a specific requirement of public transport companies.

## 3 Monitoring parameter and control algorithms

The most relevant monitoring parameters of air quality are the air humidity and the CO2-concentration of the air. The concentration of harmful gases from ambient air, e.g. exhaust gases, hydrocarbons, etc. will be detected by external air quality sensors and the gases will be refrained from the vehicle cabin by filters or by flap switching to re-circulation air. The cabin humidity content and CO2-concentration is hence directly influenced by number of passengers. The CO2-concentration is also a good indicator for estimating bus occupancy, since passengers are generally the sole source of CO2-emissions within the bus [14].

Every passenger breathes out a CO2-volume flow of 12-20 l/h depending on the level of activity, and water vapour up to 65 g/h depending on the temperature [9] and [13] (see Fig. 1). Additional humidity is added to the cabin by clothes, etc. This needs to be removed from the cabin or reconditioned in order to maintain the acceptable limits of comfort, health and safety and to meet legally required maximum limits.

| Cabin air temperature in °C | 18 | 20 | 22 | 24 | 26 |
|---|---|---|---|---|---|
| Heat loss, convection and radiation in W | 100 | 95 | 90 | 75 | 70 |
| Moisture emission in W | 25 | 25 | 30 | 40 | 45 |
| Total performance in W | 125 | 120 | 120 | 115 | 115 |
| Moisture emission in g/h | 35 | 35 | 40 | 60 | 65 |

Fig. 1: Human heat and moisture exhalation at rest without solar radiation [9]

With a concentration about 400 ppm CO2 is a natural content of ambient air [14]. A rising CO2-concentration increases the discontent of passengers. Even at an allowed CO2-concentration about 2000 ppm the discontent increases to over 40 % [8] (see Fig. 2).

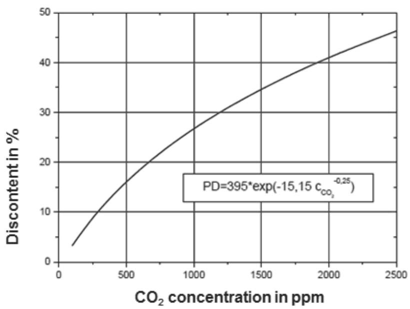


Fig. 2: Discontent depending on CO2-concentration above ambient air concentration [8]

High CO2-concentrations in vehicle cabins can cause health issues from indisposi-tion up to critical state of health like sickness, headache and difficulties in concentrating and – even up to unconsciousness. Therefor there have been CO2-limits defined by Pettenkofer, DIN EN 13779 and ASHRAE 62-2001. According to Pettenkofer, the air quality in living spaces is excellent up to 1000 ppm. This limit cannot be transferred readily to vehicles due to specific differences. DIN EN 13779 requires a limit about 1500 ppm. According ASHRAE 62-2001, a CO2-concentration of 2000 ppm is allowed at working places for 8 hours [5], [6], [7] and [12] (see Fig. 3).

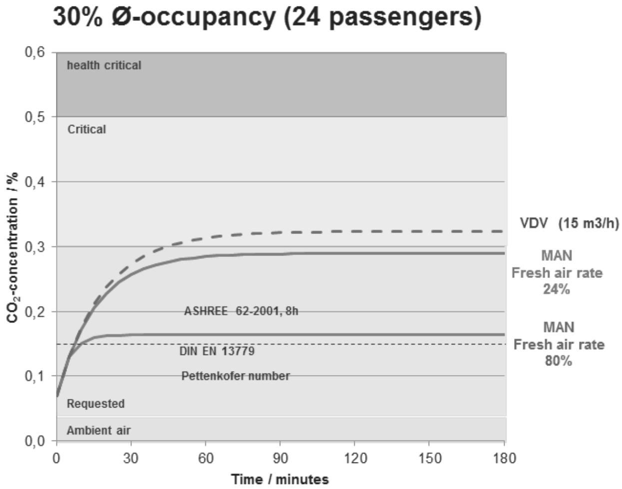


Fig. 3: CO2-concentration depending on fresh air rate and compared to different standards [5], [6] und [7]

Fogging on the wind shield due to high moisture content is safety relevant. In addi-tion, humidity affects passenger comfort in the cabin. The higher the air temperature, the lower is the upper threshold for relative humidity with respect to comfort [2] (see Fig. 4).

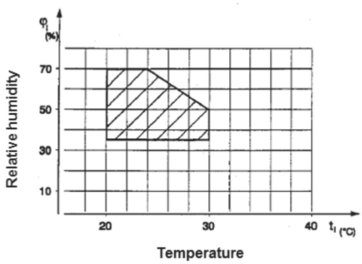


Fig. 4: Comfort zone depending on temperature and relative humidity [2]

Ambient conditions of a vehicle can change very quickly due to its mobility and hence the comfort level in the vehicle cabin, e.g. after entering a tunnel from a sunny ambient, or due to changing solar radiation because of shadowing or by changing of driving direction, which can change the temperatures of vehicle glasses, as well as the relative humidity in the cabin.

## 4 Control algorithms

While the CO2-concentration in a bus cabin - according to the state of art - can only be influenced by controlling the amount of fresh air [11], the humidity of the cabin air can be affected by both fresh air ratio or reheat. Reheat is used in combination with low air volume flows and energy-intensive condensation of water vapour of the air. Instead, if pure fresh air is used for controlling air humidity, high air volume flows are required and condensation does not take place.

Therefore, control algorithms for energy-efficient monitoring of the fresh air rate are required, which account for conditions within and outside of the cabin. In this work ambient temperatures are split into four characteristic ranges (see Fig. 5). For these control algorithms differ considerably due to the differences in external conditions.

| Ambient temperature range | Characteristic | Parameters to control fresh air rate |
|---|---|---|
| Winter<br>< 3 °C | Dry air<br>$T_{ambient} << T_{windshield} << T_{cabin}$ | • $CO_2$ concentration<br>• Relative humidity at wind shield (fresh air against fogging ) |
| Transitional season<br>3- 18 °C | Partly high air relative humidity<br>$T_{ambient} < T_{windshield} < T_{cabin}$ | • $CO_2$ concentration<br>• Relative humidity at wind shield (fresh air / reheat against fogging ) |
| Only ventilation<br>18-22 °C | $T_{ambient} \approx T_{windshield} \approx T_{cabin}$ | |
| Summer<br>> 20 °C | $T_{ambient} > T_{windshield} > T_{cabin}$ | • $CO_2$ concentration<br>• Relative humidity compatible to comfort range |

Fig. 5: Temperature ranges

In cold seasons with temperatures below 3 °C the humidity and CO2-concentration is advantageously controlled by monitoring the fresh air rate, since reheat thermody-namically and due to icing risk of the evaporator is not attractive in this operating regime.

In transitional seasons (spring and autumn) at temperatures between 3 °C and 18 °C the air can contain high humidity, which could be insufficient dehumidifying the cabin air. In these cases and at sudden fogging of the wind shield, e.g. due to quick changes of conditions as a result of mobility, a reheat-operation could be needed inevitably. Additionally the CO2-concentration of the cabin air needs to be considered. This temperature range is most interesting for energy optimization.

In the temperature range of 18-22 °C pure ventilation can be sufficient, if the internal and external thermal load can be balanced with this and the fresh air rate can be adjusted up to maximum. Therefore this range is not very relevant for an energetic optimization by controlling the fresh air rate.

In warm seasons over 20 °C the fresh air rate will be controlled depending on com-fort considerations related to cabin humidity and CO2-concentration, while fogging of the wind shield is not relevant.

In cooperation with Kempten University of Applied Sciences within a diploma thesis [1] (see Fig. 6), control algorithms for energy-efficient control of fresh air rates have been derived from process simulation depending on changing internal and ex-ternal air conditions. By using of these simulations, fuel consumption was analyzed under realistic operating scenarios. The results show a high fuel consumption reduc-tion potential by applying fresh air control strategies.

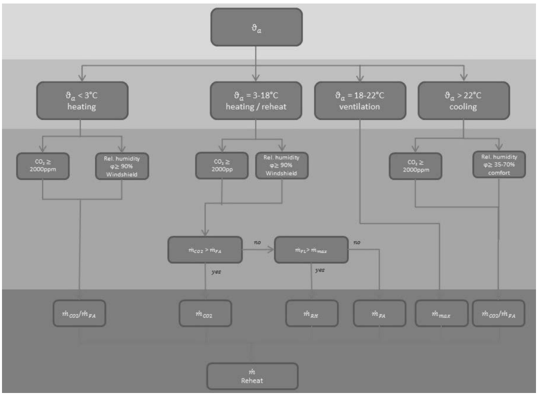

Fig. 6: Temperature ranges and control algorithms [1]

## 5 Comparison and energy-efficiency

Because of manifold factors which can impact ambient air conditions, especially in city busses, fuel consumption reduction by controlling fresh air rates can be reliable determined only by real measurements. For this purpose, MAN Truck & Bus AG has provided a customer bus with related sensors for field monitoring to determine the effect of different operating conditions like school holidays, weekends, rush hours, early and late drive services, different ambient conditions and other external influ-ences like shadowing, tunnel driving, etc.

The city busses operate 20 hours from 5:00 o’clock in the morning until 1:00 o’clock in the night with an annual mileage of about 60,000 km and an average speed of 16 km/h, whereby an average distance between two stops is 450 m and the average driving distance of passenger is about 4.5 km [10].

For this work representative data of three temperature ranges of weekdays were for further analysis. Presently MAN controls the fresh air rate only depending on ambient temperature, whereby the fresh air rate is reduced at extremely low and high temperatures in order to reach the desired temperature. Instead the new control strategy is controlling the fresh air rate by monitoring air qualities.

Fundamental the energy consumption will be determined by the internal load, solar radiation and the ambient temperature (thermal load and conditioning of fresh air), and by this the amount of fresh air.

The first case (see Fig. 7) investigates operation of a city bus during warm seasons (summer) within temperature ranges between 25 °C and 33 °C. During the day the temperatures increases up to 33 °C, while the ambient relative humidity changes little. Between 14:00 – 18:00 o'clock at high ambient temperatures the current control unit reduces the fresh air rate to reach the desired temperature of the cabin. Nevertheless the energy consumption is high due to high ambient temperatures. Both the current and new (monitored) control strategies have most similar fuel consumption in phases of high occupancies (about 8:00 o'clock and 18:00 o'clock). On the typical summer day shown, the potential of fuel consumption reduction is on average about 0.68 l/h which is comparably high, whereby the COP-values of the air conditioning unit are in average about 2.5.

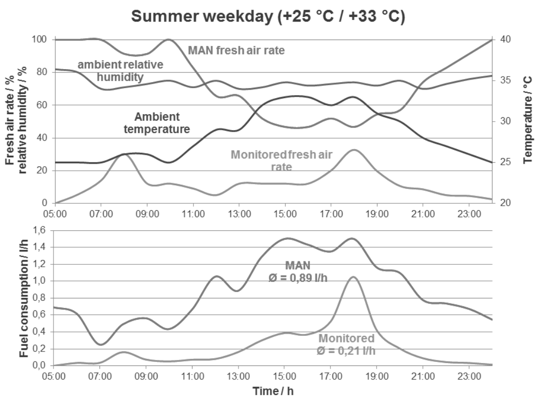


Fig. 7: Summer case

The second case (see Fig. 8) analyses operation during transitional season (spring and autumn) with a temperature range between 9 °C and 19 °C. The current control unit does not reduce the fresh air rate due to moderate temperatures. Nevertheless the fuel consumption is comparatively low, but with a high potential for fuel consumption reduction of on average 0.35 l/h, which is proportionally high due to a low COP of about 0.8 of the auxiliary heater.

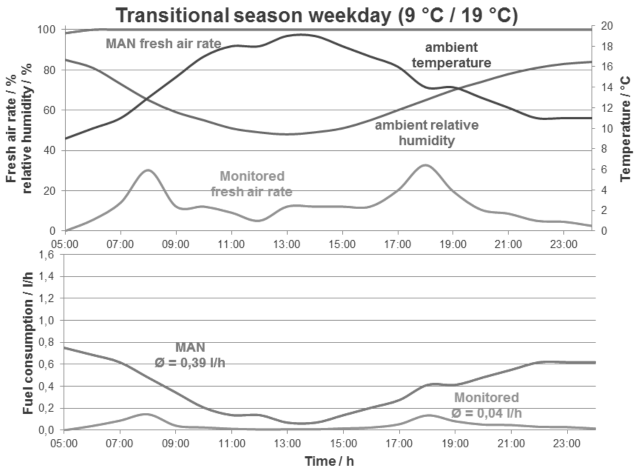


Fig. 8: Transitional season case

The third and last case (see Fig. 9) represents a cold season (winter) with a temper-ature range between -14 °C and -6 °C with relative harsh ambient conditions. The current control unit de-throttles the fresh air rate with increased ambient temperatures. In early hours the controlled (monitored) fuel consumption gets close to those of the current control unit due to high occupancy of the city bus and high throttling of fresh air rates by the current control unit. At such a winter day the potential for fuel consumption reduction is on average 1.09 l/h, which is highest due to a low COP of auxiliary heater of 0.8 and due to big temperature differences between ambient and cabin temperatures.

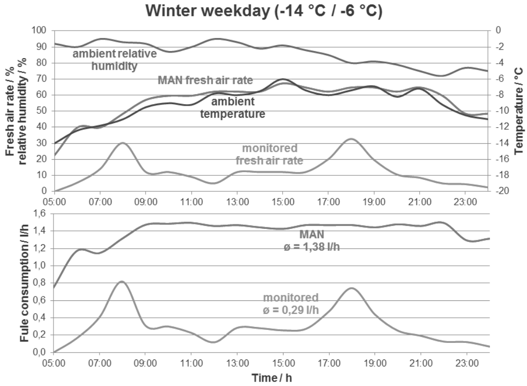


Fig. 9: Winter case

## 6 Annual consideration

For estimating the potential for fuel consumption reduction different vehicles types need to be considered: diesel, hybrid and battery. The mixed type hybrid is however not considered in this investigation.

The most significant difference of potentials between of diesel and battery busses is in the temperature range of 10-18 °C, because heat demand is satisfied by engine heat for the diesel busses, while the battery busses need extra energy of their batteries.

The highest potential of fuel consumption reduction is at temperatures below18 °C: In winter below 3 °C due to big temperature differences of 17 K or more between ambient and cabin temperatures, and during transitional season of 3-18 °C due to the high occurrence of these temperatures with 60.9 % (see Fig. 19). The effect is in-creased by the low COP of the auxiliary heater of 0.8.

| | Fuel consumption reduction | | |
|---|---|---|---|
| | Diesel | Battery | Ratio |
| Summer cooling >22 °C | 0.03 l/h | | 8.6% |
| Only ventilation 18 °C – 22 °C | 0.00 l/h | | 15.1% |
| Heating by engine / battery 10 °C – 18 °C | 0.00 l/h | 0.26 l/h | 43.5% |
| Transitional heating 3 °C – 10 °C | 0.97 l/h | | 17.4% |
| Winter heating <3°C | 1.12 l/h | | 15.4% |
| Fuel consumption reduction full year | 0.35 l/h | 0.46 l/h | |
| | 3.4% | 4.6% | |

Fig. 10: Fuel consumption reduction

The results show the potential for fuel consumption reduction of about 3.4 % for diesel-city busses and of 4.6 % for battery-city busses.

This could be translated into a reduction of the annual fuel consumption of 750 - 1000 l depending on the bus type.

## 7 Summary and outlook

The results show the high potential for fuel consumption reduction by controlling the fresh air rate, especially in city busses with an average occupancy about of 30%.

The reduction of energy consumption in seasons with heating demand is highly relevant especially for electrified vehicles (battery-city busses) because of the impact on driving range and battery capacity.

If a heat pump is used for heating, the potential for fuel consumption below 18 °C is reduced correspondingly.

The position of the CO2-sensor is important for determining the correct CO2-concentration and hence the energy reduction potential, which can be relevant for future further investigations. There are spots within the bus with low air exchange und correspondingly high air aging. A CO2-sensor placed in the recirculation air measures average CO2-concentrations risking that not allowed high CO2-concentrations in bus areas with high air aging are insufficiently detected.

These potentials for fuel consumption reduction could be further improved by in-dividual or zonal air conditioning with corresponded sensors.

The monitoring and controlling of fresh air rates is also compatible with the latest recommendation of VDV, which is valid from 2017. Furthermore it is able to fulfill the expected directions of the European Commission with respect to future regarding CO2-emission.

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# Development of an Electric Powertrain System for Truck Trailers

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**Abstract**

Due to the steady growth of level of traffic with a concurrent rising shortage of fossil fuels, energy consumption reduction becomes more and more important in research and development of vehicle manufacturing. In the passenger car sector, hybridization of the vehicle powertrain has become the most promising approach for reduction of fuel consumption respectively $CO_2$ emission and is already present in series production. Contrary, hybrid technology in heavy-duty vehicles can only be found in special-purpose vehicles for inner city operation.

The concept introduced in this paper deals with hybridization of heavy duty vehicles and is designed for long-haul operation. Core of the concept is the electrification of one axis of the trailer, leaving the tractor a conventional vehicle. The concept is based on an electric propulsion unit, consisting of electric motors, power electronic, a traction battery and a control unit, all mounted on the trailer. By usage of a specific developed sensorial kingpin, the trailer becomes a stand-alone hybrid system, which can operate independent of the tractor vehicle.

The task of the propulsion unit is the recuperation of kinetic energy by recuperative braking and the storage of this energy in the traction battery. Afterwards, the buffered energy can be used for electric traction support, for example in uphill driving situations. The reduction of combustion engine load leads to a reduction of fuel consumption and $CO_2$ emission.

In a first step, the goals and boundary conditions for the development of the powertrain are introduced. The dimensioning of the powertrain components is done using simulation programs with input of logged real world driving data and represents a multicriteria optimization of maximum fuel saving potential, absolute cost and amortization period.

In the next step, different electric motor topologies as well as different motor-gearbox combinations are investigated and contrasted. Advantages and disadvantages of different approaches, packaging opportunities and costs of manufacturing are shown.

Finally, the selected powertrain unit, which satisfies the requirements regarding power, robustness, efficiency and cost, is presented in more detail.

**Motivation**

The transportation sector in Europe experiences a continuous growth in freight road transport mileage, sales and total number of medium- and heavy duty vehicles. This leads to a current share of about 30 % in road based greenhouse gas emissions caused by freight transport, while the share in total numbers of vehicles locates at only 6 % [1 to 3]. Today, 73 % of all goods are transported by road, while transportation mileage is expected to double its number until 2030 [3]. This makes heavy duty vehicles an important factor for reaching the desired energy consumption reduction of 40 % in the traffic sector from 2005 until 2050 [4].

One opportunity to reduce energy consumption and greenhouse gas emissions, known from passenger cars, is hybridization of the vehicle powertrain. Although being state-of-the-art technology in the portfolio of car manufacturers, hybrid powertrains have not become established in the heavy-duty sector yet. Most of research in hybridization of long-haul vehicles deals with electrification of the tractor powertrain, leaving the trailer a fully passive vehicle.

In contrast, content of the research project introduced in this article is the electrification of a truck trailer for long-haul application. Fundamental functionality is recuperation of kinetic energy in downhill or braking situations as well as electric traction support in uphill or acceleration situations. As a result, the fuel economy of the vehicle is enhanced, which leads to a reduction of the vehicles $CO_2$-emission.

**Research Project Introduction**

Development of the hybrid electric powertrain mentioned above is done within the framework of the research project “evTrailer – stand-alone electric propulsion cooperation system for truck-and vehicle-trailers” which is funded by the German federal ministry for economic affairs and energy (BMWi). The research community consists of 5 consortium partners plus 2 associated partners. In this paper, the focus will be on dimensioning the powertrain components with a detailed look on development of the electric drive unit.

Figure 1 shows the schematic structure of the electric trailer powertrain consisting of two electric motors / generators, power electronics and the traction battery. The trailer control unit (TCU), which contains (amongst other functions) the operation strategy, is located on the trailer as well. By using a sensorial coated Kingpin (developed at Fraunhofer IST, Braunschweig, Germany) it is possible to detect the traction force between tractor and trailer. This traction force detection allows a standalone operation of the electric trailer without intervention in the conventional tractor powertrain.

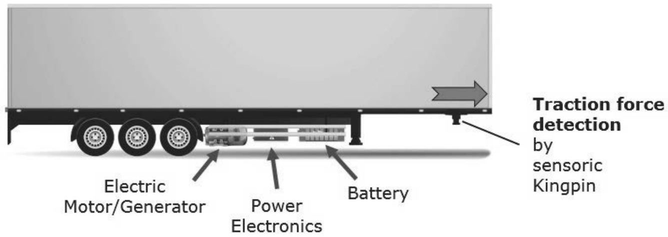



Fig. 1: Schematic layout of the Electric Trailer Powertrain

**Powertrain development goals and boundary conditions**

The first task in development of the evTrailer powertrain is the dimensioning of the electric powertrain components, mainly maximum power of the electric motors and usable/total capacity of the traction battery. Following the development process for hybrid powertrains, this task is executed using numerical simulation models [5]. In this case a backward simulation model is used, allowing a large amount of variations to be investigated in relatively short time, due to fast calculable simulation model structure. In a second step, selected results are being verified in a more complex and more precise forward simulation.

Main goal of the hybrid concept is a reduction of fuel consumption of the tractor vehicle by 16-24%. To be economically interesting for possible customers, the additionally incurring costs have to be over-compensated by saved fuel costs within the duration of the first ownership. Therefore, the amortization period goal is set to be lower than 4 years. Moreover, proper operation of the electric traction system has to be ensured over a typical heavy-duty lifetime span and is set to greater than 700.000 km. Table 1 summarizes the goals and requirements on the electric trailer powertrain.

Table 1: Goals and Requirements

| Goal / requirement | Value |
|---|---|
| Fuel consumption reduction | 16-24 % |
| Amortization period | < 4 years |
| Durability | > 700.000 km |

Besides the goals and requirements, there exist several variable boundary conditions, which have to be investigated in the dimensioning process of the trailer powertrain. One variable factor is the overall trailer mass, which varies from 15 to 30 tons and has influence on vehicle energy demand, maximum inclination speed and recoverable kinetic energy. Another variable boundary condition is the power of the tractor vehicles combustion engine, which ranges from 350 to 460 kW in modern heavy duty long-haul trucks. The most variable boundary is the driving route to optimize the powertrain on, consisting of the road- and speed profile. Possible use cases for the evTrailer powertrain are short routes with less than 50 km length and largely urban driving with low speed and multiple stop and go phases as well as long-haul routes with over 500 km length and mostly highway driving at constant high speed. The road elevation profile can also vary between flatland areas and mountainous terrain, which has influence on the energy demand as well as on the amount of recoverable energy. Hence the selection of the driving route has decisive influence on the results of the component dimension optimization and is therefore described in more detail below.

**Route selction**

Currently, there is no certification of driving cycles, as known from passenger cars, for heavy duty vehicles. Certification of heavy duty trucks takes place on the engine test bed and addresses pollutant emission exclusively [6]. $CO_2$ emission is currently subject of research for future certification procedures, but today there is no legislative guideline regarding driving profiles for fuel consumption / $CO_2$ optimization [7]. With introduction of EURO VI emission standard, a real-world emission verification procedure, called In-Service-Conformity (ISC), became mandatory [8]. According to the ISC, truck manufacturers are committed to prove the compliance with the pollutant emission limits in real-world driving scenarios with portable exhaust gas measurement systems (PEMS) over a period of at least 5 years or 700.000 km. The driving profiles of these ISC-tests are based on legislative specifications, which will be also used for optimizing the evTrailer powertrain: The speed profile should consist of 20 % inner city driving ($v < 50$ km/h), 25 % rural driving (50 km/h $< v <$ 70 km/h) and 55 % highway driving ($v > 70$ km/h). The duration of the test should be at least 4 – 6 times the duration of the engine certification cycle WHTC, which results in a length of about 3 hours and thereby a road length of ca. 180 km.

For optimization of the powertrain components, logged speed profiles from real world driving tests, meeting the requirements depicted above, were implemented in the simulation. Additionally, elevation profiles from routes without real world driving data, were simulated with a constant vehicle speed, issuing the energy saving potential of electric supported up/downhill driving. Table 2 shows a summary of the optimization boundary conditions.

Table 2: Optimization Boundary Condition

| Boundary condition | Value |
|---|---|
| Trailer mass | 15 – 30 tons |
| Tractor combustion engine power | 350 – 460 kW |
| Driving distance | 50 - 500 km |
| Speed profile | ISC conform / const. |

**Simulation and Optimization**

The dimensioning of the electric powertrain components is designed as a multicriteria optimization under multiple combinations of boundary conditions using a backward simulation model. The structure of the backward simulation model is shown in Figure 2. Input quantities are vehicle speed and elevation, which are processed backwards along the chain of effects by calculating the wheel power required to reach this driving state, the state of electric motors and internal combustion engine and resulting, the fuel consumption and battery state of charge (SOC).

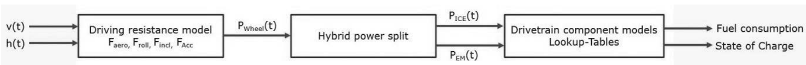



Fig. 2: Backward Simulation Model Structure

Contrary optimization criteria are fuel consumption / $CO_2$ emission reduction on the one hand and additional fixed costs for the powertrain components on the other hand. Variation parameters are the maximum power of the electric motors and capacity of the traction battery. For the optimization process itself, a genetic algorithm is chosen. The output of the multicriteria optimization algorithm is a point set, assigning one group of result quantities to a group of variation parameters, as shown exemplary in Figure 3 for one simulation. Towards the coordinate origin, the point set is limited by the Pareto front, characterized by the property that an improvement of one result quantity is only possible by a deterioration of another quantity.

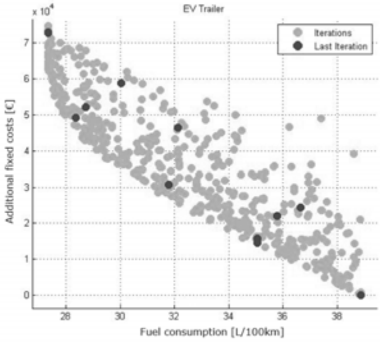



Fig. 3: Pareto set

From the multitude of optimization results, one set of parameters had to be chosen to carry on working with. Besides the monetary result quantities and the fulfillment of the objectives listed in Table 1, further topics were taken into account, like acceptance of potential customers or technical feasibility. Table 3 shows a summary of the dimensioning result. The combination of 2 x 75 kW maximum electric power with a total of 100 kWh battery capacity showed the most satisfying results. To ensure a battery lifetime of 700.000 km, the usable capacity was limited to 50 % with a swing between 80 % and 30 % SOC.

Table 3: Optimization Summary

| Result Quantity | Value |
|---|---|
| Electric motor maximum power | 2 x 75 kW |
| Total battery capacity | 100 kWh |
| Usable battery capacity | 50 kWh |
| Amortization period | 3,5 years |

The selected configuration in Table 3 is being verified using a forward simulation model with a model structure shown in Figure 4. Contrary to the backward simulation model, the forward computing model consists of a closed-loop structure with a driver model as a vehicle speed controller, resulting in a more realistic, yet more complex model with a significant higher computing effort.

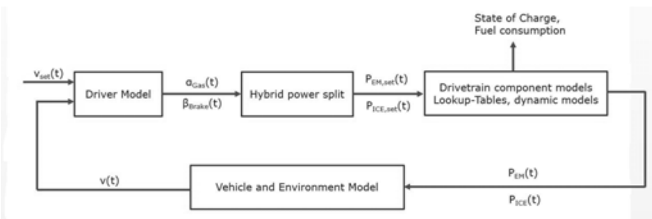
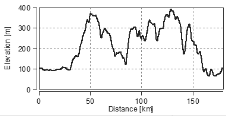
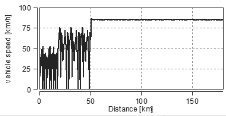



Fig. 4: Forward Simulation Model Structure

Table 4 shows the comparison between two different route types. The route on the right side is a simulation of an ISC-conform speed profile in a flat area, showing the potential of the electric traction support while accelerating and breaking, the other one is a simulation of constant driving speed in a mountainous area in middle Germany, showing the fuel saving potential while up- and downhill driving. Further, the difference between fuel savings of a low-load (15 ton) and a fully-loaded trailer (30 ton) is listed, showing that the fuel saving goals (Table 1) can be achieved in every situation.

Table 4: Fuel Saving Results

| Road type | | Elevation profile | | Speed Profile | |
|---|---|---|---|---|---|
| | |   | |   | |
| | | Fuel consumption [L/100km] | Diff [%] | Fuel consumption [L/100km] | Diff [%] |
| 15 ton | conv | 28,29 | 24,2 | 27,56 | 16,3 |
| | ev | 21,43 | | 23,03 | |
| | | Fuel consumption [L/100km] | Diff [%] | Fuel consumption [%] | Diff [%] |
| 30 ton | conv | 39,76 | 18,4 | 38,59 | 13,0 |
| | ev | 32,45 | | 33,59 | |

**Speed-/Torque-Curves**

As a result of the final forward simulation, the representative speed profile and a typical wheel size for trailers, conclusions on the needed torque/speed curve for the e-traction-system are drawn. For an easier motor calculation average load curves for operating times of one and ten minutes are built. Figure 5 shows the demanded curves for one of two driven wheels regarding a rolling circumference of 3.09 meters.

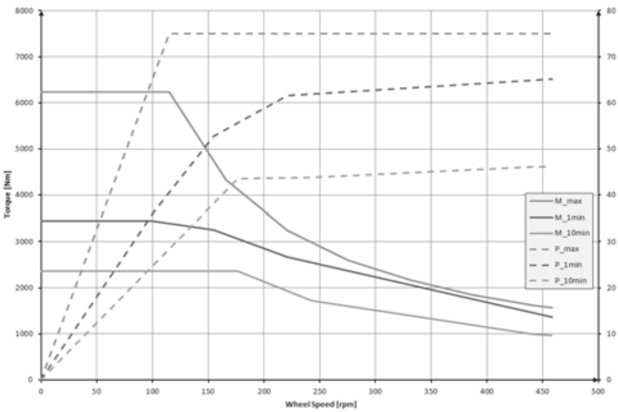



Fig. 5: Torque-/Speed-Demands

Although it is only an auxiliary drive-system a rather high shaft torque is needed to cover an effective recuperation and driving performance for saving a notable amount of fuel. A corresponding nominal power for a S9-cycle is at a level of approximately 45kW. The maximum power of 75kW can occur within a period of five to ten seconds over a high speed range. In the next step, an appropriate propulsion module has to be determined.

**Further specification topics on the propulsion module**

Beside the torque- and speed demands there are some other important goals to meet. Main further technical topics are: location and motor sizes, weight, cooling conditions, approval restrictions or facilitations and the price.

During the whole conception process the most emphasizing goal is a saleable product in the end. Integrating an auxiliary drive into a transport vehicle has different purchase motivations than for example an electric drive system in a full-electric or hybrid passenger car. Purchase arguments like a driving pleasure, comfortable travel feeling or a considerable vehicle range is far behind the argument of a short amortization time. Factors like the initial costs, fuel savings, remaining trailer payload, remaining transport room capacity and maintenance costs are essential development issues.

**E-drive concepts**

In principal there are some different approaches to prove. Technical issues as well as commercial aspects are taken into account. In the first step possible propulsion integration concepts were discussed, an overview is shown in figure 6. The project partner's choice is highlighted in the red-lined path on the right side. Distributed drive modules may open a better adaption to future modified specifications. And they allow a torque vectoring for an improved traction performance.

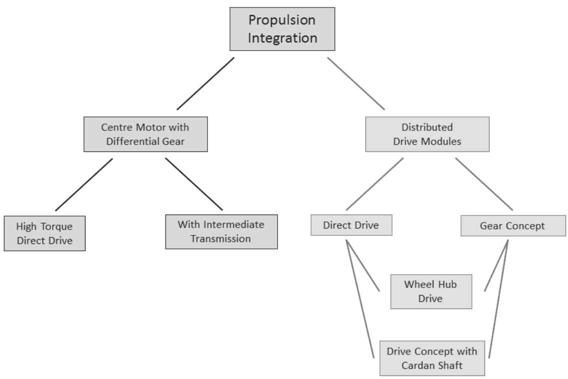



Fig. 6: Type of Propulsion Integration

Figure 7 illustrates the principle power transmission concepts, which are pointed out for calculations more in detail.

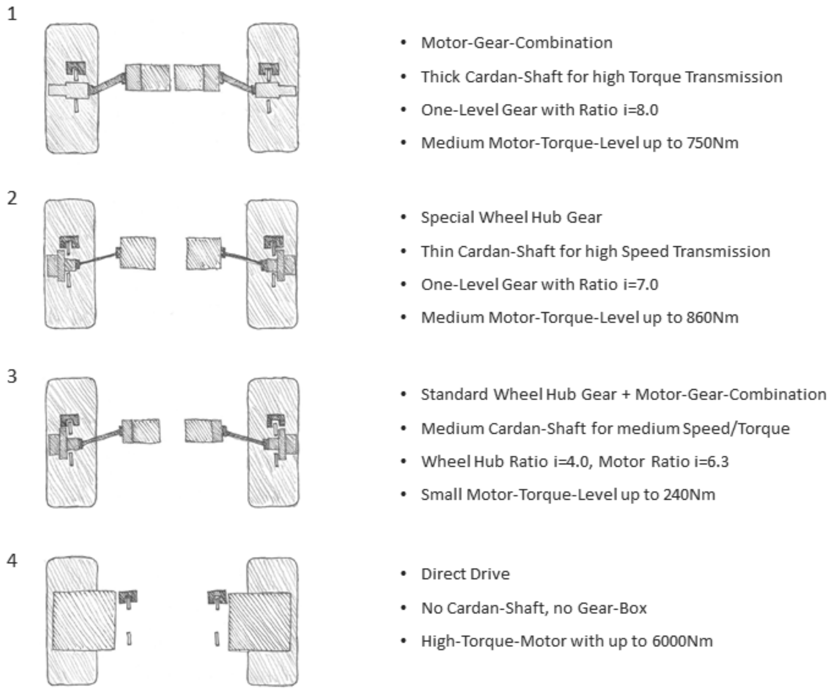



Fig. 7: Principle Power Transmission Concepts

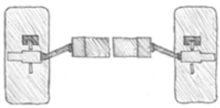
The concepts 1 and 2 lead to nearly the same motors. So these two concepts are not considered separately concerning to the electric machines. However, the wheel hub gear with a ratio of i=8 is a much more special part than a comparable motor gear.

## Detailed Motor Calculation

The following matrix shows the calculated motor modules with their properties concerning to size, technical data and price. Each calculation is based on water cooling with up to 50°C inlet temperature. Every motor concept treats a radial flux topology. Inertia’s allow a feeling about the dynamic stress penetrating the mechanical transmission path.

Table 5: Overview of calculated Machine Types

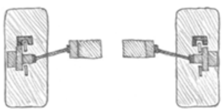
1



Motor-Gear-Kombination
Gear-Ratio i=8
S9-Power 45kW@1400rpm
Overload Power 75kW@950...3800rpm
Overload Torque 750Nm

| | | 1.1 Induction | 1.2 PM-Synchronous distr. Windings | 1.3 PM-Synchronous conc. Windings |
|---|---|---|---|---|
| Pole Number | | 8 | 6 | 16 |
| Diameter x Length | [mm x mm] | 355 x 370 | 300x340 | 300x210 |
| Volume | [l] | 36,6 | 24,0 | 14,9 |
| Rotor | | Aluminium Cage | Surface Magnets | Surface Magnets |
| Encoder | | Inkremental | Resolver | Resolver |
| Efficiency 45kW@1400rpm | [%] | 93,5 | 94,5 | 94,5 |
| No-Load-Losses 80km/h (per motor module) | [W] | 300 | 1850 | 3350 |
| Weight (Active Parts) | [kg] | 128 | 72 | 41 |
| Weight (Motor) | [kg] | 155 | 84 | 49 |
| Inertia (Motor/Motor-Gear) | [kg*m²] | 0,468 / 29,9 | 0,061 / 3,9 | 0,056 / 3,6 |
| Price Motor (1000 Pcs./a) | [€] | 1780 | 2160 | 1510 |

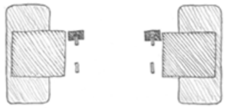
3



Wheel-Hub-Gear + Motor-Gear-Kombination
Gear-Ratio i=4x6.3=25.2
S9-Power 45kW@4400rpm
Overload Power 75kW@2950...11800rpm
Overload Torque 240Nm

| | | 3.1 Induction | 3.2 PM-Synchronous distr. Windings | 3.3 PM-Synchronous conc. Windings |
|---|---|---|---|---|
| Pole Number | | 4 | not calculated | 8 |
| Diameter x Length | [mm x mm] | 270 x 350 | | 215x215 |
| Volume | [l] | 20,0 | | 7,8 |
| Rotor | | Aluminium Cage | | Surface Magnets |
| Encoder | | Inkremental | | Resolver |
| Efficiency 45kW@1400rpm | [%] | 95,0 | | 95,5 |
| No-Load-Losses 80km/h (per motor module) | [W] | 1000 | | 4700 |
| Weight (Active Parts) | [kg] | 75 | | 29 |
| Weight (Motor) | [kg] | 86 | | 35 |
| Inertia (Motor/M.-1. Level/ges) | [kg*m²] | 0,068 / 2,7 / 43,2 | | 0,0067 / 0,266 / 4,24 |
| Price Motor (1000 Pcs./a) | [€] | 1350 | | 1230 |

4



Direct Drive
No Gear
S9-Power 45kW@175rpm
Overload Power 75kW@120...470rpm
Overload Torque 6000Nm

| | | 4.1 Induction | 4.2 PM-Synchronous distr. Windings | 4.3 PM-Synchronous conc. Windings |
|---|---|---|---|---|
| Pole Number | | off the target | not calculated | 60 |
| Diameter x Length | [mm x mm] | | | 510x345 |
| Volume | [l] | | | 70,5 |
| Rotor | | | | Surface Magnets |
| Encoder | | | | Resolver |
| Efficiency 45kW@1400rpm | [%] | | | 87,0 |
| No-Load-Losses 80km/h (per motor) | [W] | | | 4100 |
| Weight (Active Parts) | [kg] | | | 152 |
| Weight (Motor) | [kg] | | | 198 |
| Inertia (Motor/Motor-Gear) | [kg*m²] | | | 4,3 |
| Price Motor (1000 Pcs./a) | [€] | | | 5270 |

Very special motor topologies like the switched reluctance machine (loudness, special and expensive inverter), synchronous reluctance machines (special inverter, inappropriate field weakening performance and power-density), transversal flux machines (special inverter, complexity in structure) and the separately excited synchronous machine (additional rotor exciting device, inappropriate power-density, complexity in structure) is not considered more in detail.

## Conclusion

Exclusion procedures will help finding a good solution for this auxiliary drive system. Concept 4.3 results in a big, heavy and expensive motor with a high loss production. The advantages of this motor type like integration benefits, a low inertia and getting rid of gear-boxes and oil cannot be used.

Concept 3.1 is preferred to concept 1.2. Weight and motor sizes are similar but the initial price and the loss production of the induction motor is better. Moreover for concept 1.2 there is still the challenge of handling the dangerous back-emf. The PM-synchronous/salient-pole machine as an improvement of this PM-machine is maybe a possibility to come closer to the technical demands. Nearly the same weight, a little higher price, a remarkably better no-load-loss but as well a more special inverter and adjustment work will come up with this concept.

The concepts 1.3 and 3.3 have a good initial price level, but the high loss generation is not tolerable concerning to a system amortization by fuel savings.

In spite of the higher weight, prices of the induction machines can compete with the synchronous machine. The main advantage is the very low no-load loss generation and the remark-

ably better fuel consumption. In addition it is a robust motor that doesn't produce a dangerous back-emf, so an approval process is much easier.
The most interesting concepts for a realization within the ministry funded project are based either on concept 1.1 or 3.1, both with special adapted induction motors. Nevertheless the higher weight will result in a reduced payload.

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# Electric Drivelines in Semi-Trailers

## TRANSFORMERS: An additional Way to Hybridisation

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**Abstract**

This contribution is based on results obtained in the project "TRANSFORMERS", which has received funding from the European Commission in the FP7-programme. The project has the objective of 25% less $CO_2$ per t.km, by improved aerodynamic measures, innovative loading efficiency measures and a hybrid-on-demand driveline for truck-semitrailer combinations, [1]. Besides giving insight in the overall project, this publication focusses on the trailer mounted hybrid-on-demand (HoD) driveline. One key aspect is the successful registration of the semitrailer with the electric drivetrain together with a certification organisation.

### 1 Introduction

The transportation of goods on roads is an important mode of transport in today's economy – if not even the most important in Europe. Although alternative propulsion systems are investigated, especially for inner city distribution, the majority of these on-road transports use diesel powered trucks. In the White Paper of the European Commission on Transport Efficiency the goal of a $CO_2$ reduction by 60% by 2050 is targeted, [2]. In order to achieve this goal it is very important to increase the transport efficiency for future road freight transport in tonne-kilometres. This can be achieved by maximizing load efficiency as well as fuel efficiency. Both aspects are targeted by the TRANSFORMERS project.

The TRANSFORMERS project consortium consists of 13 partners from the truck, trailer and road transport industry as well as scientific partners, [1]. The project is co-funded by the European Commission in the FP7 programme.

While today truck-trailer combinations have a fixed design to perform a wide variety of transportation tasks, future vehicle combinations could be easily adapted to the specific needs of each load and transport mission. TRANSFORMERS will achieve this with the following innovations:

- A distributed, modular, and mission adaptable Hybrid-on-Demand (HoD) driveline concept that is applicable to both, existing and future trucks
- A pre-standard electric HoD Framework that supports a broad market introduction of hybrid commercial vehicles and provides planning certainty for future Research Technology & Development (RTD) activities
- Mission-based configurable aerodynamic overall truck-trailer design
- Load efficiency optimised trailer interior design

TRANSFORMERS focusses on achieving these key innovations within the existing European legal and regulatory framework.

This paper will focus on the development of the modular Hybrid-on-Demand driveline to increase the fuel efficiency of the truck-semitrailer combination. The requirements for this development from an end user perspective were discussed in a previous paper, [3].

For the demonstrator vehicle two conventionally propelled trucks (one from Volvo and DAF each) are combined with a Schmitz Cargobull semitrailer, which is equipped with the new driveline concept. This shows the applicability of the system over multiple truck brands. The mechanical integration of the driveline is described in [4]. Fig. 1 shows the combination during public road testing.


Fig. 1: TRANSFORMERS Truck-Semitrailer combination

## 2 System Architecture

As described above the vehicle combination consists of a conventionally propelled truck and a semitrailer equipped with an electric drivetrain. Fig. 2 shows the structure of the demonstrator vehicle, where the trailer is coupled to a largely standard truck (Case A). In this case the Trailer Drivetrain Management System (TDMS) activates its internal Trailer Energy Management System (TEMS). The TDMS controls the functionality on the trailer and requests torque from the Electric Motor Generator (EMG).

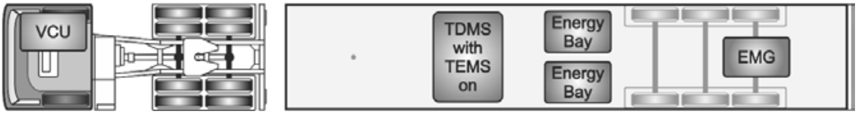


Fig. 2: Structure of the HoD-Driveline for a HoD-Trailer coupled to a standard truck (Case A)

Future trucks – especially hybridised trucks – may already include a Vehicle Energy Management System (VEMS). If a HoD-Trailer is coupled to such a truck, the TEMS is switched off and the trailer can be used by the truck as an electric propulsion and braking device (Case B). This is considered to increase the fuel efficiency potential compared to Case A, because the energy management can be optimized over the whole vehicle combination, rather than just for the trailer itself. The resulting structure is depicted in Fig. 3. The trailer distinguishes between Case A and Case B by the presence or absence of messages from the truck.

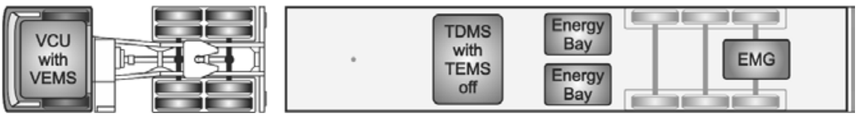


Fig. 3: Structure of the HoD-Driveline for a HoD-Trailer coupled to a VEMS-Truck (Case B)

The logical system architecture for the HoD-System is shown in Fig. 4. Beside the management system TDMS it defines the interfaces to the outside subsystems:

- **VCU-Interface**: The communication interface between the truck and trailer with respect to the HoD system.
- **EBS-Interface**: This is the interface to the braking system on the trailer. This communication is important to ensure a proper brake blending functionality between service brakes and electric braking, see [4].

- **EMG-Interface**: This interface includes the communication between the TDMS and the EMG as well as the electrical interface in order to control the EMG power flow. This interface is part of the framework to support the development of framework compliant EMGs.
- **ESU-Interface:** This interface includes the communication between the TDMS and the Electrical Storage Unit (ESU) as well as the electrical interface. As with the EMG-Interface, this framework definition shall support the development of framework compliant ESUs.

The communication between HoD-System and truck is handled via the VCU interface and indirectly of the EBS interface, which provides information from the truck, too. For the simplified Case A solution a read only communication from truck to trailer based on ISO 11992-2 and -3 is sufficient for the system operation. In the demonstrator vehicles signals are also sent from the trailer to the truck to provide visual feedback for the driver.

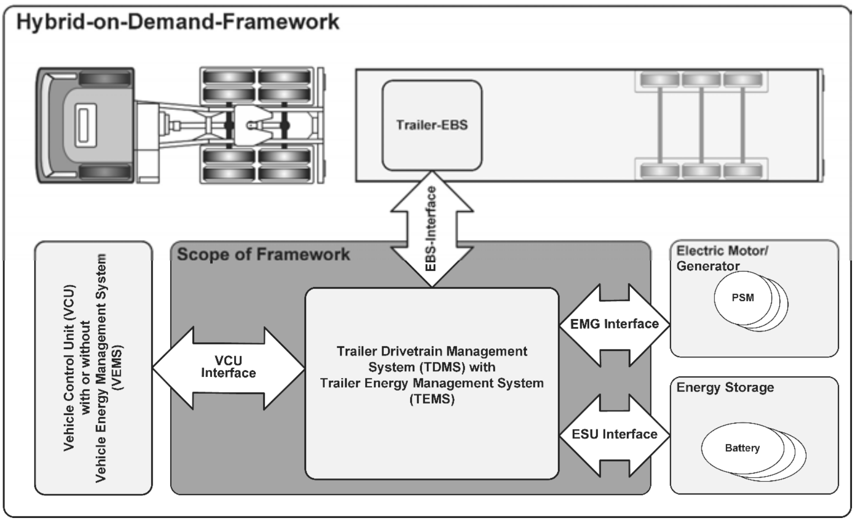


Fig. 4: Logical System Architecture of the HoD-Framework

A detailed view of the components within the trailer is provided in Fig. 5. The mechanical drivetrain is composed of the electric machine, a transfer box with a clutch and the differential at the driven axle. The combination of ESU, Inverter and EMG is currently limited to 80 kW continuous power. The clutch fulfils two tasks: 1. It decouples the EMG from the driven axle when no torque is requested to reduce drag torque and 2. It is used to bring the trailer in a safe state, when a fault in the HoD system occurs, see section 3.

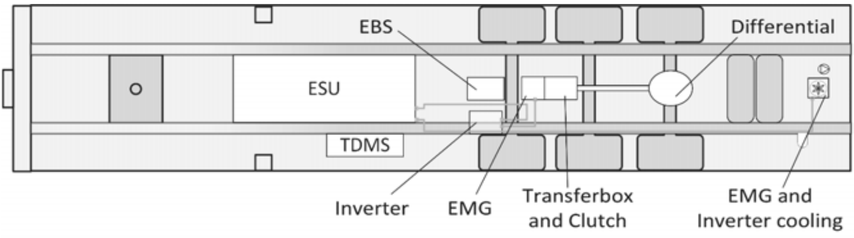


Fig. 5: Top view of the TRANSFORMERS trailer with the location of important components

The truck is operated by the driver in a standard way with standard controls. Depending on certain conditions, e.g. ESU State of Charge (SoC) and no ABS intervention, electric power is added by the EMG to the power of the internal combustion engine (ICE) of the truck automatically. When braking, the EBS on the trailer performs a brake blending between electric braking and service brakes without any intervention from the driver, [4].
Furthermore, the electric braking is applied, when the truck retarder or engine brake is requested by the driver. This is the favoured method of braking for long haul applications, rather than the service brakes. This substantially increases the amount of energy recuperated – first because of its primary use and second because of a higher amount of electric braking power compared to service brake applications.
Additionally a pure electric braking functionality was implemented for test track only. The electric braking in the trailer can be requested separately as long as no power is requested from the ICE. Pure electric braking provides the greatest recuperation potential, because no kinetic energy of the truck is transformed to heat in either service brakes or retarder. Technically it is a stretch brake, which conflicts with current regulations. It would be favourable if future regulations would have exceptions from this strict rule for hybrid applications.

## 3 Safety Concept for Demonstrator Vehicle

An important topic was the safety concept of the system – not only for the testing itself, but especially for testing on public roads. The goal was to stay within the European legal and regulatory constraints, to allow for a registration of the trailer. To achieve this the consortium worked very closely with TÜV Rheinland and Knorr Bremse to find technical solutions that are within the current regulations and to assess the necessary changes made to the existing vehicles.

Besides, following relevant regulations ECE R10, R13 and R100, functional safety also needed to be addressed. The process was based on ISO 26262, although officially it is not yet applicable for heavy duty commercial vehicles. The item definition determined the scope of the hazard and risk assessment (HARA). It was important not to repeat the process for the whole truck and the whole trailer, but to focus on the changes introduced by the HoD-system and their implications on the existing systems. Even with this restriction a large number of vehicle conditions needed to be considered. Beside various driving situations this included also standstill situations like normal parking or in a workshop. All those situations were structured according to their effect on the vehicle behaviour in a pre-study, in order to reduce the actual number of situations to be analysed in the HARA.

The result was a list of safety measures, which needed to be implemented by a number of system components to achieve safe parallel paths, especially for hazards classified with the highest risk (ASIL D). The three most important points are:

- Emergency switch in the truck to disable the HoD-system in the case of a serious error,
- Clutch in the HoD-drivetrain to decouple the EMG from the driven axle, and
- Trailer braking system, which ensures safe braking all the time and disables the HoD-system in critical situations, e.g. in ABS or VDC intervention.

The trailer braking system can itself directly open the clutch in case of communication loss to the HoD-system or if an unstable driving condition is detected. This ensures that the HoD-system cannot disturb the standard ABS/EBS operation and cannot make such a situation worse. Nevertheless, the HoD-system is constantly checking itself and shuts down in case of a detected fault.

Table 1 shows a list of some essential conditions for the HoD operation. About the same number of internal conditions are checked in addition to ensure a safe operation of the truck-trailer combination. All those conditions ensure that the operating states of truck and trailer can be safely determined and are plausible. Only if this is the case, the HoD system becomes active. In the case of implausible states or detected failures the system is deactivated immediately.

Table 1: Examples of essential conditions for HoD operation

| **General Conditions** | **Add. Cond. For Propulsion** | **Add. Cond. For Braking** |
|---|---|---|
| Ignition is on | Truck ICE torque request >0 | Truck ICE torque request =0 |
| All Communication OK | Brake request =0 | Service or endurance brake request >0 |
| EBS allows operation (no ABS, VDC, etc. active) | Battery SoC high enough | Battery SoC low enough |
| Vehicle is driving forward | | |
| Velocity > Threshold | | |
| Gear engaged | | |
| Torque should fade in/out | | |

It needs to be highlighted that the semi-trailer is not able to drive autonomously. The correct communication from the truck needs to be established so that torque is added when driving and brake blending functionality is enabled. If no correct communication can be established to the truck, the system remains switched off and the clutch will be decoupled. Thus, the trailer behaves like a standard semi-trailer, which can be towed by any truck.

Before starting public road testing, the behaviour of the truck trailer combination was tested by a number of experts from different organisations on closed test tracks under various driving conditions (high mu, low mu, different loading conditions, etc.). The vehicle remained safe all the time. When provoking faults, the installed safety measures worked as intended. This finally resulted in a successful registration of the trailer with the HoD-system installed, and paved the way for public road testing.

## 4 Commissioning and First Test Results

The commissioning and testing of the TRANSFORMERS vehicle combination took place in various locations in Europe. The installation of all components in the truck and trailer, and the commissioning of the HoD-system started at the facilities of Fraunhofer IVI. It was followed by the brake blending development and testing at Knorr Bremse. Subsequently, the actual vehicle testing and fine tuning was undertaken at the Volvo test track before on road testing in Sweden. Further testing was carried out on the DAF test track in the Netherlands. The following steps were performed successfully:

1. Commissioning of the ESU, including management functions like cooling, heating and safety,
2. Commissioning of the EMG including its inverter,
3. Commissioning of the clutch, especially the closing process,
4. Combination of ESU, EMG, Inverter, Clutch and TDMS to a fully functional electric drivetrain, and
5. Combination of the hybridised semi-trailer with the two tractor units.

This stepwise approach allowed for an early start of commissioning as soon as components were available.

Cooling and heating of the battery is an important task to ensure that the battery stays within its specified temperature region. This reduces aging and avoids malfunction of the battery. Furthermore, it is necessary for using the full power capability of the battery. The same cooling functionality was also used for the EMG and the inverter but with a separate cooling circuit.

The EMG (always including inverter from now on) was first commissioned on a test rig with external power supply. This was done to check the basic communication and control before connecting the transfer box and clutch and installing the system in the trailer.

Once EMG control was working properly, the clutch closing process was tested. A dog clutch was chosen for this project, which is a good selection for this purpose with respect to wear and maintenance efforts. Nevertheless, the closing process needs special attention not to destroy the clutch or connecting parts due to high jerks. An example of a closing process is depicted in Fig. 6. When closing of the clutch is requested, the EMG enters speed control mode to speed up the motor to a certain synchronization slip between the input of the clutch and the output, which is connected to the moving wheels. When the correct speed is reached, the EMG enters torque control mode with $T = 0\ Nm$ and the clutch is closed. The correct closing of the clutch is detected when the slip between input and output shaft of the clutch vanishes. When this is safely detected the actual driving or braking torque is applied by the EMG. Depending on the EMG target speed, the closing of the clutch takes about 0.8 to 1 s.

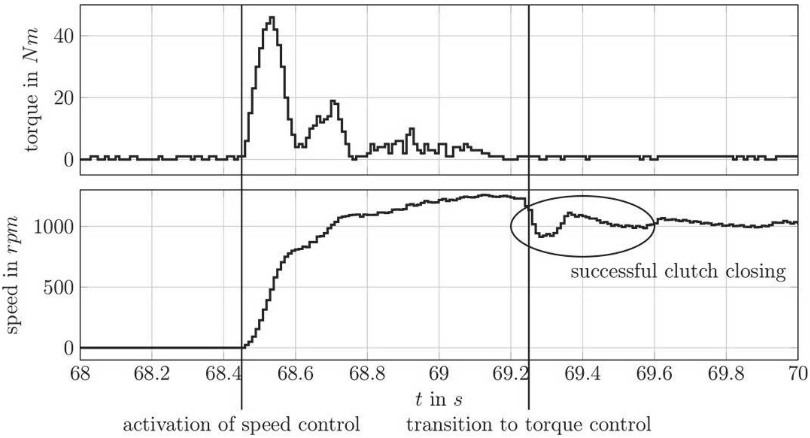


Fig. 6: Clutch closing process in a moving vehicle during commissioning

After successfully testing the individual parts they were combined to build the complete HoD-drivetrain in the trailer. The whole system was then tested under the central control of the TDMS. Special attention was paid to the mutual checking of the ECUs and the resulting fault handling strategies. These tests were further extended together with the two tractor units until the approval was granted to drive the vehicle on public roads, see section 3.

Public road testing was performed by Volvo in Sweden after additional safety testing at their test track. Fig. 7 shows measurement data of a full test run over more than 300 km on public roads. This test run includes a short city part and larger motorway and country road sections, representing a long haul application. The truck was mainly driven in cruise control on the motorway sections as well as manually by the driver on other sections. In all situations the system worked as planned and assisted the tractor internal combustion engine (ICE) during propulsion and recuperated energy during braking. A compromise needed to be found there, to actually use the system for fuel saving rather than just increasing the performance.

Given the relatively constant speed profile – as it is typical for long haul applications – the major energy flow in and out of the battery is caused by the height profile rather than acceleration and deceleration. The energy normally wasted in a retarder or engine brake, when going downhill is stored in the battery. Later this energy is used to help on the next uphill. Fuel saving is achieved by the electric boost itself, but also by avoiding downshifting of the tractor ICE transmission, which keeps the engine in more efficient operating points. The analysis of the exact fuel saving over a variety of long haul test cycles is still ongoing.

The next step was to hand over the trailer to DAF for testing in simulated heavy traffic conditions. The majority of the energy flow will then be caused by acceleration and deceleration and is therefore a completely different application compared to the long haul case shown in Fig. 7. It is considered a more typical application for a hybrid vehicle. It should be able to show a higher fuel saving capability, but is also more prone to achieve just a performance boost instead.

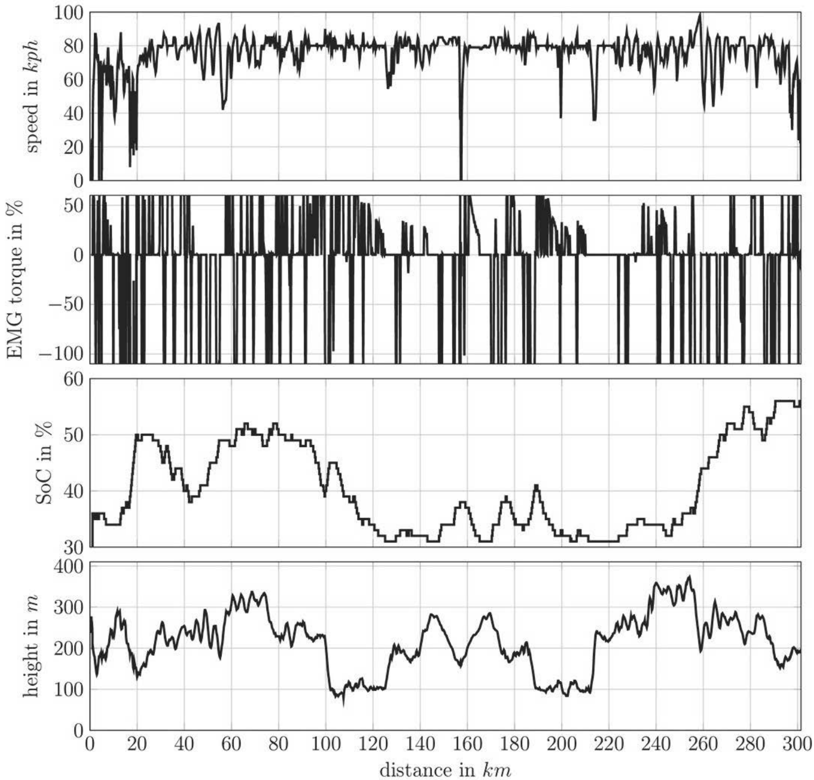


Fig. 7: Measurement data from a full >180 km test run on public road

## 5 Conclusion

As part of the European TRANSFORMERS project an electric drivetrain was successfully installed in a semi-trailer. It utilizes the available space under the trailer to hybridise the whole combination based on a standard truck. The development process considered state of the art regulations and functional safety concepts. Thus, it was possible to register the trailer with the drivetrain installed.

The test results so far indicate significant fuel savings in long haul applications even in the simple Case A scenario with no influence on the truck ICE. Even higher fuel savings are expected for Case B scenario with a holistic energy management over the whole vehicle combination. Tests for heavy traffic conditions around cities are in progress. Test and evaluation results will be published in a future paper.

## Literature

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# Requirements of Chinese domestic market for introduction of disc brakes for medium and heavy tractor truck axles

## Sino German collaboration to enhance the product introduction process into Chinese domestic market for a demanding component

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### Abstract

Chinese commercial vehicle market is demonstrated and the new regulations limiting overloading are expressed. The domestic Chinese logistic system stands in front of a dramatic change from a TAXI-like organization towards western logistic chains. This leads to a demand for robust and secure vehicles, offering long lasting service intervals. The disc brake can fulfill these demands and will therefore cannibalize drum brake application at least for tractor trucks. YIHE has started a transition to a German way of development using the German MSCDPS® product creation process. With the help of European experts a general market benchmark was performed. With the knowledge of European experiences made with the introduction of disc brakes, specific testing could be developed and performed to check if disc brakes are able to fulfil domestic Chinese market demands. Tests performed under normal service conditions showed very well fit to requirements. This testing program now will be extended to more critical service conditions and misuses for example as applied by the YIHE Tai Shan downhill test.

This knowledge already has led to develop specific components which will be introduced after approval by severe testing to fulfill also future market demands when high powered tractor trucks will drive with increased speed and so need raised braking torque and dissipate more heat energy so boosted heating up of components has to be taken into account. The YIHE disc can soon be introduced and a new YIHE hub unit for increased service life is under development and first test vehicles are tested under service conditions.

**Content**



# 1 Introduction

## 1.1 Zhucheng YIHE Axles Co., Ltd.

Zhucheng YIHE Axles Co., Ltd. was founded in 1994, and is located in the city of Zhucheng, Shandong province, which is in the middle between Beijing and Shanghai. It is a large axle production base with an annual output of 1.2 million sets of steering axles. At present, YIHE produces in Zhucheng the company headquarters at 10 professional workshops, nearby in Zhuxie plant, also nearby the new energy axle factory, at Pook where commercial vehicle seating factory is situated and with the Changsha plant, Hunan province. The main products are front axle for commercial vehicle, front suspension for passenger vehicle, Light truck rear axle, tractor axle (front axle, front drive steering axle), harvesting machinery, commercial vehicle front axle beam, all kinds of steering rod, U bolts, and commercial vehicle seating.

2,500 staff members are actually occupied in the company. In 2016, the total sales revenue was 2.2 billion yuan, and the commercial vehicle front axle got a market share of 23%. Product variance for front steering axles starts with 0,5 t up to 9 t capacity, covering mini truck, light truck, heavy truck. The main customers are FOTON, SINOTRUCK, JAC, Dongfeng automobile, BYD automobile and many others. Zhucheng YIHE Axles Co., Ltd.is ranked in the top 500 enterprises of Chinese machinery industry and in the top 100 enterprises of China auto components. YIHE is member of high-tech enterprise of Shandong province.

In order to improve the ability to the technology research and test, YIHE Axle and Shandong University of Technology established the commercial axle CAE research institute to carry on the work of light-weighting, applied analysis and so on; YIHE Axle cooperates with University of Shanghai for Science and Technology in the road spectrum data acquisition, inspection and testing, and the development of standards and other aspects, and the joint research institute of advanced chassis system development is set up. YIHE joins the national industry standards development team of passenger car axle and subframe which is led by University of Shanghai for Science and Technology with the participation of SAIC. YIHE Axle cooperated with Shandong University in the application of new materials, talent training, and other aspects, and on-the-job postgraduate courses are established. In order to meet the international standards, and realize the development trend of commercial vehicles in Europe, the company cooperates with the Ebertconsulting GmbH in commercial vehicle front axle technical standards, process standards, test standards, professional personnel training, and during the cooperation of two years, mayor improvements in the way of collaboration, systematically solving issues and encouraging and empowerment of the team members are achieved.

### 1.2 Ebertconsulting GmbH

Ebertconsulting offers change consulting especially for commercial vehicles industry. Ebertconsulting uses its own method MSCDPS® which is a protected trademark. The partners have been high ranking professionals in this industry and depend on long lasting experience in optimizing and adapting lean processes and for all steps during the product creation process. Its approach is people centered – the empowerment and commitment of participants and stakeholders is essential for sustainable success. Therefore the most recent social scientific methods and insights are the basics for its work. Ebertconsulting relies on two columns for their work – technical and social expertise.

### 1.3 The method MSCDPS® - frontloading, training, mentoring

Since April 2014 Ebertconsulting collaborates with the company YIHE. First an audit was executed to get information about processes, products. It was found out: good resources - especially human resources - are available. After the audit a 5 step program according to the needs of the company and the different departments was initiated. This program also dealt with specific issues to be solved quickly***.***

The 3rd Level of cooperation and support of the YIHE company has been started short time ago. The strategy is oriented on Ebertconsulting own method, the MSCDPS®, which gives a way to optimize processes in medium size companies and which is following the Toyota philosophies. This method is based on a two-ways-approach: product creation and also human resources. The method is focusing on both quality and innovation and relies on commitment and empowerment of the people involved.

The nine characteristics of this model are: employee participation, customer requirements, transparency and visualization, communication, executive and employee empowerment, issues as a guide, studying paragons, lean production processes, learning management (going and learning locally).

The Ebertconsulting five level program to excellence starts with a vision and also with cleaning up and introducing quality thinking, transparency and proper processes. In level two companies are supported in their supplier integration, in organizing functional expertise and in developing a chief engineer system. The third level means: adapt technology to fit the people and the processes, create a leveled product development process and front load this creation process. Level four facilitates standardization, establishes customer defined value and the alignment of the organization through visual communication. In the last level – the fifth – the organization builds a culture to support excellence and relentless improving, people will use powerful tools for organizational learning and towering competence is developed in all processes, especially in technical processes for the engineers.

It costs a lot of power of volition, lot strength and involved people have to be supported intensely. This is part of the program and it is managed by intense personal coaching, mentoring, supervision and creating of a culture of feedback. But patience is crucial! Change just happens in small steps. So the process of change has to be planned carefully, implemented successfully and carried out with a long term perspective.

## 2 Market analysis of pneumatic disc brake of commercial vehicle in China

From 1997, China began to popularize disc brake and anti-lock braking system on buses and trucks. The imported parts were mainly used for high level quality products because of the high price. In 2004, the Ministry of transport imposed mandatory requirements; all the front wheels of all special school buses and other trucks with dangerous goods larger than 9 m length should be equipped with disc brakes.

With the improvement of the traffic conditions and the development of high-grade highway, the speed and properties of the vehicles improved significantly. People are used to travel with fast and comfortable cars equipped with disc brakes. The disc brake can improve the safety of cars and reduce the dust pollution and noise pollution during the process of brake, solve the problem of frequent maintenance and other problems so that it should be used widely in the car. These features also will drive the introduction into commercial vehicle market.

Zhucheng YIHE Axle Company is one of the biggest axle manufacturers, the company follows commercial vehicle development trend, and pays close attention to the market trend of disc brake. Since 2013, the number of brake disc brake drum has increased annually see **Fig. 1** below.

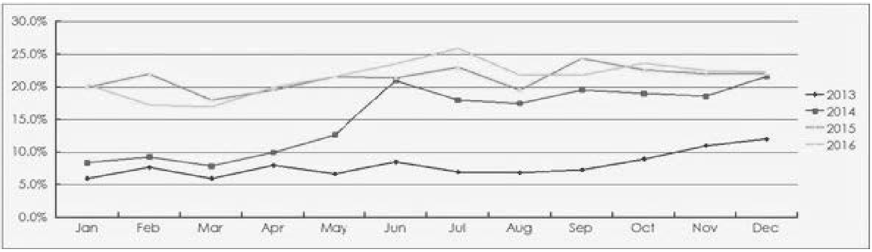


Fig. 1: The figures of sales proportion of Commercial vehicle pneumatic disc brake axle in year 2013 to year 2016

### 2.1 China logistics system

China logistics system is in the process of the end of "upgrading the hardware of logistics" and the beginning of "the era of logistics managing cost". Today still a lot of transportation is still organized like a taxi system, drivers waiting with their vehicles at specific parking and loading areas to be hired for a transportation task. Vehicles are owned personally by the driver or his family and the initial financing is the biggest task to start the business. Therefore the initial cost of the vehicle is of mayor concern and the long lasting of components is not financially honored. Specifically, with the increasingly large-scale and specialized pattern of industrial structure in China, logistics industry enters the integration stage, from disorder to order with the large application of information technology, the rise of e-commerce and the promotion of cost control. Various new forms are emerging, such as supply chain management, LCL (less than container load) transportation and further advanced systems.

With the dual promotion of economic of globalization and e-commerce, it becomes inevitable trend of the logistics industry to transform from traditional to modern. Under the guidance of system engineering, the essential properties of modern logistics are concentrating on the information technology, strengthening resource integration and optimizing the whole process of logistics. The composite growth rate of the tertiary industry in China is expected to reach 16 % during the" national-13th-5-year" period. The growth rate of basic logistics services (warehousing and transportation) will reach only about 10 %. However, the high-end logistics service growth will reach more than 30 %. Supply chain management, professional third party logistics and cold-chain services will usher in a rapid development period, considering the overall growth rate of logistics industry can reach 20 % and basic logistics service growth can only reach 10 %, it is expected that high-end logistics services will usher in an average annual growth of about 30 % during the period of “national-13th-five-year”.

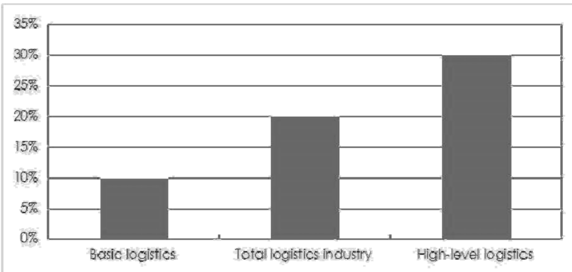


Fig. 2: Growth forecast of subdivision of China logistics industry in “national-13th-five-year” (unit: %)

With the arrival of China express delivery service era, the diversification trend of express enterprises will be more obvious, more and more express enterprises will upgrade through diversification strategy into integrated logistics service providers. The rapid growth of express business directly promotes the investment of infrastructure construction, including transshipment center, trunk transport vehicles, all cargo carrier and visualization, automation, intelligent mechanical equipment, which is trying to build intelligent logistics system and improve operational efficiency and reduce costs.

## 2.2 Customer Feedback

YIHE initiated a Customer feedback program to learn the needs and potential acceptance of the new braking system. Customers from FOTON service station in Tangshan, Hebei province and SINOTRUCK service station Liaocheng, Shandong Province were asked. Their feedback has been very clear and positive minded towards the introduction of disc brakes as follows:

1. Small amount of moving parts and low friction of auxiliary bearing support, small friction resistance, high braking efficiency;

2. Standard parts are used in the design and the less number of parts and high proportion of the duplicate parts is convenient for the supply of spare parts. Replacing the brake lining is the most major maintenance work of the air disc brake, the maintenance record of the vehicle manufacturer shows that it takes 80% less time of the replacement of the disc brake lining than the replacement of the drum brake lining and the maintenance is simple;

3. The clearance between the brake lining and the disc is small, so that the operating time of the pneumatic piston is shortened, the power transmission ratio of the brake mechanism is improved , and the volume of the brake can be more compact with the same braking force;

4. The air consumption is lower than before because of the usage of diaphragm chambers with standardized stroke.

5. The structure is compact with small size and light weight.

## 2.3 Overloading – recent regulations

On September 21, 2016, in the GB1589 standard [6], the Ministry of transportation, Ministry of public security, Ministry of industry and other departments jointly issued a series of notice documents on" governance overload ", including the opinions on further improvement of truck illegal modification and overload, the special action plans of regulation truck overloading behavior and the governance work scheme of vehicle transport. The standard of vehicle overloading is more stringent than the last one. So the introduction of the policy was widely concerned by logistics and shipper enterprises, also truck drivers.

Fig.3 : China Jiangsu net- Overloading truck damaged the bridge

The structure of highway transportation vehicles changes greatly. At the volume point, the volume of the vehicle is reduced from 130-160 cubic meters to 85 cubic meters, taking light truck as an example, the loading decreased by 35 %. From the weight aspect, the loading limitation of six-axle truck is reduced from 55 tons to 49 tons, meanwhile 5% overloading allowance is canceled. So, 2-7 tons will be decreased per vehicle than before, and the loading capacity reduces 10% to 15%. The six-axle vehicle is required to load 49 tons, the four-axle vehicle (4x2 towing vehicle plus two axle trailer) gross weight limit changes from 35 tons to 36 tons, but using air suspension, the maximum limit is still 37 tons.

### 2.4 Developing trend of commercial diesel engine power in China

On January 6, 2016, at the business annual meeting of the joint truck, Yuchai joint impetus launched the largest, most torque, the largest truck power engine YC6K 13 in China. It is said that this engine displacement is 12.939 liter, the horsepower covers 490 - 580. It redefines the Chinese heavy-duty truck diesel power industry standard, and becomes a new benchmark.

High horse power, low speed and high torque means that the engine starts fast, accelerates fast and climbs the slope easily, this has become the direction of the development of domestic heavy truck engine, the technology of heavy truck engine has been developing quickly.

## 2.5 Tractor truck trailer – differences in configuration Europe to China

Chinese truck trailer combinations represent a very robust, but simple technical standard. Generally there is no load sensing valve used, as can be seen in the European brake layout **Fig. 4** shown below symbol " x)", so no adjustment of brake forces due to loading of the vehicle is applied. The braking force is always applied as needed for a fully loaded vehicle. This braking behavior of the trailer creates an overstretch effect, the tractor truck is drawn by the trailer and this seems to work as if the vehicle combination is stabilized against jack knifing.

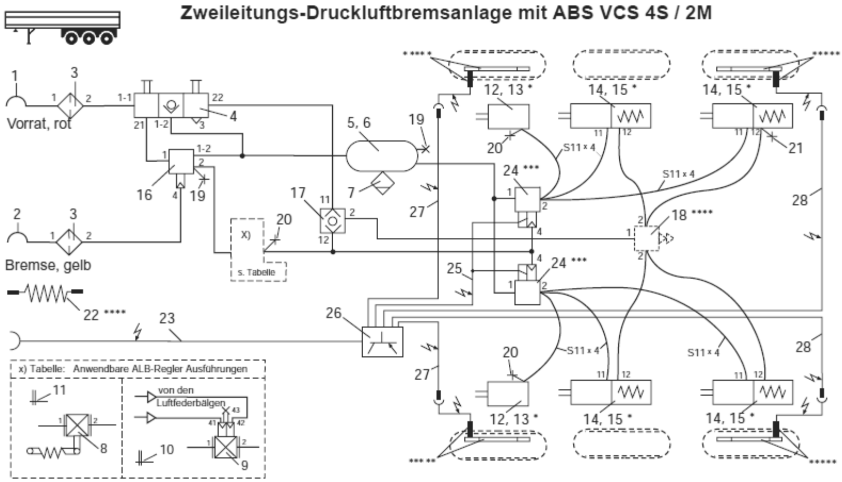


Fig. 4: Pneumatic brake scheme for 3 axle trailer equipped with ABS. European standard 2003 [5]

Additionally to this described vehicle behavior due to the widely use of drum brakes drivers are used to an under braking of the complete tractor trailer combination especially if long slopes are moved down and thermic fading takes place. So there might occur a certain risk, that the better security of the truck disc brake might be overcompensated by more aggressive driving and braking which leads to higher temperatures and so overheating of components.

## 3 European experience introducing disc brakes

The widely introduction of disc brakes took place in Europe starting in 1996 with the new ACTROS truck of DAIMLER which was equipped with 4 disc brakes at all wheel ends for on road application. In the beginning European trailers were still equipped with drum brakes and got no electronic brake system or so called EBS. The heat distribution towards the bearings due to the heat flow and radiation of the disc for different tractor truck trailer combinations and for different service conditions containing long stiff slopes in the beginning had been underestimated. This effect in the beginning has been even worse, when trailer widely had been still equipped with drum brakes, because trailer drum brakes were overheated and got heat affected fading but for the disc brake of the tractor truck the different effect occurs, the brake force increased due to the heat effected growing of the disc towards its friction pads. Also underestimated has been the effect of heating up when the tractor trailer combination was directly parked after downhill drive, the heat could not be transmitted to the cooling air and crouched slightly into all components which were heated up significantly. The increasing temperatures were prone to reduce lifetime of bearing grease or to destroy the rubber lips of the bearing sealing.

These issues had been solved in Europe or disappeared by introduction of EBS systems which adapted braking forces of tractor trucks and trailer and of course with the widely introduction of disc brakes also for trailers, so the missing fading of disc brakes is similar for tractor and trailer. And of course service tests had been developed in Europe for different tractor truck trailer combinations and using different typical downhill roads to check for the robustness of the disk brake axles.

## 4 Way to go

Since 2005, YIHE Company began the development of disc brake front axle, mainly applied in the light truck. In 2010, the production of medium and heavy truck became more and more, at the end of 2016, the disc front axle accounts for 21.75 % of the total axle products, and the trend is increasing year by year. See **Fig. 5** below.

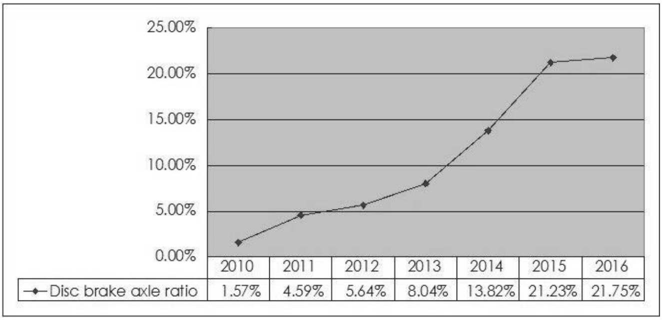


Fig. 5: YIHE output ratio of pneumatic disc front axle from year2010-year 2016

FOTON, SINOTRUCK and JAC are the most representative commercial vehicle manufacturers in China, and the proportion of disc front axle from YIHE to deliver to the above three main customers is shown in **Fig. 6**

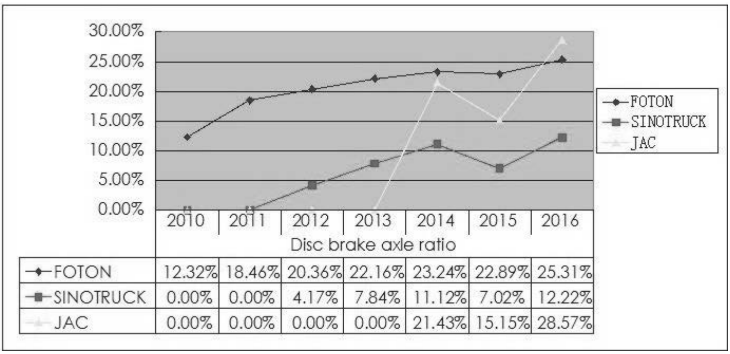


Fig. 6: The proportion of disc front axle from YIHE to deliver to the main customers from year 2010 to the year 2016

In addition, according to the statistical analysis of production and marketing data and the suppliers of YIHE company, by the end of 2016, the hydraulic disc brake front axle is 90 %, the pneumatic disc brake front axle is 10 %, the heavy truck products are all pneumatic disc front axles.

### 4.1 Future development of disc brake for commercial vehicle in China

Dustiness and corrosion prevention

The terrain of China is complex and the regional climate difference is big, so disc brake products are required to adapt to diverse environment. At the same time, the influence of users' traditional habits has to be anticipated, so higher robustness of disc brakes are required than those in Europe and America.

Lightening weight, simplifying structure, reducing cost

Only by the lightening weight and constantly simplifying the structure can reduce the cost of the product to increase market competitiveness, and also be convenient for users to grasp the basic maintenance advantages.

Development of intelligent sensing device

With the improvement of safety awareness, the intelligent braking safety has new requirements, and the electronic technology also enters the axle assembly. Electronic alarm system will be widely used by the axle equipped with disc brakes in order to prevent the brake failure caused by pad wear. It should collect the parameters such as pad wear, brake temperature etc., and then transmit it to the driver or favourably transportation company to monitor the staus of the brake.

### 4.2 Test of disc axles under service conditions and misuse

With the maturity of the pneumatic disc brake technology, it has the incomparable advantages with hydraulic pressure and drum brakes. It is the time for disc brake to be applied in the whole industry.

Many brake manufacturers and automobile manufacturers in Europe have made a comprehensive comparison test of disc brake and drum brake, the results are shown in **Table 1**.

Table 1: The comparison of performance indexes of disc and drum brake

| Content | Disc | Drum |
|---|---|---|
| Brake temp. ℃ | ≥900 | ≤400 |
| Brake factor | 0.75 - 0.80 | 2.0 - 4.0 |
| Time of friction disc change | <0.5 | 4 |
| Radiation capability | 85 | 140 |
| grinding-in mileage | <100 | >1000 |

The Chinese domestic vehicle OEs introduced equipment, checked the right conditions and so got the ability to carry out the necessary test work of disc brake front axle.

FOTON Daimler company tested the new product from YIHE Company. The following is a test of the 6.5 ton front axle of YIHE Company, equipped with KNORR-BREMSE air brake caliper, Conmet company brake disc, and KNORR-BREMSE air chamber.

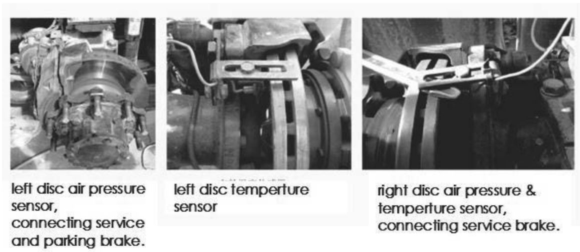


Fig. 7**:** Positioning of sensors to check brake pressure and temperature

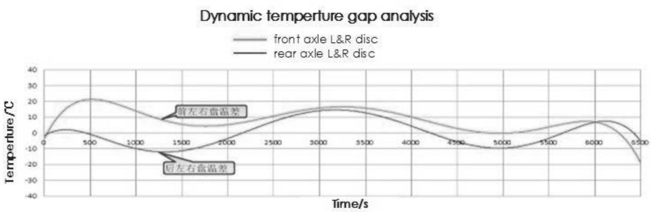


Fig. 8: Results of temperature testing – temperature differences left and right side and front and rear axles

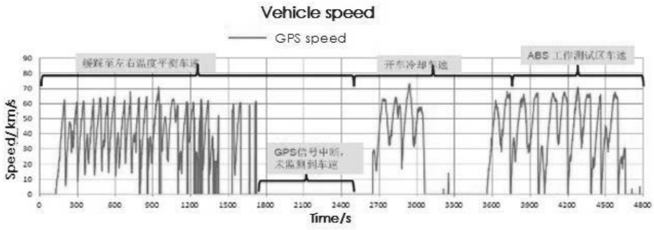


Fig. 9: Speed versus time for results of temperature testing see Fig. 8 – temperature differences left and right side and front and rear axle

The test of FOTON Daimler of the 6.5 ton disc axle from YIHE Company showed that the performance for typical service conditions could meet the relevant requirements:

- The temperature difference of the brake of the front axle is about T=20°C;
- When temperature keeps balance, the brake disc temperature is at moderate T=350°C

JAC tested the performance of the 3.5 ton disc brake of front axle from YIHE Company, including front emergency braking, rear emergency braking and heat effected fading braking.

- The temperature difference of left and right disc brake of the front axle is about T=12°C;
- When temperature keeps balance, the brake disc temperature is at T=175°C

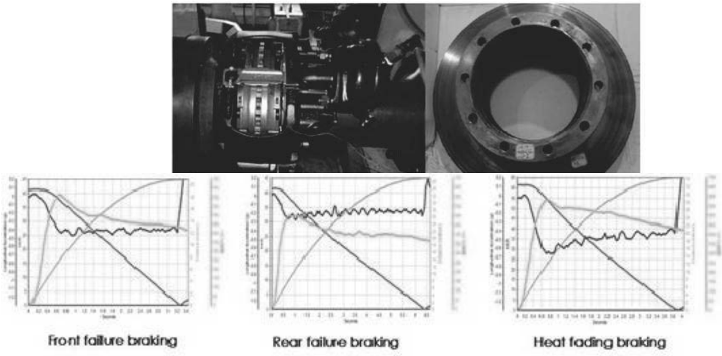


Fig. 11: JACdisc brake testing results during emergency testing test: red line speed; green line pedal force; blue line longitudinal deceleration; orange line distance versus time in seconds

With the knowledge of European experiences made with the introduction of disc brakes, specific testing has been developed and performed to check if disc brakes are able to fulfil domestic Chinese market demands. The initial tests performed under normal service conditions showed very well fit to requirements.

This testing program now has to be extended to more critical service conditions and to cover some kind of misuse. First dynamometer testing had been started using dynamometers in Germany. As one result YIHE could gain an ECE R13 type approval for its 6.5 ton disc brake axle [7].

To gain the the type approval, specific components have been developed and will be introduced into series. A YIHE disc will soon be introduced and a new YIHE hub unit for increased service life is under development and first test vehicles are tested under service conditions. After approval by more severe testing to check if also future market demands when high powered tractor trucks will drive with increased speed and so need more braking torque and dissipate more heat energy so heating up of components has to be taken into account, can be fulfilled.

Robustness against misusing is a major concern for Chinese braking application, therefore a testing program similar to the European “Rossfeld downhill misuse test” has been initiated. The YIHE Tai Shan downhill test gives similar heavy demands. In the future commercial vehicle dynamometer testing will be executed also in China - a first dynamometer capable for commercial vehicle brake testing has been erected in Dalian in collaboration with Dalian JIAOTONG University.

Fig. 12: Tai Shan mountain, Shandong province, altitude 1.533 m, prominence 1.505 m

## 5 Outlook

Chinese market participants are critical customers and aware of risks introducing new technology into their markets. Therefore they benchmarked the introduction process of pneumatic disc brakes into European truck market and started a front loading driven project to avoid issues and learn from experience suffered by the European predecessors. One result besides the practical testing programs and experiences has been the creation of an adapted product creation process leaded by the German MSCDPS® method and which now starts to harvest the first fruits in avoiding field issues and developing components suitable also for future increasing demands and world markets.

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# Development of an 8-speed Automatic Transmission for Medium-duty Trucks and Buses

## Market analysis, selection, detailed definition and comparison of concepts and rollout of a segment-optimized transmission system

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**Abstract**

Which of the many, very different transmission technologies are generally suitable and which of the variants is best suited when the task is to develop an advanced transmission system for specific vehicle segments? Which specific criteria must this system fulfill? And, once the ideal concept has been calculated, how can it be transformed into a volume production product without losing sight of strict cost objectives while still setting benchmarks in practice? To answer these and other questions, this paper discusses which actions ZF has taken so far in designing a new transmission for medium-duty trucks and buses. The first step was to conduct a global market analysis examining which transmission types will be in demand for the targeted commercial vehicle segments in the future. This analysis pointed to an increasingly strong trend towards automatic shift systems.

A further analysis confirmed that powershift technologies – in other words, torque converter transmissions (AT) and dual-clutch systems (DCT) – had the most potential to fulfill the current and future requirements of the target vehicles. Further testing using a highly complex simulation and analysis method developed specifically for this application revealed that the best results were achieved with a DCT featuring 7 speeds and a spread of 10.1 as well as with an AT featuring 8 speeds and a total spread of 7.65.

A follow-on investigation then compared how these different systems rated in terms of the key criteria, i.e., weight, installation dimensions, potential fuel consumption savings, gas engine compatibility, hybridization options and performance. To help put these results into perspective, the analysis also included a widely used automated manual transmission with 6 speeds. At the end of this analysis process, the 8-speed AT concept, with which ZF has been

setting standards for passenger cars for a long time, was confirmed as the optimum transmission for the new applications.

Based on this transmission, known as ZF 8HP, ZF harnessed maximum synergies to develop a new system for medium-duty trucks and buses which meets all specific commercial vehicle requirements. Its combination of characteristics sets a significant segment benchmark – particularly in terms of efficiency, performance, future compatibility and comfort.

**1. Market Analysis and Identifying Specific Requirements**

Similarly, the demand for manual transmissions (MT) in commercial vehicles is constantly declining – they are being increasingly replaced by automated manual transmissions (AMT) or automatic transmissions (AT). According to ZF prognoses, this applies in numerous, large-scale market regions and especially for medium-duty trucks: In NAFTA countries, for example, the AT installation rate is predicted to increase to almost 100 percent in this segment by 2025; in the EU, this figure is set to rise from 40 percent today to around 90 percent during the same time. On a global scale, this figure is expected to rise by 30 percent to over 50 percent. A similar phenomenon is predicted for buses: If the current trend continues, by 2025 no more manual transmissions will be fitted in new vehicles.

Within the increasingly growing AT/AMT segment, those transmission types which shift gears without tractive force interruption will emerge most strongly due to the continually higher demands in various different criteria. Among other aspects, the comfort generated by power shifting (which has always been an elementary feature in North America) will become an increasingly decisive factor in Europe and Asia, too, while also ensuring maximum efficiency.

As a consequence, the question arises which of the various powershift transmission concepts is most suitable for the targeted commercial vehicle segments – particularly in view of the fact that, globally, the medium-duty truck and bus market segments generate comparatively low market volumes. Another factor is the extreme price sensitivity of the market for small and medium commercial vehicles. Therefore we must respond to the demand for an advanced powershift solution with an overall cost-efficient transmission concept, which can be rolled out with preferably low-budget development costs and, as a consequence, low product costs. Hence there is the need to fulfill all the specific requirements of particular applications – from pickups, light- and medium-duty trucks to buses and special vehicles – based on one single concept: Preferably, this must be simple to adapt to the specific model, ideally by leveraging maximum synergies from existing transmissions and offering the potential to fulfill all the essential criteria in practice without exception.

For the vehicle segments under review, the most viable transmissions available are therefore the dual-clutch transmissions (DCT) of a countershaft design or the torque converter automatic transmissions (AT) of a planetary design.
An extensive ZF analysis examined both the DCT and torque converter AT transmission concepts and evaluated how effectively these concepts met the global key requirements of commercial vehicles. Accordingly, the study not only focused on criteria such as robustness and comfort, but also on the potential reduction of fuel consumption and $CO_2$ emissions in all relevant cycles. One important aspect in this context was to examine the feasibility of hybridization, extending to all-electric driving down to the so-called "last mile." Another issue to be clarified was which transmission design contributes most significantly to improving both comfort and performance – by power shifting, preferably in all gears and also when skipping gears. Finally the study also closely examined what was the best way to increase the power-to-weight ratio and the permissible input torques with a view to future engine generations and which system proved the most flexible and easy-to-use at handling commercial-vehicle-specific challenges such as the design of power take-offs and compatibility with gas engines.

## 2. Concept Study – Evaluation of Different Transmission Concepts for Medium-duty Truck and Bus Applications

In addition to defining the aforementioned analysis criteria for the torque converter AT and DCT powershift technologies, a detailed comparison of the systems currently available on the market was also made, which also included automated powershift transmissions. The section below outlines the key findings and results of this analysis which are relevant for the target segments.

AMTs are seen as the state-of-the-art transmission for heavy commercial vehicles, particularly in Europe. These are predominantly transmissions with fully integrated mechatronics, while automation systems based on existing manual transmissions are still widely spread on emerging markets. However, only the first generation of automated transmissions for light commercial vehicles in the van category had been realized with AMTs, which were primarily actuated electromechanically or electro-hydraulically. Already the second generation of these vehicles completed the shift in concept from manual to full powershift transmissions. Based on developments in the passenger car sector, torque converter stepped automatic transmissions soon became extremely successful in these vehicles. AMTs have virtually disappeared from the market in this segment.

6-speed AMTs have established themselves today in the medium commercial vehicle segment (in the 7.5 to 18-ton category). Depending on the requirements at hand, these transmissions usually feature a spread of approx. 10 for vehicles with a maximum gross combination weight (GCW) of 26 tons. These systems are usually closely associated in design with the manual transmissions available in this class.

9-speed and 12-speed AMTs with a total spread of approx. 12 are primarily used for the moderate volume segment of midrange vehicles with a higher total vehicle mass of around 36 tons (incl. trailer). On account of the low quantities produced for this segment, these are mainly manual-transmission-based AMTs. This segment alternatively uses transmissions taken from the heavy-duty segment. Specific developments usually prove to be financially unviable. For this particular comparison of transmissions, on account of its highest volume total, an existing electro-hydraulically operated 6-speed AMT with a maximum permissible engine torque of 1,100 Nm was used – as designed for vehicles with a GCW of up to 26 tons.

## 3. Detailed Study of the Torque Converter Automatic Systems

The torque converter AT based on a planetary gearset architecture is particularly widespread on the North American market. Their predominant features include an impressive comfort, wear-free launch and a high performance. Depending on the application, systems with either 5 or 6 gear steps are used in the target segments. In Europe, this type of transmission was mainly restricted to special applications for municipal services, such as buses, refuse trucks or fire engines. The field of search examined in this study covered torque converter ATs ranging from the popular 6-speed designs with 3 gear sets and 5 shift elements to 12-speed systems with 5 gear sets and 7 shift elements.

Because of the broad range of possible solutions, complex, highly developed algorithms programmed on computing clusters were deployed for transmission synthesis and result evaluation.

Using multi-criteria optimizations, the results were optimized in order to better fulfill the specifications and analyzed using an automated benefit analysis. To identify a transmission concept which delivers a clear increase in customer benefits, it was first necessary to conduct a more detailed analysis of vehicle applications in which the transmission is intended for use. Besides specifying the number of clutches, brakes, gear sets, etc., the number of gears and the required spread are also important benchmarks. Prior to the synthesis, the application was also examined for its sensitivity with regards to the step range, spread and number of gears. The results confirmed that the increase over 8 gears and the rise in spread over 8 offers few benefits in terms of fuel consumption.

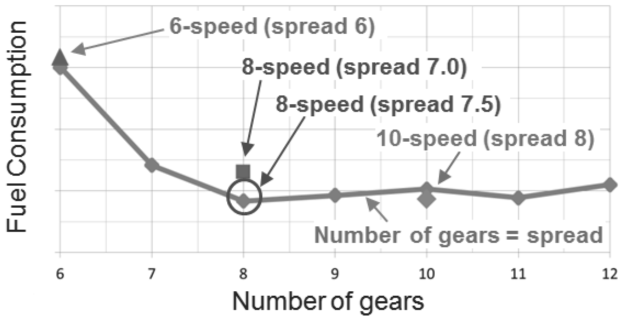


Fig. 1: Variation of Spread and Number of Gears

The above-mentioned search field with a maximum of 5 gear sets and 7 shift elements produced a virtually endless range of possible solutions, which is why this analysis prompted new strategies: The implemented solution originally involved launching a conventional global search for multi-gear transmissions with relatively broad search conditions. This analysis was restricted in scope by adding a downstream calculation process with target specifications for boundary conditions specific to commercial vehicles.

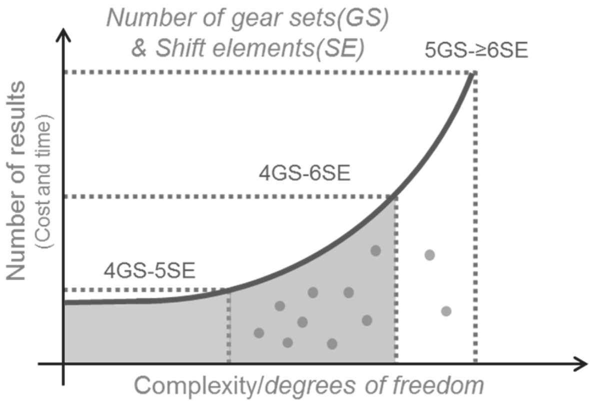


Fig. 2: Rise of Possible Results Depending on Degrees of Freedom

The second aspect involved applying limited search fields, which considerably restricted the system limits, allowing only "viable solutions" to be identified.

A third aspect was to use a so-called structure search where parts of the gear set are preset. This reduced the synthesis results to just a few hundred versions, which could then be categorized into concept families. The supporting and speed factors were then evaluated. The design feasibility regarding the arrangement of shafts and bearings and the hydraulic accessibility of shift elements was evaluated as well. The desired characteristics of the best concepts were then calculated based on operational stability criteria and transferred to a design draft. The next step involved categorizing the transmissions according to their expected efficiency and fuel consumption, drivability in the particular overall vehicle as well as costs. To evaluate consumption and the resulting emissions most effectively, it was and still is necessary to be aware of the efficiency of components installed in the driveline early on in the process.

To do this, the specific losses of all transmission components were programmed into one computational model. In this way, both the measured characteristic maps and other computational models which had been compared in advance could be integrated into the simulation. The non-load-sensitive losses and load-depending efficiency values generated by the gearing and pump design were then integrated as characteristic maps into the process simulation. Especially the gearset concepts featuring more than 8 speeds at first seemed to confirm advantages – if only slight ones – by reaching consumption-optimized areas of engine characteristic maps. However the higher drag torques caused by the additional required gear sets and shift elements eliminated these advantages. Furthermore, the losses caused by the friction of rotary units and the hydraulic loss for additional shift elements also had negative effects.

The key finding from the specific AT part of the study identified that the ZF 8-speed concept, already used in passenger cars and light commercial vehicles also proved the most suitable transmission in this case: No other transmission concept achieved a higher spread and better level of efficiency with the same number of shift elements and gear sets. A further increase in the number of gears would only result in increasing the number of components and the installation dimension requirements of the transmission. This means that the ZF-internal transmission concept named ZF-PowerLine for new applications is, with regard to its efficiency and cost-benefit ratio, considered the current segment benchmark for torque converter ATs. It is therefore ideal for further comparisons with other established technologies.

| | Shift elements | | | | | Ratio | Phi |
|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | | |
| 1 | X | X | X | | | 4.889 | 1.566 |
| 2 | X | X | | | X | 3.123 | 1.536 |
| 3 | | X | X | | X | 2.033 | 1.240 |
| 4 | | X | | X | X | 1.639 | 1.292 |
| 5 | | X | X | X | | 1.268 | 1.268 |
| 6 | | | X | X | X | 1.000 | 1.205 |
| 7 | X | | X | X | | 0.830 | 1.299 |
| 8 | X | | | X | X | 0.639 | 7.651 |
| reverse | X | X | | X | | -3.757 | -0.760 |

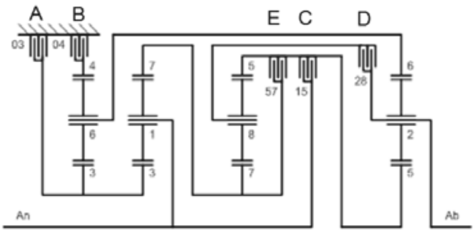


Fig. 3: 8 Speed AT Gear Set Concept

## 4. Analysis of Automatic Transmission Systems on Dual-clutch Basis

DCTs with wet or dry dual clutches have gained popularity over the years primarily in the European passenger car sector. Such systems have since been rolled out in volume production on the commercial vehicle sector as well, with 6 speeds proving to be sufficient for light trucks. Similar to the previous evaluation of the ATs described above, this evaluation of the DCT focused on searching for a particular gear set to identify the ideal transmission design for a system of this type in light and medium commercial vehicles.

In the case of transmissions with ideal progressive step range, the investigation into the optimum number of gears and spread resulted in 7 transmission stages with a total spread of approx. 10. A transmission synthesis tool, programmed especially for this task, focused spe-

cifically on gear sets with 6 to 9 gears. These gear set designs were then sorted in advance, and their desired characteristics were calculated as mentioned above and transferred to a design draft.
The percentage of loss was then determined, taking into account hydraulic, electromotive and pneumatic principles required to generate actuation energy. The analysis results revealed that the best model was a dual-clutch concept featuring 7 speeds, a virtually ideal progressive step range with a spread of 10.1 as well as a wet dual clutch with hydraulic control.

As a result, the following concept comparison features a torque converter 8 speed AT and a 7-speed DCT. To classify the results more clearly, the currently most widely used 6-speed AMT was also included in the comparison. The comparative results specifically for commercial vehicles are explained in terms of their key criteria in more detail below.

## 5. Comparative Evaluation Based on Priorities Specific to Commercial Vehicles

For vehicles of this class, it is obvious that the main priorities are weight and payload reserves. The weight-optimized design of the dual clutch meant that the DCT could record a weight advantage over the AMT. Both concepts were however confronted with the excellent power-to-weight ratio of the AT planetary transmission concept, which therefore proved the clear winner in this criterion.

In the criterion of installation dimensions, the most relevant aspects are transmission length, ground clearance and especially the so-called "showroom," i.e., the area above the chassis. A preferably low integration effort as well as the option of realizing power take-offs and different all-wheel drive concepts are also part of this evaluation category. The study found that all concepts could in principle meet the installation dimension requirements. Both powershift transmissions however proved to be slightly longer than the AMT; this additional length was attributed to the dual clutch on the DCT and the additional space required for the power take-off locations on the AT. None of the examined powershift transmissions however exceeded the length of today's 9 or 12-speed AMT transmissions which are also used in the target vehicles.

In terms of efficiency, not only is the fuel consumption recorded by target vehicles with the particular transmission in realistic cycles decisive; it is also relevant for the evaluation for the pending $CO_2$ certification. For this reason, a variety of applications and tonnages were simulated with each driveline configuration on a variety of actual routes. The ACEA profiles specified for the certification were also included in the virtual evaluation. The necessary shifting strategies were adapted to each specific transmission so that different driving modes, such as "eco" for a very economical and "power" for a power-oriented driving style, could be studied. To compare the consumption results effectively, it was however important to ensure a simulation with equal performance, which means: Each transmission concept must complete the preset cycle in the reference vehicle with the same driving duration and speed, respectively. Here the DCT could not fully achieve the reference consumption values set by the AMT as the current industry leader. Besides drag and shift losses of the dual clutch, another disadvantage was due to the bearing losses of the countershaft gear set. Due to the additional torque magnification within its converter, the automatic transmission concept was able to distribute the 8-gear steps on a smaller spread range than that which transmissions with friction clutch offer. This generated a small single-step range of gears and, opened up the path to efficient fuel map areas of modern combustion engines. In this case, the 8th gear was also designed as a double overdrive. This helped to lower the engine speed at higher vehicle speeds, which considerably reduced the consumption, especially in mixed operation (e.g., extra urban). It also showed that modern automatic transmissions have advanced significantly with the help of sophisticated software functions – the aspects of neutral idle control at stop, torque converter lock-up and shifting strategy are particularly worth mentioning here. One key factor which contributed to efficiency is the high-performance hydraulics system with vane cell pump, which has been optimized in terms of leakage behavior, pressure management and the frictional behavior of individual components. Shift elements with systematic multidisk separation also help to reduce consumption.

In so far as alternative fuels are concerned, the gas engine represents an efficient technology capable of reducing nitrous oxide and fine dust in urban areas. However, related to the driveline, the sluggish responsiveness of these types of units is a disadvantage. In conjunction with AMTs and their tractive force interruption, this caused minus points in terms of drivability and performance. In contrast, the powershift transmissions proved themselves as perfect partners.

The aspect of electrification should be monitored depending on the primary operating area of the vehicles: In urban traffic, for example, all-electrically powered vehicles will definitely be used more frequently. For commercial vehicles with a mixed application profile, i.e., with a significant percentage of highway share, a hybrid drive is available (based on economic efficiency criteria), which covers only the urban "last mile zero emission zone" in urban traffic in all-electric mode. In this respect, future transmission concepts must be suitable for effective and, above all, cost-efficient hybridization. As seen from the concept perspective, however, the integration of an electric engine in the DCT transmission is comparatively more complex and means that more installation space will be required. The AT hybrid transmission has virtually identical installation requirements, as the electric motor is installed in lieu of the torque converter. Its modular approach also enables the installation of an ISG (integrated starter generator) with boost, while the previous hydraulic control unit can still be used.

The performance criterion focused, among others, on the aspects of acceleration, suitability for fast shifting and the option of skipping gears. One final point worth mentioning is the demand for fast multiple downshifting specifically in urban traffic, when the transition from cruising in traffic with very low engine speed to sudden accelerations due to traffic conditions must be performed satisfactorily. Since the next precalculated gear must always be preselected in the dual-clutch transmission, the spontaneous change of driver's requirements can sometimes produce circumstances which cause an uncomfortable delay in shifting. Skip shifting is not always possible due to the large jumps in gear steps and the resulting load on the synchronizers. In terms of the acceleration values however, both powershift concepts – DCT and torque converter AT – offer a considerable advantage in contrast to today's AMT. The lower a vehicle's motorization, the more positive the effect on performance.

## 6. ZF-PowerLine – Study Results Transformed into a Product Innovation

The study results were decisive in convincing ZF to develop a new 8-speed torque converter AT specifically for medium-duty trucks and buses. Under the product name ZF-PowerLine, which is a continuation of the internal concept name 8AP, it distinguishes itself in crucial points from other torque converter ATs, DCTs and AMTs which have previously been available in these segments. Compared with the reference AMT, it can lower fuel consumption by up to 3 percent and increase efficiency by up to 10 percent in comparison to the current, widely spread torque converter AT with 6 speeds. At the same time, it accelerates trucks by approx. 25 percent faster from 0 to 60 km/h. Weighing 150 kg, it also defines new standards in terms of power-to-weight ratio. Other attributes include good drivability, a variety of assistance functions and its suitability for gas engines as well as hybrid drives.

The realization of all these aspects within the ZF-PowerLine presented major design challenges. The objective was to leverage as many synergies as possible from the ZF 8HP and incorporate them into the new transmission. The latter describes the passenger car AT which is already being used in millions of vehicles and which was the foundation for the new transmission; for many years, it has been setting standards for the automatic transmission in passenger cars. The 8HP gear set concept with four planetary gearsets and five shift elements delivers a high total spread of 7.65, which also helps to reduce fuel consumption.

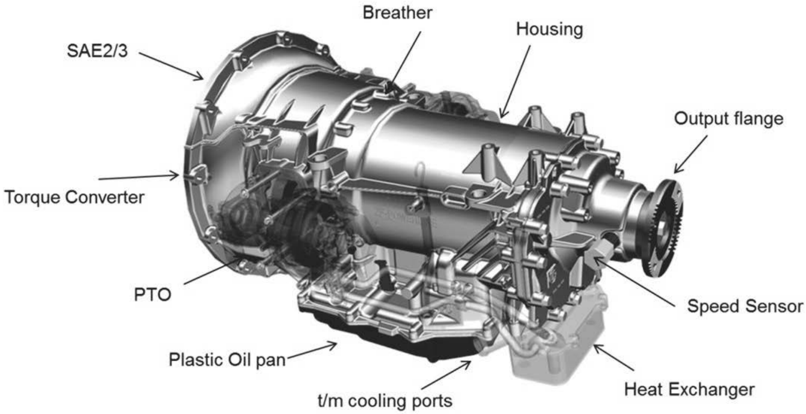


Fig. 4: ZF-PowerLine 8 Speed AT

However, in an unchanged state, the 8HP could not be adapted for medium-duty trucks and buses. All transmission components subject to mechanical loads had to be designed with larger dimensions. This was the only way of achieving the target of using the ZF-PowerLine for engines with a power of up to 1,400 Nm while keeping it fit for a mileage of up to 600,000 km. It was possible to adapt the 8HP mechatronics module, although commercial-vehicle-specific modifications had to be made. On-board supply systems with 24 V, as found in Europe, Asia and South America in trucks, additionally require a suitable 24 V TCU (transmission control unit). Due to the enlarged shift elements and a new torque converter, the hydraulics module was also modified.

As a completely new feature in comparison with the 8HP, the ZF-PowerLine offers the option of installing an oil-water cooler directly on the transmission housing. Power take-offs (PTO) for up to 650 Nm in single mode are available as an extension for tipper hydraulics, snow plows and spreaders. An automatic transmission brake can also be extended. In terms of the

GCW, a maximum of 36 tons is possible with the ZF-PowerLine for special applications with trailers.

A multicore TCU is responsible for the control of the ZF-PowerLine, whose software originated in the passenger car segment. Thanks to the shift-by-wire concept, there is no mechanical link to the interior. Endowed with various shifting strategies, selectable driving modes, CAN communication and diagnosis tools, the ZF-PowerLine also deploys passenger car functions which are supplemented with special solutions for commercial vehicles. For example, the NIC (Neutral Idle Control) is an additional function available for reducing fuel consumption: Whenever the vehicle is stationary, the transmission system opens a clutch, reducing the drag torque. The fuel saving from this measure alone is between 1 to 2 percent. The stop/start function, which especially places high requirements on the transmission's oil supply, enables considerable increases in efficiency of up to 5 percent.

Special control functions were also developed for PTO operation in the commercial vehicle applications. The ZF-PowerLine can also be equipped with an electronic Hill Start Assist for added comfort and safety. The adaptive cruise control (ACC) also provides driver assistance coupled with enhanced safety. Last but not least, the ZF-PowerLine also supports high-performance emergency braking assist systems.

## 7. ZF-PowerLine: Summary and Future Prospects

Whether in terms of performance, shift quality, efficiency or functions and comfort features: By transferring automotive standards in certain commercial vehicle segments, the ZF-PowerLine is setting a new benchmark with its combination of characteristics. It also offers the option of including all the special features and extensions relevant for medium-duty trucks and buses. According to current plans, volume production is scheduled to start in the 1st quarter of 2020. The hybrid capability of the ZF-PowerLine offers further significant potential for fuel consumption reduction – especially because here a powerful electric motor can be integrated with relatively little effort.

# Holistic Simulation Tool for the Commercial Vehicle Powertrain Development

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**Abstract**

In the near future, the commercial vehicle sector will be faced with more stringent emission and greenhouse gas ($CO_2$) standards as well as high customer requirements regarding total cost of ownership. These challenges can be met with different approaches and technologies, for example by incorporating Waste Heat Recovery (WHR) system applications. A WHR system makes use of the Organic Rankine Cycle (ORC) to recover part of the wasted exergies, which is particularly interesting for heavy duty vehicles operating most of their time at high loads and constant speeds. Other vehicle types can benefit from hybrid powertrain approaches. This highlights that a detailed pre-analysis, based on computational simulation, of the systemic boundary conditions is a prerequisite for the specific concept decision and integration of such an application.

Within this paper, an integrated simulation model will be presented, which is - in the field of commercial vehicle and powertrain development - a part of the holistic research approach pursued by the *FEV Europe GmbH* and the *Institute for Combustion Engines of the RWTH Aachen University (VKA)*. The simulation model includes the vehicle itself and its subassemblies and can perform transient simulations using any drive cycle which is of interest for the specific application. Besides presenting the holistic simulation model, fuel consumption reduction potentials within the commercial vehicle segment, like Waste Heat Recovery applications, will be shown.

**Introduction**

The continuous growth of the industrial sector worldwide over centuries created a soar in energy demand which has found a satisfying supply in fossil fuel. According to a recently published OECD-study, nearly 30% of $CO_2$ emissions in 2014 came from the transportation sector, surpassed only by the electricity and heat sector [1]. Contrary to the heat and electricity production, the transport sector has not yet undergone a thorough optimization and there is potential to do so in a short timeframe due to the relatively short vehicle design lifetime. It thus represents the ideal sector to act on, not only due to its relatively small inertia, but also to the simple financing through indirect taxation covering technological costs directly by buyers.

Following the above order of priorities, in the frame of the “2050 low-carbon economy” policy, the European Union (EU) targets a reduction of 60% below 1990 levels of $CO_2$ emissions by 2050 [2], but no regulation has currently been enforced concerning heavy-duty vehicles (HDV), which are major contributors to the $CO_2$ emissions. That there is a need for far-reaching efficiency improvements of the EU’s HDV fleet is shown in Figure 1:

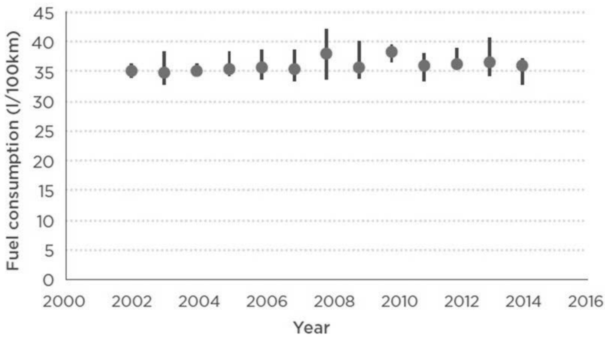


Fig. 1: Fuel consumption trends for tractor-trailers in the EU from 2002 to 2014 [3]

The picture points out the annual average fuel consumption and therefore, the efficiency trends of representative tractor-trailers. Although the tailpipe emissions have been significantly reduced over that period, it is obvious that efficiency improvement has stalled in recent years [3].

Due to the wide variety of vehicle configurations on the HDV market, determination of total energy consumption and $CO_2$ emissions via test bench measurements is expensive and time consuming. Therefore, computational simulations are a compulsory part of the development procedure for state-of-the-art and future HDV powertrains. Advanced simulation models are able to handle the complexity of the systems to be considered, although the models and control strategies need to be set up at considerably greater expense and much greater complexity. For this reason, the *FEV Europe GmbH* and the *Institute for Combustion Engines*

(*VKA*) of the *RWTH University* developed a holistic simulation model, which is able to cover all disciplines of vehicle engineering with the aim to improve their overall system concept regarding the upcoming $CO_2$ certifications.

## $CO_2$-Trends for Heavy Duty Commercial Vehicles

In contrast to the passenger car development, the commercial vehicle development is strongly driven by costs and less by emotions. Furthermore, the derivatives of commercial vehicles are more diverse compared to those of passenger cars. This is caused by specialized requirements for a smaller total number of vehicles sold. A further drive for development are the interests of the commercial vehicle operator, who is - among other things - interested in low fuel consumption in order to obtain low total cost of ownership (TCO). The share of fuel costs of 30%, which is even above the wage costs of the drivers, illustrates the huge influence of the vehicle's fuel consumption level on manufacturers and operators [4]. The currently rising pressure from the worldwide upcoming GHG reduction legislations, however, requires a faster development in this area, which makes the new legislation standards a big drive for technology development in the field of HDVs too. The $CO_2$ legislation requirements for commercial vehicles vary from region to region regarding their time frames and target values. Current GHG emission limitations can be found in the USA and Canada, China and Japan.

In the EU's HDV sector, there are currently no legislation requirements for $CO_2$ emissions in force. For this reason the European Commission (EC) started examining potential legal guidelines for lowering the $CO_2$ emissions from HDVs in 2006. On this basis, in 2009 the effort to develop a type approval protocol for a $CO_2$ certification was launched by the EC. Due to the diversity and specific characteristics of the HDV sector, the certification procedure is a combination of component testing and simulation modelling with a simulation tool named *Vehicle Energy consumption Calculation Tool* (VECTO), which was commissioned for this purpose. Results along with this monitoring will then be the basis for future legislations and the release of this procedure is scheduled for the 2017 to 2018 time frame [3]. The simulation tool VECTO is based on vehicle longitudinal dynamics with specified input data for the vehicle and engine characteristics. A library consisting of vehicle components is set up for the required input data. These components are added in all possible design variations with their relevant properties to the database in form of characteristic maps [5].

VECTO will play a major role in terms of reporting and monitoring $CO_2$ emissions from HDVs in the future in the EU, but it cannot replace detailed simulation models. In the following chapter the holistic HDV simulation platform, developed by *FEV* and *VKA* will be introduced. The importance and functionality of this tool will be described with two specific case studies: exhaust aftertreatment (EATS) and WHR simulation. These examples were chosen because these technologies are not part of VECTO and must be simulated with advanced external tools to give a detailed prediction on their impact on fuel consumption and $CO_2$ emissions.

**Holistic HDV Powertrain Simulation Concept**

The holistic simulation platform for HDV powertrain simulation is based on established software products in the automotive industry like GT-Suite and MATLAB/ Simulink, which can be linked via co-simulation. The core principle of the modular structure is given in Figure 2. The main platform is structured into five sub-categories: Driving strategy, controls, base powertrain with the sub-level thermal management and new technologies. Due to its flexible structure and the precise definition of interfaces between the sub-categories and the modules itself, each category can be exchanged and expanded easily. This offers the possibility to choose customized modules according to the given requirements. Depending on customers’ needs a pre-defined sub-model can either be fed with detailed data, which leads to fully calibrated and validated models, or physically based models can be chosen instead. This principle leads to an extensive library of tailor-made simulation model solutions.

Considering the vehicle model as starting point when simulating the drivetrain, two main modelling procedures can be defined: the forward and backward calculation method [6]. Both model types are available in Simulink and were chosen according to the available input data. The forward model with its driver module - represented by a PID-controller - is very detailed and therefore needs a lot of input data, like transmission efficiencies, coast down curves or miscellaneous inertias. If this data is not available the simpler backward model, with a pre-defined and fixed shifting strategy, can be chosen to at least simulate first predictions. Furthermore, Figure 2 also shows, that the vehicle model makes use of the sub-models from the “Base Powertrain” as well as from the “Driving Strategy and Controls” category.

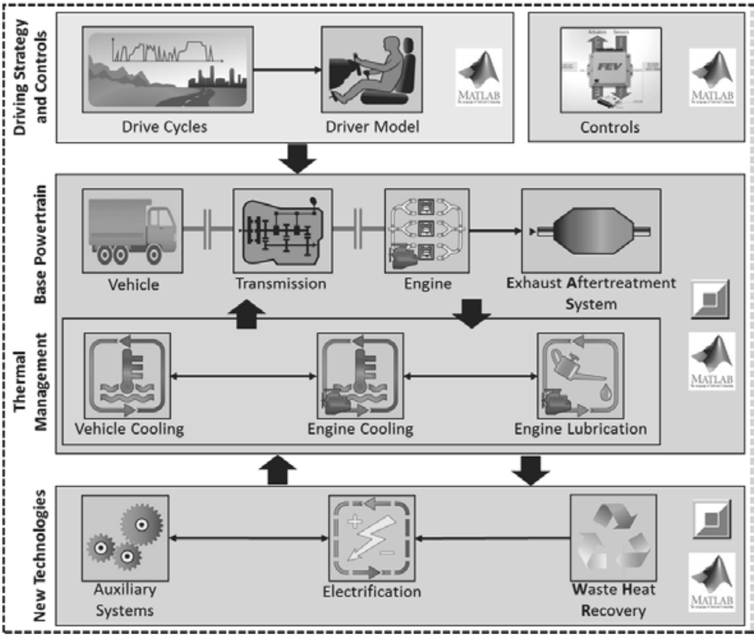


Fig. 2: Holistic simulation model with subassemblies and internal interfaces

The route and speed information, which are converted into speed and torque requirements by the vehicle model are fed into the engine model. Similar to the aforementioned options for the vehicle model set up, different degrees of detail can be offered for the engine model and integrated into the simulation platform via their defined interfaces. First of all the engine models can be categorized into physical and mathematical models. The physical models include in-house developed physically based mean-value engine models (MVEM) and GT-Power engine models. The latter are a powerful tool for gas-exchange calculation and show very precise simulation results, however simulating transient cycles is only possible, if detailed combustion data from the test bench is available. Since this is not always the case, physical engine models based on MATLAB/ Simulink with a varying degree of detail have been developed. As the nature of the *FEV* MVEM is physical based, it provides the user the consideration of a wide variety of real driving conditions, like for example ambient conditions (high altitude, low temperature), different driving styles and shifting strategies [7]. Furthermore, the mathematical model methodology is able to scale engine maps based on a set of base engine parameters. Its biggest advantage is the fast availability of simulation results. The comparison of all models available is given in Figure 3:

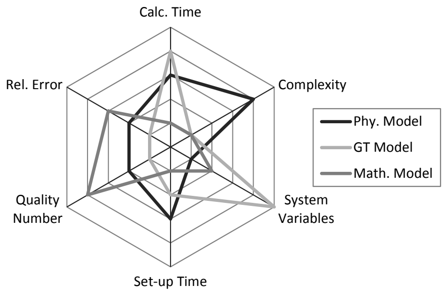


Fig. 3: Qualitative comparison of the three different model approaches [8]

The developed EATS models, which get their input form the engine models described before, consist of two parts. The physical calculation of thermodynamics and flow mechanics is responsible for the temperature and kinetic behaviour of pipes, canings and bricks. The chemical calculation of transfer-reactions, including the adsorption and reaction mechanisms inside the catalytic layers considers the conversion and formation of the involved emission species. Each component can be interpreted as a multi-dimensional geometric part in axial as well as in radial direction.

Another important point, especially with regard to a detailed general overview on the powertrain, is the simulation of the vehicle, as well as engine cooling and lubrication system. These modules, according to Figure 2, belong to the sub-category thermal management and are simulated in GT-Suite. These models have been classified into a separate sub-category, since a detailed thermal analysis is not necessary for every base powertrain application. But the other way around, a thermal management analysis can also be performed independently from the overall model, if the relevant input data is available. Nevertheless, the availability of thermal models is very important, especially with regard to the integration of new technologies and their additional cooling requirements.

In the future, the sub-category “New Technologies” will become more and more important and as currently such case studies cannot be investigated with VECTO, alternative simulation methods must be developed to assess the efficiency of these applications. A first step in this direction can be achieved with the analysis of the need-based controlled auxiliary units, which demand a specific degree of electrification. One example of the research activities of *FEV* and *VKA* in the field of HDV hybridization is given in [9]. This is an example for the use of the forward method within vehicle simulation of advanced hybrid powertrains for commercial vehicles. Figure 4 shows the model structure for range extended electric vehicles (REEV) with internal combustion engine (ICE), where special focus is put on the operation strategies:

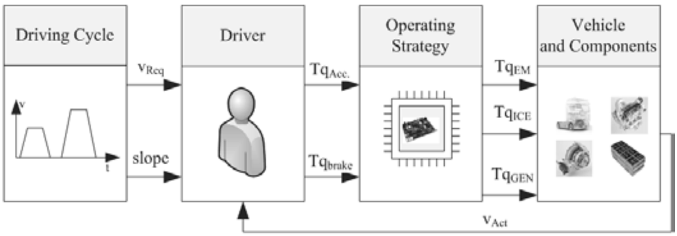


Fig. 4: Forward facing simulation model for REEVs with ICE [9]

The speed and slope data of the given drive cycle is the input for the driver model, which requests a torque determined by the driving resistances of the vehicle. According to defined operating strategy, the torque request is distributed to the electric traction machine, ICE and generator. The battery and fuel cell, which are also integrated in the overall concept, supply the system with energy. All components, which are either based on physical effects or lookup tables, have been calibrated with vehicle and component measurements. [9]

As the requirements and model complexities tend to increase in the future, coupling the software according to the aforementioned approach is limited, to keep acceptable simulation runtime. Furthermore, the possibility to exchange models between multi-disciplinary engineers and scientist is a challenge. For this reason advanced future solutions to handle this issues are needed and can be found with the platform xMod$^{TM}$, which is an open multi-model integration and co-simulation platform, using of different languages and tools and works with different entities [10]. The platform structure is given in Figure 5:

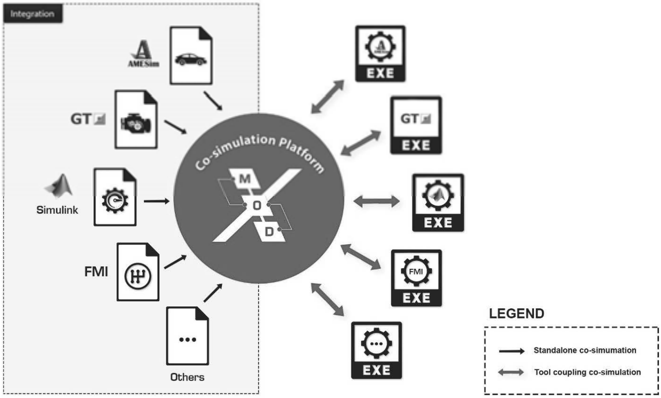


Fig. 5: xMod™ co-simulation platform

In late phases of a development process, the next step is the substitution of sub-models by a real component (hardware in the loop (HiL) testing). This is already considered within xMod™ with the help of a direct link between model in the loop (MiL) and HiL applications.

## Exhaust Aftertreatment System Simulation

The SimEx component toolbox provides various parts for simulation of exhaust aftertreatment systems such as pipes, sensors, dosing systems, catalysts, particulate filters and valves. From these components, the EATS layout can be composed. The interface between all components consists, apart from control signals, on a virtual exhaust gas mass flow including all relevant information on temperature, pressure, mass flow and the different concentrations of emission species. Figure 6 shows an exemplary layout used in most of the heavy-duty applications today. Virtual sensors provide the opportunity to connect control structures directly to the plant model to consider different strategies very easy. Apart from the simulation of these strategies, also signal manipulation is available for the test and development of diagnostic monitors.

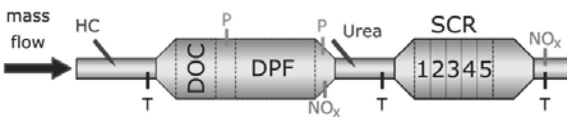


Fig. 6: SimEx Exhaust Aftertreatment System Model

While the EATS and its control strategy are of utmost importance for the design of the complete powertrain, the VECTO tool mainly concentrates on the engine performance. Therefore, detailed analyses on the impact of different EATS approaches are not possible. The SimEx toolbox as part of *FEV*'s holistic powertrain simulation environment is intended to fill this gap. Close coupling to the engine out emission optimization, the operation of the whole system will be investigated towards its capabilities regarding emission reduction and fuel saving.

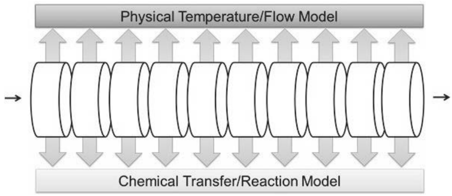


Fig. 7: SimEx slice-based calculation

The original SimEx architecture design is based on quasi-1D approaches, which separate all components into slice-based subparts. Figure 7 pictures the relationship between the physical and the chemical models. The temperature distribution, as well as the presence of reaction partners, can be modelled very detailed. In combination with a slice-wise execution order, the results achieve very good accuracy, especially in the highly active frontal area of the catalyst. Figure 8 shows the accuracy of the SCR model in a transient vehicle cycle.

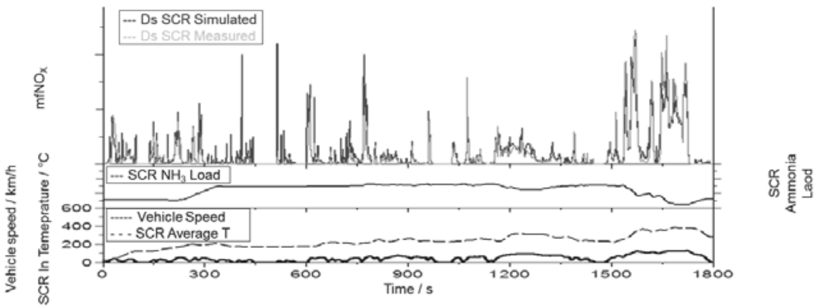


Fig. 8: Simulation results MVEV and SimEx

This deep knowledge of the systems behaviour is prerequisite for the optimization of the control strategy. One example for such an optimization is shown in Figure 9. The $NO_X$ emission could be reduced up to 20% nearly without any drawback on PM and FC.

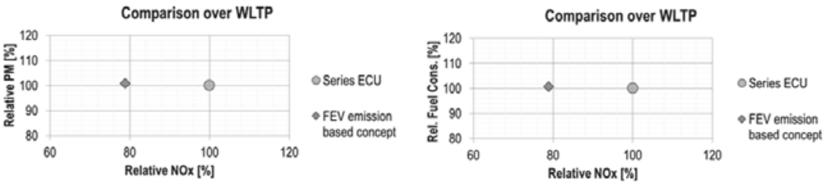


Fig. 9: Simulation results MVEV and SimEx

Another advantage of these advanced models arises from the link to investigations of more sophisticated technology like e.g. Waste-Heat-Recovery.

## Waste Heat Recovery Simulation

Due to its modular structure the holistic simulation platform can be prepared for a case study with an integrated Organic Rankine Cycle, the layout is given in Figure 10:

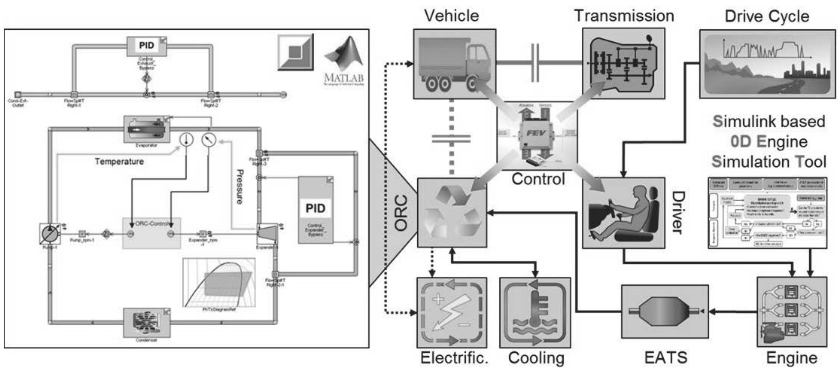


Fig. 10: Holistic simulation model (right) with integrated ORC (left)

The Organic Rankine Cycle differs from the traditional Clausius-Rankine Cycle in the use of the working fluid. In the traditional cycle water is used, whereas the ORC uses a higher molecular weight organic fluid. Analysing the system for a 6-cylinder 11L HD on-road engine, ethanol was found to be an appropriate fluid, taking the thermodynamic and economic issues into account. The 1D ORC simulation model is built up in GT-Suite, whereas the evaporator and parts of the control system are modelled in MATLAB/ Simulink and are coupled with GT-Suite via co-simulation. The evaporator model is based on the finite volume approach, which is powerful and robust, but has higher computational effort. Due to the dynamic length adaption it additionally follows the theory of the moving boundary method. One further important component of the process is the expansion machine. For that reason a dynamic ORC expander assessment matrix was developed to evaluate different expander types. The displacement type expanders – especially the piston type – showed advantages with ethanol as fluid and mechanical coupling with the engine and are thus investigated first. With a higher degree of electrification within HDVs in the future, an electrical coupling will also be possible. To guarantee a safe and optimal operation a detailed control strategy must be developed. Currently the ORC control includes a temperature and pressure control as well as various off-design strategies. Both control parts consist of a feedforward control in combination with a PID-controller. The optimal temperature and pressure curves are determined offline with a design of experiments (DoE) methodology, based on an additional MATLAB ORC tool.

The ORC model is able to perform steady-state and transient simulations. For the design process the so-called VECTO Long Haul Cycle was chosen for this analysis [11]. The cycle input is given as a velocity and slope information over a specific time period. The conversion of cycle information into speed and torque output, which is required by the engine model, is performed by the vehicle model. The vehicle model, which was used for the analysis presented within this paper, is modelled in MATLAB based on the previously described “backward” method, with a simplified shifting strategy, instead of a PID controlled driver. It is also possible to couple the ORC model with a “forward” vehicle model. The gained speed and torque information are directly fed into the engine model. The engine is modelled with a “hybrid” approach. All pipes are modelled within GT-Suite taking the thermal inertias into account. The combustion process is modelled with a physically based and scalable engine model (S0DEST) [8]. This model has complete engine maps as output, since GT-Power models are mostly only calibrated for full load. The created engine maps feed the GT-Suite model with information for exhaust gas temperature and mass flow. For the ORC system the exhaust gas temperature downstream the EATS is of interest. For this reason an EATS system is modelled in GT-Suite, which is able to simulate the heat losses between the turbocharger and EATS. The loss modelling is physically based and validated with test bench data. It was shown that the EATS has a negative influence on the temperature level but a positive effect on the transient behaviour. The exhaust gas temperature after the EATS model is directly fed into the ORC GT-Suite sub-model.

Finally, the system performance of the holistic vehicle model with integrated ORC is simulated for the Long Haul Cycle and the resulting fuel savings are calculated. For the determination of the system performance the net power is considered, which implies that the performance requirement of the pump is subtracted from the gained expander power. The results are given in Figure 11 (left). The maximum net power output is close to 14 kW, whereas the average power is around 4.46 kW. However, the system seldom produces more than 10 kW, since the ICE operating point must be in a very large torque range over a longer driving period in order to heat up the EATS and thus providing the evaporator with sufficient energy. The fuel consumption excluding ORC is directly determined by using the fuel consumption map, which is fed the required torque and speed information coming from the cycle input. Applying an ORC, a load shift occurs, which reduces the engine torque and therefore the fuel consumption. The cumulated fuel consumption either including or excluding an ORC is presented in Figure 11 (right). The fuel savings achieved by this simulation are 3.8 %, resulting mainly from high load points during the second half of the cycle.

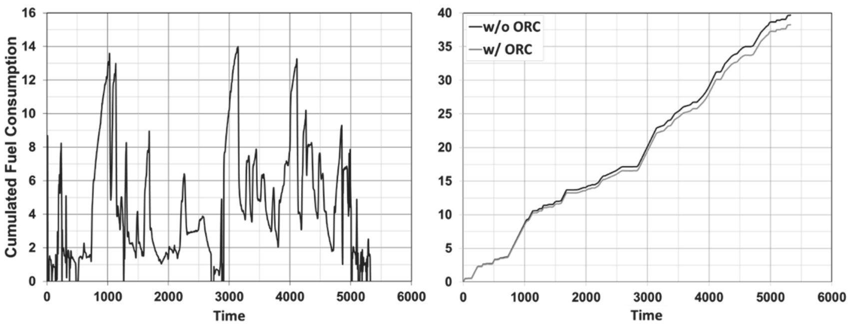


Fig. 11: Net power (left) and cumulated FC w/ and w/o ORC (right) in Long Haul Cycle

The system simulated within this study only considers the tailpipe exhaust. When it is combined with an EGR heat exchanger – depending on the EGR rates – up to 40 % more fuel could be saved. This complex and interdisciplinary investigation has shown how important holistic simulation approaches are.

## Conclusion

The paper presented the holistic simulation approach of *FEV* and *VKA* for the commercial vehicle powertrain development. With the help of two practical examples the capability, especially in the field of new technologies, was proven. In the future new and challenging requirements have to be fulfilled regarding TCO and GHG legislation. To cope with this issue in a realistic timeframe and amount of costs the simulation becomes more and more important. For this reason powerful simulation tools for the early design stage as well as for coupling with test bench issues are a non-negligible part of future HDV powertrain development.

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# The next generation of natural gas trucks

## Development of a 4x2 tractor with a natural gas engine

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**Abstract**

The development of a natural gas truck is a new challenge in the long history of truck development.

Up to today only Diesel and (partially) Gasoline powered trucks have been successful in the long haulage application of trucks. The truck industry is encouraged to find alternatives to these engine concepts to suit future emission regulations and to slow down the global warming process. The most competitive concept that is available today is a Natural Gas powered combustion engine. Trucks with natural gas engines are quiet, have a cleaner combustion process and therefore emit less $CO_2$.

Liquid Natural Gas is stored at a temperature of -130 °C in which condition it has a higher energy density than Compressed Natural Gas. This makes LNG an interesting fuel concept also for the long haulage application. The typically requested range of a long distance truck is > 1.000 km. IVECO installs 2 LNG tanks with a capacity of almost 200 kg each. In combination with the fuel efficient 8,7 liter Cursor NG engine a maximum range of > 1.500 km (mission profile depending) is possible. First independent tests in the flat profile mission of the Netherlands showed even possible ranges of > 1.600 km. This range is quiet attractive for customers as it means the truck can operate on the main routes through Europe with the already available, but thin, net of gas stations. In fact one of the first customers of the IVECO Stralis NP C9 operates his trucks on a route from Spain through France and Belgium up to the Netherlands. To match such mission profiles the new 8,7 liter engine provides a power output of 400 hp max and up to 1.700 Nm of torque.

Beside the fuel efficient engine and a sufficient tank capacity the powertrain is a very important factor to match long haulage criteria. A suitable and reliable powertrain can be carried over from the successful Diesel versions of long haulage trucks. Also IVECO followed this strategy and uses components of the Stralis Diesel. Axles, transmissions, propeller shafts and even the gearbox are carry-over parts. This means that also the efficient automated gearbox is available for the NG trucks. Previously used automatic gearboxes are

not fuel efficient while manual gearboxes lead to driver dependent fuel consumption. The widely used automated gearbox is the best choice for the customer in terms of reliability and total cost of ownership (TCO).

To summarize: LNG powered trucks are a new alternative for any customer that wants to keep the same level of comfort, operating range and TCO but also wants to decrease the emission and hence increase the environmental friendliness of his truck or fleet.

## 1 Requirements for the development of a LNG powered long haulage truck

The main requirements of an NG truck that has to compete against Diesel trucks are:

- Operating range > 1.000 km
- Equal or better TCO
- Similar performance
- Equal reliability & safety
- Higher environmental friendliness

These 5 requirements need to be respected to fulfil customer needs.

The following chapters give an example how an engineering department can translate these customer needs into technical design.

## 2 Operating range

To achieve an operation range > 1.000 km the fuel consumption should be targeted to be < 30 kg/ 100 km on standard highway mission.

To achieve this target first of all the engine needs to be very efficient. The stoichiometric combustion process provides a good effectiveness of the engine. Unfortunately it also leads to high combustion temperatures, which will be discussed in the chapter performance. The 8,7 liter Cursor 9 Natural Gas engine demonstrates the state of the art in natural gas truck engines. It is based on the Cursor 9 Diesel engine and therefore has the same base dimensions. Nevertheless several components have been designed specifically. Such as: piston, piston rings, liners, cylinder head, ignition system, knock detection, injectors and others. The 6 cylinder engine demonstrated in several tests that it is able to achieve the target on fuel consumption. On a typical highway mission the truck, loaded to 40 t, can operate with less than 30 kg / 100 km. Fig. 1 shows the engine as it is installed in the Stralis NP C9.

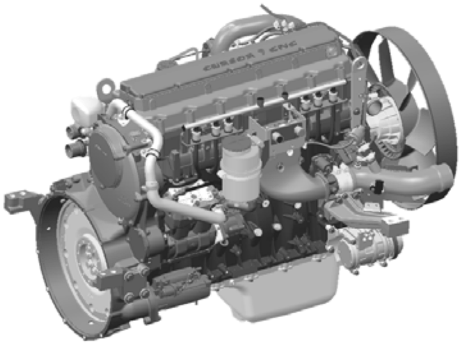


Fig. 1: FPT Cursor 9 NG engine

In addition to the engine the full powertrain efficiency needs to be considered when targeting the fuel consumption. The powertrain of a gas truck can be the same as on Diesel trucks. Automated gearboxes can be applied as well as low rear axle ratios. The rear axle ratio clearly depends on the mission. On average we recommend to use a 3,36 in combination with the C9 engine and the direct drive automated gearbox. This is providing a sufficient performance in combination with a low fuel consumption. For customer with a flat mission profile a rear axle ratio of 3,08 is available as well, while a ratio of 3,7 can be chosen for hilly mission profiles.

No special aerodynamics have been developed for the Stralis NP.

In addition to a low fuel consumption, the applicable fuel capacity is the 2$^{nd}$ main driver for an high operating range. The fuel capacity should be as high as possible and was targeted to 380 kg of LNG. The tank size is limited by the wheelbase, the max allowed width of the vehicle and the chassis height. In this project we used a standard tractor layout with a wheelbase of 3.800 mm. Considering the wheel size, the mudguards and the necessary ground clearance of 200 mm according to ECE R110, the usable length for fuel tanks is ca. 2.425 mm at a diameter of 26”. The chosen LNG tank finally has a length of 2.292 mm. It’s not possible to use the full available space, as the tank needs to be accessed sideways to operate valves inside the tank shroud. The LNG tank has a diameter of 26”. The usable fuel capacity of tanks in this dimension is almost 200 kg. In the double LNG tank configuration the max fuel capacity is 400 kg. Fig. 2 shows the packaging of the truck in double LNG configuration.

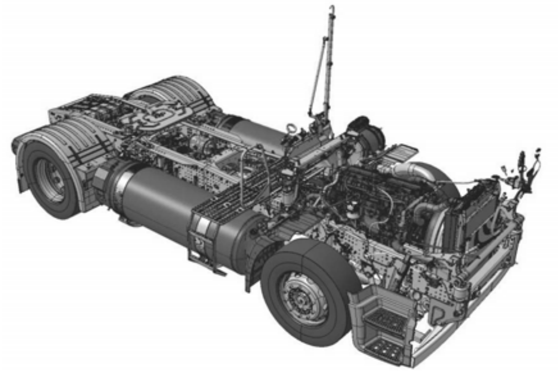

Fig. 2: Vehicle layout in double LNG configuration

The vehicle is also requested with CNG tanks. The length of a CNG tank is limited to 1.750 mm unless you apply a second T-PRD (Temperature –Pressure Release Device) to be compliant with the ECE R110 bonfire test. Therefore the capacity of the CNG version is 2 x 4 x 115 liter. This amount is sufficient for an operating range of > 500 km. In Fig. 3 you can see the vehicle packaging in double CNG configuration.

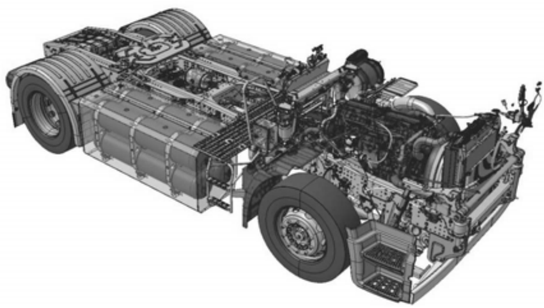

Fig. 3: Vehicle layout in double CNG configuration

The vehicle is designed in a modular way and therefore available also as CNG + LNG configuration. See Fig. 4.

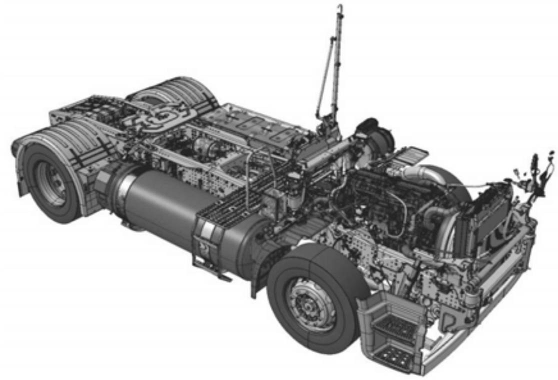

Fig. 4: Vehicle layout in CNG + LNG configuration

For the max operating range a customer would choose the double LNG configuration. Depending on the mission profile and the load of the vehicle, a max operating range of 1.500 km is possible with the Stralis NP.

## 3 TCO

This chapter focuses on the technical impact to the TCO (Total Cost of Ownership).

The first impact is directly related to the previous chapter: The fuel costs. Although the fuel consumption varies on several impacts, a simple comparison of a typical Diesel versus the LNG truck can be performed as follows.

The average prices of fuel in the Netherlands (leading country in LNG):

LNG: 1,09 €/ kg

CNG: 1,00 €/ kg

Diesel: 1,20 €/ liter; AdBlue: 0,60 €/ liter

Considering a consumption of 30 liter Diesel (+ 2 liter AdBlue) or 30 kg gas per 100 km, each km costs:

LNG: 0,327 €/ km

CNG: 0,30 €/ km

Diesel: 0,36 €/ km + 0,012 €/ km

If we would consider only the fuel costs, a customer safes 4,50 €/ 100km using an LNG truck instead of a traditional Diesel equivalent.

Beside the fuel costs, the Engineering department directly influences also the vehicle price. The following NG specific systems and components impact the vehicle cost:

- Spark ignition engine

Gas powered engines are of higher costs than the widely spread self-ignition Diesel engines. Beside the additional spark plugs, the lower volumes and the cost intense material of the components increase the costs.

- Fuel tank

At least in the LNG configuration, the tank is one of the most expensive components of the truck. In fact it causes most of the delta in comparison to a Diesel.

- Gas system

The pipes to supply gas from the tank to the engine are designed in stainless steel. In addition to the pipes themselves, the necessary fittings are quiet expensive.

- Pressure regulator

The LNG and CNG pressure regulator is an additional component in comparison to a Diesel and therefore increase the cost of the vehicle.

- After treatment system

A natural gas truck needs no complicated after treatment system. A TWC (three-way catalytic converter) element is sufficient to respect the Euro VI emission limits. The cost of a Diesel after treatment system is higher than on a Natural Gas. This is even valid when we consider the higher cost of the temperature resistant materials that are necessary in the NG ATS.

- Maintenance interval

Due to the high thermal load the maintenance interval is shorter than on Diesel vehicles. On the Stralis NP a maintenance interval of 75.000 km has been achieved. Compared to previous gas trucks this is an increase of 50 %. Nevertheless the typical maintenance interval of a Diesel is still much longer.

Several impacts on the TCO can’t be considered as fixed in general but depend on the customer. Nevertheless internal calculations show that the higher investments due to the vehicle price can be amortized within 2 years.

## 4 Performance

- Engine and ATS

The 8,7 liter engine provides a power output of 400 hp and a max torque of 1.700 Nm. These values are very close to a Diesel engine of the same displacement class. The max torque is already available at 1.200 rpm which reduces downshifting in uphill driving and leads to a comfortable and powerful driving experience. Fig. 5 shows the power and torque output in relation to the engine speed.

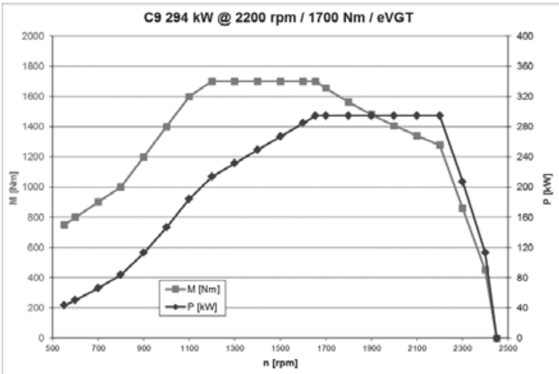


Fig. 5: Engine reference curve

The high performance of the engine leads to high temperatures that can reach levels > 750 °C.

The combustion temperatures inside the engine make it necessary to use special spark plugs in Iridium and Platinum material. These spark plugs ensure a correct ignition of the gas and air mixture and are capable to achieve a maintenance interval of 75.000 km.

The exhaust manifold has been upgraded to a high temperature resistant material, but the layout is a carry-over from the Diesel engines.

The turbocharger is connected to the oil circuit of the engine, which provides sufficient cooling.

The high temperatures cause high stress on all components. Hence special high temperature resistant materials have been implemented. To choose the correct material it’s important to understand the mechanical properties at the application temperature. Several materials for the application in the exhaust system have recommended temperature ranges of up to 1000 °C but are in fact not suitable. The strength of the material is drastically lower in the upper temperature range than in the medium range. Fig. 6 shows the material properties of a suitable material for the application on Natural gas trucks. Temperatures > 800 °C can already become critical.

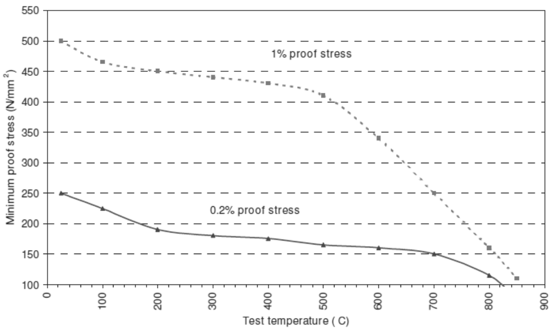


Fig. 6: Material properties of 1.4828 steel (source: Datasheet of FERROTHERM 4828, Edelstahlwerke Südwestfalen GmbH, Created: 25.07.2000, Revision No. 4828-0)

In addition to the directly impacted components like the exhaust pipes and box, surrounding components need to be shielded from these temperatures. A suitable solution is an insulation and/ or a heat shield. The best choice depends on cost and general vehicle layout. On the Stralis NP a mix of both possibilities has been identified as the best solution. As can be seen in Fig. 7, the area highlighted in turquoise is an insulation of the pipe while the components highlighted in orange and yellow are heat shields.

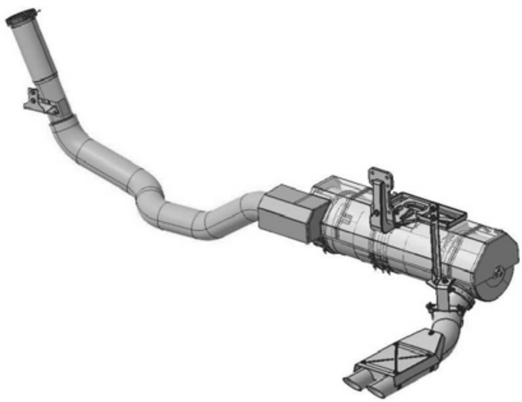

Fig. 7: Exhaust line layout

- Automated gearbox

It has been a widely spread opinion that automated gearboxes can't be adapted to a gas truck. Actually it is absolutely feasible, it is just very challenging in terms of calibration.

A gas powered engine is typically less stable than a self-ignition engine and therefore it's more complicated to find a good software calibration. The reaction time of the engine leads to a longer shifting time. This is probably the most obvious difference in terms of performance to a Diesel truck. Future developments on the engine and its software will close this gap towards the Diesel.

- Retarder

Current gas truck engines have no engine brake. To fulfil the endurance brake test all these vehicles are equipped with a Retarder. Retarder are available also on traditional trucks and are chosen quite often as optional by the customer to reduce maintenance costs in terms of brake pads and discs.

- Cooling system

To keep the stress level as low as possible, a suitable cooling system has to be applied. For the FPT Cursor 9 NP engine, a radiator size of 84 dm² has been identified and successfully tested. The cooling system of a Natural gas truck (see Fig. 8) is not only necessary to manage the engine temperature, but also to cool down the Retarder and to heat up the vaporizer of the LNG tank respectively the CNG pressure regulator. The evaporation of LNG has a positive impact on the overall temperature balance of the system. At full load the coolant flow through the evaporators reaches approximately 1.800 liter/ h. Passing the evaporator, the cooling liquid is cooled down by ca. 10 K.

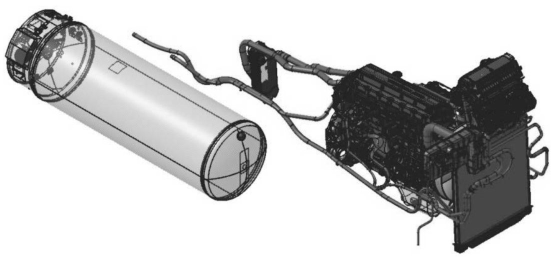

Fig. 8: Cooling system layout

**5 Reliability & safety**

Most of the components of a Natural gas truck are identical to a Diesel truck. Therefore the reliability of these components is already validated to be very reliable. IVECO designs and tests its Diesel vehicles for a total mileage of 1.200.000 km. The specific components of a Stralis NP have been successfully validated in the same way.

To test the reliability of the trucks, IVECO performs a very challenging Pavé test on it's own test track close to the design and validation centre in Ulm. In addition to this Pavé test, all trucks are extensively tested on public roads.

Beside the reliability there's a strong focus on the safety of the NG vehicles. The gas system and all of it's components are fulfilling the ECE R110. In addition to the ECE R110, IVECO implements some further safety features to make the truck and the use of it as safe as possible. One example is the safe vehicle release function. To avoid accidents of unsafe vehicle release from a gas station, sensors block the engine from starting if the filler neck covers are still open. I this way a demolished fuel supply line and damages of the connectors are avoided in case a user forgets to disconnect the gas station filling pipe. Fig. 9 shows the LNG tank with the open filler neck cover.


Fig. 9: LNG tank with filler neck cover

## 6 Environmental friendliness

- Lower particle/ $CO_2$ emission

The spark ignited combustion process of Natural gas produces less $CO_2$ than a Diesel combustion process. In addition it produces almost no particles. In comparison to the Euro VI limits, the gas engine produces 60 % less $NO_x$ and 98 % less particles.

- No Adblue necessary

Due to the low $NO_x$ values, a gas vehicle needs no SCR with AdBlue.

- Lower noise emission

The Stralis NP is available with the Silent truck certificate. This certificate allows night time delivery in several areas as the noise caused by the truck is lower or equal to max 71 dB(A). In comparison to the homologation limit of 80 dB(A) this is a certain reduction of noise for the environment.

Image references:

# Intelligent Connectivity Solutions

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ZF Friedrichshafen AG, Friedrichshafen

**Kurzfassung**

OPENMATICS, Anbieter der gleichnamigen Telematik-Plattform und eine Tochtergesellschaft der ZF Friedrichshafen AG, stellt eine Technologie vor, um Waren während des Transports online zu überwachen.

Hauptkomponente dieser Plattform sind auf Bluetooth Smart basierende „TAGs“, welche an den Ladungsträgern befestigt werden. Die Daten der überwachten Ware können dann von der Telematik Onboard-Unit während des Transports ausgelesen und in die Cloud- Plattform übertragen werden. Alternativ ist ein Auslesen auch mittels handelsüblicher Tablets und Smartphones möglich.

Durch den Einsatz einer Telematik Onboard-Unit erschließen sich zusätzliche Möglichkeiten, die Daten vom Fahrzeug mit den Daten der Ware zu kombinieren.

Die Präsentation wird die Bluetooth Smart Technologie vorstellen und anhand von umgesetzten Anwendungsfällen die damit verbundenen Möglichkeiten aufzeigen.

**Abstract**

OPENMATICS, provider of the identical named Telematic platform and subsidiary of ZF Friedrichshafen AG, released a technology to track commodities during transportation.

Main parts of the platform are “TAGs” which could be mounted on transportation cradles and which are based on the Bluetooth Smart technology.
During the transportation the data of the tracked commodities will be forwarded to the cloud platform via the telematic onboard unit.
Alternatively the data could also be read using an “off-the-shelf” smartphone or tablet.

Due the usage of a telematic onboard unit additional opportunities to combine vehicle data with commodities data are possible.

The presentation will introduce the Bluetooth Smart technology and demonstrate the possibilities referencing to already implemented use cases.

**Einleitung**

Industrie 4.0 und Telematik wachsen zusammen.

Telematik-Systeme in Nutzfahrzeugen dienen dazu:

- Flottenmanager über den Standort und Zustand der Fahrzeuge zu informieren und Fahrzeuge und Fahrer optimal zu managen
- Disponenten eine optimale Routenplanung zu ermöglichen und dem Fahrer Planänderungen und Aktualisierungen „ad hoc“ mitzuteilen
- Werkstattleiter die Wartung und Instandsetzung ihrer Fahrzeugflotte vorausschauend zu planen

Was bisher fehlt, ist die Online-Überwachung der Ladung selbst.

Zwar werden zum Beispiel im Kühltrailer die Umgebungsbedingung überwacht und Abweichungen von den vorgegebenen Grenzwerten gemeldet,

aber dauert das Be- und Entladen bei temperaturempfindlicher Ware zu lange, bringt es nichts, wenn danach die Trailer-Telematik die Temperaturen im Kühltrailer überwacht.

Deshalb ist es wichtig, die Umgebungsbedingungen direkt am Transportgut zu erfassen, zu speichern und bei Abweichungen von definierten Grenzwerten so schnell wie möglich den Disponenten zu informieren.

Um diese Lücke zu schließen, haben wir die Telematik-Plattform um eine Ladungsträgerüberwachung erweitert.

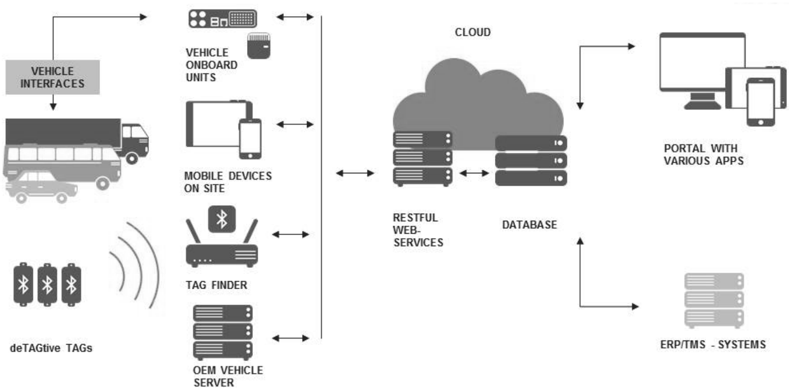



Bild 1: OPENMATICS Plattform mit Ladungsträgerüberwachung

## OPENMATICS Plattform

Die App-basierte OPENMATICS Plattform besteht aus einer Onboard-Unit, welche Daten aus dem Fahrzeug erfasst und über die Mobilfunkverbindung in das Cloud-System überträgt.

Erweitert wurde das System um die auf Bluetooth Smart basierenden TAGs.

## Bluetooth Smart

Bluetooth Smart bietet viele Vorteile gegenüber anderen Funktechnologien wie RFID.

- Durch den geringen Energieverbrauch können lange Laufzeiten realisiert werden
- Verwendung kostengünstiger Lesegeräte durch den Einsatz von gängigen Smartphones und Tablets
- Verfügbarkeit der Schnittstelle in vielen Telematik Onboard-Units
- Die Übertragungsreichweite der Funkstrecke ist für 10m spezifiziert. In der Realität und abhängig von der Antennengeometrie sind aber unter Normalbedingungen auch 30m und im Freifeld bis zu 100m erreichbar
- Durch den Advertising-Mechanismus ist ein schnelles und einfaches detektieren, lokalisieren und synchronisieren des Senders möglich
- Durch den Ursprung im Consumer-Markt sind kostengünstige System-On-Chip Bausteine vorhanden

**TAGs**

Die TAGs basieren auf einer standardisierten Kommunikationsplattform, welche mit verschiedenen Sensoren ausgerüstet sein kann.

Dadurch ist es möglich Use Case spezifisch optimierte TAGs einzusetzen:

- Nur ID: Für das reine Tracking in Prozessketten werden TAGs eingesetzt, welche zyklisch eine eindeutige ID senden
- Sensoren zum Erfassen der Umweltbedingungen während des Transports wie zum Beispiel Schock, Temperatur, Luftfeuchte und Licht
- Umfeldsensoren zum Messen von Distanzen für den Einsatz zur Personenzählung im Stadtbus

Bild 2: TAGs

**Beispielhafte Use Cases**

**Tracking von Trailer und Wechselbrücken**

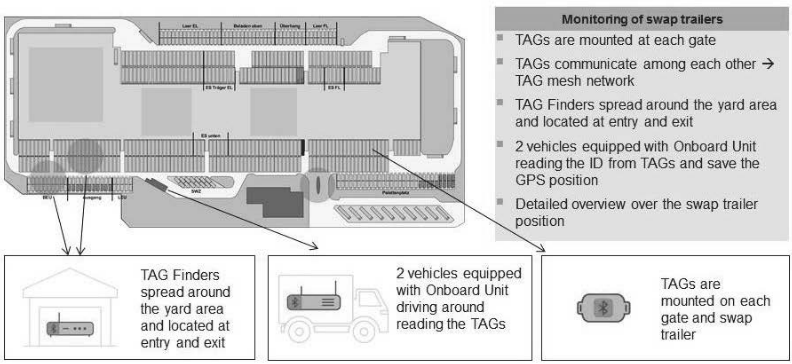



Bild 3: Tracking von Trailern und Wechselbrücken auf dem Logistikzentrum

Hierbei werden die Wechselbrücken und Trailer mit „Nur ID“ TAGs ausgerüstet. Das Einfahrtor wird mit fest installieren Lesegeräten (sogenannte TAG-Finder) bestückt. Über den Ladebuchten werden im Abstand von 50m TAG-Finder montiert. An allen Ladebuchten werden stationäre TAGs installiert. Die Wechselbrückenhubwagen (sogenannte Wiesel) werden mit einer Onboard Unit ausgestattet.

Ein einfahrender Trailer wird jetzt direkt am Einfahrtor automatisch detektiert und dem Fahrer eine Ladebucht zugeordnet. Sobald der Trailer an der Ladebucht abgestellt wird, wird er vom stationären TAG der Ladebucht erkannt und dies an einen installieren TAG-Finder über den Ladebuchten gemeldet. Alle auf den Parkflächen abgestellten Trailer werden vom vorbeifahrenden Wiesel detektiert und ihre GPS-Position ins System übertragen. Dadurch ist der Yard-Manager immer über den aktuellen Aufenthaltsort aller Trailer informiert.

**Transportüberwachung von schockempfindlichen Gütern**

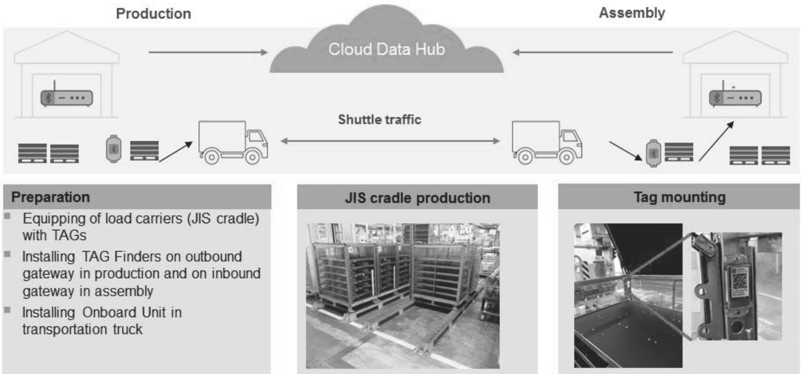



Bild 4: Transportüberwachung empfindlicher Güter

In diesem klassischen Einsatzfall werden die TAGs entsprechend der zu überwachenden Umweltbedingungen ausgewählt. Die Montage der TAGs erfolgt an zirkulierenden Ladungsträgern. Danach werden die Grenzwerte der zu überwachenden Umweltbedingungen in einem Profil definiert und in der Web-Applikation oder dem ERP-System dem TAG zugewiesen. Sobald der TAG in den Bereich eines Lesegeräts kommt, wird das Profil aufgespielt. Durch das Ausrüsten des Transport-LKW ist die komplette Transportkette überwacht. Der Disponent wird sofort über eine Abweichung der definierten Transportbedingungen informiert und kann entsprechend reagieren.

## Schnelleres Ausrüsten von Kühltrailern

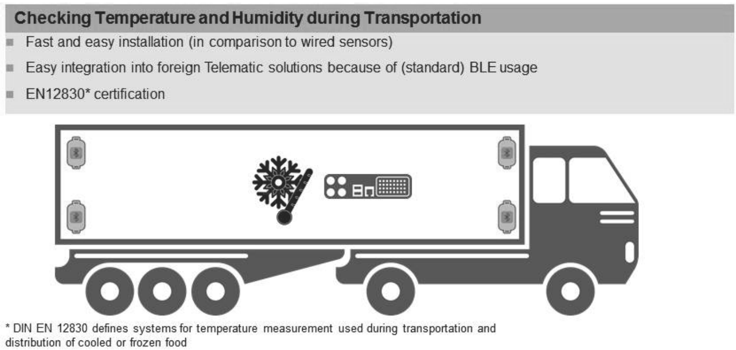



Bild 5: Installation im Kühltrailer

Bisher werden Kühltrailer durch die Festinstallation von Temperatursensoren ausgerüstet. Der Einbau erfolgt hierbei kabelgebunden durch Anschluss an die Trailer-Telematik-Unit. Durch die Verwendung von TAGs kann jetzt die Installationszeit drastisch reduziert werden. Ebenfalls können über die Trailer-Telematik-Unit auch die TAGs an den Ladungsträgern ausgelesen werden.

## Zusammenfassung

Durch die Erweiterung der Telematik-Plattform um die Zustandserfassung des Ladeguts kann die Infrastruktur und hier besonders die Onboard-Unit effektiver genutzt werden. Dadurch entsteht ein Zusatznutzen für den Flottenbetreiber, welcher die hohen Investitionskosten relativiert.

Für den Disponenten wird der Transportvorgang transparenter und er wird praktisch in Echtzeit über den Zustand der Ware informiert.

Die Bluetooth Smart Technologie sorgt dafür, dass die Lebensdauer der TAGs auf bis zu 5 Jahre ausgeweitet werden kann.
Als Lesegeräte können kostengünstige Consumer-Produkte verwendet werden. Durch die Flexibilität des Systems und der Komponenten lassen sich sehr viele Einsatzszenarien abdecken und mit Daten der klassischen Telematik kombinieren.

# Impact of European Driving and Resting directives on efficient planning of vehicles

Ing **Dirk Staelens**, WABCO Fleet Management Solutions

**Abstract**

Regulation (EC) No 561/2006 provides a common set of EU rules for maximum daily and fortnightly driving times, as well as daily and weekly minimum rest periods for all drivers of road haulage and passenger transport vehicles, subject to specified exceptions and national derogations. The scope of operations regulated is tremendously diverse, it includes: passenger transport and road haulage operations, both international and national, long and short distance, drivers for own account and for hire and reward, employees and self-employed.

The aim of this set of rules is to avoid distortion of competition, improve road safety and ensure drivers' good working conditions within the European Union.
The compliance with these provisions is subject to continuous monitoring and controls, which are carried out on national and international level via checking tachograph records at the road side and at the premises of undertakings.

This paper will explain how telematics can help drivers and fleets to comply with this directives and explain how trips can be optimized with help of telematics.

## Introduction

Drivers' hours and tachograph rules were introduced on a community wide basis with the introduction of Council Regulation (EEC) 543/69[4] on 25th of March 1969. This regulation introduced:

- Minimum age limits for drivers, drivers' mates and conductors
- Limits on continuous and daily driving time
- Minimum durations and other conditions in respect of breaks and daily and weekly rest periods
- The requirement to record activity and promote the use of automated recording

It hoped to improve the social conditions of those involved in the road transport industry, improve road safety and also address competition issues with transport by road, rail and inland waterways.

Regulation (EEC) 3820/85[5] was introduced on 20th December 1985 and repealed Regulation (EEC) 543/69 and was itself repealed by Regulation (EC) No 561/2006 on 11th April 2006.
Each subsequent Regulation attempting to further the aims of the outgoing regulation, correct any matters that had come to light brought about by drafting inaccuracies and taking into account other related regulations. [2]

## AETR

The European Agreement Concerning the Work of Crews of Vehicles Engaged in International Road Transport (AETR) rules are now the same as the EU rules on driver hours.
The following countries are covered by the AETR rules: Albania, Andorra, Armenia, Azerbaijan, Belarus, Bosnia and Herzegovina, Kazakhstan, Liechtenstein, Macedonia, Monaco, Moldova, Russia, San Marino, Serbia and Montenegro, Turkey, Turkmenistan, Ukraine, Uzbekistan

**Overview of EU regulations [1]**

- Daily driving period shall not exceed 9 hours, with an exemption of twice a week when it can be extended to 10 hours.
- Total weekly driving time may not exceed 56 hours and the total fortnightly driving time may not exceed 90 hours.
- Daily rest period shall be at least 11 hours, with an exception of going down to 9 hours maximum three times a week. Daily rest can be split into 3 hours rest followed by 9 hour rest to make a total of 12 hours daily rest
- Weekly rest is 45 continuous hours, which can be reduced every second week to 24 hours. Compensation arrangements apply for reduced weekly rest period. Weekly rest is to be taken after six days of working, except for coach drivers engaged in a single occasional service of international transport of passengers who may postpone their weekly rest period after 12 days in order to facilitate coach holidays.
- Breaks of at least 45 minutes (separable into 15 minutes followed by 30 minutes) should be taken after 4 ½ hours at the latest.

**Extra complexity for fleets and drivers**

<u>Specific rules for vehicles with double manning.</u>

Different rules apply where more than one driver is operating as a crew. Each driver is obliged to complete a daily rest period of at least 9 hours in the 30 hours since the commencement of duty following a weekly or daily rest period. In order to qualify for this derogation there must be at least two drivers on board the vehicle available for driving except for the first hour (aggregated) when one driver may drive alone.

<u>Ferry/Train, Out of Scope and out of cabin activities of drivers.</u>

A driver travelling to a specific place, other than the employer's operating center, indicated to him by his employer in order to take over and drive a tachograph equipped vehicle is satisfying an obligation towards his employer and therefore not able to freely dispose of his time. Hence, any time travelling to or from a location which is not the driver’s home or the employer's operating center and where the driver takes charge of or leaves an in-scope vehicle, regardless of whether the employer gave instructions as to when and how to travel or whether that decision was made by the driver should be recorded as 'other work'

Generally during a rest, a driver shall be able,to dispose freely of his/her time. However, a driver is entitled to take his/her break or rest, daily or weekly, when he/she is travelling by ferry or train, provided that he/she has access to a bunk or couchette. Any time spent travelling "shall not be counted as a rest or break unless the driver is on ferry or a train and has access to a bunk or couchette".

Firmware versions of digital recording equipment (digital tachograph) calculates driving and resting times with different algorithms.

As digital tachographs record more accurately than analogue tachographs drivers involved in frequent or multi-drop stop operations may be faced with higher records of driving time when using a digital tachograph than it would be with an analogue tachograph. And in the evolution of the firmware versions of the digital tachographs, algorithms to calculate driving times are adapted to lower the recording of driving time.

Definition of journey types that falls under the regulations.

Transport types that falls under the regulation.

The vehicle must be designed to carry goods or passengers and normally used as such; hence a mobile crane or a concrete pumping machine (that carries no concrete) immediately falls out of scope.

Unclear definitions of a ‘break’, a ‘day’, a ‘nightrest’, a ‘weekend rest’ etc

Impact of attestation letters

The primary source of information at the roadside checks is the recordings made by the tachograph, and the lack of records should only be justified with an attestation if tachograph records, including manual entries, were not possible for objective reasons. In all circumstances, the complete set of tachograph records, complemented by the form, when necessary, shall be accepted as sufficient evidence to prove compliance with Regulation (EC) No 561/2006 or the AETR, unless there is a justified suspicion.

### Tachograph equipment

Tachograph equipment makes the necessary recordings that are crucial to any compliance checking carried out by control officers. These recordings are either recorded to a tachograph record sheet or digital data files and are collected either automatically or as manual (driver) inputs. It is the inspection of these recordings which for the most part enables control officers to establish whether the rules on driving times and rest periods have been complied with.

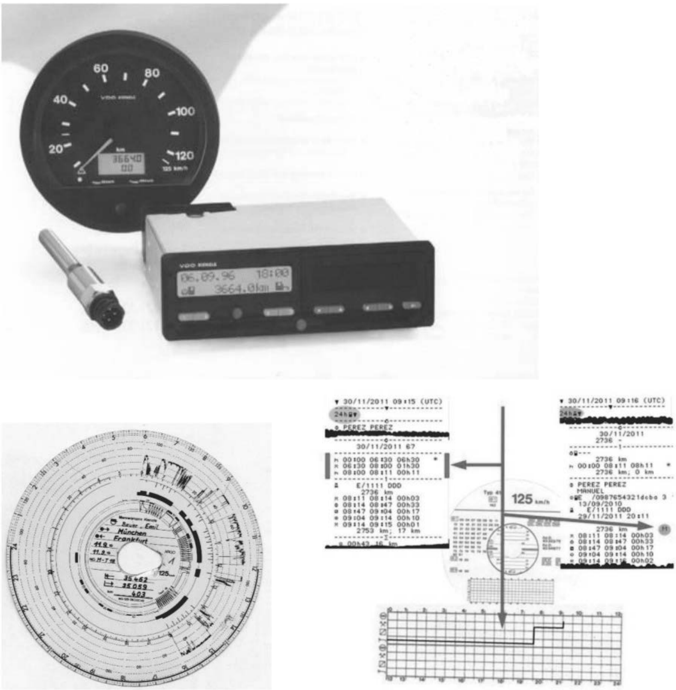


Fig. 1: Analog and Digital tachograph, analog paper disc and printed report from digital tachograph

**Impact on fleets on the operational activities and impact on violations**

Fleets can be made liable for infringements made by the drivers.

Fines are defined by each country individually. Example German fines [3]

Uninterrupted driving time > 4,5 hours and daily driving time > 9 hours
Driver: up to 30 min: € 15,- up to 60 min: € 30,- + every ½ hour more: 30 €
Haulier: up to 1 hour: € 60,- + every ½ hour more: 60 €

Weekly driving time > 56 hours
Driver:up to 2 hours: € 30,- + every hour more: 30 €
Haulier:up to 2 hours: € 60,- + every hour more: 60 €

Daily resting time < 11 hours
Driver:up to 30 min: € 15,- up to 1 hour: € 30,- + every hour more: 30 €
Haulier: up to 1 hour: € 60,- + every hour more: 60 €

Weekly resting time
Driver: up to 1 hour: € 30,- + every hour more: 30 €
Haulier: up to 1 hour: € 60,- + every hour more: 60 €

Fines can go up to 5000€.

Next to the risk that carriers are liable for the infringements of their drives, carriers must be able of generating vehicle tours, considering information regarding driving times, breaks and rest periods. The dynamic nature of road transport creates a challenge as actual and planned driving and rest periods may not coincide. This push carriers to have a dynamic route planning (manual or via systems) to anticipate on upcoming risks on driving and resting times.

**Software engines to calculate real time remaining driving and resting times to assist drivers and dispatchers.**

The complexity of the regulations makes it difficult for drivers and dispatchers to calculate the remaining driving and resting times, as the combination of several rules will determine how long the driver can still drive and how long the minimum next break or rest period will be. This is however extremely important, as an incorrect calculation or estimation will result into infringements, or out-of-time loading or unloading activities with penalties as a result.

Complex software engines are developed to calculate in real time the remaining driving and resting times, based on the output of the digital tachograph, to assist drivers and dispatchers to optimize the trip planning

These algorithms allows the users to parametrize the engine:

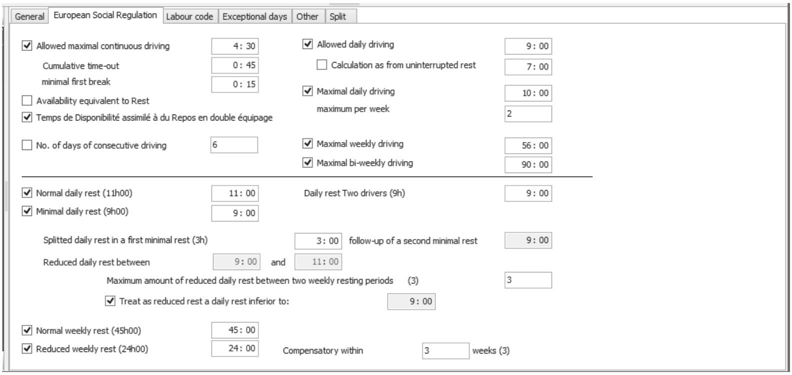




Fig. 2: Parameter settings of remaining resting and driving engine of Transics.

The data that is received in realtime from the digital tachograph and transferred to the backoffice servers via the telematics, is used for the algorithm and visualized in realtime to drivers and dispatchers.

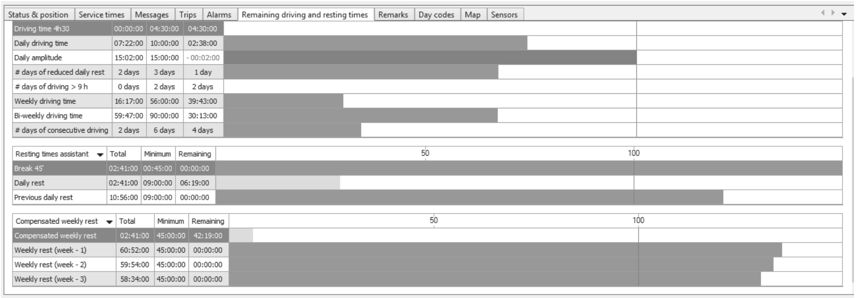



Fig. 3: Cockpit view for the real-time remaining driving and resting times for 1 driver in Transics telematics portal

As the data is also important for the decision taking of the driver, the remaining driving and resting times are also visualized for the drivers.

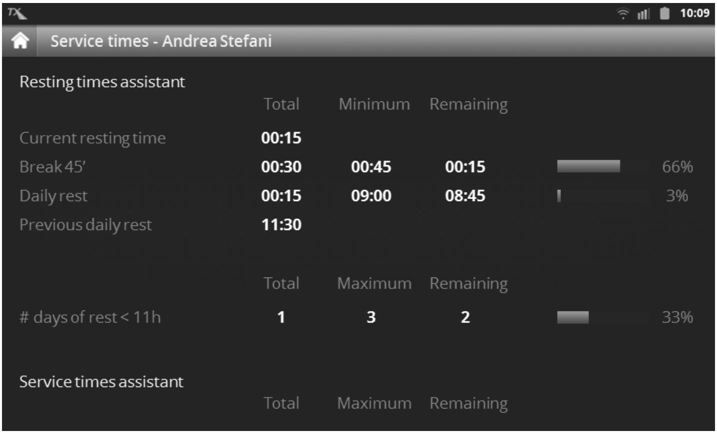



Fig. 4-5: Cockpit view for the real-time remaining driving and resting times for 1 driver in Transics on-board computer screen for the driver.

**API to feed Dynamic Vehicle Routing systems**

Due to the strict driving and resting times regulations, and the impact of the real-time traffic situations that can cause deviations on expected time of arrivals (ETA), information of telematics systems about driving and resting times ( next to position info and position updates ) is a crucial input for Dynamic Vehicle Routing systems. As this information must be retrieved real-time and in an automated way, API's that deliver this information are key.

3 elements are basic in the information flow:

1) Planning information ( trip schedule with planned stops and planned time of arrival per stop) is send from planning software ( TMS software) to telematics platform
2) The remaining driving and resting times of the drivers are calculated in real-time, based on information of the digital tachograph
3) Time and distance of next stop are calculated in real-time, taking the remaining driving and resting times of the driver(s) in the truck and real-time traffic info.

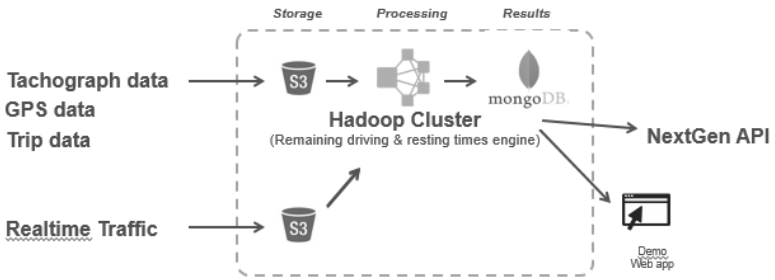
3 API functions enable an automated exchange of information between a telematics system and a dynamic routing system:

4) API to send and update Planning information ( trip schedule with planned stops and planned time of arrival per stop) to the telematics system
5) API to send the remaining driving and resting times of the drivers to the dynamic routing system
6) API to send time and distance of next stop to the dynamic routing system.

**New software models to optimize driving times**

Machine learning, predictive modelling and data analytics are the enabler to create a next level of API's that can calculate remaining driving and resting times more precise and will enable fleets to optimize the driving times of their vehicles.

These new 'big data' API's will not only support the operations of fleets, but will also optimize the assets (trucks and semi-trailers) and logistic processes.



**Summary**

Today’s drivers and fleet dispatchers are challenged by the increasing complexity of driving and resting time regulations. This require increased knowledge and availability of data for drivers and dispatchers.

Software engines that are fed with real-time data from digital tachographs and telematics systems are helping drivers and dispatchers to have real-time views on remaining driving and resting times, so that they have information available to take correct decisions on the trip planning.

New software models, based on big-data architectures will enable to predict more precise the remaining driving and resting times (based on multiple sources) and give insights to fleets how to optimize the driving times.

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European Commission Mobility and Transport

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# Combination of apps and open platforms with telematics solutions will improve flexibility, security and data consistency for fleets and shippers

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## Abstract

Fleets today are forced to use Apps by their customers. Next, more and more free aps are offered to fleets and drivers. This leads to an increased complexity of the operational processes of fleets, in combination with their today use of telematics.

This paper will explain the complexity of fleets in their operational processes, the security risks that Apps will bring in case they can have access to the vehicle ECU's and the back-office systems of fleets and shippers.


## Introduction

More and more apps are developed for professional drivers of HCV's.

- Driver Utility apps
- Fleet Management apps
- Freight Visibility apps

The Driver Utility Apps (Truck Stops, Parking, Food, Social networks …) can help the drivers to improve working conditions and free time. The driver is free to use the apps and are not managed by the fleet.

The Fleet Management Apps are replacing part of the traditional FMS systems (text messaging, order follow up, working hours) and are managed and controlled by the fleet. Drivers are imposed to use the App.

The Freight Visibility Apps are imposed by shippers and cargo owners to the fleets. The shippers are imposing the app, so that they can follow in real-time in a generic way for all their carriers the cargo. The fleet has no access to the data and it creates operational complexity to install the Apps, train the drivers in the usage and handle 2 data flows (1 to the fleet and 1 to the shipper).

**Benefits and risks of apps for the business processes of fleets**

Mobile apps are delivering new functionalities that allow the supply chain for further digitization. Good examples are the new digital CMR apps that will replace the paper CMR in the future. Other examples are the mobile apps for automatic identification of trucks, trailers, loading and unloading stops, products and pallets via QR and barcode scanning, sign-on-glass and picture transfer in case of problems with the loading and unloading activities.

On the other hand, some cargo owners, 4PL's and shippers are also using the app technology to create their own app and retrieve real-time data of their shipments, without the need to integrate data via the back-office applications of the fleet. They are imposing fleets that the drivers are using their app during the transport of their goods.

First disadvantage for the fleet is the operational process to install the apps on the smartphone of the drivers. MDM (Mobile Device Management) tools needs to be installed to manage the smartphones of the drivers. Nevertheless, the wide range of operating systems of smartphones, and the incompatibility of Aps with certain operating systems is hard to manage and can not be solved via MDM tools. This can result that drivers needs to use more than 1 smartphone for trips for several shippers.

Second disadvantage is the training of drivers to use the different apps of their customers. The use of these apps needs more attention from drivers, as they are not guided through their workflows as with hardwired embedded telematics systems.

Third disadvantage is the reliability and consistence. These apps are sending data (from other sources) directly to the back-office application of the shippers. While the data of the onboard telematics systems are sent to the back-office of the fleet. Apps and telematics systems are using other sources (ex. GPS speed versus wheel speed) and drivers are not always adding the same inputs at the same time and same place, which give conflicts between fleets and shippers that then needs to be clarified by the fleets.

Forth disadvantage is the importance of the driver to use the app and the smartphone in a correct way. Even with MDM tools are smartphones vulnerable by actions of the driver (switching off phone, gps, app, data communication etc).

## Cybersecurity risks with Apps

Apps that are connected wired or wireless directly with the vehicle systems, are vulnerable for cyber-attacks that can affect critical vehicle systems as engines and brakes.

As apps can also connect directly via internet to the back-office systems, the apps are vulnerable for cyber-attacks that can affect damage and disruptions of the business processes of fleets and shippers.

## open mobile platforms with apps and closed telematics platforms

The flexibility of apps and open mobile platforms has clear advantages. Disadvantages can be lowered by combining these apps and mobile platforms with a closed telematics platform.

Building Blocks:

Telematics device that is hardwired with the vehicle and vehicle systems. Only supplier software runs on the telematics device, no third party applications can run on the device.

Data communication with backend systems via a private APN with no connectivity to the public internet.

Wireless extension of the telematics device via a service on the smartphone. A service on the smartphone exchange data with the telematics device via secured wireless communication (Bluetooth, Wifi,,…) :

Data from the telematics device or from vehicle systems can be readby third party apps that are installed on the smartphone via a standardized interface. This enables that the telematics device and the app use the same source of data and prevent apps to read/write directly to the vehicle systems.

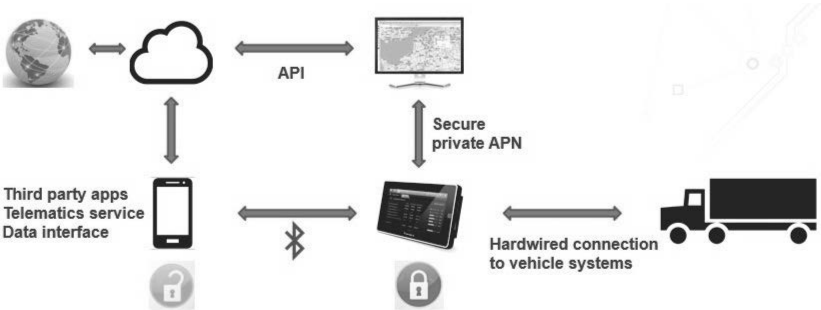
The service can start automatically a third party app with the correct driver, truck and fleet credentials that are stored in the telematics systems. This enables a better use of the apps by the drivers, as they are guided to use the correct app via the telematics system.

Via a standardized interface between the service and the apps, a third party can send data that is entered on the app to the service. The service will forward this data to the telematics system. This enables that fleets and shippers can have view on the same data.

Third party apps that can connect to smartphone service of telematics.

API that enable data and information transfer of apps and telematics devices to third parties.

Schematic visualisation:




## Summary

Today's fleets and shippers are challenged by increasing need of real-time data to increase the supply chain visibility. Apps are an enabler to create more visibility in a flexible way, but have significant disadvantages regarding security and the consistency of data.

Combining the flexibility of apps with the advantages of a closed telematics platform will bring more visibility in the supply chain combined with the advantages of security and data consistency from a closed telematics platform.

Standardization of interfaces of apps and telematics services will be the key of success for a real improvement of visibility in the supply chain and to lower the extra operational costs for fleets .

# Automotive Feature Store – Cloud-based software development and functions distribution for commercial vehicles

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## 1. Abstract

Innovative use cases for commercial vehicles as well as changing conditions of usage lead to the need to change the calibration of the vehicle or to add additional functionality after production in the field.

Today, the features which are available for commercial vehicles and the behaviour of these vehicles are defined during the development phase. Later on, any functionality or application update, if at all, can only be done in the service workshop or by specialist on site. In addition, the processes and tooling to perform an update usually is not unified but different per target control unit.

To change this situation, Bosch develops an open ecosystem starting from the development environment in the cloud up to the global management, licensing and distribution of software applications.

The ecosystem supports a uniform function development

- during the development of the vehicle
- during the validation of the vehicle / applications
- and after production in the field, i.e. during the complete life cycle of the vehicle

This allows to introduce customer-specific functionality in the vehicle easily, on short notice and at any time worldwide. A Firmware-update-Over-The-Air (FOTA) as well as adding dedicated software applications (Software-Update-Over-the-Air, SOTA) is supported.

This contribution discusses the basic approach, development steps and gives examples.

## 2. Motivation

In the cellular communication sector, today the main sales revenue (around 70%) is generated by selling features (called “apps” in cellular communication), services and analytics. Whereas hardware, communication network, computing and storage amount to the remaining 30% [1].

How could the picture be in the automotive sector in future? Even though the boundary conditions and especially requirements regarding safety and security are significantly different, the advantages of a flexible download of individual features after production in the field are apparent.

From an end user perspective it is very useful to add additional features to his vehicle on short notice and maybe just for a limited timeframe. For example, when a vehicle usually drives around in central Europe it makes sense to download a feature which adapts the heating strategy to the specific climatic conditions for a trip to e.g. Scandinavia. This features changes the sequence in which the engine, the goods and the driver are provided with thermal energy. In Scandinavia warmth has to be provided for the driver before the goods are heated.

This paper introduces an approach which enables such a feature download as well as a cloud based development environment and distribution which is supporting the following objectives:

- Customer requires an additional feature on short notice
- Flexible roll-out of a feature in shorter time
- Shorter time to market, especially for entry level products
- Reduced risk to introduce new features
- Supporting 3rd parties to add new feature, e.g. body builders

## 3. (R)Evolution of the feature development

Today, the user of a commercial vehicle can select features from a fixed feature[1] set only. It is fixed during the ordering process and can only be modified later by a service workshop if at all and to a limited extent. The OEM or supplier develops the functionality to implement these features typically by a complex development environment which can be operated by an expert only. Furthermore, this development environment differs for different target control units. It is specific for automotive application. The use of established and well used consumer electronic (CE) methods and technologies is rarely possible.

Eventually, the software of a control unit can only be updated completely (complete Basic- and Application Software). Partial update or adding of a single software application is not possible. This situation is depicted in Fig. 1 in the upper line marked “Today”.

Bosch objective is to advance the current situation and support an open selection of features by the user out of a wide range in a resource optimized way. The introduction of a worldwide accessible development system for device independent development and distribution is a further objective. This development system is called ecosystem according to [4].

To reach the objectives introduced in section 2, the current development approaches have to be changed and new technologies have to be applied. Fig. 1 shows the required changes and their benefits.

[1] Feature: a prominent or distinctive (user-visible) aspect, quality, or characteristic of a system or systems

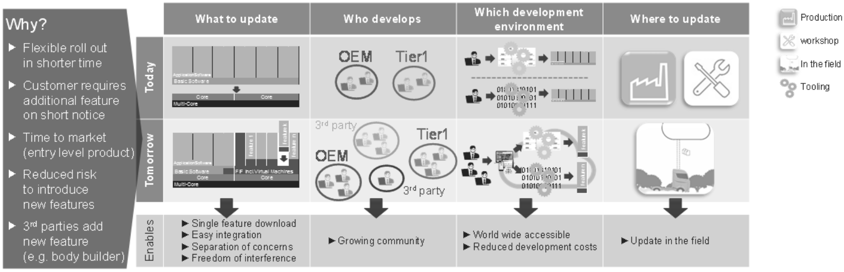


Fig. 1: (R)Evolution of the development process: Fields of innovation to introduce new vehicle features at any time, worldwide by anybody.

**“What to update?”**

Today for any change in the software, the complete software of a control unit has to be exchanged. Comparing this with adding or updating a mobile app on a smart phone, a first approximation would be that for every new app or the update of an app the operating system as well as all apps would have to be updated. The objective for automotive applications is to reach a similar approach as for smart phones, where an individual app can be added or updated without changes in the operating system or to other apps.

For automotive applications we see the need of a framework to integrate a new feature as a piece of software into control units. This Feature integration Framework (FiF)

1. handles the information required / provided by the new feature,
2. integrates the feature in the runtime environment of the control unit,
3. is handling the scheduling, start-up, shut down and the error handling of all features.

The FiF ensures an easy integration and includes a hypervisor which provides several virtual machines. It guarantees the separation of concerns and freedom of interference between a feature and the remaining software.

**“Who develops” with “Which development environment?”**

Today, the OEM[2] or the supplier (Tier1[3]) develops new features. Already for a third party, e.g. a body builder, it is difficult to introduce new features. The development itself is done with a specialized tool chain which is operated by specialists. Furthermore, the development methodology and tool chain often differs for different vehicle domains and control units.

Our objective is to enable an easy and rapid development of new features. On the one hand to open it for additional persons at OEM and Tier1, but also to additional parties like body builders, service providers, insurances or maybe even to anybody who is interested. Of course, such a decision to go from a closed development community to an open one has to be done very carefully. An open community opens the potential that numerous creative persons can contribute to the features. On the other hand, the challenge to ensure safety, cyber security, and legal compliance is increasing.

The step towards a growing development community is supported by introducing a uniform, cloud-based development for different domains and control units. This step is worthwhile, even for a closed development community of OEM and Tier1, to save tool and training costs.

**“Where to update?”**

Without the opportunities provided by connectivity, the initial application of the software in a control unit is done in the plant whereas later on any change or update of the software can be done in the service workshop only. Connecting the truck by an over-the-air interface to the cloud offers the opportunity, to do the software update anywhere at any time. Of course, non-functional requirements like safety, security and availability have to be considered to decide, whether an update in the field can be performed at a specific time and place [3].

Today the initiative to perform a software update is with the OEM. However, the motivation to introduce a new feature is mainly with the end user who needs this feature on short notice, or

[2] OEM = Original Equipment manufacturer

[3] Tier1 = Direct supplier to OEM, Tier2 = Sub-supplier to an OEM

by a body builder, who wants to add an attachment to the vehicle. The initiation of the update process by different parties is supported by a cloud based feature development and distribution approach described in this paper and will be elaborated more in detail in the next sections.

Due to the fact that several new methodologies and technologies are needed for a cloud based feature development and distribution, a step-wise introduction is mandatory to cope with the complexity of the overall approach.

**Stepwise introduction**

A first step towards cloud based feature distribution is the introduction of an over-the-air interface. This approach increases the availability of the vehicle and shortens the time to roll out a software update for a complete fleet of vehicles.

The other fields of the ecosystem remains as it is today. So this approach requires the consideration of the complete software of a control unit and is called Firmware-Update-Over-The-Air (FOTA) (Fig. 2). FOTA is already available today and used in the field.

The next step is the introduction of a uniform, cloud-based development and distribution environment as well as the FiF (Fig. 3). This approach is called Software-Update-Over-The-Air (SOTA). It enables the flexible integration of individual features at any suitable time. The development community is still limited to OEM and Tier1, but supports to expand the number of developers within this community. On the other hand, high licenses costs for tools can be avoided when a “pay per use” billing for the cloud-based development environment is used. This is especially interesting for smaller companies or a low number of feature developers.

The final step is to open up the development community to further parties (Fig. 4). To which extent this will be done has to be evaluated carefully with respect to the advantages and risks, as discussed above.

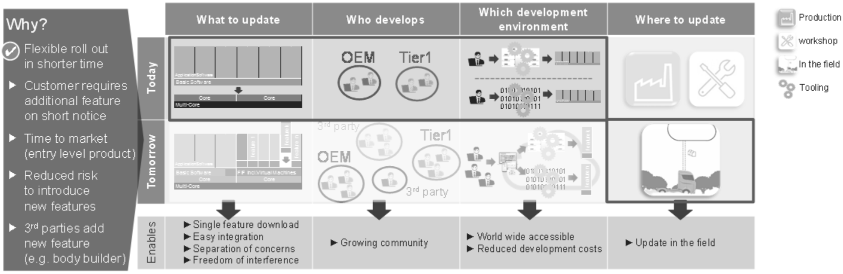


Fig. 2: Firmware-Update-Over-The-Air (FOTA)

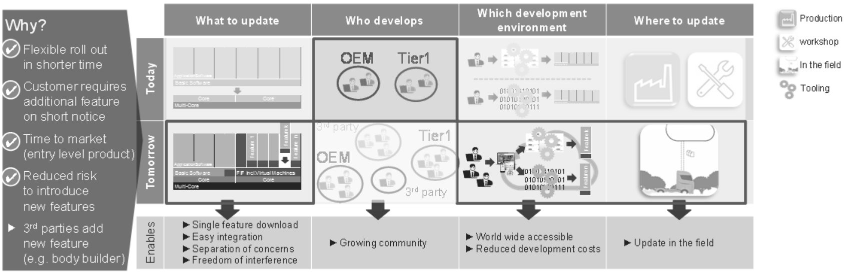


Fig. 3: Software-Update-Over-The-Air (SOTA)

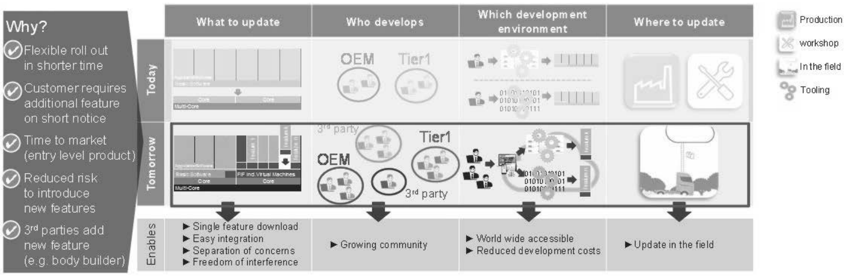


Fig. 4: Software-Update-Over-The-Air (SOTA) by anybody

## Required Technology

Fig. 5 summarises the objectives and benefits discussed so far and lists the required technology as well as a solution, offered by Bosch, to implement a cloud-based feature development and distribution.

For any update in the field connectivity is required. Therefore, a Connectivity Control Unit as an over-the-air interface of the vehicle is needed. Depending on the E/E architecture a gateway is in place which provides an extra level of security. Such a security gateway is advisable to make it even more difficult for an intruder to get into the vehicle over-the-air. A detailed discussion of automotive security concepts can be found in [6].

To enable a uniform world-wide accessible development environment, a cloud-based approach is needed. This is described in section 4.

In the vehicle a framework to integrate a new feature into the vehicle functionality is needed. This framework provides the information from the vehicle, which is needed for a feature, and the control values which are used by the feature to realize the intended functionality. To ensure that any new feature does not unintendedly alter the remaining vehicle functionality, a hypervisor has to be used. It ensures the separation of concerns and the freedom of interference, respectively.

Bosch has developed a light weight hypervisor which can be used on microcontroller (μC) based control units. In addition, a FiF to be used for μCs is available which integrates the feature into the basic software of the control unit. It handles the scheduling, start-up, shut down and the error handling for all features.

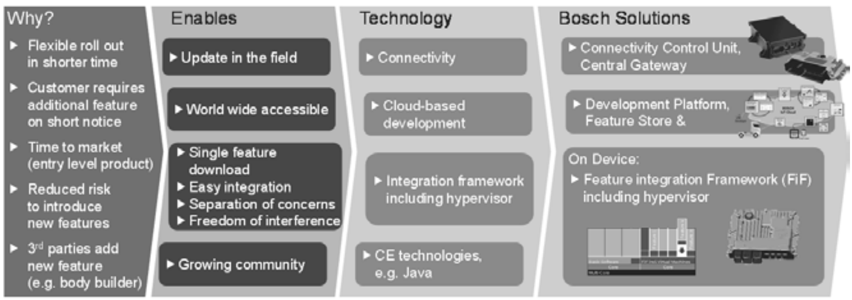


Fig. 5: Required technologies and proposed solutions

If more and more features or more complex features are needed, a technology leap is unavoidable, i.e. microcontroller based control units are no longer sufficient but microprocessor based computers are required. This provides an increase in computing power and memory (Fig. 6). Likewise, the use of CE based programming languages as Java to ease the extension of the development community requires the introduction of microprocessor technology as well.

Furthermore the introduction of other innovative functionalities such as *Automated Driving* and *Predictive Energy Management* [2] will result in similar resource demands. Therefore, this increased resources will be available in the vehicle in future anyway. This supports the re-use of existing, well established CE technologies like POSIX.

Bosch also has developed a microprocessor based solution for in vehicle usage.

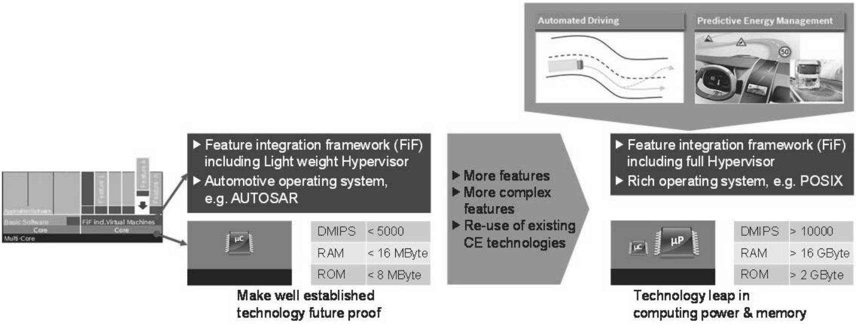


Fig. 6: Required technologies on device

## 4. Cloud-based development and distribution

So far the in-vehicle approach and the required technologies were discussed. In this section the Bosch solution for a cloud-based feature development and distribution is introduced.

Since the automotive sector has much higher requirements regarding safety and cyber security than cellular communication, for example, an automotive specific solution is needed.

### Feature Store

Fig. 7 shows the elements required in the cloud. The “Feature Store” provides the user front-end to find and select a required feature as well as to handle the billing. Furthermore, it handles the coupling to the FOTA and SOTA infrastructure which has to select the right version of a firmware or feature for a specific vehicle. This ensures the correct interplay of the features with the remaining software in the vehicle.

In addition, the different stakeholders typically take different roles depending on the download approach. For FOTA the download process is initiated by the OEM. The end user may be in the loop to decide the right point in time when the software update in the vehicle should take place.

In case a user downloads a new feature for his vehicle (SOTA), he initiates the download process himself. The Bosch "Feature Store" and "Feature Development Platform" takes care of the different roles owned by a stakeholders.

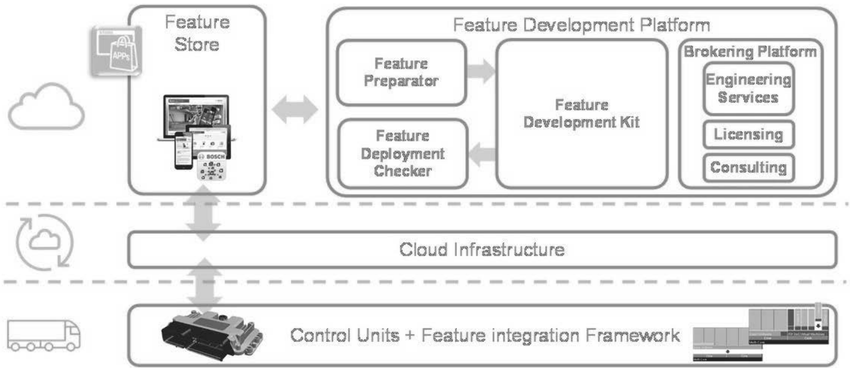


Fig. 7: Feature Store & Development Platform

## Feature Development Platform

Before a feature can be selected in the feature store it has to be developed. This is done with the "Feature Development Platform". It consist of the elements "Feature Preparator", "Feature Development Kit", "Feature Development Checker" and a "Brokering Platform". The interplay between the "Feature Preparator", the "Feature Development Kit", the checker and the feature store are shown in Fig. 8.

The Bosch approach supports a model-based development. For the development of a feature, the interfaces available in a vehicle have to be known. This information is provided by a so-called data dictionary. It lists the available information as well as values which can be manipulated by the feature. Furthermore the resource requirements of a feature and dependencies (feature *A* requires feature *B*, feature *A* excludes feature *B*) between features are defined. This activities are part of the "Feature Preparator".

After the development of the functional model the code for a selected target is generated and built. To ensure the quality, safety and security of a feature the functionality is simulated and/or tested. The test consists of two steps. The objective of the first step is to ensure that the implementation meets the requirements of the desired features. The second step verifies that the implemented feature fits into the overall system, i.e. the target vehicle. Moreover, the functionality has to be optimized to treat the in-vehicle resources with care.

Another aspect which has to be considered besides safety and security is the homologation of the vehicle. The freedom of interference provided by the FiF ensures that non-homologation relevant features do not compromise the type approval of the vehicle. For homologation relevant features (e.g. related to emission regulations) the type approval has to be renewed by a designated test laboratory and certification body according to EN ISO/IEC 17020, 17021 and 17025.

However, a feature which is designed for a marketplace needs some additions compared to a conventional software as of today. For example, it needs graphical parts like an icon for the feature store (User Interface Development) and a pricing model.

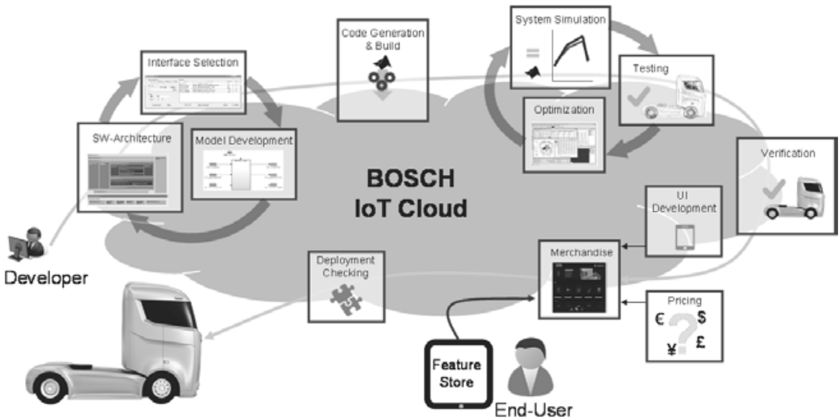


Fig. 8: Development Journey

When a customer selects a feature it has to be verified first that this feature can be deployed to his vehicle. For example, due to the individual vehicle equipment not all features run in all vehicles.

The described cloud-based approach has the great advantage, that a uniform development process for different target control units can be used which is accessible worldwide. Furthermore, smaller companies do not need to invest into complex and therefore costly tooling but pay for the usage of the cloud-approach use based.

Based on the selected characteristic of the desired feature the most suitable development tooling can be selected. Besides a development in the cloud an offline approach can be chosen. For the second variant the development is done completely offline and just the final results are uploaded to the feature store.

Beyond the feature development the Bosch approach also comprises a brokering platform (Fig. 7). This platform supports a customer to get the right support for his feature development with respect to engineering services, licensing and further consulting services.

The Bosch solution covers the required elements for a cloud-based feature development and distribution as well as the components to implement the connectivity and host the features in the vehicle. This solution is explicitly an open approach which supports that individual development steps are elaborated by different parties and that an interoperability with different clouds is possible.

## Integrated Connected Vehicle Services

In addition to the *Feature Development Platform* and the *Feature Store* introduce above, Bosch offers further elements in the cloud to provide integrated, connected vehicle services. Fig. 9 summarizes the supported services. A more detailed description can be found in [5].

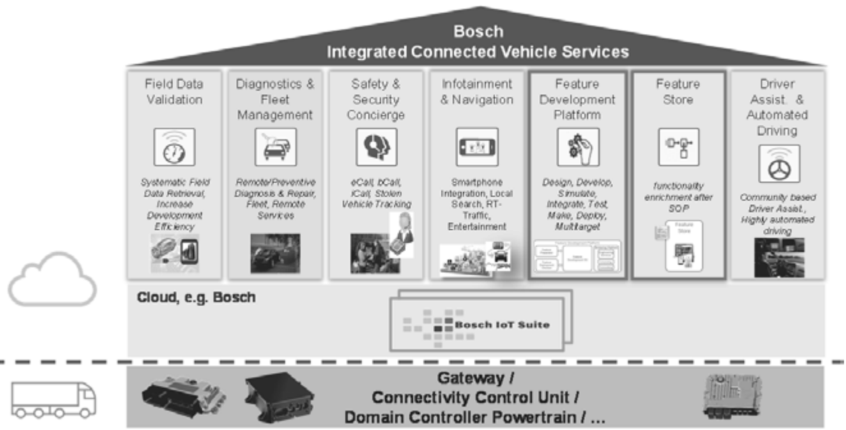


Fig. 9: Integrated Connected Vehicle Services

- *Field data validation* enables the collection of vehicle data in the field for typical driving situations. Thus, relevant component data can be acquired and the loads in real life situations can be evaluated. This helps to improve the design of components.
- *Diagnostics & fleet management* comprises predictive diagnostics which prevents the sudden failure of a component but instead enables a proactive exchange of this component. Therefore, the availability of the vehicle is increased. This comprises also fleet management services which schedule the service stop or the like.
- *Safety and security concierge* services are supporting features like emergency call (eCall), breakdown call (bCall) or tracking of stolen vehicles.
- Infotainment and navigation services are supporting for example the integration of mobiles for real time traffic information or entertainment.
- Driver assistance and automated driving services are supporting community based driving assistance functions where for examples a vehicle gets the information that preceding vehicles are breaking or supports highly automated driving.

## 5. Summary

This article introduced an approach for a cloud-based feature development and distribution by an over-the-air interface. Required technologies and a stepwise introduction of this approach were discussed.

A proof of concept of this approach was successfully performed already. First connected services are in the field. Thus we get back to the question from the beginning. Will we see in future the same revenue distribution in the automotive sector as in cellular communication?

The concepts and technologies are available „Let’s discuss your use-case & business cases and bring them alive!"

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# The Future of Telematics – Intelligent Connectivity

## A journey to exceptional fleet performance

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**Abstract**

Today's telematics systems have evolved into intelligent fleet management solutions. Innovative developments that deliver comprehensive information to all stakeholders of the supply chain about the trucks, trailers, drivers and cargo, in one single platform. Numerous truck and trailer mounted sensors generate data, which is sent to the back office in real time. At the moment, both familiar as well as new telematics players are working at an unprecedentedly fast pace towards further connecting vehicle mounted, intelligent safety and efficiency systems while ambitiously looking at ways to aggregate other types of information, specifically related to "vehicle-to-vehicle" and "vehicle-to-infrastructure" communication. Only by making intelligent use of new, digital technologies can fleet management be lifted to a higher level. But while collecting fleet information may not be new, harnessing these "big data" at today's expanding volumes, analyzing them intelligently and translating them into insights with real practical use for fleet operators is the next big challenge. Finally, the growing presence of the Internet of Things provides great potential in the future, one of which involves autonomous driving.

### Connectivity of the past

Road freight transport is the backbone of trade and commerce in Europe: today, there are some 6.4 million trucks driving on European roads, delivering 14 billion tonnes of goods per year and representing a yearly business in Europe of € 250 billion. In 2015, over 325,000 new trucks were sold in the EU, up 16.2% on the previous year. [1] Looking at these impressive figures, one might assume that the road transport business is booming. Yet still, while their order books are full, transport and logistics businesses are finding it hard to survive in today's competitive, tight margin, commercial environment.

Fleet connectivity is the key towards achieving efficiency, productivity and operational advantages and overcoming today's challenges. This concept is not necessarily something new: connectivity has actually been around from the early days of telematics. Fleet connectivity can be viewed in terms of generations, whereby satellite GPS tracking would represent the first generation and cellular connectivity the second. [2] Fleet management solutions have utilized satellite-enabled GPS navigation to help back office personnel and fleet managers pinpoint the location of their vehicles. Conventionally, the "connected fleet" describes something fleet management providers have been doing for a few decades now − delivering data to the back office via a connected vehicle.

In this respect, in today's Europe, around 23% of trucks and 6% of trailers are equipped with telematics FMS solutions and thus "connected" in the traditional sense. However, the potential for such fleet management solutions is enormous and it is expected that telematics penetration will reach 30% by 2022, generating €6.3 Billion. [3] According to the Financial Times, in five to seven years, industry executives estimate that telematics will be an integral part of all vehicle fleets. [4] This estimation runs quite parallel with the idea uttered by Deloitte that Telematics systems in trucks will become standard in the Triad markets by 2026. [5]

As for the "connectivity" most fleets are familiar with today, that is changing rapidly now. As we go beyond mere dot-on-a-map technologies, we need to consider the "connected fleet" in new and different ways.

**Service-oriented connectivity**

In the face of stagnating and declining commercial vehicle sales volumes, Original Equipment Manufacturers (OEM) have started truck digitization efforts and have tapped into connectivity, telematics and IT services to stay profitable, to secure new service-oriented business models and to reap the many advantages connectivity can bring: consider new revenue potential from tailored aftersales upselling, brand strengthening opportunities and customers retention resulting from services that generate new types and high volumes of customer data.

Many industry players from tire companies to mechanical parts manufacturers are busy developing connected solutions and are gradually evolving into fleet connected service providers: Continental entered the telematics world through the acquisition of Siemens VDO in 2007. Pirelli introduced *Cyber Fleet* in 2012, in partnership with Autotrac. Michelin entered fleet telematics through the acquisition of Sascar in 2014. That same year, WABCO embraced telematics with the acquisition of Transics. Recently, Cummins launched the on-board telematics system: *Connected Diagnostics*. Goodyear launched its connected fleet management: *Goodyear Proactive Solutions* and in the course of 2017 Knorr-Bremse will launch the in-house telematics brand, *TruckServices ProFleet Connect*, in alliance with Microlise. [6]  These are just a few examples to illustrate the trend of the evolution of Tier I providers from hardware and parts builders towards integrated vehicle service providers.

The resulting truck and trailer digitization makes way for a third generation of "connectivity" and offers an entire new dimension for connected vehicles, contributing immensely to the installed base of connected telematics worldwide, which is expected to reach close to 40 million commercial vehicles by 2020. [7]

This type of connectivity can provide data for detailed fleet analytics.  This means having the possibility to pull in vehicle-centric data in real time from a truck, a trailer and other peripheral equipment, such as video sources and then do intelligent things with it that lead to value added services. Near real-time visibility of rolling stock and remote equipment, over-the-air engine software updates and revisions, detailed video footage-based accident reconstruction, near instantaneous maintenance feedback, dynamic scheduling, etc.; these are all service-based components of the new connected fleet − a concept that is still evolving. [8]

**WABCO's current Intelligent Connectivity**

As a global technology provider to the commercial vehicle industry and − in close cooperation with Transics International, a leader in fleet management solutions − WABCO is on a constant mission to improve vehicle safety and efficiency.  By embracing innovative connectivity technologies, WABCO empowers fleet operators to take safety and efficiency to the next level and to unlock true commercial advantage.  In recent years, WABCO has led the way towards connectivity by bringing to market intelligent vehicle systems that capture and share data − with drivers, fleet managers, 3rd party logistic providers and even others shippers − in real-time.

Merged services of Transics and WABCO collect and present data on vehicle braking, stability, and safety systems, backed by real-time alerts and automated reporting. Some examples:

(1) One of the single biggest causes for premature tire wear is under inflation, which in its turn is caused by tire pressure loss, which in 85 % of all cases starts with a small leakage that cannot be detected on sight. WABCO's wireless tire pressure monitoring technology, which is linked to Transics' trailer and truck FMS, can detect such small leakages and delivers tire performance data directly to the back office so that tire tread life can be extended significantly, replacement costs can be reduced and maintenance or repair can be scheduled appropriately.

(2) Tire pressure monitoring is just one example of "remote diagnostics", which will eventually extend to all vehicle systems. Remote truck and trailer diagnostics represent an important step in bringing vehicle connectivity closer to a future model of predictive maintenance. Only 3% of fleets use remote vehicle diagnostics to monitor the status of vehicle systems. However, as the number of sensors on vehicles increases, the potential for such fleet management solutions is enormous. Under a predictive model, data collected from sensors provides a basis for calculating future performance, enabling maintenance schedules to be determined by analysis rather than by a prescribed timeline. Predictive maintenance reduces downtime by identifying issues before failures or collateral damage occur. In the case of an actual technical failure, the driver can be directed to the nearest service partner − who can prepare himself − for repairs or maintenance, ensuring that driver and vehicle are back on the road as quickly as possible. Another form of "remote diagnostics" is that of monitoring reefer fault codes over distance. These alarm codes can provide information regarding regular maintenance intervals or describe severe reefer shutdown. The ability to remotely monitor reefer fault codes gives fleet operators peace of mind that problems can be identified and fixed before they result in downtime or loss of load.

(3) WABCO's *SmartDrive* driver performance management system uses video-based recording technology to record driver behaviour and also offers insights and analytics based on real-time data capturing from WABCO's advanced braking and stability control technologies. SmartDrive Systems also enables predictive analytics and real-time risk identification by maintaining a database of more than 180 million analyzed risky driving events. [9] Next to accident mitigation it also protects the driver − and the fleet operator − with irrefutable evidence in actual accident situations.

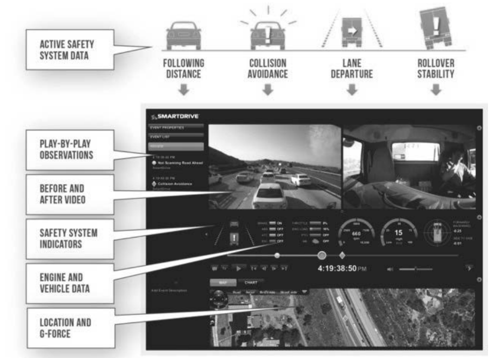


Fig. 1: WABCO and SmartDrive jointly developed analytics solutions, combining SmartDrive's video-based driving performance insights with Wabco's advanced braking and stability control technologies.

(4) OptiLock™ links vehicle security devices to Transics' FMS giving the dispatcher a full real-time view on "lock" and "unlock" door status changes. On top of that, it also entails a 2-way communication link: this makes it possible to remotely lock and unlock the cargo doors via the telematics unit, but also to "secure" the locking system, thereby preventing anyone (including the driver) from opening the cargo doors.

Fig. 2: WABCO's industrialized lock security system, OptiLock ELB-Lock®, can be remotely monitored and steered via telematics technology.

These and other systems have already or will shortly be integrated into Transics' all-encompassing back office software platform, TX-CONNECT, so as to give full monitoring and controlling capabilities to dispatching and management from a distance. This Intelligent Fleet Platform helps operators collect real-time data from a wide range of driver-, cargo- and vehicle-centric systems and sensors. In the end, TX-CONNECT reduces the complexity of fleet management to one user-friendly platform. It combines and visualizes all fleet-related information, including data from 3rd-party vehicle hardware (trailer and asset tracers, …) and third party office and transport software (TMS, ERP, salary, planning & routing, freight exchange, document management, HR, …) in clear reporting modules, resulting in manageable operational processes for all parties involved: the transport planners, managers, subcontractors and customers.

**How to avoid the pitfalls of connectivity**

(1) Too much data vs. intelligent data management

By connecting vehicle fleet technology systems, it becomes possible to capture an incredible wealth of real-time information. However, the sheer data volume and the dispersed nature of the different data segments − going from truck and trailer over cargo to driver and other third parties − could overwhelm the fleet operator, who risks collecting too much data, with little or no strategic purpose. The road to moving forward for fleet management software providers will be to manage “Big Data”, thereby turning it into useful analytics that result in meaningful recommendations and practical use.

One example to harness aggregated data could include giving drivers warnings about dangerous stretches of road. For example, cloud-based data analysis could show that a certain percentage of trucks had their rollover prevention systems activated on a particular location. Putting this kind of data in the cloud, without identifying specific trucks, would be a huge benefit for fleets. These types of Big Data and applications will make decision making faster and proactive, rather than reactive.

(2) Single-brand only vs. brand independency

In general, truck fleets are multi-brand, because companies do not want to rely on just one truck brand, as this would increase the risk and would also probably make them lose negotiation power in the moment of buying or leasing more trucks. If one relies on only the OEM’s connectivity, this brings a problem in maintaining the same kind of connectedness across the fleet, as companies would either have connected solutions to control just part of their fleet, or would have to deal with several different systems, one per each truck brand on the fleet.

This is where Transics as an independent telematics provider can help bridge that gap: even though there are different OEM systems available, the universal, neutral and independent character of Transics' Fleet Management solutions can wheel in data on a multiband level. In the end, fleets can get multi-sourced, comprehensive data, with the same driver experience and the same back-office experience across their fleet. [10]

(3) Too many hardware platforms vs. simplification

Connectivity is needed, but when looking in a cabin today, we see a lot of different hardware that monitor different sensors and systems: a truck mounted black box for driver- and truck-centric data, a trailer tracker, a console that gives tire pressure drop warnings, a device for camera visualisation, etc. On top of that, by 2020, it's expected that there will be an average of seven devices per person: from smart phones and tablets to wearable devices such as health and activity "fit-bit" trackers and smart watches. [11] This could well include equipment to monitor truck driver's heart rate, fatigue levels, and other health metrics in real time as they operate equipment. Goal is to aggregate all data generated from these separate sources, putting them together in a robust and secured cloud-based service platform and allowing that data to flow back and be visualized in a meaningful way in one all-encompassing hardware platform that is best suited for the sector.

(4) The threat of hacking vs. data security

Another major issue where telematics is concerned: the threat of hacking. The scientific proof is there to hack into the J1939 databus from onboard the vehicle. But the question is: what is the potential for the same type of hack, or perhaps a more serious disruption of the vehicle controls, via some telematics interface using WiFi, cellular or satellite connectivity. [12] The reference to the hacking of a Jeep at highway speed crystalizes the threat to truck hacking in the minds of fleet owners and governmental institutions, because if it can happen to a car, it can happen to a truck. [13] A new "ecosystem of security" for telematics will need to be created; a more "layered" security approach to telematics will be needed, including extra "gateways".

Next to vehicle hacking, there is the threat of pulling and aggregating all data to an open platform and making it vulnerable to third parties with ill intentions. Maximizing connectivity with other software suppliers is a must, but so is protecting the data flow. Even though it goes without saying that the adoption of an open platform is highly questionable in terms of data security, in recent years more and more telematics players have made the shift from a closed to an open (Android) system for two major reasons:

- Towards increased participation of all stakeholders (shipper, carrier, end customer) in the supply chain, the open (Android) platform can easily connect all parties and supply them with needed information that they demand from the market.
- Towards new, upcoming partnerships with OE-Telematics suppliers, Android is today's platform of choice to integrate house-own apps and data flows into common platforms. For example, Daimler and MAN have chosen the Android operating system and considering these and other OE players will increasingly "own" the front office side with standardly built-in embedded solutions, any independent FMS player needs to follow the "Androidisation" trend to secure their value-added position within this soon to be monopolized environment.

(5) Mobile technology vs. best solution-fit

Mobile technologies make all kinds of handheld devices, smartphones, tablets and RFID tags also part of the connectivity equation. [14] Independent tablets and smartphones are becoming the popular gateway for information and could increasingly become business enablers and drive up efficiency in the transportation sector. Their growing popularity is not without reason: they constitute a low threshold alternative from a development point of view; their built-in Internet, communication and global positioning system offer powerful "pre-installed" telematics features; they enjoy wide recognition and acceptance in the B2C environment, making them a "reliable" interface and their open platform makes it easy to incorporate additional value chain participants. As these benefits are also widely acknowledged by fleet owners & business partners, Transics and WABCO have developed a mobile and thereby flexible add-on solution to their existing in-cabin fixed on board computer. This add-on, called TX-FLEX, allows the customer flexibility outside the cabin (pre-trip inspection, "last-mile" planning info), open integration with third party transport apps, such as the use of digital CMR's, installation of personal apps for off-work features and usage of existing, embedded technologies (e.g. picture viewer, document viewer…).

Although WABCO firmly believes in the use of BYOD mobile solutions, looking at the concept of TX-FLEX as add-on solution only, WABCO holds to the vision that a mobile device should primarily be used for its intended purpose, which is that of mobility: whereas smartphones and tablets are excellent alternatives outside the cabin in terms of scanning barcodes, taking pictures, getting digital signatures and consulting last-mile planning tasks, fixed solutions should remain the preferred choice inside the cabin. The reasons why are as convincing as they are obvious: any determination to fully replace fixed solutions with mobile devices brings perilous risks a fleet owner cannot afford to take: any fleet owner must be able to rely on an industrial solution, specifically designed for the transportation sector, that can monitor and manage vehicle-critical data (extended CAN bus data, Tire Pressure Monitoring, Advanced Driver Assistance Systems, Remote Diagnostics, extended navigation features, etc.) as well as company-critical workflows (messaging, planning, activities, tachograph data, etc.) on a robust, cloud-based platform, in a secured environment and with a full hardware and software uptime guarantee.

**Internet of Things in logistics and Fleet Management**

In the transport and logistics industry, we move towards an era where every “thing” that can be connected will be connected, with each other and to a cloud-based storage platform. It’s about taking any machine, system or asset and fitting it with (multi-)sensors, microprocessors and wireless connectivity technologies (wired connections and wirelessly via Bluetooth, RFID, Wi-Fi, 3G, LTE, etc.) that generate relevant data and link each thing with other things or systems. However, this “Internet of Things” in the world of logistics is not just about making assets “sense”, it is also − and more importantly − about “sense-making”: creating value by turning the big data generated by connected assets into insights that result in business and operational changes. So paradoxically the “thing” is not the core of the Internet of Things, the data generated by these things are. [15]

This web of connected devices is already starting to revolutionize logistics and fleet management. Consider the following examples where connected technology can bring greater efficiencies and improvement to logistics service providers and fleets:

In the field of inventory management, pallets are already provided with low-cost, tiny multi-sensors and identification devices such as RFID tags inside the plank of the pallet, to collect information about location, temperature, humidity, weight, time, etc. As each pallet arrives through inbound gateways with cameras, the embedded wireless tags share data about cargo volume and dimensions. At the same time the cameras can be used for damage detection. If pallets get misplaced, sensors can alert the manager, who can track the item’s exact location. Other embedded sensors monitor the quality condition of an item and send out an alert when temperature or humidity thresholds have been exceeded. During outbound delivery, pallets are scanned again and cross referenced with databases to ensure that the right items are loaded in the right trailer. These aggregated data can be harnessed from within the plant floor and along the supply chain to save costs (otherwise needed for manual counting, scanning and tracking of pallets) and to improve inventory management and quality control. [16]

Bringing the IoT concept to commercial vehicles, we notice many fleets today are already equipped with processors, wireless connectivity and hundreds of sensors that measure temperature, pressure, vibration, velocity, acceleration, inclination, orientation, RPM, torque, fluid levels, tolerances, wear factors, GPS coordinates, etc. Particular sensor types measure the cargo load capacity of trailers to provide insights about available storage space on certain routes. IoT and the necessary analysing tools can then be used to focus on identifying spare capacities along fixed routes and make suggestions for consolidating and optimizing the route. Other sensor technology could be embedded in suspension systems and sent to a maintenance platform for analysis in order to identify material degradation or damages. IoT can also come in the form of cameras in the vehicle to monitor driver fatigue by tracking key indicators such as pupil size and blink frequency. If such a system senses the driver is losing attention on the road, it activates audio alarms and seat vibrations. The resulting safety improvements are just one of many benefits and represent a mere fraction of the limitless application range of Internet of Things in fleets and fleet management. [17]

**New connectivity-enabled communication types**

Vehicle-to-vehicle (V2V) communication is a fairly new and interesting example of how the Internet of Things is already affecting the way trucks are travelling on the road. As wireless technology allows connected vehicles to communicate with one another, drivers can be alerted to dangerous road conditions or possible collisions using vehicle systems based on Dedicated Short Range Communications (DSRC). DSRC is a technology similar to Wi-Fi and connected vehicles could also “talk” or provide the driver with information regarding tolls, work zones, traffic signals, school zones, etc.

With respect to V2V technology in commercial vehicles, WABCO is taking up a key position in continuously leveraging the advantages of predictive connectivity to provide its customers with ever-smarter opportunities to raise productivity, safety and performance. One specific example is that of WABCO’s OnGuardACTIVE collision mitigation system, which not only alerts the driver to potentially critical driving situations via acoustic, visual and haptic signals, but which is also capable of delivering up to full braking on moving and stopping vehicles and can bring the vehicle to a complete stop, should the vehicle operator fail to take corrective action himself. As one of WABCO's key safety technologies, this solution is already paving the way for platooning. Platooning uses electronic coupling to allow multiple vehicles to drive in sync; which means they can travel safely closer together, with greater aerodynamic efficiency. Once fully developed, we move towards tracking multiple trucks who drive in convoy.

Another major communication type which is in full development right now is vehicle-to-infrastructure communication. Infrastructure services such as electronic tolling and interconnected parking are already in place. Insurance companies are already making use of telematics to determine handling- and usage-based insurance tariffs. Technologies towards optimized signal timing and traffic flows to avoid traffic jams are in full development. The In-vehicle emergency call system that automatically calls the national emergency hotline in case of a serious road accident and simultaneously transmits the vehicle's GPS location data to local emergency services will be made mandatory in 2018.

**Connectivity of the future**

The Internet of Things and (the resulting) Big Data are today's enablers that will greatly contribute to the future transport society. They will be the cornerstone towards Smart technology, applied to transport and infrastructure to transfer information between systems for improved safety, productivity and environmental performance.

IoT and Big Data will − in conjunction with increasing levels of Advanced Driving Assistance Systems functionalities − open up the road to self-driving and ultimately fully autonomous vehicles. Back in 2014, the General Manager of IBM's Global Automotive Industry group suggested that “connected cars will be the ultimate Internet of Things”. [18] Already today, successful cases in other industries show the great potential of self-driving trucks for commercial fleets: consider the mining industry, where company Rio Tinto is the world's largest owner and operator of autonomous haulage system trucks, having 69 autonomous trucks in operation at the Australian Pilbara mining sites, moving high grade ore. [19] In the farming industry, John Deere and New Holland have already reached levels of respectively supervised and full vehicle automation and autonomy.

As for the trucking industry, the necessary technological developments are basically in place and working in the sense that semi-autonomous trucks may even be ready for series production as soon as in 2020, which is just a few years away from now! Industry experts anticipate that it will take until 2025 before we see fully autonomous trucks readily available for operation on public roads. This has more to do with policy issues that need to be resolved than with a technology lag. In fact, it is the truck industry that wishes to accelerate the change towards higher level of automation as it enables significant TCO savings for fleet owners: driver’s time (-81%), insurance and taxes (-40%), fuel (-11%), repair and maintenance (-15%) and others. [20]

In the future, as these autonomous vehicles will be able to send data with their environment, in the same way the latter will share data with vehicles, we will move slowly towards the Smart Mobility and Smart City concept, where vehicles can communicate with railroad crossings or traffic lights or automatically apply the brakes based on the traffic ahead. One of the early adapting cities, which is already harnessing the huge potential of the Internet of Things (IoT) is Barcelona. Next to a wealth of other application, this Spanish city has for example implemented a sensor system that guides drivers to available parking spaces. The sensors, embedded in the asphalt, can sense whether or not a vehicle is parked in a given location. By directing drivers to open spaces, the program has reduced congestion and emissions. [21]

IoT, Big Data, autonomous vehicles and Smart Cities will be interwoven to such a degree that one cannot exist without the other in the future. Although still several years away from us, the concept of Smart Mobility and Smart Cities will eventually be made possible thanks to the continued efforts and pioneering steps taken by OE-players such as WABCO today. Naturally, these are solutions where you need the entire transportation system to be coordinated. That will take a much broader kind of integration and those sorts of things are further down the line.

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