Towards inclusion of the freight rail system in the industrial internet of things - Wagon 4.0

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ABSTRACT

The freight rail system as used today is lacking behind lorries in terms of compatibility with industry 4.0 and other less recent developments in. In order to increase the capability of the freight rail system in the age of increasing digitalisation of the railway, little attention is paid to the wagon itself. In the paper, simple and cost efficient yet effective means of automating the wagons are introduced. The proposed measures are designed in a modular fashion and offer significant economical and safety benefits to specific users, making the investments required economically feasible.

1 INTRODUCTION

1.1 Observations on freight rail rolling stock

Transportation of passengers and freight is an important and growing field, for which in the light of decarbonisation sustainable modes need to be selected. It is generally agreed that rail transport is one of the more sustainable mode of transport, while customer choices of transportation mode with respect to sustainability are not yet identified. (1)

The freight rail vehicle sector across the world does rarely exhibit technological novelty, especially not in the areas of Internet of Things (IoT) and cloud services, which is considered of importance for increasing factor productivity (2). Furthermore, the integration of communication technologies into transportation systems is considered an enabler and thus highly required, despite plenty of adoption barriers (3).

While other modes of transportation seek to automate their operations as far as possible, refer to e.g. (4), freight rail rolling stock is accepted in its current state and the system optimized without considering the potential of selected investments into rolling stock (5). In cases where automation is considered, mostly automation of the mainline operation of the freight train is addressed, while the operation of the wagons remains untouched.

Another direction of development are freight rail telematics systems, which are fitted to 85 % of trucks in Europe (6). Such systems are added to the vehicle typically in the fashion of an isolated system, transferring the required data directly to its destination without aggregation of data in the vehicle. Notwithstanding the capability of such systems to solve the problem that led to its integration, a higher integration of the individual systems would improve the power of the overall monitoring performance, as proposed in (6).

While these amendments to the freight wagon will provide effective monitoring of the vehicles, their potential for optimization and cost saving is limited in that they have little potential to optimize the last mile processes, which account to approximately half of production cost (7).

The integrated and standardized approach of the Wagon 4.0 has the potential to significantly reduce the effort of last mile processes by providing a basis for application specific functionalities. In the sequel, the requirements for and the concept of the Wagon 4.0 are developed.

1.2 Driving forces in the freight rail market

The development of the Wagon 4.0 was initiated by the observation that in most developing countries the freight transport of bulk goods such as coal, oil or gas is set to decrease in the light of the decarbonisation of the energy sector. The total freight volumes will not decrease at equal pace, as an increasing number of smaller items is dispatched. These items are not only smaller, but bear at the same time more value as well as more demanding requirements in terms of punctuality and speed of delivery. For such items, most of the current rail freight systems are deemed unsuitable by the customers, who turn to road transport instead.

1.2.1 Industry 4.0

The key aspects of Industry 4.0 relevant to the railway sector are mass customization and self configuration. The former term indicates that single, highly individualised items are being produced at the same high efficiency as mass produced articles are today, while the latter term expresses the fact that in the factory of the future, machines are expected to organize themselves autonomously, e.g. in the case of failure or maintenance.

The fourth industrial revolution is fuelled by the advent of the internet of things, ubiquitous computing and affordable internet connectivity. It is anticipated to be a game changer not only for industrial production, but also for work and education.

1.2.2 Logistics 4.0

As may be expected from the vision of mass customization and self organization, Industry 4.0 will rarely require trainloads of identical material at a given time, but rather smaller amounts of varying goods at the right time. This is well in line the less recent trends of just-in-time and just-in-sequence logistics, but adds a layer of self-consciousness of the freight and the wagon in order to achieve the ability to be controlled by self organizing machines.

This leads to the transport vehicle suitable for Industry 4.0 being required to be conscious of its freight, to act automatically based upon the self organisation of the machines.

2 REQUIREMENTS OF CURRENT LOGISTICS

2.1 Market trends in logistics

Current logistics systems impose demanding requirements on the speed and reliability of the transportation chain, derived not only from Industry 4.0, but also from less recent trends such as just-in-time and just-in-sequence supply. A further factor changing the potential market of freight rail systems is the decrease in package size, which stems from the higher individualisation due to the improved connection of supply and demand thanks to internet technologies.

In contrast to this trend, rail freight systems in most countries focus their activity on bulk cargo, such as coal and ore. The amount of goods to be transported in these and similar segments are high, the transport is little demanding in terms of punctuality and, most important, can be run in block train operation. The selection and development of these freight segments is shown in Figure 1.

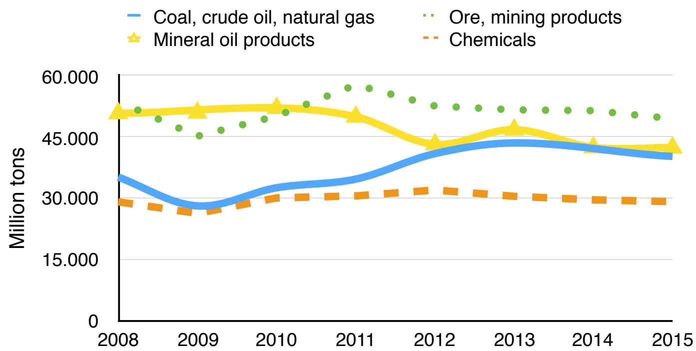

Figure 1: Development of typical rail freight segments in Germany

This preference on block operation of trains can be explained by the fact that train formation in the European system is costly and takes plenty of time. While focussing on the strength of the rail freight system, i.e. transportation of heavy bulk goods over longer distances, is desirable as long as such cargo exists, the long running economic trends decarbonisation and deindustrialisation must not be neglected in research and development in the freight rail system.

2.2 Road transport as competitor

In discussion of the decarbonisation of transport, one frequently encounters the argument that road traffic can, without major difficulties, replace rail transport if only sufficient area would be made available. Road traffic currently suffers from dependency from fossil fuels as well as a comparably low personnel efficiency. To overcome these drawbacks, several possible solutions are investigated. To reduce dependency on fossil fuels, alternative fuels, CNG and hydrogen are considered as well as electrification of main road connections, while the relative inefficiency on personnel use is aimed to be improved by help of platooning and autonomous driving.

While the automotive industry is undoubtedly a strong innovator, however the solutions presented above still pose plenty of open questions calling for fundamental research. An example is the eHighway system currently under trial in some European countries. This system aims to power a lorry through a catenary system, using a system voltage of 650 V. The supply of a larger number of lorries on a busy stretch of highway, possibly on an incline, appears impossible due to the extremely high current required. Also chemical energy storage, e.g. in batteries, suffers from a lower energy density; the energy density of diesel fuel is approximately 50 times higher than that of the most advanced batteries.

Platooning was trialled successfully in the spring of 2016 within the European Platooning Challenge. It still remains open to ensure the driver's vigilance during extended stretches of passive platooning and to enable the driver to have a break from work during these phases.

While these and other challenges will eventually be overcome, it appears sensible to use some of the existing technologies to improve the performance of the freight rail network by improving the wagon.

2.3 Desirable logistics use cases for wagons

While the rail freight system beside its known strengths such as energy efficiency and safety exhibits some drawbacks as discussed above, it can be developed to become the optimum mode of transport for many applications. To that aim, it is helpful to consider an industrial rail network containing the prototypical elements mainline connection, two production facilities and one warehouse as well as an appropriate amount of tracks, as depicted in Figure 2.

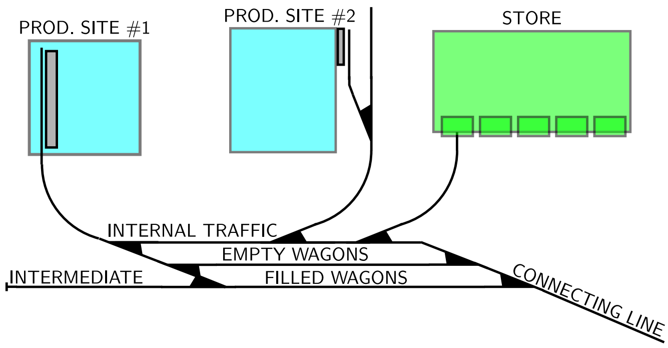

Figure 2: Intralogistics rail network

An internal rail network of this or similar topology can be used efficiently to organise supply of the factory, utilising the arriving wagons as a short term buffer, and to ship the goods. However, in order to do so, it is necessary to provide a shunting locomotive or a tractor to move the wagons. Furthermore, prior to leaving the plant on the mainline network, a full brake assessment is required, delaying the departure of the train by up to 90 Minutes from train formation. The investment in a tractor as well as the different handling of the wagons, together with the slow and labour intense relaying is indeed a disadvantage compared to road transport, where no special investment in handling equipment and no brake assessment is required.

3 THE WAGON 4.0

3.1 Introduction

Taking into account the requirements stemming from logistics 4.0 and industry 4.0, it is obvious that a wagon for this system of manufacturing needs to provide:

- Power supply: any intelligent, conscious system needs to rely on sufficient and reliable electric power supply, this power supply needs to be standardised in terms of connection and power
- Data network: a network consisting of wired and wireless technologies connects sensors and actuators on the vehicle, but also the operating personnel and the wagons within one train consist
- Connectivity: centralised 3G/5G connectivity for all elements installed on the wagon
- Localisation: a GPS/Galileo receiver forms the standard hardware of the Wagon 4.0
- Operating system: an open source operating system, the so called WagonOS, enables the extension of the system by help of apps, which can be developed by a community of developers
- Cloud infrastructure: an internet based system, containing the cyber representation of the wagon as well as appropriate algorithms and interfaces for its operation and maintenance

The supply of the wagon with electric power is conceived to be achieved by help of wheelset generators, with a small battery (app. 20 Wh in the basic version of the Wagon 4.0) as a buffer. This energy is sufficient to power the control units, the communication channels and also the automated braking system during the active time in the shunting yard.

Communication between the wagons of a train is made possible by use of short range data communication protocols, e.g. NFC. It is intended to employ a CAN based bus for the wired communication on the wagon, while for the data link to the human operator, a wireless technology such as 6LowWPAN is preferred.

In addition to simplifications for the freight customer, the provision of these technologies also leads to new business models based on the ability to acquire data and the new communication channels, making data transfer for smart load a new payload of the railway undertaking.

For the railway industry, a new business model is linked to the concept of apps for WagonOS. Apps do not only make use of the operating system, but can also contain hardware components. The integration of hardware components in apps for the Wagon 4.0 implies connecting to the wagon on either standardised interfaces, such as the connection to the power network and the vehicle bus in the of form of a form fit function interface specification (FFFIS), or individualised interfaces necessary to add required functionality to specific vehicle types.

Particularly automation and monitoring function will benefit largely from the existence of power and data connectivity in relevant positions of the wagons as well as communication to other sensors and actors. Without a FFFIS-compliant interface, the integration of such systems into the Wagon 4.0 would be prohibitive.

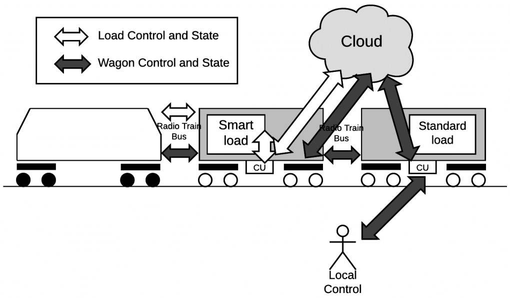

Figure 3: Wagon 4.0 in a train consist

3.2 Application example: automated pneumatic brake system

As an early example of the usage of the advantages of the Wagon 4.0 to improve the efficiency of the rail freight system, the brake system was considered. The brake system of a wagon is fully manually operated, leaving it on the one open to manipulation, while on the other hand, manual labour on the side of the tracks is required to set up and assess the brake.

The tasks required on the pneumatic brake system, such as brake isolation, quick release, G/P changeover and assessing the functionality and state of the brake, are mostly obvious to automate. The automation of the pneumatic brake system however is not done on wagons, partly due to a reluctance to invest into the wagon subsystem, partly due to the risks associated with the homologation of such a system. The economic benefits of an automated bake system however justify both efforts, as is developed in Section 3.2. The pneumatic scheme of the brake system of the Wagon 4.0 is shown in Figure 4, indicating the functions to be automated.

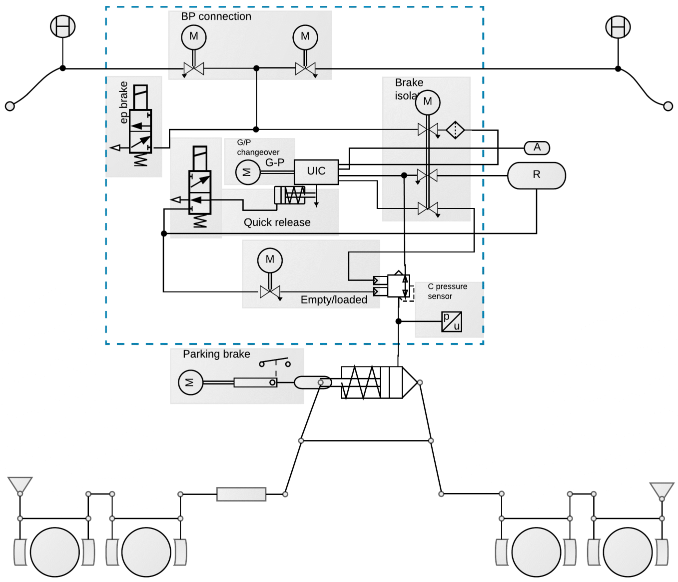

Figure 4: Pneumatic scheme of the brake system of the Wagon 4.0

The automation of the brake system can be achieved by adding magnet valves to the brake system, in addition to a pressure sensor for the brake cylinder pressure. Most of the valves are of bistable type, in this way, the safety of the system can be assured to be no worse than the existing brake by putting the whole automation system passive before the brake assessment as no change of state can take place during mainline operation. In addition to maintaining the same level of safety as the brake system according to UIC regulations, the monitoring and automation functions improve the overall safety, reliability and availability.

3.2 Operational and economic benefits

Due to the automation of the brake system, the Wagon 4.0 offers operational and economic benefits, which on their own provide sufficient return on the investments necessary in order to make the idea of the Wagon 4.0 economically viable for private operators. The main saving due to the automated brake system is the ability to provide ad hoc train preparation.

In the current system, the time for a full brake assessment (including the time for preparation and condition assessment) of a 740 m train is approximately 180 Minutes. This calculation is shown in Table 1, it is based on 30 s/wagon inspection time and 6 s/axle for checking of the brake status.

Table 1: Comparison of train preparation and brake assessment time

Step	Time current / min	Time Wagon 4.0 / min
Train preparation	39,5	1,0
Fill Brake Pipe	40,0	10,0
Condition Assessment	33,2	1,0
Tightness	1,0	1,0
Apply brakes	1,0	1,0
Check brake apply	33,2	1,0
Release brakes	2,0	2,0
Check release	33,2	1,0
Sum	183,1	18,0

While this reduction in time yields direct economic benefits via the reduced labour time, further improvements are possible thanks to the reduced usage of infrastructure, especially infrastructure of a bottleneck nature, such as port terminals. Further it provides an improved predictability, since a train can leave almost immediately after formation.

4 TOWARDS THE DRIVEN WAGON

Traditionally railway freight traffic consists more or less of the following hops:

- Movement and collection of wagons at the loading area/ and or in the private siding (siding and loading operations)
- Collection of wagons from different sidings by a regional freight train and transport to the next hub (distribution)

- Transport between hubs (long haul)

These hops will be done four times for each transport to get a full turnaround, twice up the hierarchy and twice down. The same normally applies also for road traffic in case of partial loads, e.g. palets.

4.1 Economic properties of rail freight

If you compare the economic properties of each hop of the rail freight system to its counterparts on road, it is obivious, that rail is especially economically feasible the higher you are in the hierarchy. This may get more clear with an example:

If you transport 30 wagons bewtween two hubs you will need one loco, one driver and one allocated infrastucture timeslot, these costs will get divided by 30. Furthermore you will use a quite high speed (e.g. 50 mph).

If you move 3 wagons in a siding to its loading area you will have a speed of 10 mph and therefore 50 times (!) of the cost rate per mile compared with our hub-to-hub example.

This is called a peripherial network effect. It applies for all kinds of hierarchical networks as road, telecoms, rail, gas, electricity, water, retail-distribution and much more.The last mile is the most expensive one. This especially holds true in case of road traffic. Road carriers who got hold of of a contract are therefore especially interested to compensate their high last mile costs (waiting times at the loading area included) by low costs on the long haul. Therefore traffic is often lost for rail as soon as road is involved at the end of the journey.

This is not new, even in an old schoolbook written by Otto Blum in 1930 these economics hold true. A steam loco hour was so expensive, that people optimized their use to stay competitive with road traffic. The distribution hop was optimized by using mixed trains (freight and passenger) or resorting of distribution trains before leaving the hub/ marchalling yard in order to operate sidings in less then ten minute (sidings need to be properly orientated so that the train only sets back in the siding and needs to uncouple the last wagons which need to stay there).

For siding and loading operations horses, manpower or winches were used.

So the situation did not change at all in the last 100 years. But technologiy has changed and therefore break-even-points and the degree of competitive advantages. Labor gets more and more expensive and most of the railroads are not really lean yet. This will be an advantage for rail traffic, but only in case rail wins the battle of the last mile as was true 100 years ago. If you have a significant number of wagons staying together a loco will always be more cost efficient than individual traction in each wagon. This is true for the long haul, this is true for optimized distribution. But for operations in sidings, in the loading area or for reordering a loco is quite expensive. So other solutions should be examined.

4.1 Requirements for cost efficient movement in sidings

Operations in the loading area and in sidings are heavily interlinked but currently often operated by different people. The railroad company moves the wagons and the loading agents operate the cranes, loading machines, wagon sliding walls and wagon doors. Often this means, that waiting times of either team are not avoidable.

Existing solutions on the shippers side have been horses in the past, which now have been substituted by tractors (e. g. 2-way-unimogs). But also this equipment (although cheaper than a shunting loco) generates significant costs and needs skilled users. So this will not be cost efficient if a machine like that is only used 30 Minutes per day having 24 hours. This means regarding the current competitive environment with road shipment new solutions will be needed to equip an intelligent freight wagon with limited means to move itself.

HIER KOMMT NOCH ½ SEITE

4.2 First technical concept for self-moving wagon

HIER KOMMT NOCH 1,5

5 CONCLUSION AND FURTHER WORK

The freight rail system is challenged by diminishing loads that are prone to being transported in the form of block trains, while at the same time the requirements on the logistics chain increase. The response of wagon owners is to reduce investment in rolling stock as much as possible, at the cost of a non-innovative technical product. Road freight transport acts differently; players in this market make strategic investments, putting them in a better position to interface logistically demanding customers and market. These developments will lead to a shift towards road transport, which is contrary to the targets of CO_2-reduction agreed on in Paris and Marrakech.

While road transfer and the automotive industry are rather innovative, the proposed solutions to the current challenges still require fundamental research. In this light, the Wagon 4.0, a wagon with power supply, local control units, monitoring and actuation of key elements, such as the brake, offers a visible solution reducing labour effort and infrastructure usage.

Two application examples, the automated pneumatic brake and the driven wagon are presented. Both show great economic potential to improve the economy of rail freight operation, especially for single wagon load and last mile operation.

As next steps, the implementation of demonstrator wagons and their subsystems is planned or ongoing, while also users and relevant use cases are collected and documented. Further work is also required in discussion with infrastructure managers and homologation bodies to ensure that this novel approach suits operational needs and is ready for homologation, also taking into account a migration scenario between existing wagons and Wagon 4.0.

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