Improved dynamics of vehicle movement in intelligent freight trains

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Abstract

Increasing the modal share of railways in the transportation sector is one of the most powerful lever against climate change and global warming. Especially in the freight business in Europe the share of railways has suffered mostly due to political reasons but also due to inefficiencies in management and operations. The two major targets in operations are an increase in train length of mainline traffic while keeping preparation time and acceleration times constant and a reduction of expensive labor and locomotive hours in feeder traffic and during loading and unloading operations.

These targets may be achieved by adding a digitalized electromobility system to the traditional freight wagons, called "freight wagon 4.0". While other authors have focused mainly on the IT implications, we will analyze the implications on vehicle dynamics and battery storage capacity requirements.

Keywords: Electromoblity, Internet of Things, Train Dynamics

1 Introduction

Freight transport by rail in Europe is underperforming compared to their US counterparts. This is a result of numerous economical and political factors:

- Too strong regulation on EU or national level, which has resulted in increased bureaucracy and increasing paperwork for safety approvals during the last 25 years

- Market entry barriers and lack of competition exist on all levels of the value chain
- Underperforming mostly government owned national incumbent operators, partly receiving significant subsidies
- Incompatible national legacy ATP systems as well as an expensive, complicated or underperforming European alternatives (ETCS)
- New hidden subsidies in favor of road competition especially on the last mile compared to rail freight bearing all costs including infrastructure
- Too demanding requirements for feeder traffic, e.g. the application of mainline track quality standards to private sidings
- No dedicated local feeder operators due to high legal requirements and difficult business case

In addition to the above factors, the technology applied in infrastructure and vehicles has not advanced due to lack of interest, low operational margins and complicated safety approval processes [1, 4].

Since rail traffic is more energy efficient than road, increasing the modal share of railways in the transportation sector is one of the most powerful levers against climate change and global warming. But its share can only be increased if quality and cost of service meet the requirements of modern logistics, which demand an on time delivery as well as flexiblity and cost. To achieve this, an easy access to freight customers as well as long trains operating on the mainline are necessary [3].

While the above mentioned improvements in train length and last mile accessibility are considered conventional wisdom, further improvements are achievable by harnessing some of the latest enablers of modern technology, which are the Internet of Things (IoT), Ubiquitous Computing, Energy Storage as well as affordable sensors and power electronics. Derived from discussions with relevant stakeholders, such as shippers, railway undertakings as well as wagon manufacturers and lessors, the potential for improvement by adding appropriate technology to the conventional freight wagon led to the concept of Wagon 4.0 (W40) [5].

Adding a digital electromobility system to the traditional freight wagons, thus rendering it a W40 helps to make operations in sidings and terminal more efficiently, especially when composing long trains. The system under development is an add-on to the traditional wagon, which will deactivate itself in case of failures.

2 Wagon 4.0 concept

2.1 Technological basis

The Wagon 4.0 is a holistic concept to connect the freight rail system to industry 4.0 as well as reduce operating cost on the so called last mile, which forms a large cost driver in freight rail operations. Important aspect is that all additions to the freight wagon are based on an actual business case, yielding an ROI on a relevant time scale. The main aspects of this concept are:

1. Power Supply: Continuous supply with electrical power plays a vital role in digitisation for real time logistics and asset management. The energy is supplied by wheelset generators providing a maximum output in the range of $(100\dots700)\,\mathrm{W}$ at typical commercial speeds. The power supply is currently undergoing a standardisation.
2. Communication Network: Next to power generation, the three-layer network consists of a node and gateway system, enabling communication within wagon, train and to the internet, respectively. It is foreseen to standardise the communication interface within the W40 to simplify extension.
3. Sensors: Basic sensing of the W40 includes GNSS positioning, velocity, shocks and vibration as well as brake cylinder pressure. Depending on the intended usage, further sensors may be added by help of the standardised interfaces.
4. Actuators: While sensors and networks provide useful data, the economic effect in the daily operation of the wagon is mainly generated by automating key functions of the wagon, mainly the brake. Similar to the sensors case, the W40 concept is scalable making the addition of further actuators (e.g. for trunnions) simple.
5. Shunting drive: In its highest migration level, the W40 will be enable to self sufficient operation on sidings thanks to a shunting drive. The shunting drive is supplied from energy havested during mainline operation and has sufficient power to move the wagon under consideration on sidings at shunting speed.
6. Operating System: The so called WagonOS, an open source operating system, will unify the above mentioned base concepts to allow for extending the capabilities of the W40 and to standardize communication protocols, data formats and related standards. A central operating system furthermore enables currently disjointed efforts to unite under the umbrella of a single industry standard.

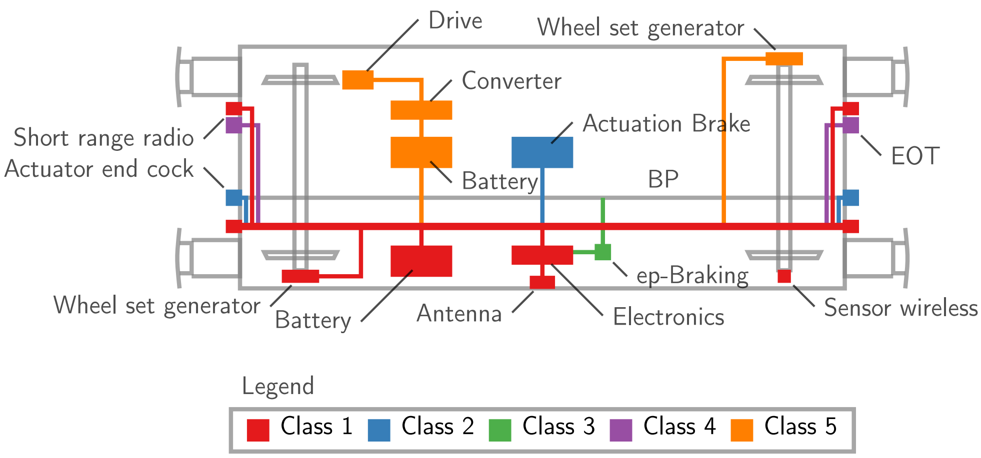

Figure 1: Wagon 4.0 structure and migration levels (classes)

The provision of these elements as depicted in Figure 1 for the W40 does not only lead to simplifications for freight customers, it also paves the way to new business models for wagon owners and railway undertakings. Such business models arise e.g. from the provision of data connection to smart cargo, e.g. high value objects that require monitoring of temperatures and vibration, making the load data a second payload of the railway undertaking.

2.2 Enablers and drivers

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.

2.2.1 Industry 4.0

The key aspects of Industry 4.0 are mass customisation and self configuration. The former term indicates that single, highly specialised items are being produced at the same high efficiency as mass produced articles today, while the latter term expresses the fact that in the factory of the future, machines are expected to organise themselves autonomously, e.g. in the case of failure or maintenance. Driving forces of the fourth industrial revolutions are the IoT, Cyber Physical Systems and Ubiquitous Computing.

2.3 Condition Based Maintenance

With the high cost of both preventive and reactive maintenance, condition-based maintenance can be considered a key enabler of the Wagon 4.0. Typically, applications follow one of two paths: either that of model-based condition monitoring or that of data driven condition monitoring. Approaches to this using the W40 infrastructure are elaborated in [8, 6].

2.4 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 with 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.

2.5 Benefits of migration towards W40

Major anticipated effects of the W40 migration are an *ad hoc* train preparation thanks to the actuated and sensorised brake system as well as the communication network. The brake system features bistable electrical valves replacing the current manual controls, namely G-P-changeover, brake isolation and empty-loaded selector, where applicable. Further, the parking brake is actuated and can be remote controlled same as the brake pipe end cocks. The brake schematic is depicted in Figure 2.

An ep-apply valve vents the brake pipe locally and in this way supports the propagation of the brake information through the train consist.

The pre-departure inspection is shortened from approximately 1,5 hours to about 10 minutes [5]. This reduces personnel required as well as idle time in yards, which leads to significant savings. In addition to automating previously manual settings of the wagon

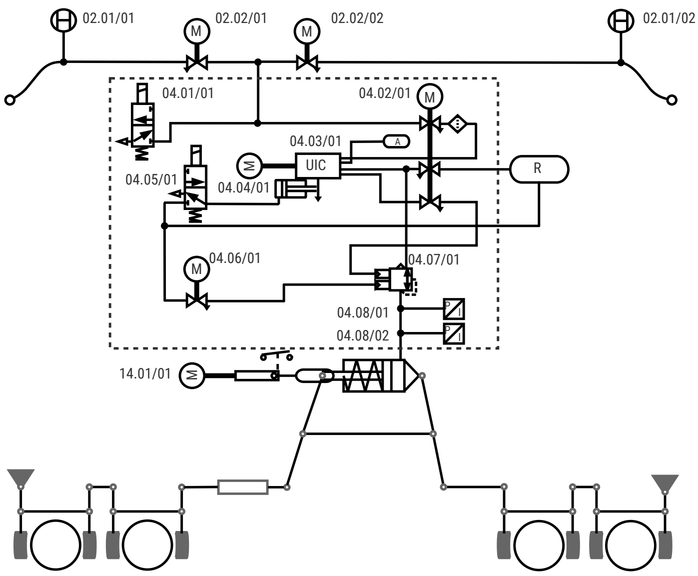

Figure 2: Brake system schematic of W40

subsystem, due to its constant connectivity and power supply, W40 can feature an ep-assisted brake system, which applies the brake almost synchronously along the train.

A second major benefit, by help of the autonomous shunting drive, is the reduction the time to serve sidings. In concert with the automatic brake setup and train launch, the autonomous shunting drive can cut the locking time due to served sidings on the track from an hour to approximately 10 minutes. Further, economic gains from saving the underused shunting devices at each siding help to amortise the investments in rolling stock in reasonable time.

The shunting drive may as well be used to support the locomotive during start of the train, which is a good example of a collaborative effort of an IoT system.

2.6 W40 drive system

The auxiliary drive only generates advantages if it can be integrated into the Y25 bogie in an economic manner. The necessary amount of traction effort and battery capacity depends on the infrastructure, the weight and the distances to be covered. This leads to three maximum operating points:

- Acceleration under the worst conditions (steep grade, minimum acceleration, initial breakaway force)

- Constant speed in the same grade
- Energy consumption app. 1 kWh per km under standard conditions

Taking into account typical setups of private sidings in Europe, tractive forces of approximately 21 kN and a traction power of approximately 15 kW is needed to allow operation in standard cases. This allows an inexpensive electrical setup using a 15 kW induction machine and a standard inverter-battery pack setup used in regenerative energy applications. Under realistic conditions a battery capacity of 5 kWh will fulfill almost all requirements.

The nominal idle rotation speed of a four-pole induction motor is at 1500 rpm. At 6 km/h which is the intended operation speed at the loading site, the wheelset turns with approximately 35 rpm. This leads to a required gear ratio of 1:43, which is only feasible with a three-stage gearbox. A coupling has to be mounted between two stages to separate the motor.

Spur gears for rail usage are too heavy and too expensive for wagon applications, therefore FH Aachen focuses on the alternatives, in particular timing belts, roller chains and friction wheels.

Timing belts and roller chains can compensate minimum relative movements between the pulleys / sprockets using idlers to keep the pre-tension in the returning strand constant. In an actual spring suspended Y25 bogie, the lateral movements prohibit the use of belts and chains, but a stiffer lateral wheelset mounting e.g. elastomer springs or in other bogie designs a link arm suspension could enable it.

Another alternative are friction wheels pressed against the tread surface of the wheels or against another friction wheel mounted on a seat for brake discs. Powered Rubber wheels are standard parts of forklifts and inexpensive. In a first attempt in CAD, a powered wheel block available commercially has been positioned in the Y25. The maximum load of the wheels depends on the speed in operation. To reduce wear the contact pressure could be applied hydraulically and regulated. Energy can be saved too, if the pressure in the hydraulic cylinders won't be higher than needed for the currently requested traction effort. Under the estimated conditions, the life cycle of the friction wheels is more than two years which matches the regular maintainance intervalls.

A simple way to integrate an auxiliary shunting drive is an arrangement similar to the Knorr Compact Freight Car Brake, which consists of two half frames with with brake shoes beeing pressed against the wheels by hydraulic cylinders. In the case of an auxiliary shunting drive, the brake blocks are replaced by friction wheels.

3 Application examples

As described in [2] the W40 makes shunting in sidings as well as loading operations and brake checks more simple and therefore more competitive, as infrastructure may be less expensive and operations are less time consuming. This is the original reason for installing electric controls and an electric traction system. Obviously, additional hardware cost are low for using these systems also during mainline operations, while one time cost for safety approvals is a non negligible portion, rendering it a sensible choice only for a class 3/5 setup. Using the existing hardware offers benefits during acceleration and braking.

3.1 Traction boost

In case the W40 is equipped with a traction system, such wagons may operate like a multiple unit vehicle and support the loco during acceleration. Assuming a train set up with 30 container cars type “Sgjs” each of them loaded with three 20’-containers, the total train mass will be typically estimated to 1 100 t. If a loco of type DB 145 (weight 82 t) is applied, it will deliver at least 250 kN of tractive effort and a typical power of 4.2 MW. When using the tractive capabilities of the W40 for a short term during the acceleration of the train, the tractive effort of the whole composition will be 880 kN, signifying an increase by a factor of 3.5. The short term power of the system will only increase slightly by 10%. That means as is shown in Figure 3, that use of the tractive capabilities of the W40 makes only sense for speeds below 20 km/h.

This velocity range however is the range which is important for freight traffic. Normally turnouts in freight yards are designed for branch speeds of 40 km/h due to cost reasons. Consequently, the most important task is accelerating up to 40 km/h as fast as possible in order to reduce occupation and locking times of train path elements in the interlocking system. As an initial estimate, the acceleration will take approximately one minute less with W40 traction applied. On heavily used mainlines, headtimes are in the range of four minutes [7], so saving one minute during acceleration of a freight train may significantly increase capacity in congested nodes.

3.2 ep-assisted braking

Thanks to the continuous power supply of the W40 and the intra-train network capability, it is possible to extend the brake system of the wagon by a valve to command an indirect

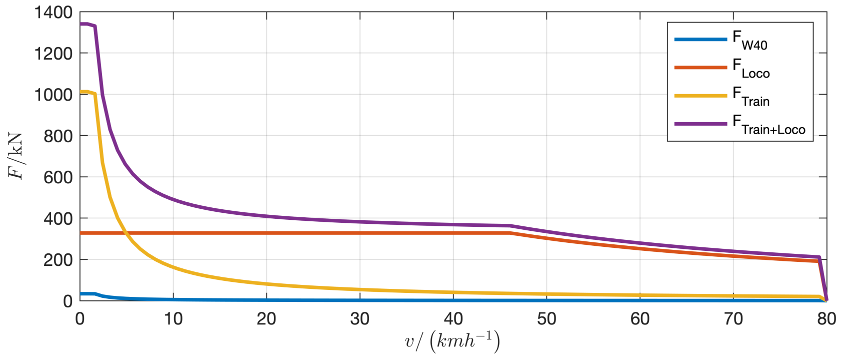

Figure 3: Traction curves of individual W40, a locomotive, a train set and their sum

electro-pneumatic brake application locally. This is achieved by locally venting the brake pipe to the atmosphere. The benefit of locally commanded brake application (ep-apply) is a faster propagation of the brake request through brake pipe, which leads to three effects:

- On operations level, the braking distances and therefore the headway are reduced.
- On train level, the longitudinal buff forces with in the consist lower than for a brake request from the front of the train (Refer to Figure 4, left column conventional braking, right column with ep-assist).
- On wagon level, a more equalised brake application leads to less wear on certain wagons, such as the first P-braked wagon in an LL-braked train consist.

The reduction of buff forces may lead to increased train masses being braked in the P-regime, which in turn also increases maximum velocities.

In terms of industry 4.0, the ep assisted brake can be considered a collaborative function, as no master is required for this functionality. Instead, the wagons support each other in braking the train, with the most sensible way to react the neighbouring wagon braking being to support the process.

Depending on the treatment of the improved functionality with respect to operations (i.e. braked weight, train length and masses) such a function does not require too high safety levels, since failures in individual wagons do not impede the overall safety of braking on train level due to the continuous brake pipe.

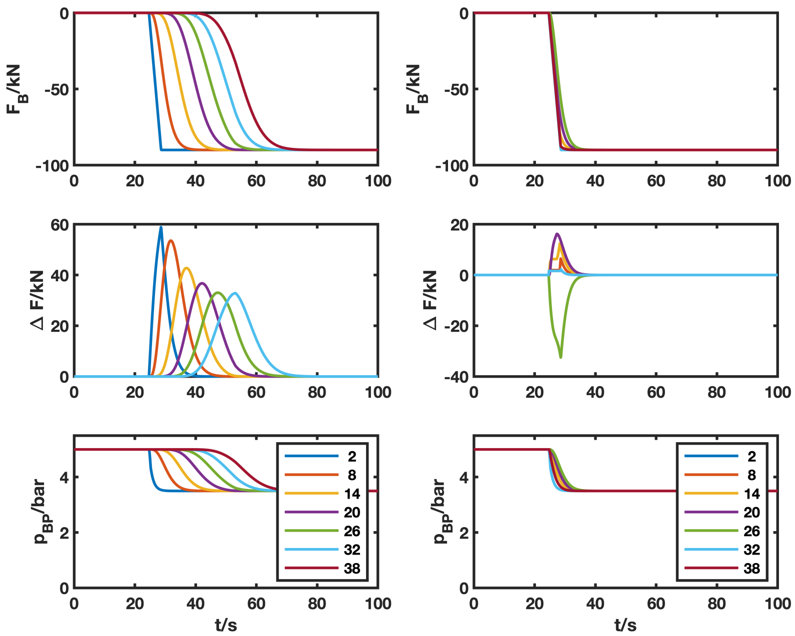

Figure 4: Longitudinal forces and brake pipe pressures of a 40 wagon train set

4 Conclusion and perspective

While originally developed for benefits in shunting yards and on the last mile, the W40 yields potential for improvement also in mainline operation. Depending on the area of usage, freight rail operation will benefit from the improved performance thanks to shorter acceleration phases as well as shorter braking distances.

The traction boost operation will help trains to accelerate as a combined effort between locomotive and wagons, thus using the shunting drive to support at start-up of the train consist. Especially diesel traction will benefit from a high tractive effort being available.

Already frequently applied in passenger trains is the ep-brake application function. In freight trains, the benefit of an electrically commanded automatic brake is even higher due to the higher masses and train lengths as well as the more conservative brake regimes.

This shows that, despite being initially designed for different purposes, the Wagon 4.0 is beneficial also for other service types. Further, dedicated lines in the e.g. heavy haul sector, may provide attractive pilot applications.

Acknowledgements

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