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NGT CARGO – A market-driven concept for more sustainable freight transport on rail

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Abstract

Greenhouse gas emissions from the freight transportation sector must be significantly reduced in line with the European Union's commitments. Shifting freight transportation from carbon-intensive modes such as air and road to more environmentally friendly modes, such as rail, can be an effective means of accomplishing this goal. In order to compete with the flexibility, speed and price of current road transportation, rail freight needs to apply new technologies and strategies such as automation, energy-dense batteries and virtual coupling between trains. NGT CARGO is a high speed freight train concept, the individual cars of which are capable of independent autonomous travel for short distances and which, as a complete train with locomotives, is capable of high speed platooning operations together with other appropriately equipped passenger and freight trains. With this concept, the capabilities and capacities of rail freight transportation can be expanded while maximizing the utilization of existing infrastructure.

Keywords: Autonomous driving; freight; high speed rail; climate; modal shift

1. Introduction

By 2030 the total volume of freight transportation in Germany is expected to increase by approximately 38% according to Schubert (2014), accompanied by a corresponding increase in CO_2 emissions from fossil-fuelled vehicles on roads and in the air. Projections show that a business-as-usual scenario would lead to CO_2 emissions approximately one third higher than 1990 levels by 2050, instead of meeting the European Union's (EU) commitments to reducing greenhouse gas emissions by 80-95% by this date. In order to meet these commitments and effectively decarbonize the transportation sector, the European Commission (2011) has determined that at least 30% of the total road freight volume should be diverted onto other more energy efficient modes, primarily rail, by 2030, with that number rising to 50% by 2050. For comparison, the rail freight modal share for international traffic inside the EU is currently steady at around 11% of current tonne-km, but with a decreasing share of Single Wagonload Freight (SWL). The European Parliament Directorate General for Internal Policies (2015) finds that SWL or less-than-wagonload shipments are increasingly being transported by road, as road transportation generally offers shorter transit and lead times, greater flexibility and often lower costs. This is central importance, as Zunder and Islam (2018) have shown that future growth in the total freight market in Europe will be driven by the shipment of SWL-appropriate Low Density High Value (LDHV) goods. These include semi-finished and finished products, which, according to Islam et al. (2015), require more flexible and reliable shipment than transport by rail can offer today. To increase the share of freight transport on rails, the goal must be to attract these goods. Apart from operational aspects such as transport time and flexibility, according to Islam and Zunder (2018) it is important to offer a competitive shipment covering the whole door-to-door transport chain. This includes a fully automated loading/unloading as well as an increased number of sidings to improve the availibilty of intermodal operations as described by Islam et al. (2016).

To reach the levels required, disruptive approaches are needed, as well as vehicles with new capabilities that allow them to cater to market segments currently served by road and air transport. As part of a system for the transportation of goods, the German Aerospace Center (DLR) is developing a highly automated high-speed train concept called Next Generation Train CARGO (NGT CARGO). This concept represents a holistic approach for SWL as well as for trainload freight, including new technologies allowing a high level of automation for loading, shunting, driving and unloading, which together should serve to improve the competitiveness of rail freight.

2. State of the art of high speed rail freight

To date Europe has seen two operational high speed rail freight services. As decribed in Jullien and Pin (1984), the TGV Postal was put into service in 1984. Based on specially adapted TGV-PSE trainsets, these trains transported mail between the metropolitan areas of Paris and Lyon. According to RCGF (2015), this service ceased operations in 2015 due to a changing market environment characterized by a decline in mail volume connected to the growth of electronical mail. Another more recent attempt to establish a high speed rail freight service is the Mercitalia Fast in Italy, as described in Railway Technology (2019). Based on an adapted ETR 500 trainset, this service aims to ship a wide variety of time-sensitive goods between the cities of Caserta and Bologna using the existing high-speed rail newtwork in Italy.

Apart from these two implemantations there have been several attempts to establish high speed rail freight services in Europe. In Bauer et al. (1990) an ICE-G network is described that was to have provided a high speed rail freight service for Germany based on the technology of the ICE trains. Correspondingly in France, Gouin (1996) described the TGV Fret, a system based on TGV technology which would have provided a high speed rail freight network throughout large parts of Western Europe. The Euro Carex consortium picked up this idea and developed it further into a high speed rail freight network connecting the major western European airports and metropolitan areas as described by Bent (2012). Concepts for possible Euro Carex vehicles were developed based on the TGV and, as presented by Gediehn (2010), on ICE technology. Another concept currently under development is for a high speed freight train for the Moscow-Kazan-Beijing corridor, as described by Bačić (2017).

In Japan a Freight Shinkansen service between the Tokyo and Osaka was proposed by Matsunaka et al (2015), with a study showing its benefits outweighing its costs by a factor of 1.805. In 2018 the China Railway Rolling Stock Corporation (CRRC) presented its concept for a highspeed freight EMU with a maximum speed of 250 km/h.

What all of latter these projects have in common is that they never left conceptual stage. While Euro Carex, the freight train for the Moscow-Kazan-Beijing corridor and the freight EMU of CRRC are still active projects, as of this writing there are no firm dates for a market debut for these concepts.

The proposed vehicles for all of the high speed rail freight networks described above have the common trait that they are based on existing vehicles for high speed passenger transport. They are, without exception, permanently coupled trainsets. It is not possible to separate the trainsets and rearrange the single cars to form new trainsets under operational conditions. The operational concepts are based on the principle of block trains, expanded to high speed rail. Combined with a focus on special goods such as mail, this leads to highly specialized vehicle concepts which have difficulty fulfilling variable demands in terms of volume and goods transported. None of these concepts have addressed the lack of flexibility in current offerings for rail freight.

3. An approach to sustainably expanding high value rail freight volumes

The case of the TGV Postal serves to illustrate the risk of an inflexible trainload-based design serving a highly specialized market. In order for rail freight to enjoy long-term success and to shift freight tonnage from roads to rails, it must be able to transport small quantities of a broad range of LDHV goods rapidly in a flexible and efficient manner. In doing so it would compete with road freight and complement rather than replace current rail freight services.

The key innovation which would offer the greatest potential for improvement is automated driving capability on the level of individual cars. This, together with achievable speeds higher than the 120 km/h typical of current freight trains, would allow a future train to compete with other modes of freight transportation, offering lower transit times, potentially a lower price and delivery directly to a logistics centre or siding convenient to the recipient. The ability to keep pace with passenger high-speed rail traffic would also increase the capacity of existing lines, while a largely cargo-agnostic design with the ability to transport a wide variety of goods would enable broad swathes of the cargo market to be served and ensure that the system can adapt to market changes.

4. Operational requirements

The NGT CARGO high-speed freight train concept consists of self-propelled, autonomous cars which serve the fine distribution and collection of goods over short distances, the so-called last mile, and high-powered locomotives to which groups of cars can couple themselves for high-speed travel over longer distances. Following a typical last mile operation, the individual cars assemble and couple themselves to locomotives to form an NGT CARGO train. An electrical connection is established between the locomotives (which are equipped with external electrical energy collectors) and the individual cars, enabling the energy storage systems of the individual cars to be recharged. The NGT CARGO locomotives are equipped with the same electronic virtual couplers as their NGT siblings, NGT HST and NGT LINK, allowing mixed platooning operations with those passenger trains, as described in Winter et al. (2011) and Krüger and Winter (2014).

To permit the autonomous operation that will enable NGT CARGO to displace local road freight traffic, the individual cars have their own sensors and traction systems with associated energy storage systems. The cars are, depending on customers' requirements and operational conditions, able to operate independently on existing routes, either individually or as a group. They can serve unelectrified sidings such as often belong to small commercial operations, thus making transloading unnecessary in many cases. A requirement analysis for individual car operation over the last mile was conducted to determine the necessary autonomous ranges and the corresponding energy demand. For this purpose, the shortest route (outward and return journey) between 30 existing freight logistics centres (FLC) in Germany and their nearest marshalling yards was taken into account, based on data from Deutsche GVZ-Gesellschaft mbH (2019). The track parameters considered (elevation profile, maximum line speed, distances) were recorded using the geographical information systems ArcGIS and QGIS. Longitudinal dynamic simulations, including dwell times for unloading and loading, to determine the energy demand of an individual car were carried out using the DLR trajectory planner TPT described in Iraklis et al. (2018). Basis on these simulations, the main parameters of NGT CARGO are listed in Table 1.

Table 1. NGT CARGO main parameters.

Parameter		
Number of locomotives in basic configuration	2	
Number of individual cars in basic configuration	10	
Number of axles in locomotive / individual car	4	
Maximum operating speed	400	km/h
Tare weight per individual car	30.5	t
Load capacity per individual car	37.5	t
Max. weight basic configuartion	816	t
Cross-sectional area	12.5	m²
Length individual car	20	m
Length locomotive	22	m
Length basic configuration	244	m
Wheel diameter	980	mm

The statistical evaluation shows that each individual car has to be designed to travel a minimum distance of 29 km autonomously in order to cover 75% of all last mile routes (Fig. 1 top left). Moreover, the gradient to be overcome is a maximum of 5‰ (Fig. 1 top right). This analysis results in an energy demand of 39 kWh and 1.9 kWh/km at the wheel (Fig. 1 bottom left and right). The 29 km range is thus sufficient to cover 56.25% of existing routes (first to last mile), however the NGT CARGO system envisages the construction of centralized logistics terminals near large metropolitan centres which would serve as hubs for local distribution and collection and be the start and/or endpoint of many cars' trips. This will result in a higher percentage of route coverage with the stated range. The individual cars also employ a modular energy storage system that allows battery capacity to be expanded for cases in which the cars' range is insufficient. Technologies are also being considered which would enable a car to either inductively or conductively recharge while loading at an outlying destination.

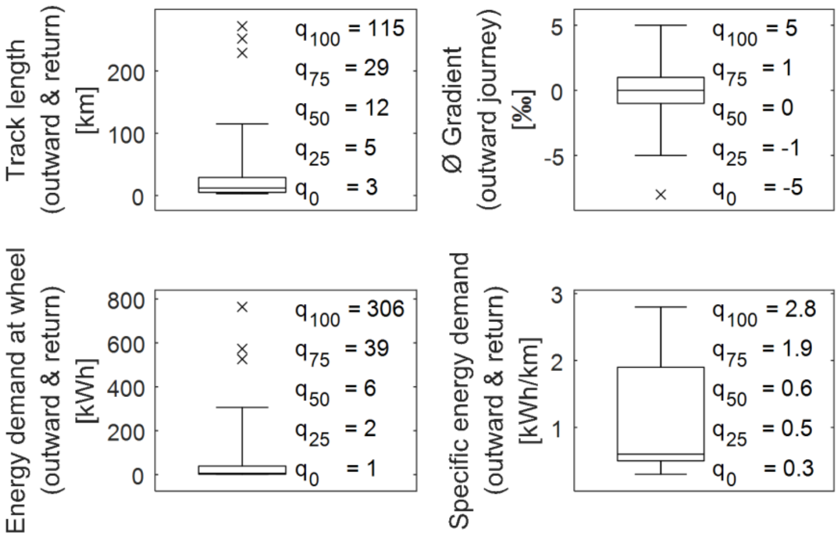

Fig. 1 Statistical analysis of data collection: q_{xy} is the xy% empirical quantile; Points marked with x are outliers that are more than 3 times the quantile distance outside the interval q_{25}-q_{75}

NGT CARGO aims to maximize line throughput by virtually coupling with NGT passenger trains travelling at up to 400 km/h. However, the traction power of the individual cars is not sufficient for operation at these high speeds. The additional required power is provided by the locomotives. In addition to providing a large proportion of the train's tractive power, the locomotives have an aerodynamic shape, a current collector, inductive power collection systems and structures which can absorb energy in case of a collision. The resulting tractive forces and driving resistances of the basic configuration with 2 locomotives and 10 individual cars, as well as for a locomotive and for one individual car, are shown in the diagrams in Fig. 2.

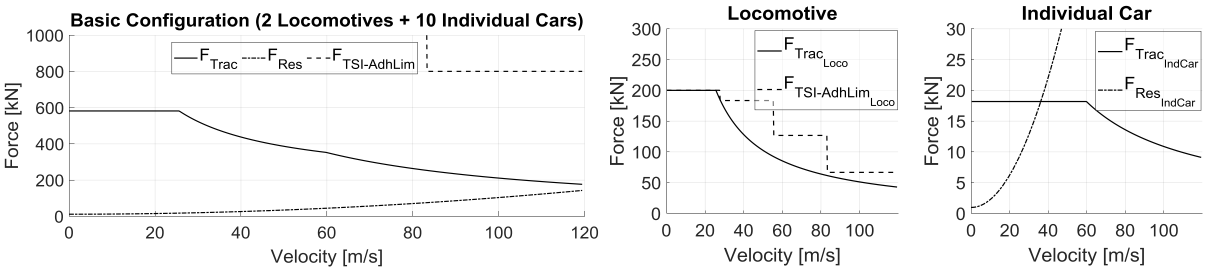

Fig. 2 NGT CARGO tractive force (F_{Trac}), driving resistance (F_{Res}) and the maximum adhesion wheel-to-rail limited by TSI 2014 ($F_{TSI\text{-}AdhLim}$) of the basic configuration, the Locomotive ($_{Loco}$) and one Individual Car ($_{IndCar}$)

In total, NGT CARGO has 21 MW of traction power at the wheels in this configuration, with each individual car supplying 1.1 MW and each locomotive supplying 5.1 MW (limited due to TSI 2014 adhesion limit).

5. Summary

In order to meet the EU's goals regarding the reduction of greenhouse gas emissions, a large proportion of current freight transportation will need to be shifted from air and road to less carbon-intensive modes of transportation like rail. To accomplish this, rail freight systems will be needed that can offer much of the flexibility of other modes with lower transit times and at a lower cost. New technologies will also need to be implemented to enable existing infrastructure to cope with increased traffic.

With the NGT CARGO system, the DLR proposes a concept wherein individual freight cars can autonomously cover distances of at least 29 km on battery power, travelling directly to sidings and logistics centres where they can be loaded with low density, high value goods that would otherwise be transported by road or air. High-powered, aerodynamically shaped autonomous locomotives enable high speed operation as well as virtual coupling between high speed freight and passenger services. These capabilities allow NGT CARGO to complement current rail freight offerings while promoting the decarbonisation of the freight sector through the displacement of current fossil-fuelled road freight traffic.

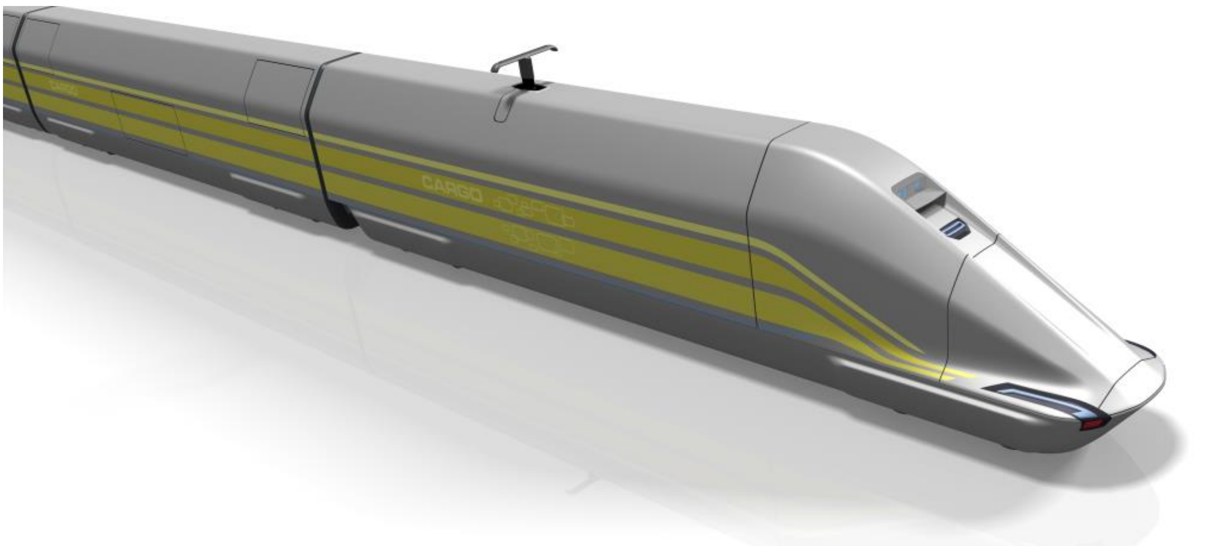

Fig. 3 Digital rendering of the autonomous NGT CARGO train

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