The Fifth International Conference on Railway Technology
RAILWAYS 2022
22–25 August 2022
Montpellier, France

Proceedings of the Fifth International Conference on
Railway Technology:
Research, Development and Maintenance
Edited by J. Pombo
Civil-Comp Conferences, Volume 1, Paper 13.3
Civil-Comp Press, Edinburgh, United Kingdom, 2022, doi: 10.4203/ccc.1.13.3

Increasing Capacity and Reducing Travel Times in High-speed Train Operations through Virtual Coupling

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Abstract

With Virtual Coupling nearing a technically viable state, an old operational concept may become practicable again in a reinterpreted form: Slip Coaching. Not only can a part of a train be left behind in through stations without the main train reducing its speed, but it also can accelerate again after stopping and be picked up by a following train. We propose a concept viable on existing infrastructure (aside from digitalisation requirements for Virtual Coupling itself) and in high-speed railway operations. The impacts range from shortened travel times over more direct connections to an increased track capacity (seats per hour).

Multiple shorter trains run as one virtual trainset in highly frequented stations and on busy routes, splitting in front of intermediate stations to stop independently of each other. A second scenario of the concept combines this with the possibility of joining two trains stopping side by side in a larger station after leaving the station to one trainset to enable running 700 m long trainsets in passenger transport.

This paper focusses on the demonstration of feasibility of the concept concerning train dynamics, vehicle configurations and operational procedures. To this end, we apply it to the route between Hanover and Frankfurt (Main) in Germany. We microscopically simulated a segment between two stations and created a possible timetable with the resulting timings, including buffers for a resilient operation.

Main results are a reduction of travel times of over 10 % and an increased capacity of seats per hour together with an improved service for intermediate stations and without the need of new infrastructure construction. This is especially significant seeing lengthy planning and construction times collide with plans to double passenger numbers in German railway transport in the next ten years. The proposed Virtual Coupling Slip Coaching concept therefore shows a powerful incentive for the continued development and certification of Virtual Coupling as an extension to the European Train Control System ETCS.

Keywords: Virtual Coupling, high-speed train, capacity, travel times, operational concept, technical requirements, Slip Coaching, microscopic simulation.

1 Introduction

While still facing regulatory hurdles, Virtual Coupling is nearing a technically viable state [1]. For the introduction of such a revolutionary technology though, we need tangible scenarios which highlight the potentials and show possible migration paths. As one crucial restriction for the use of Virtual Coupling the separation of two coupled trains with existing switch technology has been identified. We invented an operational concept for high-speed trains that enables the use of the advantages of Virtual Coupling – such as higher track capacity and the separation of trains at full speed – on the existing infrastructure (bar the signalling, of course). With our concept, increasing the track capacity (in seats per hour) is combined with shortened travel times and the facilitation of more direct connections.

The general idea is derived from the old concept of Slip Coaching, mostly used in British railway operations in the early 20th century, where single wagons were uncoupled and stopped at intermediate stations while the main train coming from London kept on driving at full speed. With virtually coupled trains, this previously very labour-intensive procedure could be reinstated and enhanced. We propose to run multiple shorter trains as one virtual trainset in highly frequented stations and on busy routes, with the addition that trailing trains can both fall behind to stop at smaller stations on the route and accelerate again to be picked up on front by a following train. Both procedures allow the main train to proceed at full speed and require only the single through track and no switches.

Main focus of this paper is the demonstration of feasibility both concerning train dynamics and the operational concept. First, we outlined possible vehicle configurations and developed multiple possible operational procedures. We then identified the route between Hanover and Frankfurt (Main) as suitable for an application of this concept. As for the train dynamics, we microscopically simulated the operation between two stations and recorded the resulting required timings and buffers for a resilient operation. From this, we calculated train travel times and a possible timetable [2].

Finally, we generalised the concept of Slip Coaching by identifying key requirements for the operational situation and the infrastructure. With this, we were able to find multiple instances in high-speed networks worldwide where it could be adopted with good prospect of success. To showcase the concept and its benefits to a wider audience, an online simulation demonstrator was created [3].

2 Methods

In cooperation with colleagues from the DLR Institute of Vehicle Concepts, we identified technical requirements for the train construction, the Virtual Coupling performance, and railway operations. This comprised the review of possible regulatory obstacles besides the Virtual Coupling itself.

Afterwards, we constructed two possible operational concepts: The “VC short” scenario with a maximum trainset length of 400 m and a “VC double” scenario with a possible concatenation of multiple trains to a full length of 700 m which are divided into two sections shorter than 400 m in main stations (as an extension of the principle shown in [4]). At intermediate stations, only parts of the trainset stop requiring less than 400 m platform length. The trainset length is limited to 700 m on standstill to allow the use of existing passing loops designed for freight trains of at max. 740 m length. The train configurations for both scenarios are shown in figure 1. To fit on the existing infrastructure and on TSI-compatible platforms, the long trainsets are split up directly in front of the main stations of Hanover and Frankfurt. So they can stop at both sides of a standard 400 m platform. This also allows the Slip Coaching trains to reverse their order so that the Slip Coaching could be used again on the next leg. For this procedure, a switch is needed. As all parts of the trainset are stopping in the main stations anyway, the switches can be used at relatively low speeds so that the adherence to the absolute stopping distance is not obstructive.

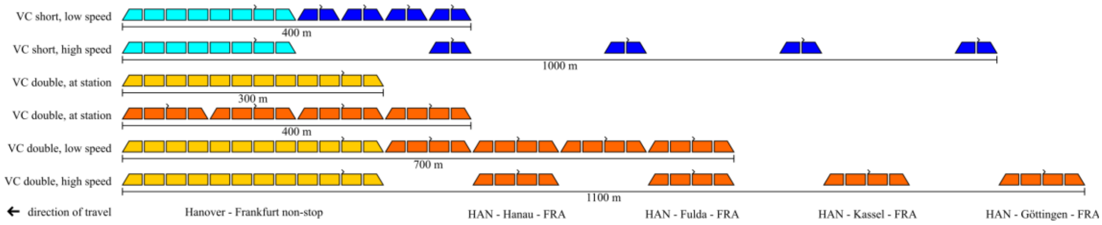

Figure 1: Possible train configurations.

For these scenarios we developed a route concept on the chosen corridor between Hanover/Brunswick and Frankfurt (Main) (see figure 2). To that end, we clustered the stations by their passenger demand and then decided which stations become Slip Coaching stations. We collected existing travel times and constructed a full timetable for both concepts.

A microscopic simulation between Kassel and Göttingen allowed us to calculate the necessary train headways as well as the energy consumption. We examined how a timetable has to be constructed to allow the operation on only one single through track and how additional tracks can be used to enhance the travel offer. The height profile of the simulated track section is shown in figure 2 alongside the corridor.

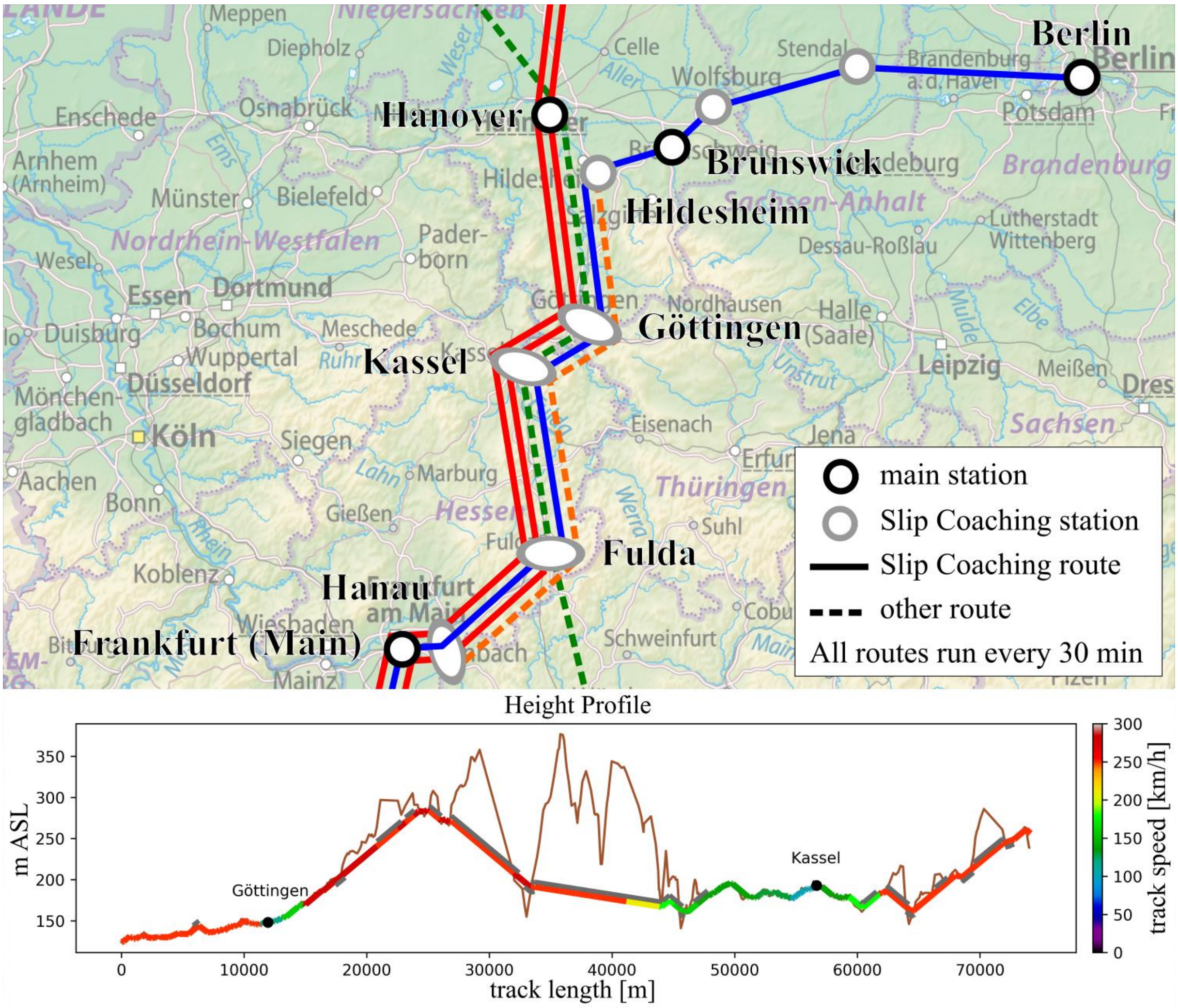

Figure 2: Route concept for the chosen Slip Coaching corridor Hanover/Brunswick – Frankfurt (Main) with elevation profile of the simulated infrastructure.

3 Results

Quaglietta [5] showed that with Virtual Coupling, an operation in any distance over a given safety threshold is possible if the two states “absolute braking distance” and “virtually coupled” are defined and as long as a continuous communication between the trains is given. This is crucial for the process of a full speed train picking up another previously stopped, accelerating train. Also, due to physical limits of the catenary system, pantographs have to be spaced at least 200 m from each other at high speeds [6]. This causes the proposed trainsets to spread out while driving, reaching lengths of up to 1100 m. As the trainsets can follow more closely at low speeds, this does not hinder operations at stations.

With these restrictions, we constructed the train sequence shown in figure 3. Slip Coaching trainsets can follow each other every 10 min, resulting in a dwell time of approximately 6 min at the intermediate stations. This ensures a sufficient stability of the timetable without unscheduled elongated dwell times interfering with the following main train. As every Slip Coaching train only has to stop once between Hanover and Frankfurt, this dwell time is acceptable. Most importantly, the main train drives non-stop from Hanover to Frankfurt. From each train starting in Hanover, both the own train (non-stop) and the next train (single stop) can be reached. This enables a direct connection to two possible destinations.

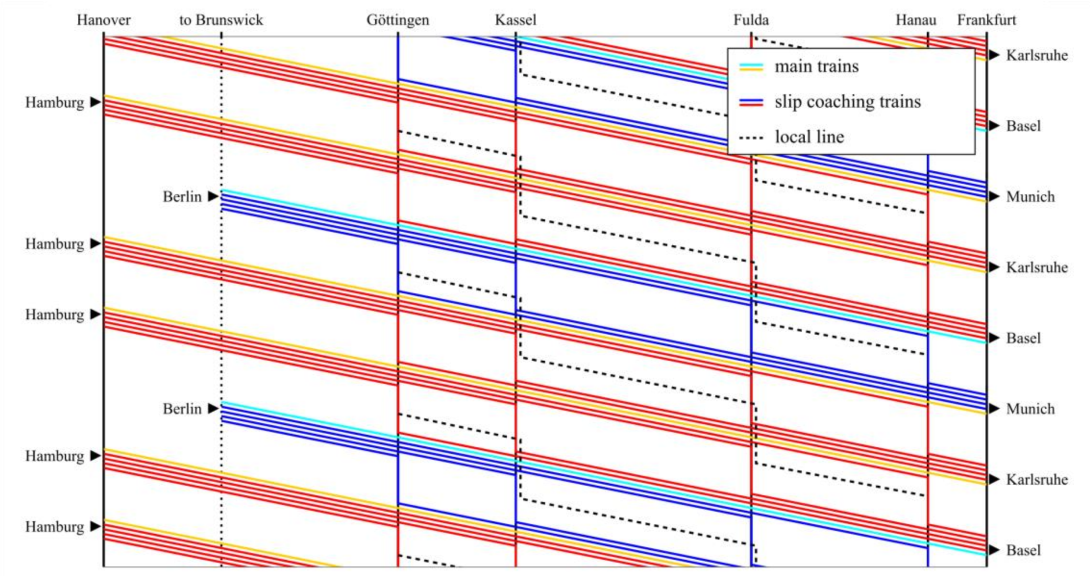

Figure 3: Timetable concept for the route concept shown in figure 2.

To connect the intermediate Slip Coaching stations to each other, an extra service with conventional trains should be established ("local line"). It does not have to reach the busy main stations, relieving capacity there, and could be integrated in the Slip Coaching cycle as seen in figure 3 on a second track in the stations.

Both the timings of the coupling procedure in different speeds and inclines, and the platform occupations at Hanover main station could be validated. Passenger capacity can be increased while travel times are reduced significantly in comparison to the proposed travel times of the Deutschland-Takt (see table 1). This is possible by only stopping once between the main stations without reducing the travel offer at intermediate stations.

From	To	Travel time Deutschland-Takt	Travel time Slip Coaching	Change
Hanover	Göttingen	0:34 h	0:34 h	± 0,0 %
Hanover	Kassel	0:53 h	0:50 h	– 5,7 %
Hanover	Fulda	1:25 h	1:17 h	– 9,4 %
Hanover	Hanau	1:59 h (transfer)	1:41 h	– 15,1 %
Hanover	Frankfurt	2:00 h	1:50 h	– 8,3 %
Göttingen	Frankfurt	1:28 h	1:24 h	– 4,5 %
Kassel	Frankfurt	1:05 h	1:08 h	+ 4,6 %
Fulda	Frankfurt	0:35 h	0:41 h	+ 17,1 %
Hanau	Frankfurt	0:12 h	0:17 h	+ 41,7 %
Travel time between Slip Coaching stations		unchanged		

Table 1: Comparison of travel times with Deutschland-Takt and Slip Coaching.

Passenger information has to be very clear and intuitive to minimise the number of mislead passengers, because large detours could occur when boarding the wrong train with trains not stopping as frequently anymore.

4 Conclusions and Contributions

The proposed Virtual Coupled Slip Coaching concept shows a viable use of Virtual Coupling in high-speed railway operations on the existing infrastructure. We confirmed the feasibility and presented a possible operational concept and timetable as well as defining additional requirements for the Virtual Coupling technology. It displays a strong incentive to drive forth the certification of Virtual Coupling as an extension of the European Train Control System ETCS.

The concept could play a major role in reaching the goal of doubled passenger numbers as stated by the German government as it does not rely on time-consuming infrastructure development. It could additionally provide attractively short travel times and operationally stable direct connections. Integration into the Deutschland-Takt would be possible as the high frequency of trains allows for good connections at most stations. The saved time (see table 1) due to reduced stops could be used to reach additional nodes of integrated regular timetables. A macroscopic passenger flow simulation confirmed an overall travel time reduction for all German passengers by implementing Slip Coaching on the evaluated corridor.

While not relying on a full automation of the train operation, economic aspects could make a manual operation of multiple short trains difficult. With system cost reductions found for automating regional railway networks with shorter trains [7], the effects of automation on the proposed concept have to be examined.

Finally, we generalised the circumstances needed for getting a substantial benefit from Slip Coaching. Mainly, a high-speed corridor between two larger cities with multiple smaller stops in-between is required to make use of the concept. Additionally, the time savings of Slip Coaching increase with the speed through trains can pass intermediate stations. The combination of two or more branches into a main corridor can enable more direct connections but is not needed. Therefore, the following exemplary corridors would be worthy of consideration for detailed studies on the Slip Coaching concept:

- Rheintalbahn, Karlsruhe – Basel (DE)
- Westbahn, Wien – Salzburg (AT)
- Direttissima, Milano – Roma – Napoli (IT)
- West Coast Mainline, London – Glasgow (UK)
- North East Coast Corridor, Boston – Washington (USA)

As soon as first real-world data from virtually coupled trainsets in high-speed situations is available, more detailed simulations and migration concepts can be developed. Regarding the presented advantages of Slip Coaching, further research on different use cases such as regional and freight transport seems promising.

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