Energy Impact of Different Intra-Platoon Spacing Policies for Virtually-Coupled Trains Sets (VCTS)

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Abstract

Virtually-coupled train sets (VCTS) is a new railway operation concept that allows trains to drive together in a harmonized fashion without a physical connection, similar to a platoon of road vehicles. Since the distance between trains is not necessarily fixed (in contrast to mechanically connected trains), VCTS may get a small time advantage every time there is a change in the speed limit of the track. This paper analyses the time difference between mechanically coupled trains and VCTS using two different inter-vehicular distancing policy (namely constant gap (CDG) and constant headway (CTH)). The analysis is carried out analytically for a simple track for sake of visualization, and numerically on a virtual but representative regional track. The results show that the time advantage for CDG policy non-negligible, while the CTH performs worse than its mechanical counterpart. This report shows also that the time advantage can be converted into energy reduction in the range from 2-12% by allowing trains to drive slower while respecting the same timetable.

Keywords: virtually coupled train-sets, VCTS, energy optimization.

1 Introduction

The goal of this report is to analyze potential time and energy savings of virtually coupled train set (VCTS) in comparison to mechanically coupled trains. VCTS is an operational concept for railway, where independent trains group together to drive in a harmonized fashion without a mechanical connection. All trains (also referred as units) inside a VCTS are perceived by the signalling system and external environment as a single train [1] [2].

While platooning for road vehicles (especially trucks in highways) has been largely discussed in scientific literature in areas such communication [3], control theory [4] and aerodynamics [5], its railway counterpart seems to have only gained traction in the past years. Partially, this is due to the increasing pressure to shift road traffic to more climate-friendly transport modals, combined with the high-cost, and sometimes infeasibility, of expanding the railway infrastructure. VCTS have the potential to increase the network's throughput by reducing the distance between trains, while providing a feasible, backward compatible transition from current railway signalling systems [6].

While all the units of a mechanically-coupled train in must accelerate and decelerate at the same time due to the physical connection between the units, an advantage of VCTS is a greater flexibility to control each unit individually yet coordinately by the tactical layer of the platoon control system [6]. For example, when leaving a low-speed zone, the first unit of the VCTS can already accelerate as soon as it leaves the zone, while mechanically coupled trains must wait for the last axle of the last unit before accelerating.

For the analysis of potential time and energy savings, this report will consider two different distancing policies between the units: constant distance gap and constant time headway.

Constant Gap Policy (CDG)

In this policy, the tactical layer of the VCTS tries to maintain a fixed distance between the units all the time. For the scope of this paper, CDG works similar to a mechanically coupled train, however with the disadvantage that the inter-vehicular distances are normally much larger, due to communication delays and required fallback protocols and require more control effort [3].

Constant Headway Policy (CTH)

For this policy, the spacing between the units inside the platoon is a linear function of the speed, so the units keep a constant headway (expressed in seconds) plus some small fixed distance for the standstill state. This policy offers the above-mentioned advantage.

2 Methods

For the analysis a VCTS using both distancing policies are simulated using the software OPEUS [7] and the time and energy they take to complete a determined journey is compared with mechanically coupled trains. OPEUS offers two simulation modes, namely All-out and Timetable. The All-out simulation calculates the fastest time a train can complete a journey and is useful to measure the raw advantage of VCTS in terms of time. With the Timetable mode, OPEUS also offers a non-optimized trajectory calculator, where trains go as slow as possible, while still respecting a given timetable. In this mode any time advantage is converted into energy savings, due to a less aggressive driving profile.

A fictive but representative regional track is used in the simulation. The service profile comprises 15 stations distributed along 70 km, as seen in the Figure 1.

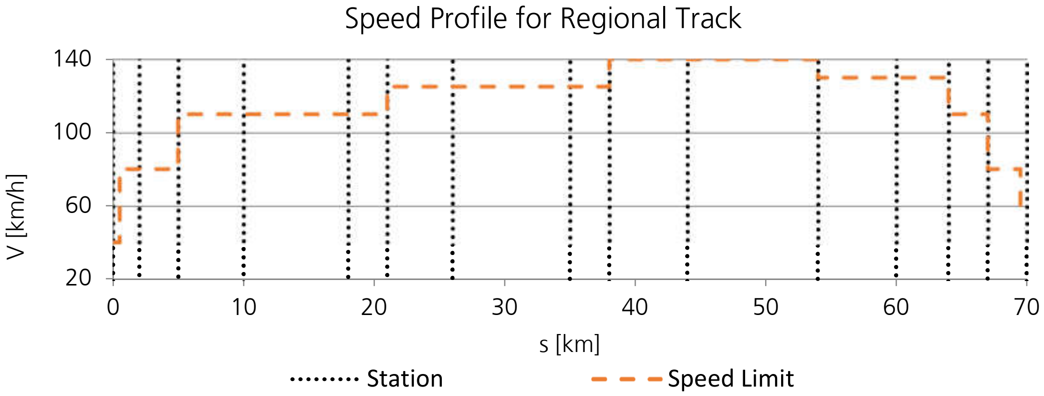


Figure 1: Speed limits for Regional Service Profile defined in the FINE-1 project [8]

The speed profile, train models and timetables were elaborated by the EU projects IMPACT (Deliverable 4.1 [9]) and FINE-1 (Deliverable 3.1 [8]) with the goal of providing a neutral platform for evaluating new railway technologies in Europe.

Since the original speed limits does not include low-speed zones around the stations, two slightly modified speed profiles (A and B) are proposed. Both scenarios include a speed limit of 40 km/h near the station, which extends for 50 m in both directions in scenario A and 100 m in scenario B, as shown Figure 2. The platforms are considered to be as long as the trains.

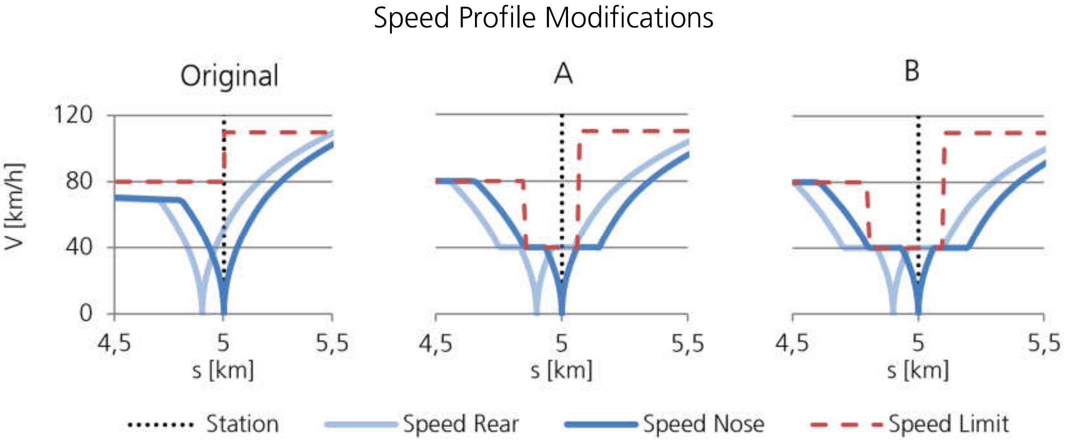


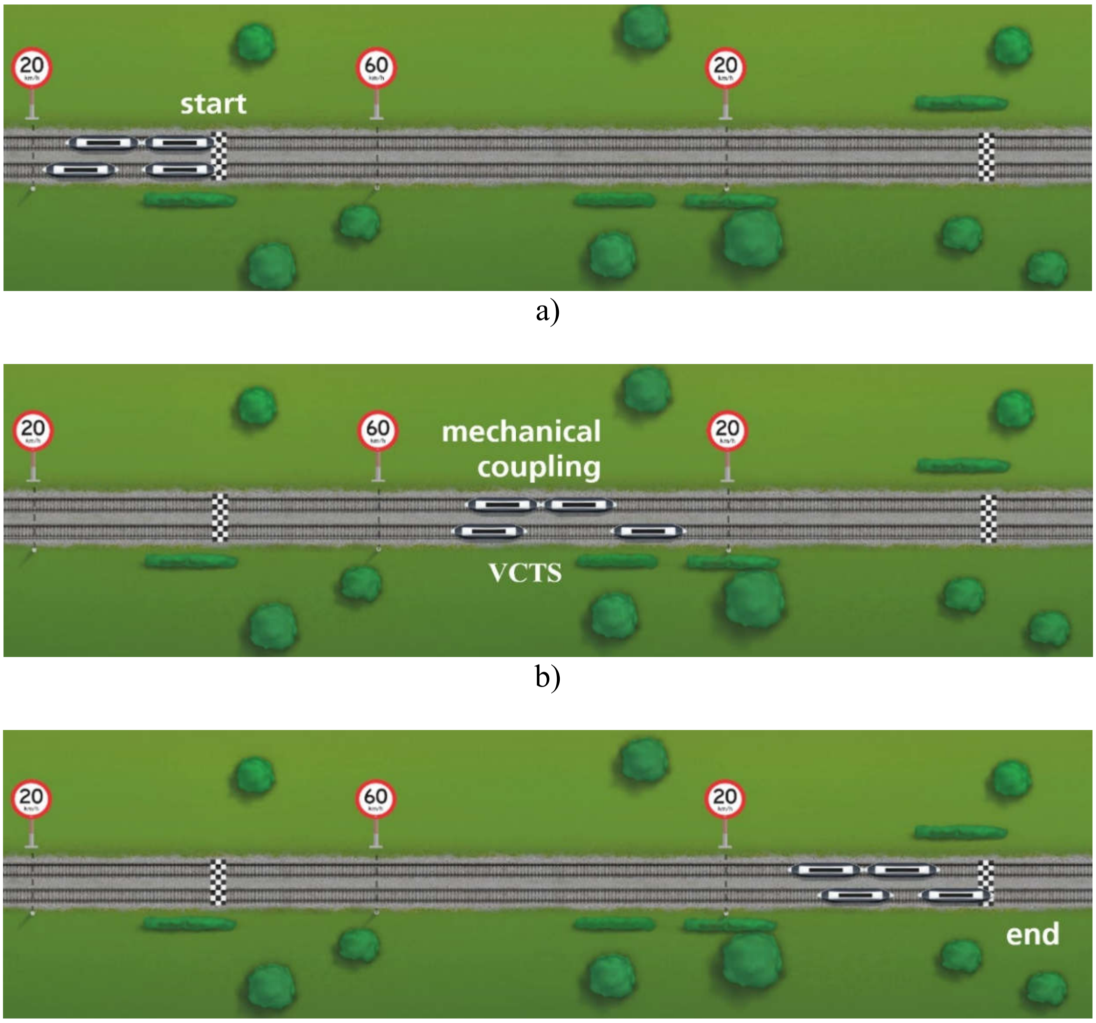
Figure 2: Section of the original service profile around a station, with speed limits in dashed orange, and the speed profile of a 100 m train with 1 m/s acceleration in blue

Each of the modified scenarios is simulated using mechanically coupled trains and VCTS that are composed by two to four units. Each unit is 100 m long. The CTH policy keeps a 1 s headway between each train inside the platoon. For the CDG policy, the gap distance is defined using the same headway of the CTH policy multiplied by the highest speed of the track (40 m). For this analysis it is assumed that all headways and distances are within the safe operation of the VCTS. The exact headway may greatly vary depending on communication technology and vehicle.

3 Results

In order to visualize the reason VCTS + CTH performs better than mechanically-coupled train, both concepts are illustrated below in a simple track with one speed change. The scenario is chronologically illustrated in Figure 3.

Simple Track Comparison Between Mechanically-Coupled Trains and VCTS + CTH



a)

b)

c)

Figure 3: Illustrative comparison between mechanically coupled trains (top tracks) and VCTS + CTH (bottom track) in the beginning (a), middle (b) and end (c) of the scenario

The time difference in the end of the track is given by Equation (1).

$$\delta t_f = \frac{(v_{high} - v_{low})\cdot \delta L}{v_{high}\cdot v_{low}} - t_{CTH}(n_{units} - 1) \tag{1}$$

Where:

v_{high}, v_{low}	the highest and lowest speed limit on the track
δL	length difference between one VCTS unit and the whole mechanically coupled train
t_{CTH}	the constant time headway between the units of the VTCS
n_{units}	the number of units of the VTCS
δt_f	resulting overall time difference between mechanically coupled trains and VCTS

Equation (1) is plotted in **Error! Reference source not found.** for different speed limits, using a two-units platoon with 100 m long units and constant headway policy of 1 s, which is well within reach with current technology [3].

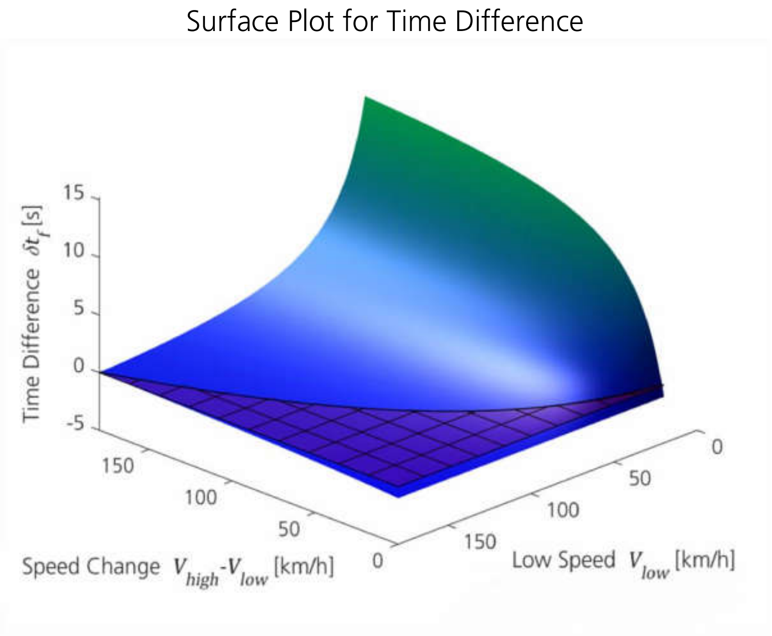


Figure 4: Surface plot of Equation (1) as function of speed change $v_{high} - v_{low}$ and low speed v_{low}

The results of the track simulation from OPEUS are presented in the **Error! Reference source not found.** below.

Speed Profile	Policy	All-out Running Time [hh:mm:ss], Difference in Time [s]			Timetable Energy [kWh]		
		2 Units	3 Units	4 Units	2 Units	3 Units	4 Units
A	MC*	01:05:53	01:07:52	01:09:51	528,6	552,3	596,3
	CTH	-61	-120	-180	-9,5	-21,9	-50,0
	CDG	+44	+89	+133	+3,2	+26,7	N.A.
B	MC*	01:07:10	01:09:09	01:11:07	540,4	583,2	646,5
	CTH	-60	-120	-180	-9,5	-40,4	-84,9
	CDG	+45	+89	+134	+11,0	+55,9	N.A.

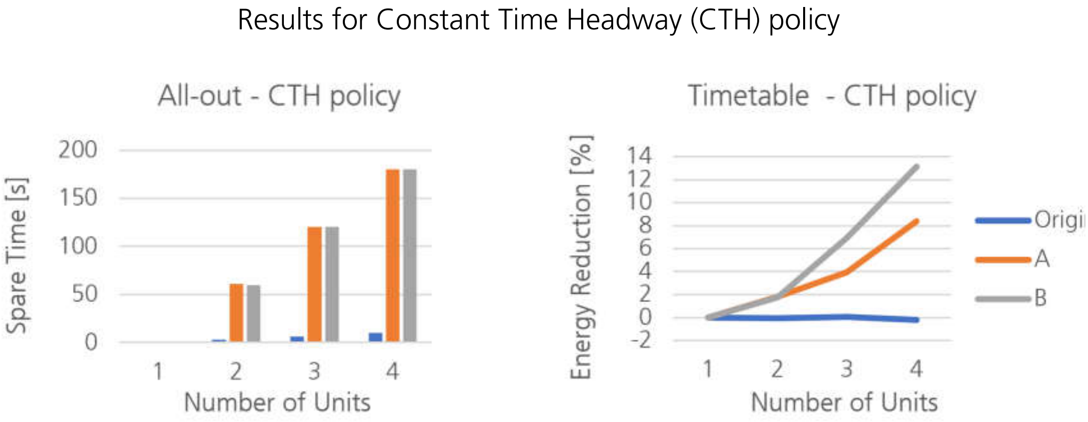
*mechanically coupled

Table 1: Result of the All-out and Timetable OPEUS simulations for the original FINE speed profile as well as the modifications A and B.

The All-out results show the time the trains take to complete the track compared to the mechanically coupled trains. For the timetable results, all trains will drive as slow as the timetable allows and try to minimize the energy consumption. The results in orange indicate that OPEUS cannot determine a solution that satisfies the timetable constraint for the given setup.

4 Conclusions and Contributions

The results from Table 1 are divided into the comparison of mechanically coupled trains with VCTS + CTH and VCTS + CDG.

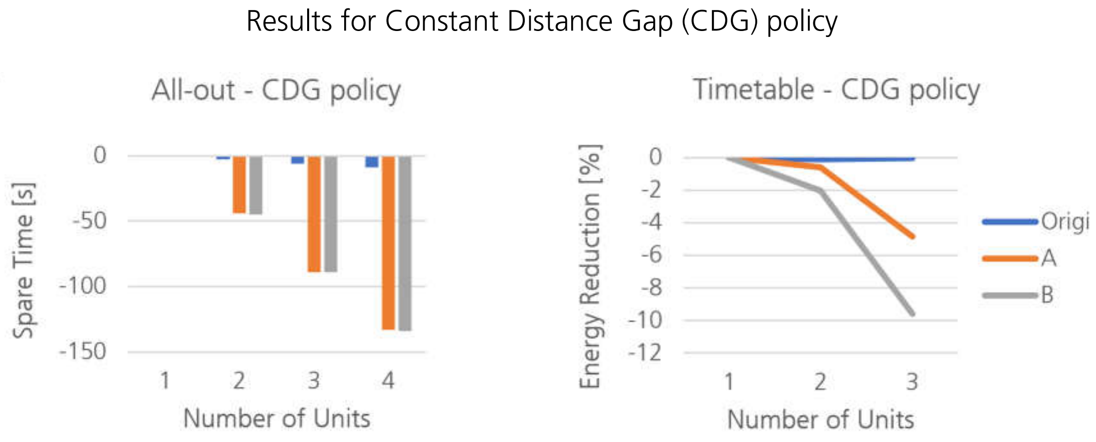


a) b)

Figure 5: OPEUS Simulation results for All-out (a) and Timetable (b) modes under constant time headway (CTH) policy

The running times of scenario A and B are identical (Figure 5 a) and both are faster for VCTS + CTH than mechanically coupled trains. It is possible to infer that the absolute time advantage does not depend on the length of the track, only on the speed limits, as expected from Equation (1). The extra time gained can also be used to increase the system robustness by allowing a larger buffer between VCTSs, increase the system's capacity by increasing the track throughput, or as mentioned, to drive slower and increase the energy efficiency of the system.

For the timetable simulation, the VCTS + CTH concept saves more energy in scenario B, where the low-speed section is longer, but the timetable is the same. This is a good indicative that VCTS + CTH may be more advantageous in more time-restrictive scenarios, where trains are driving closer to its the speed limits (e. g. when trains need to drive faster to recover some network delays). Besides that, tracks that present very low speed limits together with other high-speed sections may experience the most advantages.



a) b)

Figure 6: OPEUS Simulation results for All-out (a) and Timetable (b) modes under constant distance gap (CDG) policy

As expected, VCTS + CDG performed worse than mechanically coupled trains, due to the fact that it offers no advantage (in the context of this analysis), but significantly longer platoons. The results expose the importance of choosing the appropriate distancing policy and the platoon management system in the tactical layer to benefit from all the advantages of VCTS.

Future Work

While this report offers a preliminary analysis of the energetic consumption of VCTS, there are several other aspects that influence energy consumption (e. g. aerodynamics and control effort) that may overshadow its importance. Furthermore, more flexible intra-platoon distance policies would allow trains inside the VCTS with different properties to optimize its own trajectory in a semi-independent way considering different driving characteristics.

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