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Simulating the operation of new-generation freight-EMUs for high-speed lines: perspectives for more reliable, sustainable, and fast logistics

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Abstract

This paper aims at establishing the most appropriate maximum cruising speed for a freight electric multiple unit (F-EMU), i.e., a concept of a new-generation freight train with distributed power, diagnosable, and able to run on high-speed lines. Different scenarios were simulated on the Turin-Verona line, all considering 5 subsequent trains departing after the end of the passenger service and arriving before the scheduled night-time maintenance operations on the infrastructure. The scenarios considered the current signalling system (SCMT+ERTMS level 2) and ETCS level 3 with train-platooning. It has been shown that, because of the limitations due to the tarpaulin resistance of swap bodies loaded on the flat wagons, the most convenient speed for the design of these trains is 160 km/h, being the best compromise for line capacity and timetable robustness. Moreover, given the homotachic nature of the foreseen scenarios, train-platooning would be a viable solution for reducing delays and having a more reliable service.

Keywords: railway operation, simulation, freight trains, high speed, scheduling, functional design.

1 Introduction

Dealing with a fast and reliable freight transport service, in Italy so as in many European countries, usually means relying on road transport [1], given the highway-hinged structure of the production facilities. However, it is of paramount importance to work on achieving a modal shift to the railway, given its well-known characteristics of environmental, social, and economic sustainability.

Since the publication of the White Paper on Transport [2], a series of political choices have been made, such as the completion of some arches of the TEN-T network [3], the Rail Freight Corridors or the Shift2Rail joint undertaking, aiming at enhancing the backbone role the rail haulage should play into European logistics.

The burden should not be borne only by the infrastructure: the concept of new rolling stock [4], which nowadays is based on a 70-years-old design, can effectively improve the efficiency and reliability of the system, attracting demand from new market shares and making it possible to exploit the high-speed lines, closing the gaps on the rail haulage offer. Identifying the key parameters that make this new type of train competitive is thus pivotal, and this work clearly shows that, by exploiting the HS network [5], it is possible to achieve decisive advantages in favour of rail in the logistics modal choice. Therefore, here, the analysis of the operation of new freight electro-trains is performed, concentrating on the use of evening tracks between the departure of the last high-speed passenger train and the start of night-time maintenance operations on the infrastructure (IPO).

The focus is on the Turin-Verona high-speed line (Figure 1), connecting two important freight terminals located respectively in the west and east of northern Italy. The new distributed-power freight electro-train (F-EMU) requires a multi-current and multi-voltage collection system to be able to run on both the HS line and the traditional ones connecting the freight terminals with the Core network.

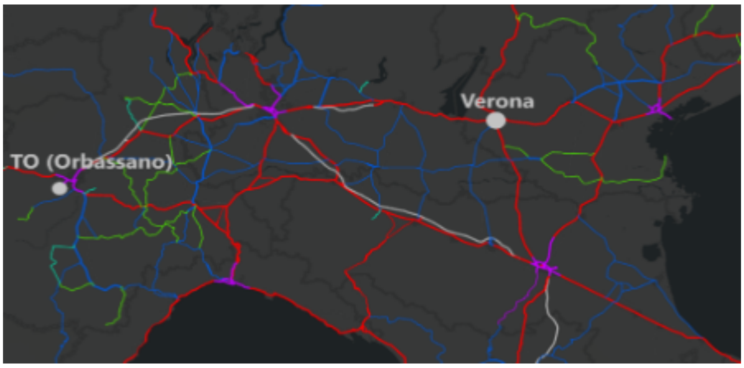


Figure 1: Turin Orbassano – Verona line.

Through the software Opentrack, the performances of the F-EMU at different cruising speeds are compared, considering the signalling system currently in place, analysing possible interferences with the timetable. Furthermore, the operation of 5 trains with train-platooning is simulated and an assessment of the impact this technology would have on the theoretical capacity of the line is carried out.

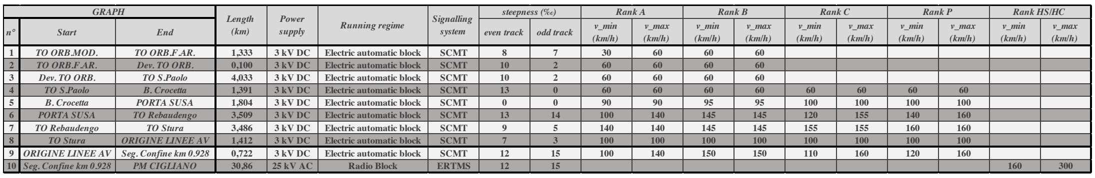
Relaunching rail transport is possible by designing innovative rolling stock that is convenient for both the environment and the infrastructure on which it runs.

2 Methods

To find aggregate quantities capable of defining a functional concept of a distributed power freight train, it is necessary to conduct a study to clarify the appropriate speed to run a homotachic service on high-speed lines in the late evening or at night. Railway operation was, therefore, simulated using Opentrack [6], a microsimulation software developed by ETH Zurich, which allows all the elements of the railway system to be considered without simplification by modelling the train's motion continuously and the signals at discrete time. Several scenarios were, then, defined to establish the influence of speed on the stability and robustness of the planned timetable.

The first step was to build the model by entering the input data concerning:

- Infrastructure of the Turin-Verona line with data provided by RFI (Italian Railway Network). The line is represented with an edge and arc model, made up of 36 graphs connecting the main localities along the journey. Each graph has its topological characteristics (excerpt in Figure 2), and every discontinuity determines the beginning of a new graph.



GRAPH			Length (km)	Power supply	Running regime	Signalling system	steepness (‰)		Rank A		Rank B		Rank C		Rank P		Rank HS/HC	
n°	Start	End					even track	odd track	v_min (km/h)	v_max (km/h)	v_min (km/h)	v_max (km/h)	v_min (km/h)	v_max (km/h)	v_min (km/h)	v_max (km/h)	v_min (km/h)	v_max (km/h)
1	TO ORB.MOD.	TO ORB.F.AR.	1,333	3 kV DC	Electric automatic block	SCMT	8	7	30	60	60	60						
2	TO ORB.F.AR.	Dev. TO ORB.	0,100	3 kV DC	Electric automatic block	SCMT	10	2	60	60	60	60						
3	Dev. TO ORB.	TO S.Paolo	4,033	3 kV DC	Electric automatic block	SCMT	10	2	60	60	60	60						
4	TO S.Paolo	B. Crocetta	1,391	3 kV DC	Electric automatic block	SCMT	13	0	60	60	60	60	60	60	60	60		
5	B. Crocetta	PORTA SUSA	1,804	3 kV DC	Electric automatic block	SCMT	0	0	90	90	95	95	100	100	100	100		
6	PORTA SUSA	TO Rebaudengo	3,509	3 kV DC	Electric automatic block	SCMT	13	14	100	140	145	145	120	155	140	160		
7	TO Rebaudengo	TO Stura	3,486	3 kV DC	Electric automatic block	SCMT	9	5	140	140	145	145	155	155	160	160		
8	TO Stura	ORIGINE LINEE AV	1,412	3 kV DC	Electric automatic block	SCMT	7	3	100	100	100	100	100	100	100	100		
9	ORIGINE LINEE AV	Seg. Confine km 0.928	0,722	3 kV DC	Electric automatic block	SCMT	12	15	100	140	150	150	110	160	120	160		
10	Seg. Confine km 0.928	PM CIGLIANO	30,86	25 kV AC	Radio Block	ERTMS	12	15									160	300

Figure 2: Excerpt of topological information of the first 10 graph of infrastructure.

- Rolling stock with data extracted from Gualco et al. [4]. For the ordinary resistances, the Davis formula for powered wagons is used, the Roeckl formula for 1435 mm gauge is used for curve resistance, instead. The positioning system is set up with loop balises and radio antennae, to allow the use of the moving block.
- Signalling with fixed block sections according to RFI schematic plans.
- Power supply substations inter-distance according to the infrastructure characteristics.

The scenarios considered involve 5 consecutive trains running on the line, with a homogeneous time interval of 7 minutes. Three maximum cruising speeds have been considered: it is intended to assess which is most appropriate between 120 km/h (i.e., the maximum speed attainable by traditional freight trains), 140 km/h and 160 km/h (limit for swap-bodies tarpaulin resistance), to have a robust timetable despite possible delays.

The analysis has been repeated considering, instead of the current signalling system (SCMT+ERTMS level 2), a moving block signalling system allowing train-platooning and therefore a non-homogeneous interval between trains dependent only on the stopping time of the chasing one.

In the simulations, all the potentialities of the system are exploited to the maximum and an 'optimistic' running profile is obtained compared to the real operating characteristics, where performances 5 to 15 % lower can occur.

3 Results

During the simulations, the aim was to carry out a service with 5 trains departing from Turin Orbassano at 22:00 and arriving in Verona Scalo before the scheduled maintenance timeslot (IPO), officially foreseen from 01:00 to 06:00. First, the ideal scenario with current signalling was evaluated. A speed of 120 km/h would not guarantee the arrival of the trains within the scheduled time, and, therefore, they would run the risk of being suppressed (Table 1).

	Departure: To-Orbassano	***Arrival: Verona scalo***	***Travel time***
	Departure time	*Arrival time*	*[h:min:sec]*
120 km/h	22:00	00:59	02:59:00
	22:09	01:06	
	22:18	01:13	
	22:27	01:20	
	22:36	01:27	
140 km/h	22:00	00:41	02:41:00
	22:08	00:47	
	22:16	00:54	
	22:24	01:01	
	22:32	01:08	
160 km/h	22:00	00:27	02:34:00
	22:07	00:34	
	22:14	00:41	
	22:21	00:48	
	22:28	00:55	

Table 1: Travel times scenario 1.

A speed of 160 km/h, on the other hand, guarantees an operating speed of 144 km/h (excluding the line sections corresponding to the hubs where the maximum speed for a freight train is set at 60 km/h) and, consequently, the margin is large enough to achieve a robust service.

The feasibility of the service is then evaluated by introducing delays. Opentrack allows a delay to be assigned only to the departure of trains using, in this case, a piecewise linear distribution, combined with a randomly generated number. This could represent potential delays accumulated along the route. In Table 2 the distribution used in the creation of the scenarios is shown.

From (s)	***To(s)***	***Probability (%)***
0.0	300.0	**20.0**
300.0	600.0	**20.0**
600.0	900.0	**20.0**
900.0	1800.0	**20.0**
1800.0	3600.0	**20.0**

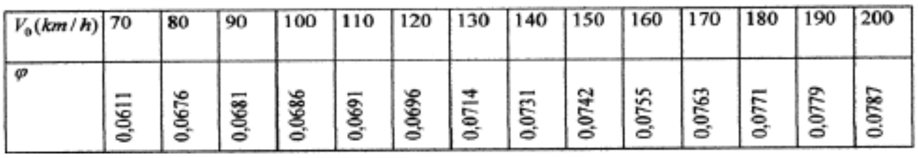
Table 2: Delay probability distribution.

Excluding the speed of 120 km/h, 40 different scenarios were simulated corresponding to the different random delays assigned by the software for the two remaining speeds. In the case of a speed of 140 km/h, there is a probability of exceeding the time limit of 24%, while in the case of 160km/h is only 12%. Hence, we demonstrated that with a high-performance train, the probability of delays affecting the maintenance slot can be successfully reduced.

Eventually, a change in the signalling system has been considered, allowing the possibility of train platooning. The braking distance is calculated as in Equation (1) from UIC formulation:

$$S_a = \frac{V^2}{\frac{1{,}094 \cdot \lambda}{\varphi(V)} + \frac{0{,}127}{\varphi(V)} \pm 0{,}253 \cdot i} \tag{1}$$

with:



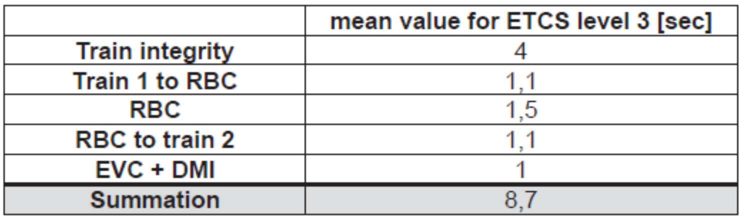
$V_0(km/h)$	70	80	90	100	110	120	130	140	150	160	170	180	190	200
φ	0,0611	0,0676	0,0681	0,0686	0,0691	0,0696	0,0714	0,0731	0,0742	0,0755	0,0763	0,0771	0,0779	0,0787

Table 3: parameter $\varphi(V)$.

and the minimum time spacing is obtained with Equation (2):

$$t_{spacing} = t_{braking} + t_{system} \tag{2}$$

where the system response [7] is:



	mean value for ETCS level 3 [sec]
Train integrity	4
Train 1 to RBC	1,1
RBC	1,5
RBC to train 2	1,1
EVC + DMI	1
Summation	8,7

Figure 3: ETCS level 3 system response [7].

And so:

Minimum time spacing	
V [km/h]	***t[s]***
120	67.08
140	66.43
160	67.03

Table 4: Minimum time spacing.

The simulations are carried out for all three speeds. The results are shown in table 5.

	Departure: To-Orbassano	***Arrival: Verona scalo***	***Travel time***
	Departure time	*Arrival time*	*[h:min:sec]*
120 km/h	22:00	00:59:19	02:59:00
	22:09	01:00:46	
	22:18	01:02:13	
	22:27	01:03:40	
	22:36	01:05:07	
140 km/h	22:00	00:40:55	02:41:00
	22:08	00:42:22	
	22:16	00:43:49	
	22:24	00:45:16	
	22:32	00:46:43	
160 km/h	22:00	00:27:27	02:34:00
	22:07	00:28:55	
	22:14	00:30:22	
	22:21	00:31:49	
	22:28	00:33:16	

Table 5: Travel time moving block scenario.

Moreover, it was possible to confront the theoretical capacity curves (Figure 4).

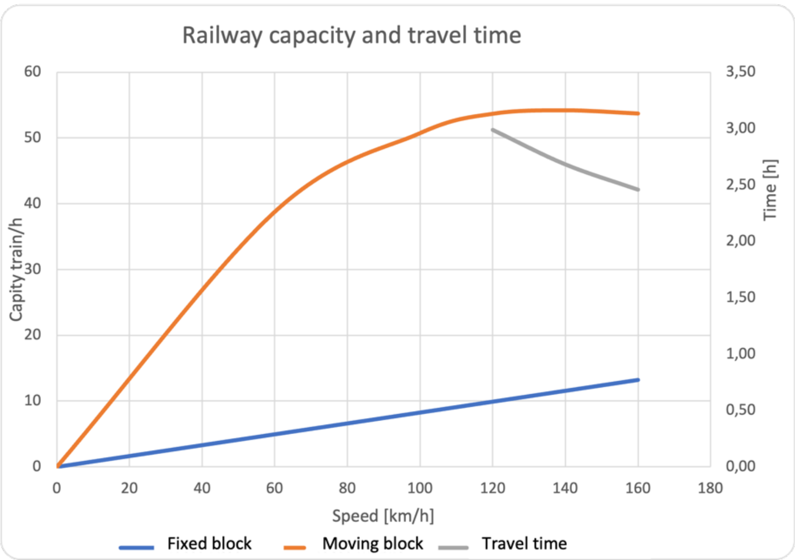


Figure 4: Theoretical railway capacity.

4 Conclusions and Contributions

The aim of this study was to investigate what would be a suitable speed for a high-speed homotachic rail freight service at night after the end of the passenger service. We have constructed and implemented a model to simulate the operation of new-generation high-speed F-EMU on the Torino-Verona line in Italy. It has been shown that for maximum speeds of 160 km/h it is possible to obtain the shortest travel time and the maximum reliability, making it a preferable choice for the design of these new trainsets.

The issue related to the robustness of the timetable is solvable through the implementation of the mobile block that results in a big increase in capacity, with saturation at 140 km/h (54 trains/h) but still excellent for 160 km/h (53 trains/h), versus the 13 trains/h with the current signalling system, thus making 160 km/h a good compromise between speed and capacity.

Other solutions to the delay problem are:

- choosing a higher speed that allows a lower probability of exceeding the current time limit;
- advancing the departure times of the trains from 22:00 to 21:00 (verifying that there are no other delays due to the precedence of the passenger trains that still circulate on the line in that timeslot);
- placing a stop of the F-EMU near the Milan Station around 23:30 to allow possible loading and unloading of containers. The train would leave headed to Verona as soon as the maintenance time slot ends;
- increasing the maximum speed of 60 km/h, set for traditional freight trains around the railway nodes.

This study, moreover, demonstrates how it is possible to exploit the residual capacity of the Italian high-speed lines with the insertion of these new trains, on which other studies are currently underway to better define performances, mechanical characteristics and the potential attractiveness for the railway undertakers and the train manufacturer.

The feasibility of a fast service before the scheduled maintenance time slot, with maximum speeds of 160 km/h, would make it possible to attract demand from markets that are currently inaccessible to traditional rail freight transport. Furthermore, these solutions would allow complying with the European sustainability objectives, decongesting roads and reducing the unit costs of transport.

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