Rolling stock for high speed on European railways: present and future development

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This paper deals with the possibility of increasing commercial speed of freight trains. First technical constraints that have so far prevented railway owners from increasing the speed of freight trains are considered. Such constraints concern both fixed installations and rolling stock; this paper focuses on the latter. Then, traction units for high speed trains operated in the most important networks of Western Europe are examined in order to identify which units could be used for hypothetical high speed freight services. Some proposals for new vehicles specifically conceived for such services are also discussed. The study points out that trains made up of luggage vans represent an interesting solution to transport freight up to 200 km/h provided that size of bundles do not exceed the width of side doors; for other load units such as containers special versions of high speed trains seem to be preferable.

1 Introduction

Almost all European freight trains run at speeds not higher than 120 km/h whilst it is well known that many passenger trains can run at 180 km/h on conventional lines and at over 250 km/h on high speed recently built lines. It could be interesting to increase operating speed of freight trains up to those values that are usual for passenger ones for two basic reasons:

- reducing goods travel time, freight transport on rail could get more attractive and competitive compared with road transport;
- should they run faster, freight trains would cause less interference with passenger ones and could be allowed to enter new high speed lines.

The first reason has been discussed on several occasions. According to a widely-accepted opinion, the travel time of goods currently moved by railway is mainly affected by handling operations and intermediate stops rather than relatively low cruising speeds. Consequently, according to that opinion, in order to improve rail freight services it would be more advisable (also in terms of investments) to reorganise the logistic chain rather than to increase the top speed of trains (Cerullo et al., 1997).

On the contrary, the second reason has its objective validity, as it can be easily proved that the traffic capacity of a railway line increases when the difference among speeds of trains belonging to various categories is reduced (Galaverna, 1999). Introducing freight trains into new high speed lines would be advantageous also in terms of profitability and return on investment of the new infrastructures; this particularly concerns those sections of European High Speed Rail Network (EHSRN) whose foreseeable passenger traffic is not intense enough to justify the construction costs.

Unfortunately, the increase of freight trains top speed, approximately up to a range between 160 and 200 km/h, or even more, arises several technical difficulties as far as rolling stock is concerned.

2 Technical constraints in rolling stock for freight trains

Excluding issues related to fixed installations, which are not the subject of this article, technical constraints that have so far prevented railway owners from increasing the speed of freight trains mainly concern:

- the braking system of wagons
- the reduction in maximum load
- traction units.

Brakes usually adopted for wagons are not suitable to operating speeds higher than 140 km/h. Even operation at 160 km/h requires important modifications to the braking system of wagons. First, this problem was faced by replacing traditional brake shoes with synthetic brake discs, but the excessive thermal stress did not result sustainable by wheels in every running condition. As a consequence, when speeds higher than 140 km/h must be attained, a new conception bogie similar to those used for passenger coaches seems to be necessary. At speeds higher than 140 km/h also a system for the brakes electronic control becomes necessary, and this makes it mandatory to provide wagons with an electric line linked to the traction unit or a generator van, as those used on non-electrified railways to supply auxiliary services of passenger coaches; electric lines for power distribution are a common presence inside passenger coaches, but till now there has been no need for electric power supply on wagons.

For these reasons, the cost of a 160km/h wagon is estimated to be 30-40% higher than the cost of a traditional wagon. It must be observed that the technical solutions that make a wagon suitable to run at 160 km/h are quite similar to those necessary to increase its speed up to 200 km/h.

Another problem is that the possibility to run at speeds higher than 140 km/h implies a reduction in the maximum load per axle whereas this fact is in contrast with current trends in freight transportation; indeed, some European railway owners intend to increase the maximum load per axle from the current value of 22.5 t/axle up to 25 t/axle (and to 30 t/axle in the long term).

Finally, operating high speed freight services requires traction units with adequate performance. The power requested to hauling is approximately proportional to the cube of speed and is a linear function of the train mass. Traditionally, the most powerful locomotives are conceived to be specialised either in passenger service or in freight service because the former requires higher speed whilst for the latter a very high tractive effort is more important. High speed freight trains, however, require both features.
Major developments for freight trains over 140 km/h come from France. A 160km/h service was introduced some years ago by National French Railways (SNCF); this was successively suspended due to economic difficulties, but more recently it was relaunched (Gourgouillon et al., 1989). In 1998 Sernam, that is the society devoted to freight services on French railways, started a 200 km/h service between Paris and Dijon along a TGV line. The main characteristics of the wagons of these trains, named V 200, are reported in the following Table 1.

Length of wagon Gahkss	**[m]**	16.790
Top speed	**[km/h]**	160 up to 200
Side door length	**[m]**	2 times 3
Bogies/wagon		Y 37 A
Axle load		11 for 200 km/h – 16 for 160 km/h
Profile (UIC)		SNCF
Tare	**[t]**	25.8
Payload weight	**[t]**	15
Floor height	**[mm]**	1275
Train configuration		9 wagons per train

Table 1 - Main features of V 200 trains

It is foreseen that these services will be extended to the Paris-Bordeaux-Toulouse line by the end of 1999.

3 Traction units for high speed freight service

In this section traction units for high speed trains operated in the most important networks of Western Europe will be examined in order to identify which units could be used for hypothetical high speed freight services. Most European high speed lines are electrified at 25 kV 50 Hz AC, but exceptions are represented by the Florence-Rome line and by German sections; so, dual voltage operation is an important feature for locomotives that might have to haul freight trains across different countries.

3.1 France

TGVs are the most important high-speed passenger trains circulating in France. Several generations of these trains are on service: TGV Paris Sud-Est, TGV Atlantique, TGV Réseau, Eurostar, TGV Duplex, Thalys, TGV Nouvelle Génération. For mail service only, a special version of TGV, named TGV La Poste, was conceived; its main features are listed in Table 2.

Build Dates	1981-1984
Top Speed	270 km/h
Number in Service	7
Supply Voltages	25kV 50Hz AC, 1.5kV DC
Length and Weight	200 m / 345 t
Configuration	1 power car + 4 trailers
Special Notes	Always operated in pairs. Carries mail only.

Table 2 - Main features of TGV La Poste

Without considering TGV lines, in France there are several sections of lines that can cope with speeds of 200 km/h and some electric locomotives can reach such speeds; the most recent ones are:

- the Class 26000 "Sybic", that can reach speeds up 200km/h; it was first introduced into service in 1988, and it is conceived for dual-voltage operation (1.5 kV DC – 25 kV 50 Hz AC);
- the Class 36000 "Astride", that has the top speed of 220km/h; similar to 26000, 30 of these locomotives were introduced in 1997; they can operate with three traction systems, i.e. 1.5 kV DC – 3 kV DC - 25 kV 50 Hz AC.

Both Class 26000 and Class 36000 locomotives could be conveniently used for freight trains up to 200 km/h on electrified routes thanks to their very good performance and three-voltage operability (Perticaroli, 1993); along not-electrified routes it would be necessary to resort to Class 72000 Diesel locomotives which are the most powerful of SNCF Diesel fleet although not very recent (top speed 160 km/h).

3.2 Germany

High-speed passenger services in Germany are operated with ICE trains of several generations.

ICE 1 (class 401, 801, 802, 803 and 804)

This is the first generation of the InterCityExpress, built since 1991. These trains have two power heads with 10 to 12 cars; they were conceived for domestic lines and for the connections to Switzerland/Austria. Nowadays, 60 ICE1 trains are in regular service at speeds up to 280 km/h.

ICE 2 (class 402, 805, 806, 807 and 808)

The second generation consists of only one power head with seven cars; maximum speed is 280 km/h. The ICE 2 is half as long as an ICE 1, but if more capacity is needed, two trains can be coupled together through an automatic Scharfenberg coupler. The trains were delivered from 1996 to 1998.

ICE 3 (class 403 and 406)

The third generation, currently being tested, will be able to

circulate faster (technically 330 km/h, 300 km/h in regular service), on steeper lines and in other countries. Therefore, the 50 trains under construction will have no separate power heads because it is necessary to distribute the power over the whole train (16 axles will be powered). German railways (DBAG) ordered 37 trains for 15 kV 16.7 Hz electric traction system and other 13 trains for 4-mode operation (15 kV 16.7 Hz - 25 kV 50 Hz - 1.5kV DC - 3 kV DC); also Dutch Railways (NS) ordered 4 additional trains for 4-mode operation. ICE3 is designed to be operated internationally, so it has to conform to the Technical Specifications of Interoperability: the length of two coupled sets will not exceed 400 m and the axle load must be less or equal to 17 t.
Other very recent German electrical locomotives are Classes 101, 145 and 152. The former class was mainly conceived for Intercity services up to 220 km/h, but it is suitable for a wide range of different services thanks to its favourable tractive characteristic. Main technical data of this powerful locomotive are listed in Table 3 (Von Michael, 1997).

Build Dates	1997 onward
Top Speed	220 km/h
Number of units	145
Supply Voltages	15 kV 16.7 Hz AC
Continuous power	6400 kW
Tractive effort	300 kN
Weight	87 t

Table 3 – Main features of Class 101 locomotive of German Railways

Classes 145 and 152 can be considered as versions of Class 101 suitable to freight service; their maximum speed is significantly lower than values usually considered within a survey of vehicle for high speed operation (140 km/h). Although less recent than the above-mentioned units, it must be remembered that also Class 103 and Class 120 locomotives can run at 200 km/h and have significantly high continuous power. At present, no high speed freight service is provided by DBAG; anyway, German power units which seem to be suitable for hauling freight trains at higher speeds than 140 km/h along electrified routes are numerous. On the other hand, no Diesel locomotive belonging to DBAG power fleet provides similar performance.

3.3 Italy

Italian high speed trains for passenger services are of two kinds: long trains with two power heads (classified as E.404 locomotives) and a variable number of cars, belonging to Class ETR500, and several generations of tilting electrical multiple units named "Pendolino" (Classes ETR450, 460, 470, and 480). Except for this special sets, the fastest Italian electric locomotive is four-axle Class E.402 that is regularly used both for passenger and freight trains; the first version of this locomotive is to be operated at 3 kV DC only whilst the second version, namely E.402B, features both 3 kV DC and 25 kV 50 Hz operation. For the route between Italy and Switzerland, four-axle Class E.412 locomotives have been recently delivered to the Italian Railways. Main technical data of these units are reported in Table 4.

Class	E.412	E.402B
Build Dates	1997 onward	1998 onward
Top Speed	200 km/h	220 km/h
Number of Units	20	80
Supply Voltages	3 kV DC/1.5 kV DC/15 kV 16.7 Hz	3 kV DC
Tractive effort	300 kN	270 kN
Continuous power	6000 kW under 3 kV DC	5600 kW
Weight	87 t	84 t

Table 4 – Technical data of Italian Classes E.412 and E.402B locomotives

When running at 15 kV 16.7 Hz AC, the continuous power of Class E.412 locomotives is reduced to 5500 kW; when running at 1.5 kV DC it is reduced to 2700 kW. Class E.412 is designed to be operated internationally, so it has to conform to the Technical Specifications of Interoperability (fiche UIC 505-1).
Apart from tilting trains, the latest Italian high-speed passenger trains, as it has been previously mentioned, built for services over present and future high-speed lines belong to Class ETR500. These trains are formed of two Class E.404 power cars and of a variable number of trailers (8 to 14). By 1999 the Italian Railway plan to deploy 60 ETR500 sets; most of these are already on service; thirty will be dual-voltage (3 kV DC/25 kV 50 Hz AC). Each ETR500 has two traction units classified as E.404 locomotives; their technical data are listed in Table 5.

Build Dates	1990 onward
Top Speed	300 km/h (275 km/h for the first four prototypes)
Supply Voltages	3 kV DC (some 3 kV DC/25 kV 50 Hz AC)
Tractive effort	290 kN
Continuous power	4400 kW
Weight	76 t

Table 5 – Technical data of Italian Class E.404 locomotives

At present, no high speed freight service is provided by National Italian Railways (FS); up to 160 km/h, for such a service the most suitable locomotives are Classes E.652, E.402, and E.412. For 200km/h services the range of potential suitable traction units would be restricted to E.402 and E.412. In Italy, conventional freight trains run at speeds that do not exceed 100 km/h (120 km/h in few cases). Freight services provided by OMNIA EXPRESS, a company belonging to FS business group, can reach 140 or 160 km/h using luggage vans, but a reduction in the allowed load per axle is necessary in these cases. The most recent luggage vans can run at the same speed of the passenger coaches with which they can form up a train, that is 160 km/h or 200 km/h for Z-series vans.

3.4 Spain

The AVE ("Alta Velocidad Española" or Spanish High Speed) is the high-speed train of Spain. It derives directly from the French TGV Atlantique, and has a top speed of 300 km/h. Also the Talgo 200, which operates along the lines Madrid-Huelva and Madrid-Cádiz using its variable gauge, runs on the high speed line. The Talgo 200 sets are pulled by electric locomotives Class 252; 15 of the 75 locomotives of this class have international gauge to pull the Talgo 200 trains on the high-speed line Madrid-Seville. Main technical data of these locomotives are reported in Table 6.

Build Dates	1992
Number in Service	15
Gauge	1,435
Top Speed	220 Km/h
Power	5.600 kW
Supply Voltages	3 KV DC/ 25 kV 50 Hz AC

Table 6 – Technical data of Spanish Class 252 locomotives

At present, National Spanish Railways provide no high-speed freight service; anyway, for such a service Class 252 locomotives seem to be the most suitable. Large gauge specific to Spanish network, except for new high-speed sections, still represent the main obstacle to the development of high-speed, good quality international freight service for Spain.

3.5 Switzerland

The features of Swiss railway lines do not allow very high speed; nevertheless the most recent locomotives built for National Swiss Railways (SBB Class 460) have a top speed of 230 km/h which will result to be useful when new line sections are opened in the future. Also for BLS company which operates Simplon international line similar locomotives were built that are classified as 465. Main technical data of these units are reported in Table 7 (Appleby, 1997).

Class	SBB 460	BLS 465
Build Dates	1991-1996	1994-1997
Number in Service	119	8
Top Speed	230 km/h	230 km/h
Supply Voltages	15 kV 16.7 Hz AC	15 kV 16.7 Hz AC
Tractive effort	275 kN	320 kN
Hourly power	6100 kW	7000 kW
Weight	84 t	82 t

Table 7 – Technical data of Swiss Classes 460 and 465 locomotives

These are the only Swiss locomotives that could haul freight trains at higher speed than 160 km/h, but constraints imposed by infrastructures are more relevant in Switzerland. Anyway, if new rail links are constructed in Switzerland suitable to 200 km/h, for hypothetical high speed freight services it will be also possible to use German or dual-voltage Italian power units.

3.6 United Kingdom

The Inter-City 225 is the fastest train running in the UK; its maximum speed is 225 km/h. Services were first introduced using Class 91 locomotives. Each set is made up of a Class 91 locomotive and 9 passenger coaches with a Driving Van Trailer at the rear. Main technical of four-axle Class 91 locomotives are listed in Table 8 (Fox, 1997).

Build Dates	1988-1991
Top Speed	225 km/h
Number in Service	31
Supply Voltages	25 kV 50 Hz AC
Continuos power	4540 kW
Weight	84 t

Table 8 – Technical data of English Class 91 locomotives

Within the power fleet of British Railways the units more suited to a hypothetical high speed freight service are those belonging to Classes 90, 91 for electrified routes and Class 43 for not-electrified routes. At present, British Railways provide no high-speed freight service except for mail services operated with special units. These are four-element electric multiple units Class 325 that are used for mail services at a maximum speed of 160 km/h; they can run at 25 kV 50 Hz AC overhead line or at 750 V DC third rail. Along not-electrified lines, a Diesel locomotive can haul them.

4 Possible high speed freight services with existing trains

High speed freight services could be operated with loco-hauled trains using some of the traction units mentioned in the previous section as well as with special multiple units. Taking into account the difficulties that arise when trying to increase the operating speed of conventional freight wagons, it seems more interesting to develop high-speed freight services on other basis than improving bogies and brakes of traditional wagons. In this section and in the following one we propose some train configurations for high speed freight services respectively based on existing rolling stock and new vehicle conception.

The most interesting train configurations that could be made up by using rolling stock currently being operated seem to be:

- trains made up of an electric locomotive and Z1-series luggage vans
- TGV La Poste
- V200 Sernam

In the following notes the above-mentioned solutions will be separately described.

4.1 Trains made up of Z1-series luggage vans

A train made up of Z1-series luggage vans could run up to 200 km/h along suitable lines of almost all Europe provided that an adequate traction unit is available. On the basis of the survey resumed in the previous section 3, for each country the locomotives that are most suited to hauling such trains can be identified; they are reported in Table 9.

Country	Locomotive class
France	BB26000, BB36000
Germany	101, 120
Italy	E.402B, E.404
Spain	252
Switzerland	460, 465
United Kingdom	90, 91

Table 9 – European locomotives suited to high speed freight services

Main operating restrictions that the use of such vans may cause to a regular freight service concern weight per surface unit and dimensions of bundles. Indeed, the floor of luggage vans can sustain no more than 500 kg/m² and the side doors are 130 cm wide. For instance, on Italian State Railways (FS) the conventional load of luggage vans is 5 t, which suggests that fast trains made up these vehicles are well-suited to transport mail and light parcels rather than heavy goods. Indeed, this would not be a problem, because high-value parcels are typically light and small in size, whilst it should be of no interest to transport low-value heavy bulk at high speed. Anyway the maximum load that could be put on a van is higher than the conventional value indicated by FS, which must be considered as an average value. The advantages specific to this solution can be recognised in the fact that Z1-series vehicles are widely used and have been running up to 200 km/h on several main lines of Italian and European network for some years; consequently, no other particular speed restriction should be observed than those of usual Intercity trains for the circulation of such high speed freight trains.

4.2 TGV La Poste and V200 Sernam

Alternatively, high speed freight services could be developed using French rolling stock such as TGV La Poste, currently in service along *Sud-Est* and *Atlantique* lines, or V 200 trains. The latter are conventional freight trains modified in order to attain 200 km/h on high speed lines. Each one of these trains is made up of a dual-voltage BB22200 locomotive and 9 wagons each of them including a payload weight of 15 t. The total mass is 457.2 t and the total length is 160 m. It has to be noted that the speed can be increased from 160 km/h up to 200 km/h provided that a reduction of payload weight is imposed (11 t/axle instead of 16 t/axle).

These trains are conceived for domestic usage and their interoperability on European network should be investigated. Anyway, new units suitable to be operated internationally could be ordered. It must also be noted that the feasibility of a freight only version of TGV, namely *TGV Fret*, has been studied by the Research Division of National French Railways.

5 New vehicles for high speed freight services

Special versions of existing high speed passenger trains and even totally new vehicles could be designed to accommodate requirements of freight transport. For instance, freight versions of both Italian ETR500 and German ICE trains could be developed so as to obtain sets similar to TGV La Poste but suitable to a wider variety of commodities. Such solutions are discussed in the following notes.

5.1 Luggage-van version of ETR500 high speed passenger trains

A luggage-van version of ETR500 sets could be realised. Such a train could run at even higher speed than 200 km/h, if the line gradient and the load should permit it. To develop such a train the same designing principles that have led to the special versions destined to mail services of French TGV, Class 325 English electric-multiple units, or a similar Swedish set, could be followed. Main differences between the special version and normal ETR500 sets would concern the presence of wide access doors and the elimination of seats, interior equipment, and most windows. The dining car of ETR500 is well suited to be considered as the basic structure for the construction of the luggage-van version, as it has wider side doors than other coaches. The maximum load could be fixed at 15 t. The major drawback of this solution is represented by costs, as a new fleet of special sets should be designed and built in order to start on services. On the other hand, some advantages can be recognised in higher performance than those of loco-hauled luggage trains mentioned in 4.1.

5.2 Freight version of ICE high speed passenger trains

Also freight versions of German ICE train could be conceived. Two different train configurations based on ICE2 could be developed to carry a greater or lesser number of containers. Current interest of German railways in special vehicles for containers may reflect the recent success of CargoSprinter diesel railcar.

According to the former configuration, each set would be made up of a ICE2 traction unit, two wagons and a driving trailer; each wagon and the driving trailers can carry two containers. The payload weight, for each container, is 12 t while the total mass of the train is 302 t. The total length is 72 m and top speed is 200 km/h. The wagons are closed and have wide side doors. This train has been conceived as to be admitted in every high speed line thanks its axle load that is 16 t only.

Also the latter configuration that has been envisaged is made up of a ICE2 traction unit, two wagons and a driving trailer but its intermediate wagons are longer than those of the previous version so as to carry three containers instead of two. Consequently, the total mass of the train is 328 t and the total length is 84 m. This solution cannot run along every high speed line because its axle load is higher than 17 t. Only the high speed lines developed for 22 t/axle allows to include this solution.

5.3 A new conception vehicle: Combivan

Another solution is represented by the development of a new conception vehicle specifically conceived for high-speed freight transportation. The Italian builder Costaferroviaria is developing such a vehicle; this wagon is called COMBIVAN and it will be able to run up to 250 km/h. Thanks to its surprisingly high top speed, one or more COMBIVAN wagons could be used as elements inserted in a passenger Intercity train without any reduction in commercial speed with respect to all-passenger configuration. Alternatively, it will be possible to operate train sets made up of COMBIVANs.

These vehicles will look like a van, with three wide doors for each side and a front door at each end. Charging and discharging operations will be performed through automatically operated special devices; the load will be automatically fixed inside the vehicle. Other technical data of these vehicles are reported in Table 10.

It is important to observe that, at present, no locomotive of European traction unit fleet for conventional hauled trains is able to attain 250 km/h on regular service (see Table 9); indeed, loco-hauled fastest passenger trains in Western Europe do not exceed 200 km/h as this is the top speed of most recent standard passenger coaches. Consequently, in order to operate a train made up of COMBIVAN wagons at 250 km/h a couple of traction units belonging to high speed train sets, such as Italian ETR500 or German ICE, should be necessarily tailored. For instance, two dual-voltage series Class E.404 locomotives, currently used for ETR500 sets, could be used (one at each end of the train).

Length	26 m
Tare	32 t
Maximum Load	32 t
Maximum axle load	16 t/axle
Top Speed	250 km/h at full load
Available volume for the load	132 m2
Maximum dimension of the bundls	244x317x244 cm (AQ6/AMA standard)
Brake system	3 brake discs for each axle

Table 10 – Technical data of COMBIVAN wagons

6 Conclusions

A notable interest is currently addressed to the possibility of increasing commercial speed of freight trains. Maximum operating speed of trains is affected by several factors concerning both fixed installations and rolling stock; this paper has focused on the latter. First locomotives currently being operated on European railways suitable to high speed freight trains have been identified. Then, some proposals for new vehicles specifically conceived for such services have been discussed. Trains made up of luggage vans represent an interesting solution to transport freight up to 200 km/h provided that size of bundles do not exceed the width of side doors; for other load units such as containers special versions of high speed trains seem to be preferable.

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