Innovative technical solutions for improved train DYNAmics and operation of longer FREIGHt Trains

D3.3 – Adaption in rail infrastructure for long-train operation

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EXECUTIVE SUMMARY

This deliverable focuses on DYNAFREIGHT activity devoted to the identification of barriers and the required adaptations needed to make 1500 m long-train operations feasible, as well as changes in train operations required. The analysis takes the main point of view of the infrastructure manager, which bears the impact of long trains circulation on the railway infrastructure. Although such kind of analysis could be extremely complex and customised in accordance to each peculiar aspects of the lines, the general analysis made in DYNAFREIGHT led to conclusions to be taken into consideration for future work and in different networks. Although the geographical scope of the analysis was the Spanish rail network (managed by ADIF), many of the conclusions obtained are directly applicable to other European networks. In a concrete way, the analysis has been carried out mainly in the Spanish section of the Atlantic Corridor and in the freight terminals of the Mediterranean Corridor.

The document is structured in five sections:

- The introductory part analyses the possible solutions that exist to increase the payload of freight trains. The main conclusion is that the best way is to increase the train length, to a higher length than the current standard, and not necessarily reaching 1,500 meters;
- In the second section different considerations related to railway lines, rolling stock and current restrictions are taken into account;
- In the third section some approaches with all the aspects related to infrastructure (both operative conditions and assets) in order to perform a specific analysis on the Atlantic Corridor are sketched;
- Based on the conclusions of section 3, section 4 analyses the aspects to be taken into account considering the design of new lines;
- Section 5 – which ends the report - analyses the different operational and design aspects to be taken into account in the freight terminals.

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ABBREVIATIONS AND ACRONYMS

AC: Alternating Current

CSM: Common Safety Methods

DC: Direct Current

EC: European Commission

EU: European Union

ERA: European Railway Agency

IM: Infrastructure Manager

RU: Railway Undertaking

S&C: Switch and Crossing

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1. INTRODUCTION

The increase in the share of rail in freight transport is a common priority to the great majority of IMs and RUs. Leaving aside the legal and regulatory aspects, both necessary to enhance the increase of rail freight traffic, technological innovation towards the increase of freight train performance is a key aspect to reach the goal.

In fact, a basic objective of each RU is to be able to transport more freight on trains, which is possible by acting on two main variables:

- *Axle load*. Considering the specific case of Europe, this value is normally limited to 22.5 T/axle. Logically, its increase -up to a standard value of 25.0T/axle- would allow a big increase of goods transported on a train having the same length;
- *Train length*. Keeping the maximum axle load at the standard value of 22.5 t/axle, the only way to increase the load would be increasing the train length. Generally, in the EU this value is not higher than 750 m with some exceptions (Table 1).

As reported in the CER “Longer trains” report (CER, 2016), the current trend among European IMs is to implement the second strategy, that is to increase the length of the freight train, since it has a smaller impact on infrastructure, especially on older lines. In the case of new lines, several studies developed by ADIF in the past have concluded that there is no greater degradation of the track by increasing the axle load (see next section).

In any case, and as analysed in this deliverable, also the increase in length implies an inevitable – but lower - impact on the infrastructure. Due to its importance in the context of the DYNAFREIGHT, the following section summarises standard consequences occurring in both scenarios.

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Country	Lenght train (max.) (m)	Notes
Austria	750	
Belgium	750	
Czech Republic	740	
Denmark	835	
England	750	
Estonia	≥ 1.000	Train up to 1.450 m are allowed, if economical operation is possible
Finland	600 – 730	
France	750	
Germany	740	
Hungary	750	
Italy	600 – 730	
Lithuania	≥ 1.000	
Luxembourg	750	
The Netherlands	740	
Norway	600 – 730	
Poland	750	
Slovakia	600 – 730	
Spain	750	See **Appendix 1**
Sweden	600 – 730	
Switzerland	750	
Portugal	< 600	

Table 1 – Overview of standard (max.) train length insome European countries (source: CER)

1.1 Increase of Axle Load

A high axle load favours freight traffic, as more weight can be loaded on each wagon, or fewer axles are necessary to accommodate the payload. If the locomotive has a higher axle load, adhesion weight can be increased, which reduces the risk of slipping and allows for higher train weights. The maximum permitted axle load applied on most of the main lines in Europe is 22.5 t. This limit was gradually raised by European IMs from the previous 20 t standard.

TEN-T guidelines[1] indicate 22.5t as a European standard to be achieved by 2030, at least in the Core Network. However, a significant number of actions must be performed to achieve the goal. For example, bridges not allowing a higher axle load would have to be rebuilt. Moreover, an increase in axle load will only be beneficial if the whole route in the corridor is upgraded to the same axle load standard.

As just indicated, in old railway lines the increase in load per axle can have negative connotations for the infrastructure (track and substructure). For example, in the case of the ADIF network, some conventional lines have structures[2]that are not prepared to support a load per axis greater than 22.5 t. An increase of the axle load from 22.5 t to 25.0 t might require substantial investments on the existing infrastructure, i.e. mainly on bridges, tunnels and tracks. Furthermore, considering that most of these lines are equipped with UIC 54 (or lower) rails, a higher degradation of rails, faster than if a standard rail type UIC 60was used, has to be taken into account.

As concerns the rolling stock, the maintenance of freight wagons in most of EU countries is less frequent than for passenger trains, the age is higher and old wagons have generally poorly optimized suspension technologies and would not accommodate a higher axle load.

In the case of new lines (including high-speed lines prepared for mixed exploitation), ADIF has carried out several tests in Madrid facility for the simulation of dynamic loads on the track (see Figure 1). Considering a UIC 60 rail track, with good maintenance and on which high-speed trains are allowed to circulate, the behaviour of a freight train of 750 m in length was simulated[3].The short-term dynamic behaviour was detected in case of transit of passenger trains at 300 km/h speed with 17.0 t/axle and freight trains up to 120 km/h with 22.5 and 25.0 t/axle. The following conclusions were possible:

[1]Regulation (EU) No 1315/2013 of the European Parliament and of the Council of 11 December 2013 on Union guidelines for the development of the trans-European transport network.

[2] Normally metal bridges.

[3]Same axle load in the locomotive and wagons (43 wagons and 86 bogies).

- Freight trains generate vibrations both on the track and in its nearest environment half of that produced by passenger trains;
- No "sleeper dance" was reported in any of the fatigue tests carried out with freight trains.

From the analysis of the long-term dynamic behaviour, it is reported:

- An excellent behaviour of the ballast when tamping with correct intervals;
- A similar behaviour for passenger trains at 300 km/h with 17.0 t/axle and freight trains at 120 km/h with 22.5 and 25.0 t/axle.

As a final conclusion of the trials and studies carried out, it should be added that it is possible make compatible the circulation of both types of trains in the same track, if the following conditions are met:

- Appropriate control is established by impact detectors and frequent move of inspections trains of the track that a mixed traffic can induce on the track;
- The wear of the rails and wheels of the rolling stock is controlled;
- Punctual tamping (even manual) is applied to most problematic sections of the track.

It must be taken into account that in this case the maintenance must be excellent, which could increase the cost compared to other types of lines where no heavier trains circulate.

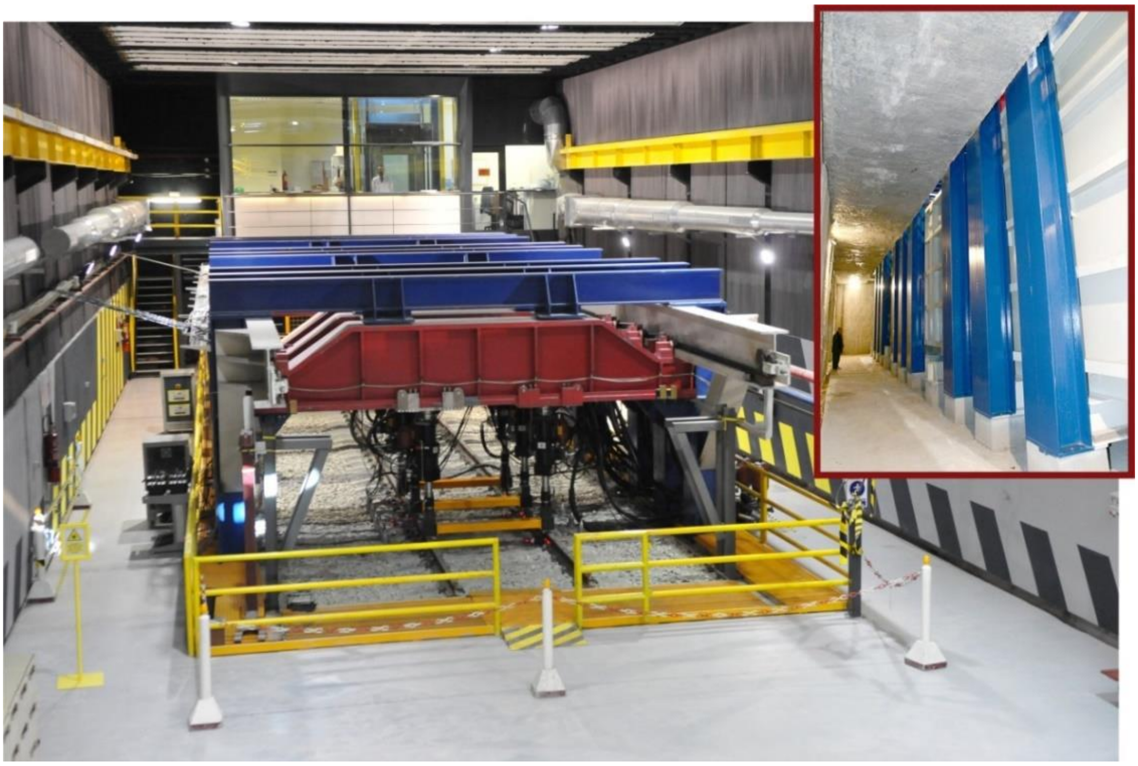

Figure 1: ADIF/CEDEX Track Box (source: ADIF)

1.2 INCREASE OF LENGTH

The increase of train length in the network will have impact on rail infrastructure and traffic management. Train lengths of 740 – 1.050 m have been recommended in regulations for TAF-TSI. The 740 m standard has been recommended for new lines on the TEN-T Core network by 2030. 740-750 m are the standard which have been applied in many countries for building and upgrading railway lines in Europe and are also established in many EU countries as the maximum train length. However, this does not mean that it is possible to operate 740 m on all main lines, there is still much to do to get this standard in many important Rail Freight Corridors in Europe.

Longer trains require investment on rail infrastructure, although less costly than those required to build double or multiple tracks, and more effective if implemented in parallel with time-table and operational planning. Longer trains are easier to handle on double track because there are normally no crossings. Sometimes the freight trains must give priority to passenger trains and then there must be stations having by-pass modules long enough to accommodate longer trains. The density of lengthened sidings is related to the general traffic density and to the

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number of longer trains running. But during night time, when freight trains have the priority, it will be easier to find suitable paths. Also, the yards must be adapted to longer trains. On single track it is necessary to adopt most crossing stations to longer trains. This can be expensive, however cheaper than building double tracks.

Length of sidings is a major barrier against the establishment of a new vision of freight service, characterised by longer trains, up to 1.500m long. Research will be required to identify the minimum number of sidings which should be lengthened together with the maximum and minimum distance between sidings. Moreover, the assessment of impact of longer trains on traffic volume is required, since if only few longer trains are implemented it would be difficult to verify the economic benefits of longer services. On the other side, if longer trains appear to be a positive solution to network capacity and increase the competition of rail freight, then research will be required into the number of sidings which it is necessary to lengthen.

The infrastructure is generally sized to allow a defined maximum train length; therefore, allowing longer trains implies checking if infrastructure modifications are not necessary, and if the quality of the service can be guaranteed at the same level for all traffic categories.

Changes and improvement son the infrastructure may affect the capacity of the electrical substations, catenary, configuration of the safety installations, signalling systems and freight terminals.

The investment required for such changes in the network will be greater as the length of the trains increases. Sometimes, it is possible to allow operational restrictions, rather than investment, but this must be carefully studied.

It is important to note that in some countries, such as Spain, the progressive introduction of high-speed lines is causing the decrease of passenger trains on conventional lines. Therefore, these types of lines are progressively being devoted to freight train traffic. This is a favourable situation to introduce long trains without making investments in the network since there should be no special interference with passenger trains.

From the RUs point of view, the operation of longer trains improves the productivity of rail freight traffic. The amount (volume) of goods that can be transported by a single train can be increased by 35% (1.000 m train) and up to 103% (1.500 m train) in comparison to a 740 m train.

It is possible that a double train (2 x 750 m) needs less space on the network than two normal trains (750 m), which means more capacity for the IM. However, this is not the only criteria to be taken into account, since longer trains have to be properly managed in a way that they do not interfere with the other traffic categories operating on the line. More “garage tracks” should be built, shunting yards should be conceived to receive longer and shorter trains, and electrical power stations adapted if needed along the track.

1.3 Comparative

The following table (Table 2) summarises the order of magnitude of impact categories in view of the two analysed strategies to increase transport volume per train. From Table 2 it can be concluded that – in standard track conditions - increasing the train length is more effective that increasing their axle load. In the case of old lines, there may be technical restrictions that impede the circulation of trains with axle load higher than the standard one. In the case of new lines, these restrictions would not exist but the necessary maintenance would be generally greater. As previously mentioned, the increase of train length of the trains does have greater effects on traffic management, although in this case, adequate strategies on operations should be applied.

Action	Impact (Old Line)			
	Traffic Management	Track Impact	Substructure Impact	Maintenance Impact
Increase axle load	Medium	High	High(1)	High
Increase the length	High	Medium-Low	Low	Low
Action	**Impact (New Line)**			
	Traffic Management	**Track Impact**	**Bridge Impact**	**Maintenance Impact**
Increase axle load	Medium	Medium-Low	Low	High
Increase the length	Medium	Low	Low	Low

(1) Problems may exist in structures, trains can not circulate

Table 2 – Benchmarking: Increase axle load vs. Increase the length (source: ADIF)

2. THE CASE STUDY: SPANISH TEN-T CORRIDORS

The present section identifies the geographical scope of DYNAFREIGHT case study for longer trains. Mediterranean and Atlantic TEN-T Corridors include some key lines of the Spanish rail network managed by ADIF. The following sub-sections describe the main features of the two corridors, identifying also key barriers as assessed by the respective "TEN-T Corridor studies"[4]Several preliminary considerations made on the compatibility of Spanish network with longer trains are made at the end of the chapter. However, such conclusions are largely applicable to other European networks.

Considerations have been grouped into three main groups:

- Railway lines.
- Rolling stock.
- Current restrictions to be considered.

2.1 Considerations on the Railways Lines

Different sections of the Spanish network belonging to the TEN-T Corridors have been selected (Figure 2) for DYNAFREIGHT case study. Such sections belong to Rail Freight Corridor No. 4 and 6 (Atlantic and Mediterranean respectively) too.

2.1.1 Atlantic Corridor

The **Atlantic Corridor** includes the existing railway lines and planned itineraries between Sines, Setubal, Lisbon, Aveiro and Leixões in Portugal; Algeciras, Madrid, Bilbao and Zaragoza in Spain; Bordeaux, La Rochelle, Nantes, Paris, Le Havre and Strasbourg in France; and Mannheim in Germany. Crossing the international borders of Vilar Formoso/Fuentes de Oñoro (Portugal/Spain), Elvas/Badajoz (Portugal/Spain), Irun/Hendaye (Spain/France) and Forbach/Saarbrucken (France/Germany). This Corridor connects the sea ports of Sines, Setubal, Lisbon, Aveiro and Leixões, in Portugal; Algeciras, Bilbao and Pasajes, in Spain; Bayonne, Nantes, La Rochelle and Le Havre, as well as the inland ports of Bordeaux, Rouen and Strasbourg in France; to the main capitals within the corridor Lisbon, Madrid, Paris, to the East of France, to Mannheim in Germany and subsequently to North and Eastern Europe.

[4] European Commission (2014).

Totalling more than 6,200 kilometres of existing lines, it includes heterogeneous characteristics of rail infrastructure with the following key points (see **Appendix 2**):

- Tracks with European gauge in France and Germany (1435 mm) and Iberian gauge in Spain and Portugal (1668 mm). This fact forces to have to design and install special facilities to modify the gauge of the wagons. In the case of locomotives, different types are used in each country;

- Itineraries with double track lines from Paris to Mannheim and Strasbourg Port du Rhin, between Le Havre, Metz, Paris and South of Madrid (Santa Cruz de Mudela), and also between Lisbon and Porto;

- Itineraries with single track lines between the south of Madrid (Santa Cruz de Mudela) and Algeciras and in the two branches connecting Spain to Portugal (Medina del Campo-Pampilhosa and Manzanares-Entroncamento), in two sections of the connection from Poitiers to La Rochelle Port in France and from Alsasua to Castejón de Ebro in the Spanish connection to Zaragoza;

- Triple voltage (25.000V AC, 3.000 V DC, 1.500 V DC) electrified itineraries between Le Havre, Metz, La Rochelle, Paris, Strasbourg Port du Rhin and South of Cordoba (Bobadilla), 15.000 V AC from the French border to Mannheim and in Portugal between Sines, Lisbon, Leixões, Abrantes and Vilar Formoso (25.000 V AC);

- Partially electrified itineraries (25.000 V AC) on the two branches connecting Spain to Portugal (Medina del Campo-Pampilosa and Manzanares-Entroncamento);

- Non-electrified itinerary between the south of Cordoba (Antequera) and the port of Algeciras;

- Several different signalization systems between Germany, France, Spain and Portugal;

- Very heterogeneous maximum gross load charge according to geographical areas connected to the topography of the existing network, with a load of 22,5 t/axle on the totality of the route.

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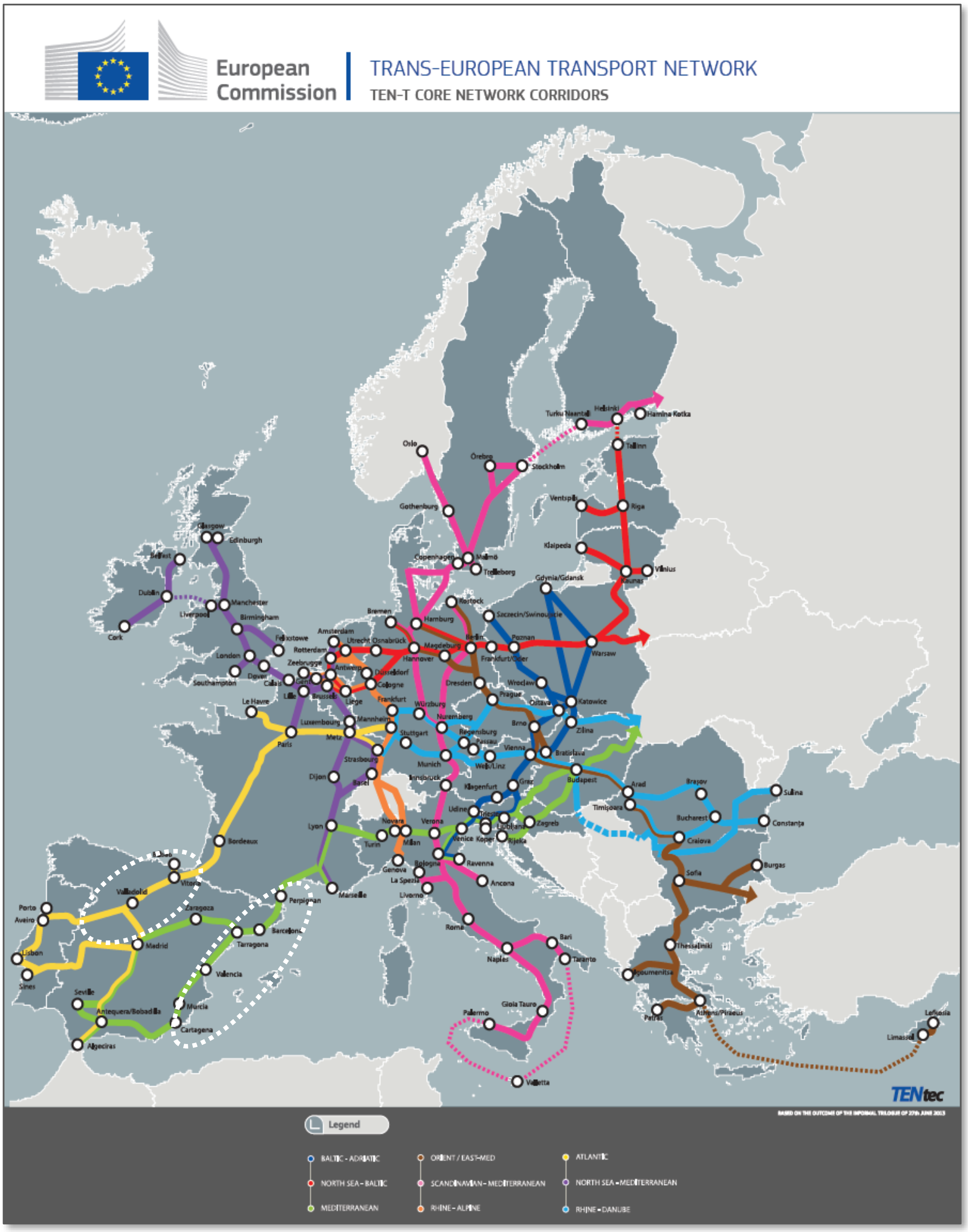


Figure 2: TEN-T Core Networks Corridors (source: EC)

2.1.2 Mediterranean Corridor

The **Mediterranean Corridor** includes the existing railway lines and planned itineraries between Almeria, Valencia, Algeciras, Madrid, Zaragoza and Barcelona in Spain; Marseille and Lyon in France; Torino, Milano, Verona, Padova, Venezia and Trieste in Italy; Koper and Ljubljana in Slovenia; Rijeka and Zagreb in Croatia; Budapest and Zahony in Hungarian (Hungarian-Ukrainian border).The Corridor includes the international borders crossings of Port-Bou/Cerbere (Spain/France), Modane/Torino (France/Italy), Villa Opicina/Divaca(Italy/Slovenia) and Hodos/Boba (Slovenia/Hungarian). This Corridor connects nine (9) sea ports and 90 terminals.

Totalling more than 7,000 kilometres of existing lines, the Corridor includes heterogeneous characteristics of rail infrastructure with the following key points (Figure 3):

- Tracks with European gauge in France, Italy, Slovenia, Croatia and Hungary (1435 mm) and Iberian gauge in Spain (1668 mm). As well as in the Atlantic Corridor, this requires the design and the installation of special facilities to modify the width of wagons. Different locomotives are used in each country;
- It should be noted that for some years there has been a direct connection from Barcelona to France in standard gauge through the Madrid-Barcelona-France HSL. This route is exploited in a mixed way (Figure 3);
- Triple voltage (25.000V AC, 3.000 V DC, 1.500 V DC) electrified itineraries;
- Non-electrified itinerary between South of Cordoba (Antequera) and the Port of Algeciras;
- Several different signalling systems between Germany, France, Spain and Portugal;
- Very variable maximum gross load charge according to geographical areas connected to the topography of the existing network, with a load of 22.5 t/axle on the entire routes in Spain.

It should be noted that in the coming years the Mediterranean Corridor will undergo an important transformation in the Spanish part. Among other actions, the track gauge will be transformed to standard gauge.

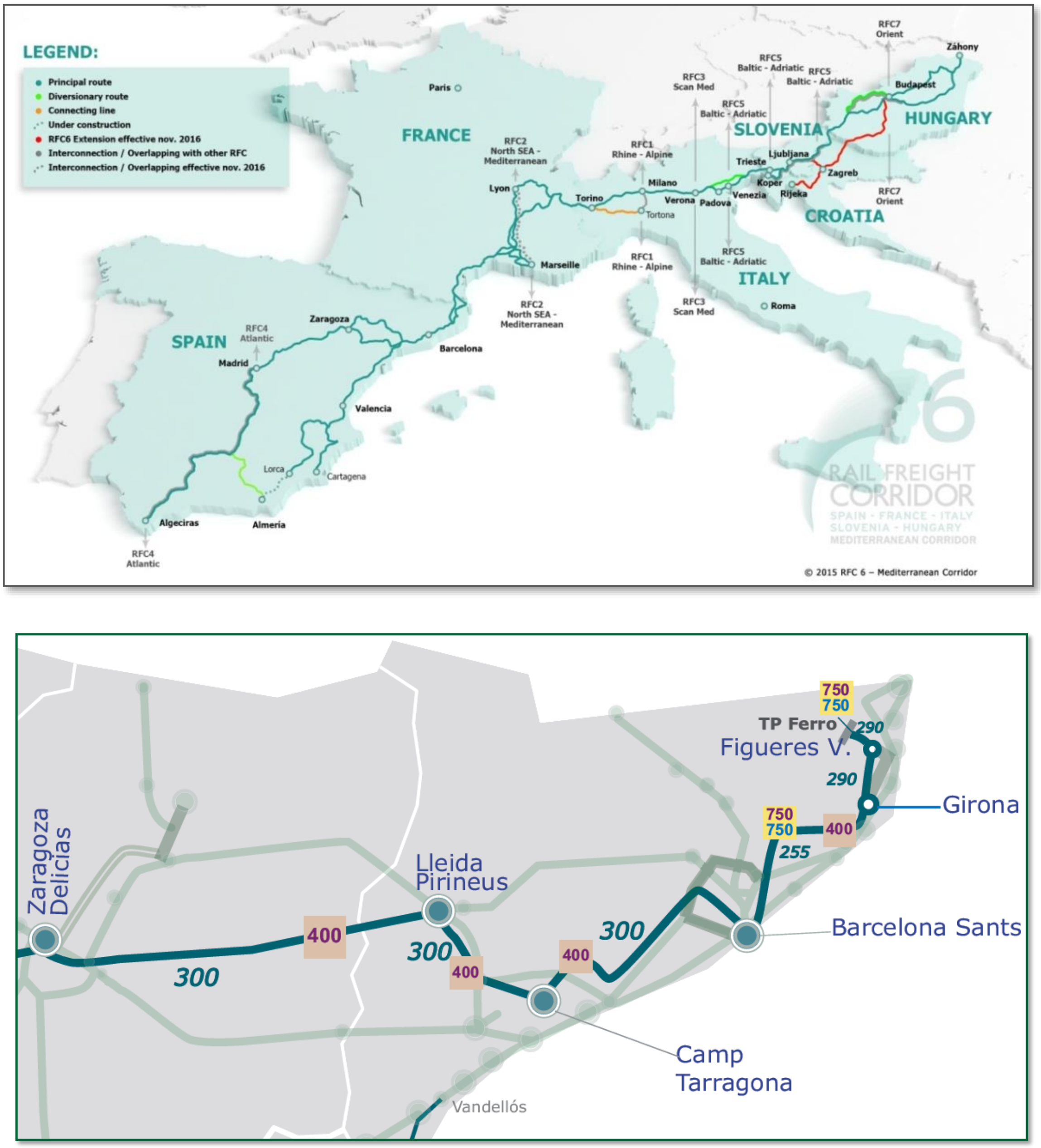


Figure 3: Mediterranean Corridor.Between Barcelona and the French border

Freight trains can circulate through the conventional network or through a section of the high-speed network that allows the mixed circulation of passenger trains (high-speed) and freight trains (source: Mediterranean Corridor/ ADIF)

2.1.3 General aspects

The creation of governance structures for Atlantic and Mediterranean Corridors fits with the spirit of the European Regulation (EU) N.º 913/2010 amended by Regulation (EU) N.º 1316/2013, which aims at developing an internal rail market, particularly regarding freight traffic, by creating dedicated corridors.

One of the goals of the Atlantic and Mediterranean Corridors is to harmonize the technical characteristics of the infrastructures and to coordinate investment to overcome the existing diversities.

Figures 4 and 5 represent schematically the specific areas selected within Atlantic Corridor for DYNAFREIGHT (sectors PS5, PS6 and PS7 in Figure 4).

Characteristics of the infrastructure are more restrictive for the Atlantic Corridor than for the Mediterranean Corridor (it is an older infrastructure with a more exigent longitudinal profile). Specifically, in the Mediterranean Corridor some actions have been carried out in recent years that have made it possible, among other aspects, for the quality of the track to be better than in the Atlantic Corridor. Likewise, actions have been carried out in bridges and tunnels, in some cases of new construction. In a concrete way, in the case of the track it has that around 83% of the Mediterranean Corridor in Spain has an excellent quality; 12% have an average quality and 5% a low quality. The bad parameters appear in track switches and turnouts especially in points or sections.

In this sense, the approach to select DYNAFREIGHT case study sections was the following:

- From a point of view of affection to the infrastructure, the interaction with long trains is more interesting in the Atlantic Corridor than in the Mediterranean Corridor. Thus, the analysis was made on the former one. If longer trains can circulate in Atlantic Corridor, they can circulate in Mediterranean Corridor too).
- The Mediterranean Corridor will be the scope for the analysis of freight terminals (Figure 6), since the most important ones of the Spanish network are located on this corridor.

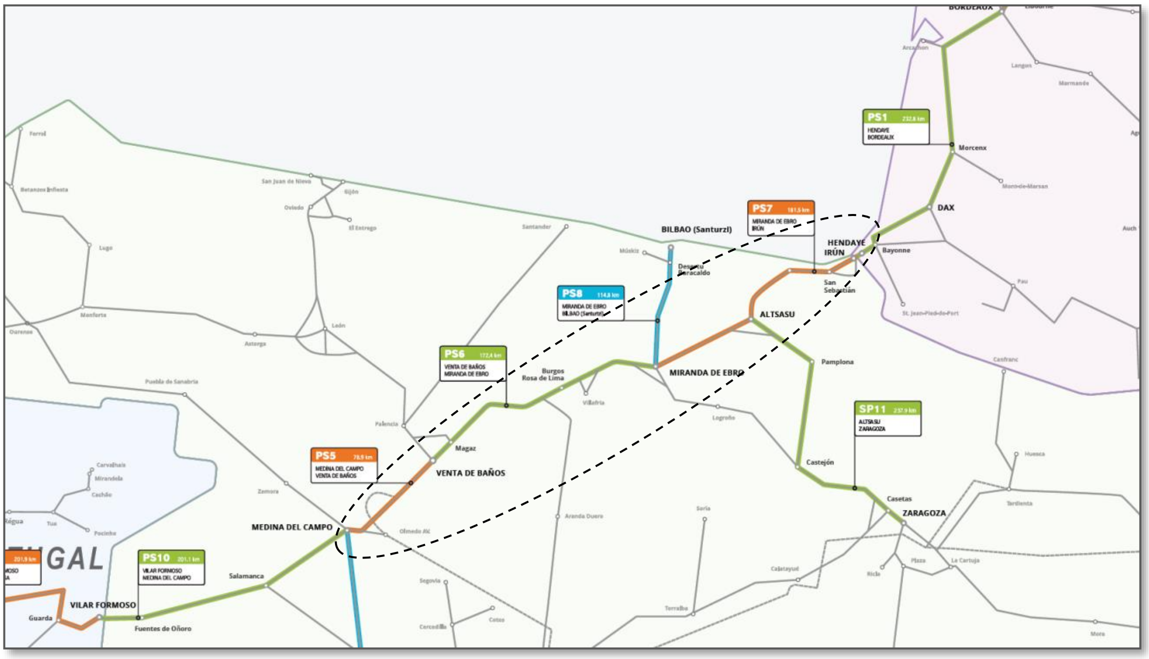


Figure 4: Atlantic Corridor. Selected section (PS5, PS6 and PS7) (source: Atlantic Corridor)

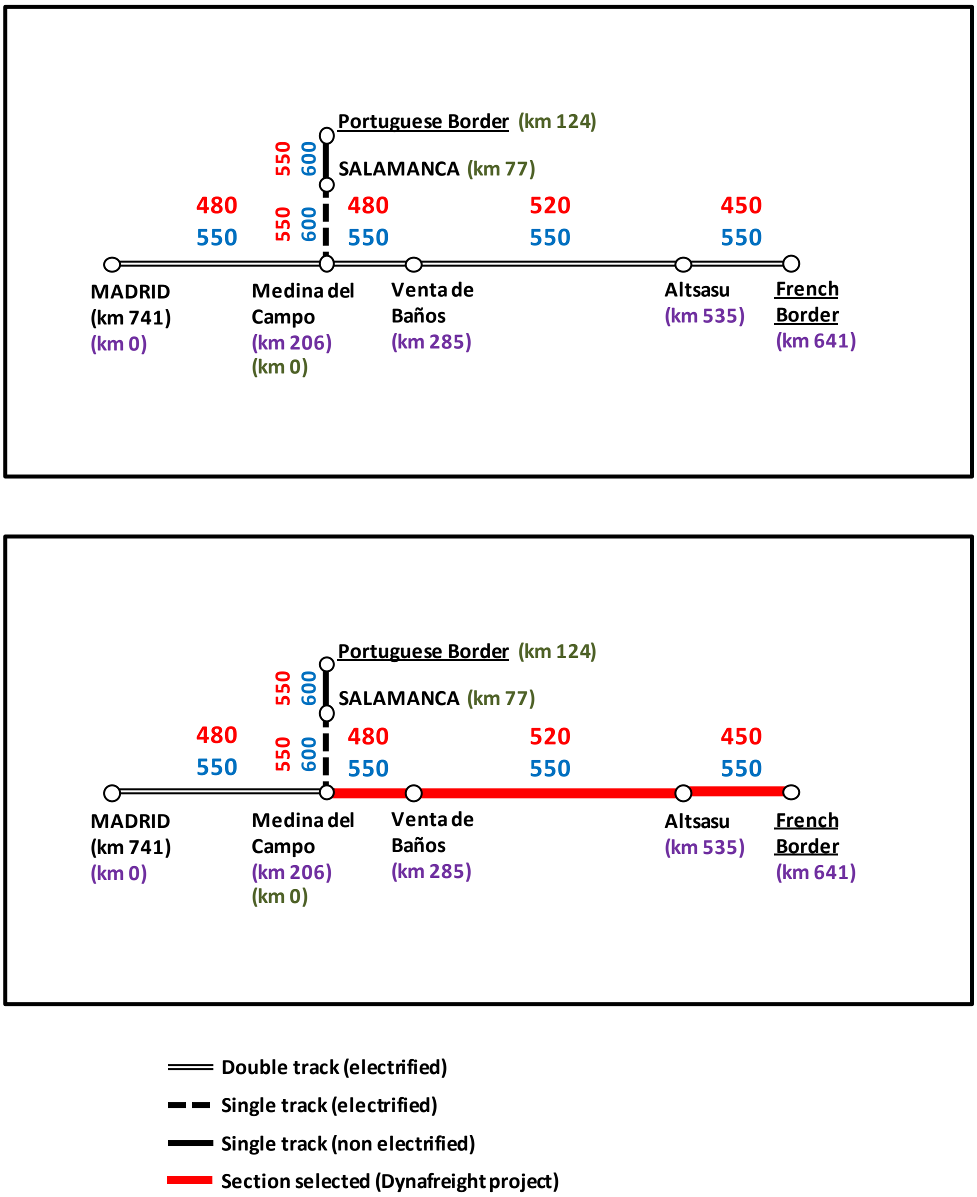


Figure 5: Atlantic Corridor. Scheme of case study area. The maximum length of freight trains is indicated (Red digit: maximum train length; Black digit: standard train length) (source: ADIF)

Figure 6: Mediterranean Corridor. General scheme of the existing freight terminals (source: Mediterranean Corridor)

2.2 CONSIDERATIONS ON ROLLING STOCK

The trains analysed in DYNAFREIGHT case study were identified according to priority aspects in the Spanish network as well as taking into account the main characteristic of the rolling stock circulating in ADIF network.

Three (3) types of long freight trains have been considered based on the type of goods transported in the Spanish network in the most recent years (TRa, TRb and TRc). Table 3shows the evolution of freight traffic by commodity. As can be seen, the main goods transported are: Steel product (TRa), Multiproduct (containers) (TRb) and Cars (TRc).

Producto transportado	Año																			
	2007		2008		2009		2010		2011		2012		2013		2014		2015		2016	
Concepto	Toneladas netas	Toneladas-kilómetro netas	Toneladas netas	Toneladas-kilómetro netas	Toneladas netas	Toneladas-kilómetro netas	Toneladas netas	Toneladas-kilómetro netas	Toneladas netas	Toneladas-kilómetro netas	Toneladas netas	Toneladas-kilómetro netas	Toneladas netas	Toneladas-kilómetro netas	Toneladas netas	Toneladas-kilómetro netas	Toneladas netas	Toneladas-kilómetro netas	Toneladas netas	Toneladas-kilómetro netas
Unidad	*Miles de toneladas netas*	*Millones de toneladas-kilómetro netas*	*Miles de toneladas netas*	*Millones de toneladas-kilómetro netas*	*Miles de toneladas netas*	*Millones de toneladas-kilómetro netas*	*Miles de toneladas netas*	*Millones de toneladas-kilómetro netas*	*Miles de toneladas netas*	*Millones de toneladas-kilómetro netas*	*Miles de toneladas netas*	*Millones de toneladas-kilómetro netas*	*Miles de toneladas netas*	*Millones de toneladas-kilómetro netas*	*Miles de toneladas netas*	*Millones de toneladas-kilómetro netas*	*Miles de toneladas netas*	*Millones de toneladas-kilómetro netas*	*Miles de toneladas netas*	*Millones de toneladas-kilómetro netas*
Siderúrgicos	5.291,14	2.556,84	5.329,54	2.470,47	3.226,46	1.605,06	4.062,20	2.071,65	4.099,04	2.091,21	3.281,28	1.722,97	3.873,43	2.064,86	3.929,31	2.236,18	4.236,10	2.320,10	4.194,58	2.345,80
Graneles	13.009,97	1.992,90	11.071,25	1.790,49	8.692,19	1.175,24	6.031,14	975,75	7.087,39	1.007,24	7.985,12	993,91	6.819,05	837,87	6.904,03	1.091,17	7.789,80	923,32	6.311,73	870,14
Multiproducto	3.361,71	1.526,77	3.175,25	1.461,37	2.767,50	1.210,23	2.964,43	1.313,84	3.615,04	1.482,35	3.717,44	1.669,95	3.779,84	1.433,41	4.004,65	1.617,93	5.153,24	1.979,23	4.723,30	1.968,24
Automóvil	841,00	484,00	670,22	352,62	507,39	236,49	607,98	268,98	629,31	267,53	553,70	201,06	656,22	249,41	746,76	299,22	899,44	390,47	817,17	376,27
Resto	5,30	2,00	21,08	8,54	3,51	1,15	2,43	1,00	2,04	0,90	202,75	52,65	198,66	44,70	317,65	63,83	0,00	0,00	0,00	0,00
Vagón completo nacional	**22.509,12**	**6.562,51**	**20.267,34**	**6.083,50**	**15.197,05**	**4.228,17**	**13.668,19**	**4.631,23**	**15.432,83**	**4.849,22**	**15.740,30**	**4.640,55**	**15.327,19**	**4.630,25**	**15.902,40**	**5.308,32**	**18.078,57**	**5.613,12**	**16.046,78**	**5.560,44**
Vagón completo internacional	2.838,00	1.265,00	2.256,00	1.028,00	1.584,77	764,33	1.526,86	724,22	1.738,28	754,99	1.301,53	557,68	1.578,62	681,56	1.583,29	682,23	1.648,80	771,94	1.552,26	671,12
Subtotal vagón completo	**25.347,12**	**7.827,51**	**22.523,34**	**7.111,50**	**16.781,82**	**4.992,50**	**15.195,04**	**5.355,45**	**17.171,11**	**5.604,21**	**17.041,83**	**5.198,23**	**16.905,81**	**5.311,81**	**17.485,69**	**5.990,56**	**19.727,37**	**6.385,06**	**17.599,04**	**6.231,56**
Vagón intermodal nacional	4.350,00	2.865,50	4.480,45	3.067,68	3.914,16	2.274,58	4.953,41	2.682,99	5.416,68	3.179,84	5.801,72	3.165,93	5.646,87	3.093,21	5.513,16	2.779,72	6.556,93	3.673,64	7.073,19	3.711,24
Vagón intermodal internacional	1.575,00	519,00	1.443,00	484,00	1.227,62	447,26	1.289,95	540,47	1.555,84	808,31	1.561,96	1.024,98	1.768,00	960,50	1.900,37	592,45	2.165,87	752,90	1.946,10	701,03
Subtotal vagón intermodal	**5.925,00**	**3.384,50**	**5.923,45**	**3.551,68**	**5.141,78**	**2.721,84**	**6.243,36**	**3.223,46**	**6.972,52**	**3.988,15**	**7.363,68**	**4.190,91**	**7.414,86**	**4.053,72**	**7.413,53**	**3.372,17**	**8.722,80**	**4.426,54**	**9.019,29**	**4.412,27**
Sin clasificar															2.492,91	940,00				
Total	31.272,12	11.212,01	28.446,79	10.663,18	21.923,59	7.714,34	21.438,40	8.578,91	24.143,63	9.592,37	24.405,51	9.389,14	24.320,67	9.365,53	27.392,13	10.302,73	28.450,17	10.811,61	26.618,33	10.643,84
Total nacional	**26.859,12**	**9.428,01**	**24.747,79**	**9.151,18**	**19.111,21**	**6.502,75**	**18.621,60**	**7.314,22**	**20.849,51**	**8.029,07**	**21.542,01**	**7.806,48**	**20.974,05**	**7.723,46**	**21.415,55**	**8.088,04**	**24.635,50**	**9.286,76**	**23.119,97**	**9.271,69**
Total internacional	**4.413,00**	**1.784,00**	**3.699,00**	**1.512,00**	**2.812,39**	**1.211,59**	**2.816,80**	**1.264,69**	**3.294,12**	**1.563,30**	**2.863,49**	**1.582,66**	**3.346,62**	**1.642,07**	**3.483,66**	**1.274,68**	**3.814,67**	**1.524,84**	**3.498,36**	**1.372,15**

Table 3 – Distribution of freight traffic in Spain by commodity (source: ADIF)

The Multiproduct and the Cars transport have a strategic importance in the domestic and international transport (with France and then with Europe). The Steel product is strategic for the domestic market too. In the case of car transport, Renault, which runs several factories near Atlantic Corridor lines, demands several trains to Paris. Currently these trains have an average length of about 700 m.

Considering that the type of locomotive and wagons are very diverse, Table 4 summarizes the type of rolling stock used as a standard for the three traffic segments surveyed, according to Renfe internal knowledge. Figures 7 to 10 show some images and plans of such rolling stock.

Train	Rolling Stock							
	Loco				Wagon			
	Type	Model	Traction	Power (kW)	Type	Weight (t)	Cargo (t)	Length (m)
TRa	Bo´Bo´	TRAXX Renfe S/253	Electric	5.400	Shimms JJ5	21,00	60,00	19,90
TRb	Bo´Bo´	TRAXX Renfe S/253	Electric	5.400	Sgs MMC	24,00	56,30	12,04
TRc	Bo´Bo´	TRAXX Renfe S/253	Electric	5.400	Laaers MA7	38,00	22,00	31,00

Table 4 – Rolling Stock used in Dynafreight Project (source: ADIF and RENFE)

Figure 7: Loco TRAXX Renfe S/253 in Spanish Atlantic Corridor (source: ADIF/Renfe)

Figure 8: Wagon Shimms JJ5(Steel product) (source: ADIF)

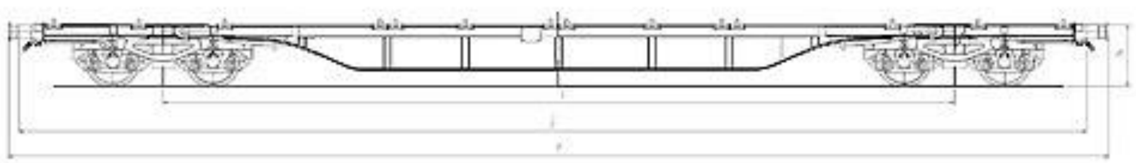


Figure 9: Wagon Sgs MMC(Containers) (source: ADIF)

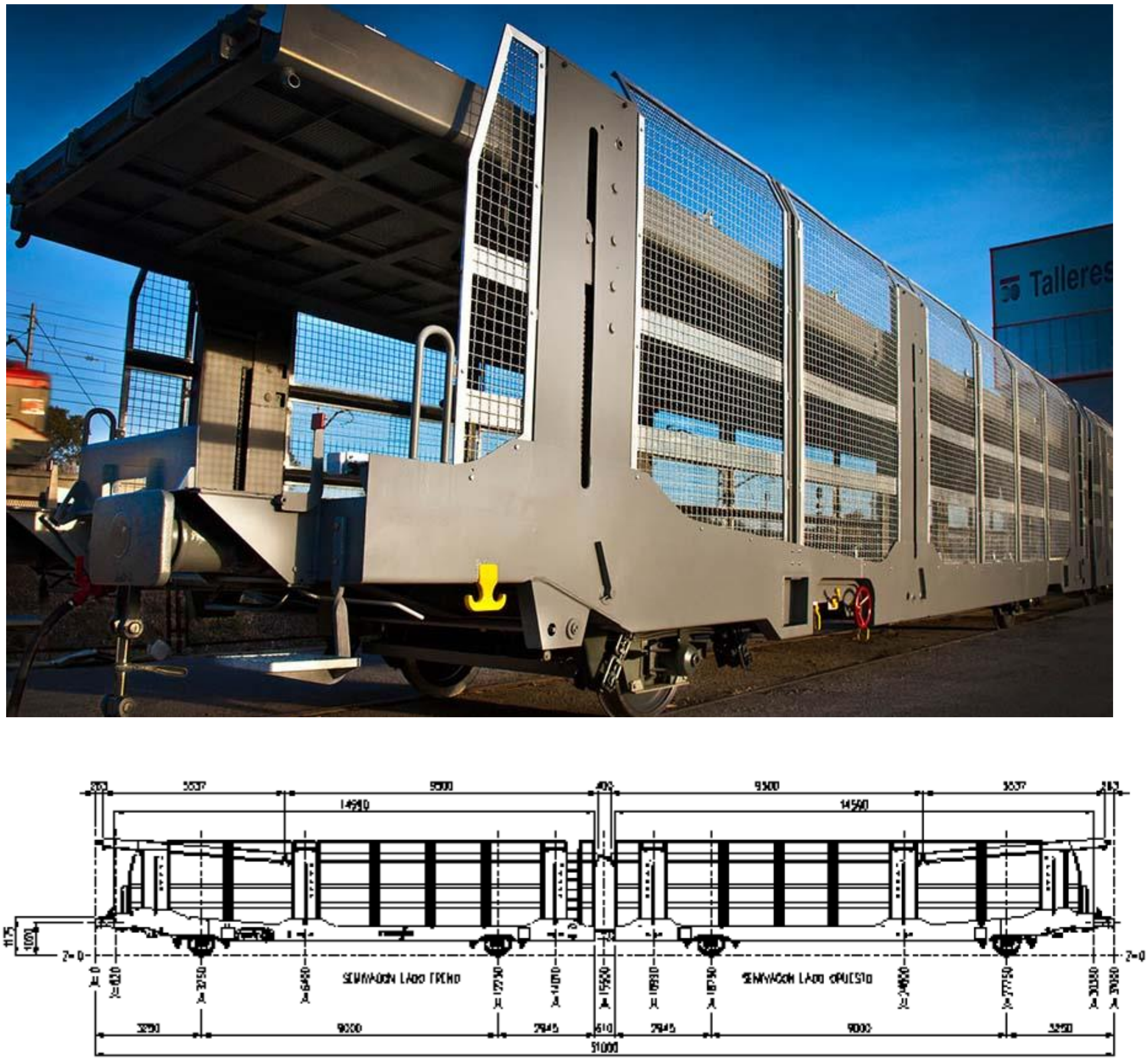


Figure 10: WagonLaaersMA7 (Cars) (source: ADIF/Talleres Alegria)

2.3 Main restrictions

The train length on Spanish segments of Atlantic and Mediterranean Corridors is limited due to the following main reasons:

- National regulations
- Gradients on the line sections
- Tracklength limitations combined with operational guidelines of the IM.

Generally, national regulations of all countries allow trains long up to 740 m. In Spain, national regulation limits trains to 750 m and to 2,500 t maximum train weight. The maximum speed for freight trains is 100 km/h.
It has been considered that in no case the maximum weight value (2,500 t) currently regulated by national regulations should be exceeded. In this way it is intended that the results of the present analysis can be realistic, only considering that limitations on train length are waived.
In tables 5 to 7 a simple analysis has been carried out characterized by the following aspects and conclusions:

- For each type of train, the weight is calculated according to the number of wagons. In turn, for each type of train, three (3) load configurations are considered: fully loaded (TR*x* (100)), half loaded (TR*x* (50)) and unloaded train (TR*x* (0)).
- For each assumption, the cells colored in "green" indicate a theoretical situation allowed (not exceeding 2.500 t).
- In the case of the TRa train, it is not possible to compose a train of 1.500 m. The maximum lengths obtained as a function of the load are 373 m, 578 m and 1.264 m (total load, partial or no load respectively).
- In the case of the TRb train, the maximum lengths obtained as a function of the load are 597 m, 975 m and 1.493 m (total, partial or no load, respectively).
- In the case of the TRc train, the maximum lengths obtained as a function of the load are 1.271 m and 1.488 m (total and partial/no load, respectively).

Therefore the only train products suitable to apply the longer train concept are the container and car transport trains (TRb and TRc). In principle, the composition of long trains for the transport of Steel products would be discarded because the current regulations would not allow it, unless wagons used for steel transport are empty.

Nº wagons	Length (m)	TRa (100) Weight (t)	TRa (50) Weight (t)	TRa (0) Weight (t)
10	120	800	519	237
11	132	880	570	261
12	144	960	622	284
13	157	1.040	674	308
14	169	1.120	726	332
15	181	1.200	778	356
16	193	1.280	830	379
17	205	1.360	881	403
18	217	1.440	933	427
19	229	1.520	985	450
20	241	1.600	1.037	474
21	253	1.680	1.089	498
22	265	1.760	1.141	521
23	277	1.840	1.193	545
24	289	1.920	1.244	569
25	301	2.000	1.296	593
26	313	2.080	1.348	616
27	325	2.160	1.400	640
28	337	2.240	1.452	664
29	349	2.320	1.504	687
30	361	2.400	1.556	711
31	373	2.480	1.607	735
32	385	2.560	1.659	758
33	397	2.640	1.711	782
34	409	2.720	1.763	806
35	421	2.800	1.815	830
36	433	2.880	1.867	853
37	445	2.960	1.918	877
38	458	3.040	1.970	901
39	470	3.120	2.022	924
40	482	3.200	2.074	948
41	494	3.280	2.126	972
42	506	3.360	2.178	995
43	518	3.440	2.230	1.019
44	530	3.520	2.281	1.043
45	542	3.600	2.333	1.067
46	554	3.680	2.385	1.090
47	566	3.760	2.437	1.114
48	578	3.840	2.489	1.138
49	590	3.920	2.541	1.161
50	602	4.000	2.593	1.185
51	614	4.080	2.644	1.209
52	626	4.160	2.696	1.232
53	638	4.240	2.748	1.256
54	650	4.320	2.800	1.280
55	662	4.400	2.852	1.304
56	674	4.480	2.904	1.327
57	686	4.560	2.955	1.351
58	698	4.640	3.007	1.375
59	710	4.720	3.059	1.398
60	722	4.800	3.111	1.422
61	734	4.880	3.163	1.446
62	746	4.960	3.215	1.469
63	759	5.040	3.267	1.493
64	771	5.120	3.318	1.517
65	783	5.200	3.370	1.541
66	795	5.280	3.422	1.564
67	807	5.360	3.474	1.588
68	819	5.440	3.526	1.612
69	831	5.520	3.578	1.635
70	843	5.600	3.630	1.659
71	855	5.680	3.681	1.683
72	867	5.760	3.733	1.706
73	879	5.840	3.785	1.730
74	891	5.920	3.837	1.754
75	903	6.000	3.889	1.778
76	915	6.080	3.941	1.801
77	927	6.160	3.992	1.825
78	939	6.240	4.044	1.849
79	951	6.320	4.096	1.872
80	963	6.400	4.148	1.896
81	975	6.480	4.200	1.920
82	987	6.560	4.252	1.943
83	999	6.640	4.304	1.967
84	1.011	6.720	4.355	1.991
85	1.023	6.800	4.407	2.015
86	1.035	6.880	4.459	2.038
87	1.047	6.960	4.511	2.062
88	1.060	7.040	4.563	2.086
89	1.072	7.120	4.615	2.109
90	1.084	7.200	4.667	2.133
91	1.096	7.280	4.718	2.157
92	1.108	7.360	4.770	2.180
93	1.120	7.440	4.822	2.204
94	1.132	7.520	4.874	2.228
95	1.144	7.600	4.926	2.252
96	1.156	7.680	4.978	2.275
97	1.168	7.760	5.029	2.299
98	1.180	7.840	5.081	2.323
99	1.192	7.920	5.133	2.346
100	1.204	8.000	5.185	2.370
101	1.216	8.080	5.237	2.394
102	1.228	8.160	5.289	2.417
103	1.240	8.240	5.341	2.441
104	1.252	8.320	5.392	2.465
105	1.264	8.400	5.444	2.489
106	1.276	8.480	5.496	2.512
107	1.288	8.560	5.548	2.536
108	1.300	8.640	5.600	2.560
109	1.312	8.720	5.652	2.583
110	1.324	8.800	5.704	2.607
111	1.336	8.880	5.755	2.631
112	1.348	8.960	5.807	2.654
113	1.361	9.040	5.859	2.678
114	1.373	9.120	5.911	2.702
115	1.385	9.200	5.963	2.726
116	1.397	9.280	6.015	2.749
117	1.409	9.360	6.066	2.773
118	1.421	9.440	6.118	2.797
119	1.433	9.520	6.170	2.820
120	1.445	9.600	6.222	2.844
121	1.457	9.680	6.274	2.868
122	1.469	9.760	6.326	2.891
123	1.481	9.840	6.378	2.915
124	1.493	9.920	6.429	2.939
125	1.505			

Table 5 – Analysis with TRa (source: ADIF)

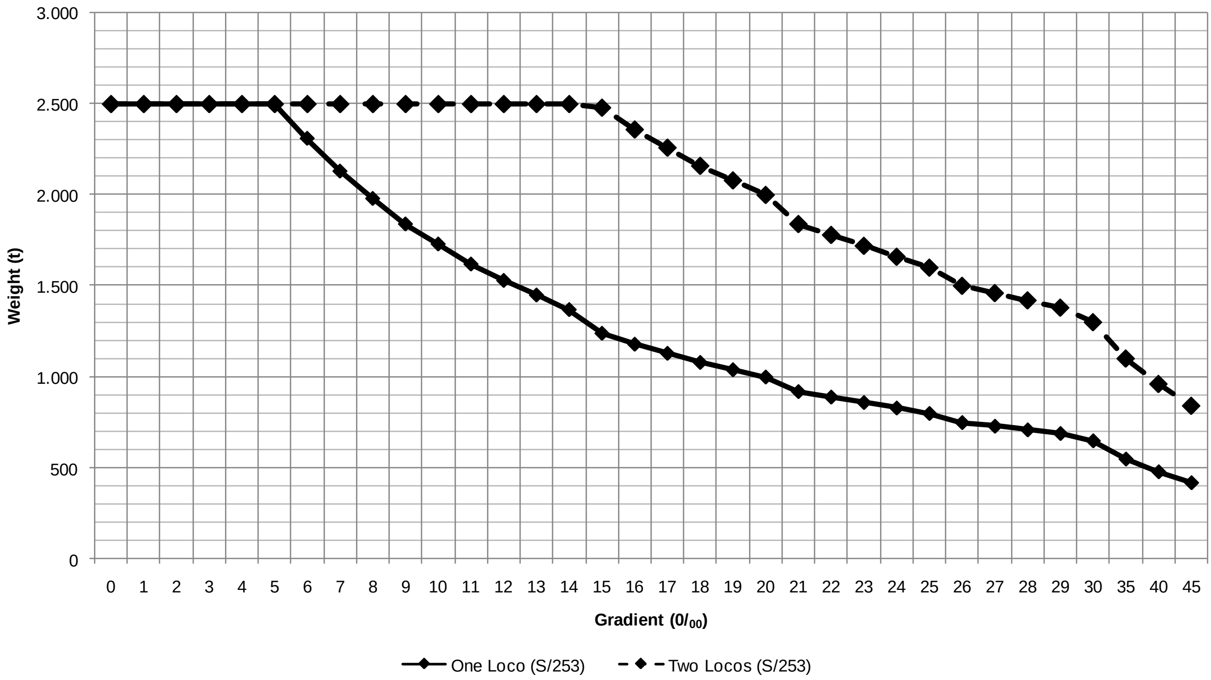
Nº wagons	Length (m)	TRb (100) Weight (t)	TRb (50) Weight (t)	TRb (0) Weight (t)
10	199	810	510	210
11	219	891	561	231
12	239	972	612	252
13	259	1.053	663	273
14	279	1.134	714	294
15	299	1.215	765	315
16	318	1.296	816	336
17	338	1.377	867	357
18	358	1.458	918	378
19	378	1.539	969	399
20	398	1.620	1.020	420
21	418	1.701	1.071	441
22	438	1.782	1.122	462
23	458	1.863	1.173	483
24	478	1.944	1.224	504
25	498	2.025	1.275	525
26	517	2.106	1.326	546
27	537	2.187	1.377	567
28	557	2.268	1.428	588
29	577	2.349	1.479	609
30	597	2.430	1.530	630
31	617	2.511	1.581	651
32	637	2.592	1.632	672
33	657	2.673	1.683	693
34	677	2.754	1.734	714
35	697	2.835	1.785	735
36	716	2.916	1.836	756
37	736	2.997	1.887	777
38	756	3.078	1.938	798
39	776	3.159	1.989	819
40	796	3.240	2.040	840
41	816	3.321	2.091	861
42	836	3.402	2.142	882
43	856	3.483	2.193	903
44	876	3.564	2.244	924
45	896	3.645	2.295	945
46	915	3.726	2.346	966
47	935	3.807	2.397	987
48	955	3.888	2.448	1.008
49	975	3.969	2.499	1.029
50	995	4.050	2.550	1.050
51	1.015	4.131	2.601	1.071
52	1.035	4.212	2.652	1.092
53	1.055	4.293	2.703	1.113
54	1.075	4.374	2.754	1.134
55	1.095	4.455	2.805	1.155
56	1.114	4.536	2.856	1.176
57	1.134	4.617	2.907	1.197
58	1.154	4.698	2.958	1.218
59	1.174	4.779	3.009	1.239
60	1.194	4.860	3.060	1.260
61	1.214	4.941	3.111	1.281
62	1.234	5.022	3.162	1.302
63	1.254	5.103	3.213	1.323
64	1.274	5.184	3.264	1.344
65	1.294	5.265	3.315	1.365
66	1.313	5.346	3.366	1.386
67	1.333	5.427	3.417	1.407
68	1.353	5.508	3.468	1.428
69	1.373	5.589	3.519	1.449
70	1.393	5.670	3.570	1.470
71	1.413	5.751	3.621	1.491
72	1.433	5.832	3.672	1.512
73	1.453	5.913	3.723	1.533
74	1.473	5.994	3.774	1.554
75	1.493	6.075	3.825	1.575
76	1.512			

Table 6 – Analysis with TRb (source: ADIF)

Nº wagons	Length (m)	TRc (100) Weight (t)	TRc (50) Weight (t)	TRc (0) Weight (t)
10	310	600	490	380
11	341	660	539	418
12	372	720	588	456
13	403	780	637	494
14	434	840	686	532
15	465	900	735	570
16	496	960	784	608
17	527	1.020	833	646
18	558	1.080	882	684
19	589	1.140	931	722
20	620	1.200	980	760
21	651	1.260	1.029	798
22	682	1.320	1.078	836
23	713	1.380	1.127	874
24	744	1.440	1.176	912
25	775	1.500	1.225	950
26	806	1.560	1.274	988
27	837	1.620	1.323	1.026
28	868	1.680	1.372	1.064
29	899	1.740	1.421	1.102
30	930	1.800	1.470	1.140
31	961	1.860	1.519	1.178
32	992	1.920	1.568	1.216
33	1.023	1.980	1.617	1.254
34	1.054	2.040	1.666	1.292
35	1.085	2.100	1.715	1.330
36	1.116	2.160	1.764	1.368
37	1.147	2.220	1.813	1.406
38	1.178	2.280	1.862	1.444
39	1.209	2.340	1.911	1.482
40	1.240	2.400	1.960	1.520
41	1.271	2.460	2.009	1.558
42	1.302	2.520	2.058	1.596
43	1.333	2.580	2.107	1.634
44	1.364	2.640	2.156	1.672
45	1.395	2.700	2.205	1.710
46	1.426	2.760	2.254	1.748
47	1.457	2.820	2.303	1.786
48	1.488	2.880	2.352	1.824
49	1.519			

Table 7 – Analysis with TRc (source: ADIF)

There will be another important restriction regarding the load capacity of the locomotive used. Even being the locomotive with more power of the Spanish fleet, the locomotive S/253 has necessary traction restrictions depending on the existing slope of the line. The latter is evident from Figure11, where the maximum capacity based on the line gradient is showed: when a single loco is used, up to $6^{0}/_{00}$ maximum ramps, the capacity is maximum. As this value increases, the capacity decreases. The characteristics are also indicated considering the circulation of double-locotrains.



Gradient ($0/_{00}$)	Max. Weight (One Loco) (t)	Max. Weight (Two Locos) (t)
0	2.500	2.500
1	2.500	2.500
2	2.500	2.500
3	2.500	2.500
4	2.500	2.500
5	2.500	2.500
6	2.310	2.500
7	2.130	2.500
8	1.980	2.500
9	1.840	2.500
10	1.730	2.500
11	1.620	2.500
12	1.530	2.500
13	1.450	2.500
14	1.370	2.500
15	1.240	2.480
16	1.180	2.360
17	1.130	2.260
18	1.080	2.160
19	1.040	2.080
20	1.000	2.000
21	920	1.840
22	890	1.780
23	860	1.720
24	830	1.660
25	800	1.600
26	750	1.500
27	730	1.460
28	710	1.420
29	690	1.380
30	650	1.300
35	550	1.100
40	480	960
45	420	840

Figure 11: Loco TRAXX S/253 (restrictions with the ramps) (source: ADIF/Renfe)

According to the CER studies there are two different kinds of long trains:

- One or two locomotives with more wagons than standard. The first one consists in adding wagons within the traction capability of the locomotives. In this configuration, the train is heavier and less reactive, what can create adverse conditions in heavy traffic situations. Depending on the load of each wagon, the traction capability can be reached before the length limitation.

- Two locomotives connected over remote control. The second one consists in connecting two trains with one locomotive on the head of the train and one in the middle of the train. A remote control system between the first and the second locomotive is needed. The train reacts more or less like a single train, is better adapted to heavy traffic conditions, but the locomotive has to be upgraded with new equipment. Connecting two trains with one locomotive in the front and one in the middle over remote control is not regularly used yet and has to be studied.

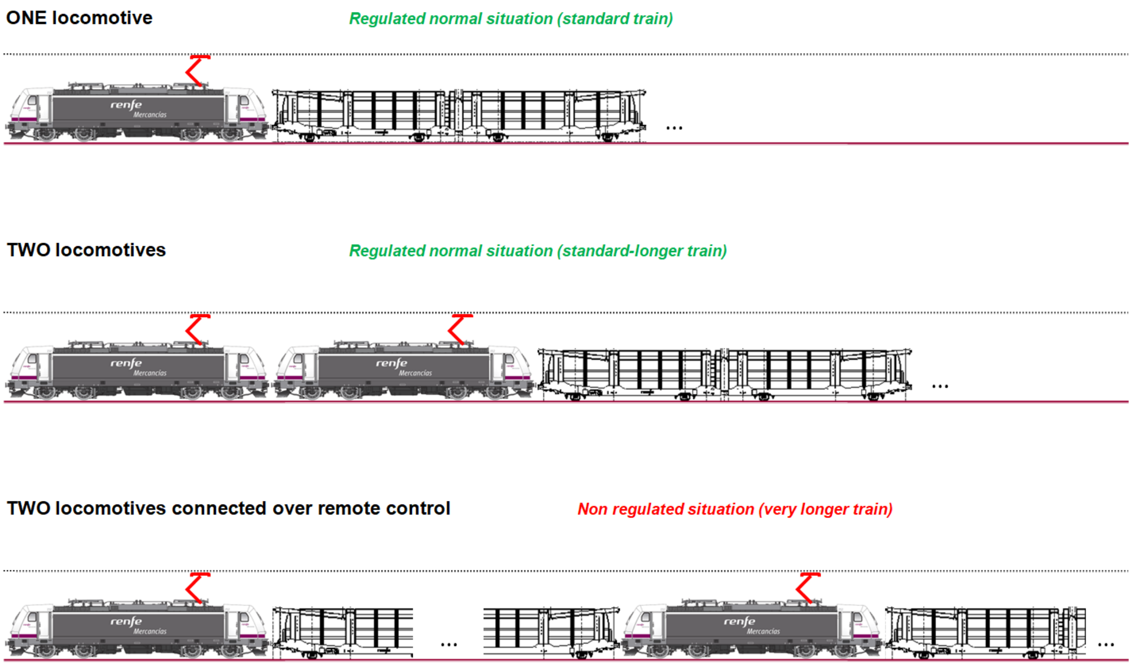


Figure 12: Possible configurations (source: ADIF)

3. OPERATIONAL ASPECTS ALONG THE RAILWAY LINES

The purpose of this section is to analyze the different components and operational aspects of the railway infrastructure, concluding in a general way which ones would be more affected by the circulation of long trains. Since the railway infrastructure is a multidisciplinary system, with many elements and techniques involved, an independent analysis of each one of them must be carried out.

In a first approximation, when it comes to relating the possible affections of freight trains (regardless of their length) with the infrastructure, the IM as usual analyzes issues such as the following:

- *Environment*. Unstable ground in cuttings, ground support and surrounding slopes (rock fall) creates a hazard. The weather conditions are important and in the case of freight trains can have a greater virulence (for example, cross wind on the goods of wagons).

- *Single track*. Where traffic in both directions shares a single track, this creates a capacity bottleneck. Also, the damage rate is higher so that maintenance is required more frequently, and there's no second track for the traffic to use during maintenance.

- *Old infrastructure*. Old infrastructure needs more frequent maintenance, and may lead to permanent speed restrictions. Examples: bridges; switches and crossings (S&C) on wooden sleepers.

- *Geometry*. In mountainous regions, and sometimes in urban environments, there may be severe constraints on the track geometry, leading to high gradients, tight curves, possibly even flat curves or curves with short transitions. This leads to permanent speed restrictions and an increased rate of track faults.

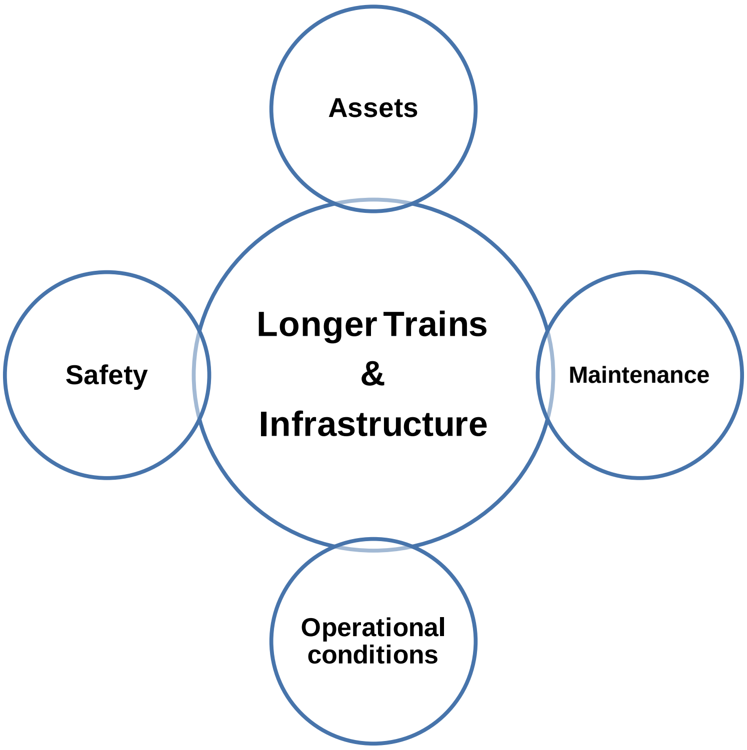
- *Track faults*. Wear, rolling contact fatigue, rail breaks, poor rail profile, misaligned welds, and poor technical condition of sleepers, fastenings, S&C and continuously welded rail.

- *Signalling*: Extending train length may affect the safety of certain critical points to be surveyed, inducing some small investments, including the control command system, which has to be adapted to the extra length.

Clearly there is a strong argument for upgrading old infrastructure and moving from single to double track; renewal costs will be high, but subsequent maintenance costs will be significantly

lower. The increase in system capacity and removal of speed restrictions are additional benefits.
Most importantly, track geometry and track components are a major source of faults, particularly in S&C, tight curves and steep gradients, and there is scope to improve the materials, designs and monitoring and inspection technologies.

Specifically, it is proposed to carry out a general analysis of the condition, considering four (4) main sections: Operational conditions; Assets (components of the infrastructure itself); Safety (impact); and Maintenance (impact).



3.1 Operational conditions

Table 9 shows a general summary of the condition produced in each of the different operating conditions identified. The comparison is made taking as reference the circulation of a freight train of up to 500 m in length. In this way, depending on whether it is an old line or a new line, it is indicated if the circulation of a train with more length than the reference train produces a greater (🡅), equal (=) or lower (🡇) impact.

It should be noted that the characteristics of both types of line are the following:

- Old Line. UIC 45/54 rail; Iberian gauge (1.668 mm); Double or Single track; DC power supply system; Periodic maintenance and inspection.

- New Line. UIC 60 rail; Standard gauge (1.435 mm); Double track; AC power supply system; Daily maintenance and inspection.

Operational conditions	Old Line	New Line	Notes
Capacity	↑	↑	(1)
Composing & Decomposing	↑	↑	(1) (2)
Train dynamic	↑	↑	(3)
Braking	↑	↑	
Train aerodynamic (Cross Wind)	↑	↑	
Train aerodynamic (Crossing)	=	=	
Gauge change	↑	No impact	(4)
Level crossing	=	No impact	Low impact

(1) Important impact of the sidings (length).

(2) Important impact in freight terminals.

(3) Consider also the gradients and curves.

(4) Specific situation on the border between Spain (ADIF) and France (SNCF). This situation occurs only in the conventional network (old lines) because the new lines already use standard gauge.

Table 8 – Operational conditions. General analysis (source: ADIF)

3.1.1 Capacity

As can be seen, the condition produced is greater in almost all of the situations contemplated. In this way the capacity is going to be negatively affected because a train of great length will usually have more problems to be turned aside. This is because, for example, in the case of the Spanish network, intermediate sidings do not usually have tracks with more than 600-700 m. For this reason, long trains must be operated considering that they cannot be parked to make way for other more priority trains (for example, passenger trains). If the line has only one track, the capacity problem will be even greater (Figure 13). From a blocking sections point of view (directly related to capacity), no major restrictions are identified.

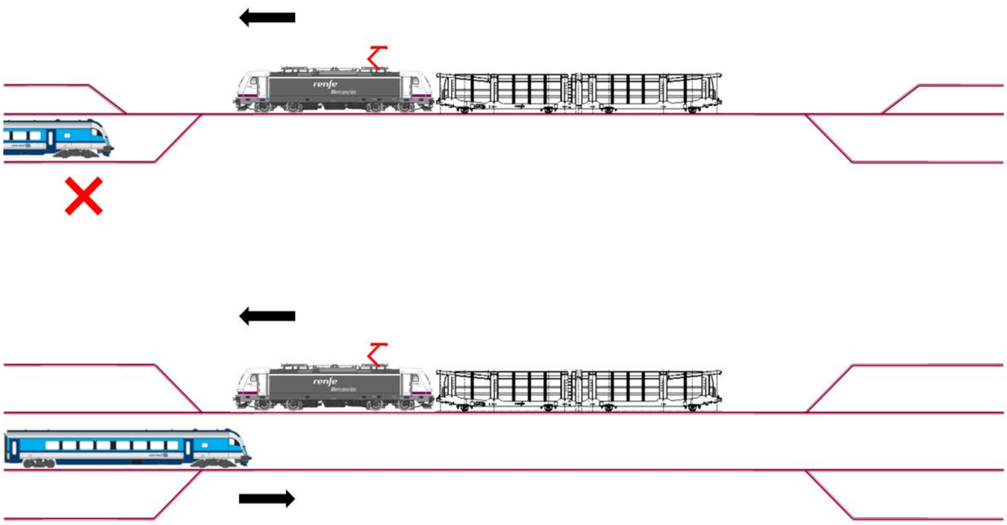


Figure 13: Problematic of the single track (source: ADIF)

3.1.2 Composing & Decomposing

Composing long trains (around 1.000 – 1.500 m) requires at least two locomotives because of train dynamics. This necessitates having enough adapted long tracks to compose the train and also to park it on sidings to let it be overtaken by other trains when required by the traffic management. This condition will be analyzed in a specific way in section 5 since it is directly related to the operation in freight terminals.

3.1.3 Train dynamic

According to CER document from a train dynamics point of view, when the main brake pipe is opened only at the front to brake a train down, there is a time offset between the start of braking of the first and the last wagon. While the first wagons already have full braking power, the last wagons are still pushing because the braking signal has not reached the end of the train. The last part of the train is running up onto the first already braking part and it comes to high compressive forces at the couplings between the wagons. If the longitudinal compressive forces become too strong, they may in combination with other factors (such as tight curves) lead to a derailment of the train. How long the time offset of the cylinder's response will be, particularly depends on the train length and the braking position.

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The reverse happens when the train starts to move. While the first wagons already run the last wagons still have braking power. This causes longitudinal tensile forces which could lead to a breaking of coupling. The distribution of locomotives in the train could be a solution but a limitation of the time lag between activation of the brakes on the master loco and the reaction on the slaves has to be ensured. The longer the trains are, the heavier they will be. Tensile forces within the train can get higher than the couplings can tolerate. Compressive and tensile forces have to be evaluated in order to avoid derailment (compressive forces) and coupling breaking (tensile forces).

Concerning *gradients*, the main problem is to check the capacity of the couplings to accommodate the traction forces in the most critical situations. The major problem may appear with longer trains not yet equipped with reinforced couplers or automatic couplers. In that case restarting a train on a steep gradient will imply issuing strict operational procedures to be applied, in order not to break the couplings.

Regarding the curves, as analyzed in the Deliverable 3.2 of the present project, its characteristics in the line layout are of crucial importance in the circulation of trains. Regardless of aspects associated with the behavior and evolution of the rail (this point will be discussed briefly in the next section), the large compressive forces may cause derailment when the train negotiates curves, in particular tight S-curves.

3.1.4 Braking

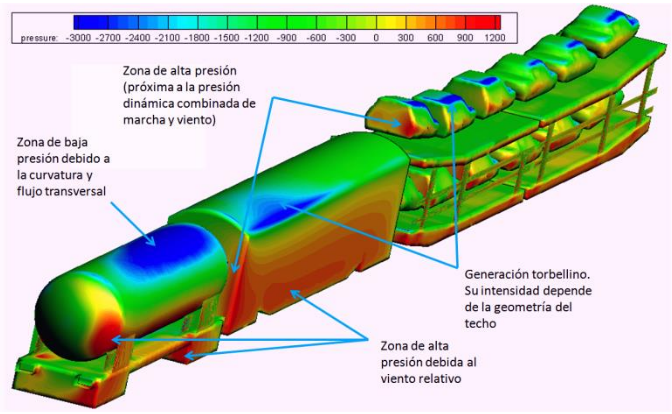
With regard to braking, the first check to be performed is to detect what the new stopping distance of the longer train is, as most of the safety installations are based on a maximum stopping distance to determine the signals and the preannouncement signals positioning. It might be necessary to move some of them. When a train is stopped by the signalling system it is necessary to check if, at the releasing of the brakes, the elasticity of the couplings will not create risks at critical points as the tail of the train may move. Of course this elasticity is extremely low with automated couplers or with draw bars but quite significant with classical UIC couplers.

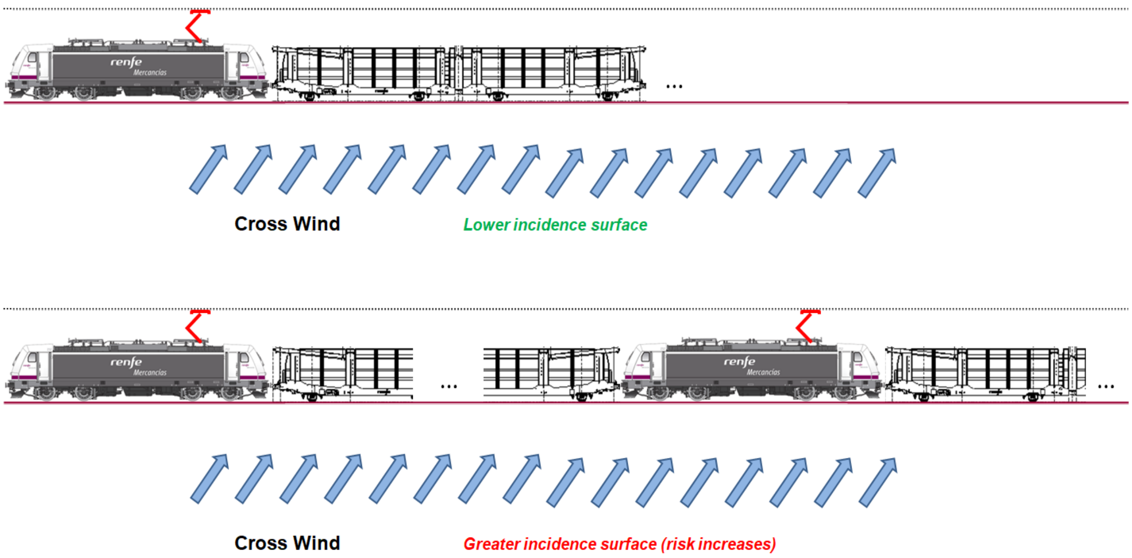
3.1.5 Train aerodynamic

As reflected in Table 9, the aerodynamic aspects will have greater affection for long trains, mainly due to the following factors:

- In the case of *cross wind* that can affect the railway line, a longer train will be more exposed to this wind, with greater risk in traffic (Figure 14).In any case, the same operative prescriptions will be considered as for standard trains (in the case of ADIF, with wind speeds above 90 km/h, speed reductions and additional checks on the fastening of the good must be established).

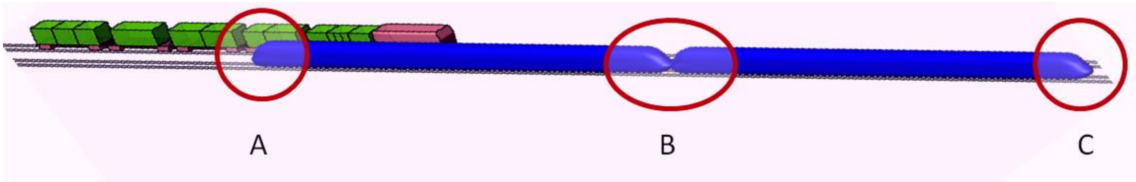
- In the case of *crossings with passenger trains*, and considering the physical process that occurs[5], if the length of the freight train is greater, again there will be greater risk because there will be more exposure of the freight train. In the case of the ADIF network, the mixed operation of passenger trains and freight trains allows, during the crossing, the passenger train to reach the maximum speed of 200 km/h. Regardless of the length of the freight train, no further problems are expected in this regard.





[5] It should be noted that in the crossing process, only a force is produced when the front or end of the passenger train passes in front of the freight train. The rest of the freight train has no condition (Figure 15).

Figure 14: General representation of the exposure of a freight train to the lateral wind.As expected, a standard train will have less surface area exposed to the wind, decreasing the incidence risk(source: ADIF)



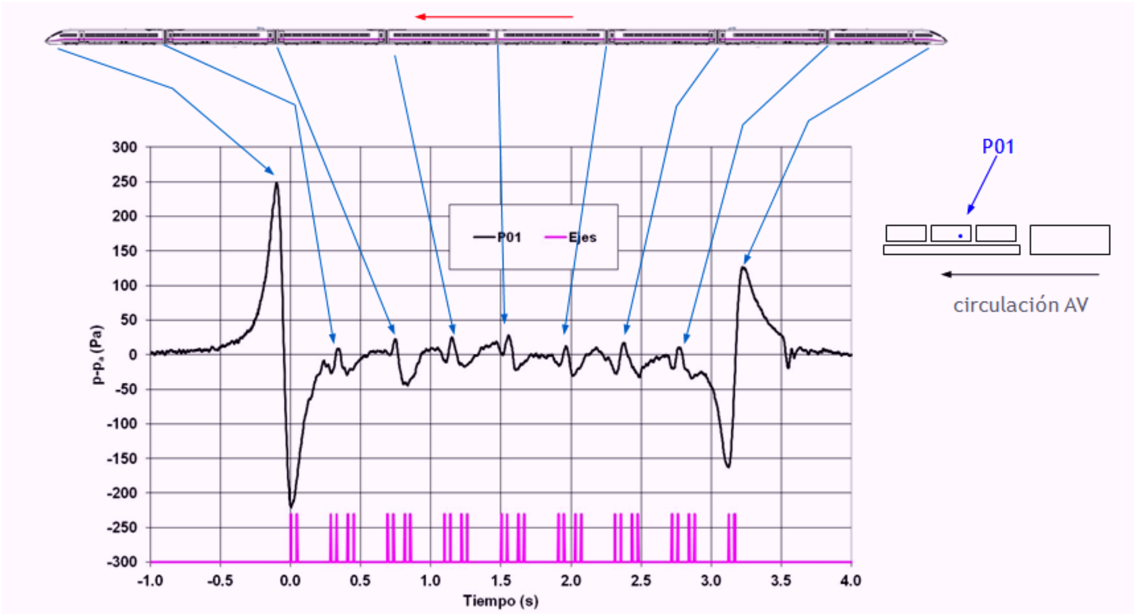


Figure 15: General representation of the crossing (freight train & passenger train). Typical pressure signal that occurs during the crossing (overpressure / depression due to the effect of the front and end of the passenger train) (source: ADIF)

3.1.6 Gauge change

The different gauge between the Spanish and French networks means that the freight trains must carry out conditioning actions for their gauge. Currently, the solution is to substitute each axle of the wagon with another of the new gauge (Figure 16). There are also operations to exchange the load between different trains (one per gauge).

A new option contemplated in recent decades has also been the development of variable-gauge axles specially designed for freight wagons (Figure 16).

Whatever the solution adopted in these borders, the objective is always the reduction of the costs and the time of the operations of exchange of these good between the two countries, eliminating the bottlenecks that are introduced by the fact of passing from a rail network to another.

However, regardless of the solution used, changing the gauge of the wagons of a long train (considering the case of two locomotives connected by remote control, at a certain distance) is very complicated, since it will be necessary to adapt these terminals to these new characteristics. This situation will be analyzed in section 5.

We can conclude here that the traffic of long trains between two networks of different gauge will not be in principle viable from an economic and operational point of view, having to condition the same gauge to the two lines.

Figure 16: Above: Axle exchange process in Spanish/French Border; Below: Variable gauge axle (source: ADIF/Transfesa)

3.1.7 Level crossing

In the analysis carried out, no problem was detected in the level crossings with roads. In no case could a level crossing be considered interrupted by the parking of a long train. In this sense, no additional problems have been identified with respect to a standard train.

3.2 Assets

With the same criteria above, Table 9 contains the general summary of the condition produced on each of the assets of the infrastructure.

3.2.1 Track

In principle, the elements of the track that are most affected by the circulation of long trains are the rails, both those of general section and those existing in the switches. In this sense it is logical to think that a continuous move of more axles would produce greater fatigue to this element, especially in the case of curves of small radius or in the case of a switch. Considering that the rolling of a long train does not have to produce greater incidences on the rail (especially considering that the maintenance of the wagons is correct), it has been considered that a possible rail break would have a greater impact on a long train.

In this way, if a break occurs when the longer train passes by its front, the consequences of having an accident may be greater than if it were a standard train (Figure 17). It should be noted that a large number of accidents occur precisely because of a broken rail.

Asset			Old Line	New Line	Notes
Track	Ballast	*Flying*	=	=	No impact
		Wear	=	=	Low impact
	Dynamic		=	=	Low impact (1)
	Geometry		↑	↑	
	Fasteners		=	=	No impact
	Joints	*Weld fatigue*	↑	↑	(2)
	Rail	*Fatigue*	↑	↑	(2)
		Wear	↑	↑	(2) (3)
		Noise/vibration	↑	↑	
	S&C	*Fatigue*	↑	↑	(2)
		Wear	↑	↑	(2) (4)
		Noise/vibration	↑	↑	
	Sleepers		=	=	
OCL	Dynamic		=	=	Low impact (1)
	Geometry		=	=	
	Contact Wire	Wear	↑	=	Low impact (5)
Power Supply System	Power		↑	↑	(6)
Signalling	ASFA (class B system)		↑	↑	(7)
	Block section	Axle counter	↑	↑	
		Circuit Track	=	=	Low impact
	ERTMS		=	=	Low impact (8)
	Interlocking		=	=	No impact
Structures	Bridges		=	=	Low impact
	Tunnels		=	=	Low impact
	Platform (stations)		=	=	No impact
Telecommunications	Fixed		=	=	No impact
	Radio system		↑	↑	(9)
Others	Hot Box Detector		↑	↑	
	Impact Detector		↑	↑	
	Change Gauge Facility		↑		No impact in new lines

(1) As the speed of circulation is low (up to 100 km / h) the dynamic effects have no incidence.
(2) Increased risk of a broken rail.
(3) Longer trains results in higher wear on curved lines.
(4) Longer trains results in higher wear on deviated track.
(5) Considering two locomotives capturing energy in DC, there will be a greater number of electric arcs.
(6) Greater power demanded.
(7) Class B system: Case of Spain (ASFA System)
(8) The system allows train lengths of up to 4.000 m.
(9) Communication between master and slave locomotive.

Table 9 – Assets. General analysis (source: ADIF)

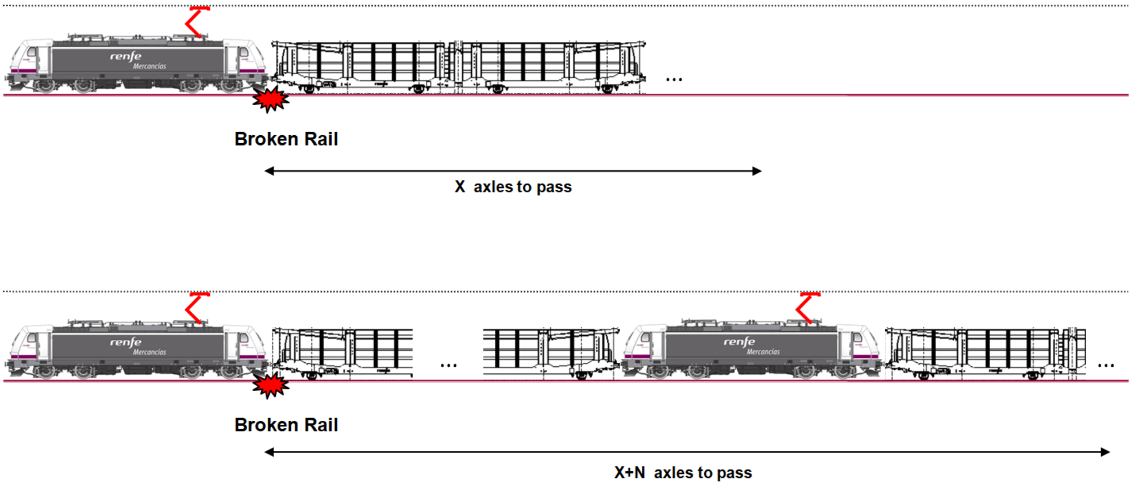


Figure 17: Problematic rail break with a long train (source: ADIF)

In fact to verify safety risks on the railway sector in the European Union, the European Railway Agency (ERA) has established safety Management System (SMS). In this SMS, all railway companies from the member states are encouraged to report irregularities and accidents. This facilitated statistical evaluation safety critical areas in the railway system. Important elements of the SMS are the precursors of accidents that are incidents where no damages have occurred, but under certain circumstances an accident could happen. Figure 18 shows the event chain of an accident occurrence and possibility of prevention by identifying the crucial point. In this chain the crucial point are the precursors. A precursor is any incident or group of incidents that mostly lead to an accident. When this incident (precursor) is detected, it is possible to avoid an accident by corrective action. If the precursor is not detected or ignored, there may be an accident.

The evaluation of the total precursors of accidents in the European railway track systems from 2010 to 2012 showed that by far the greatest rate of the incidents were caused by rail breaks followed by track buckles and wrong side – signalling failures (Figure 19).
Rail defects mainly include problems related to weld, internal defects, worn out rails, head checks, squats, spalling and shelling, surface cracks that are originated from rolling contact fatigue (RCF). Railway infrastructure owners endeavor to prevent these defects in order to reduce the probability of the occurrence of rail breaks and related accidents.

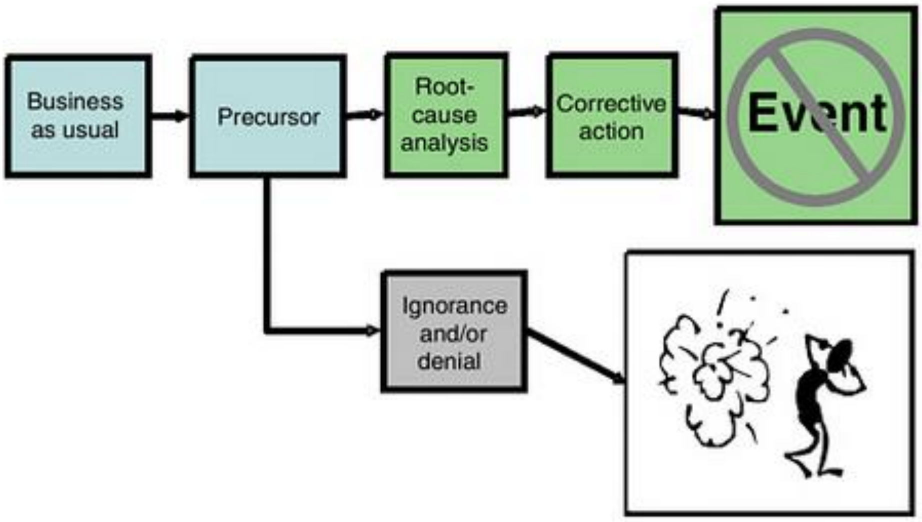


Figure 18: The arise of an accident and opportunities to avoid them (source: UIC)

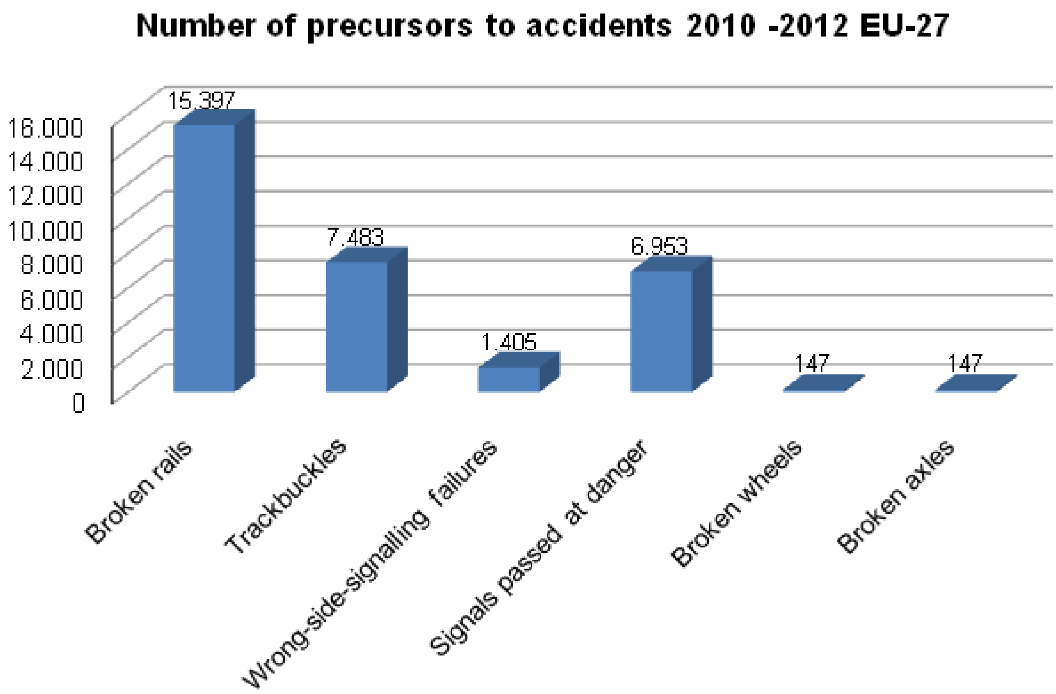
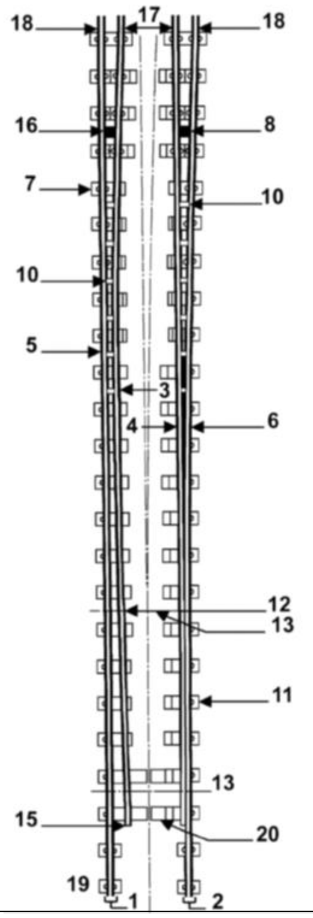
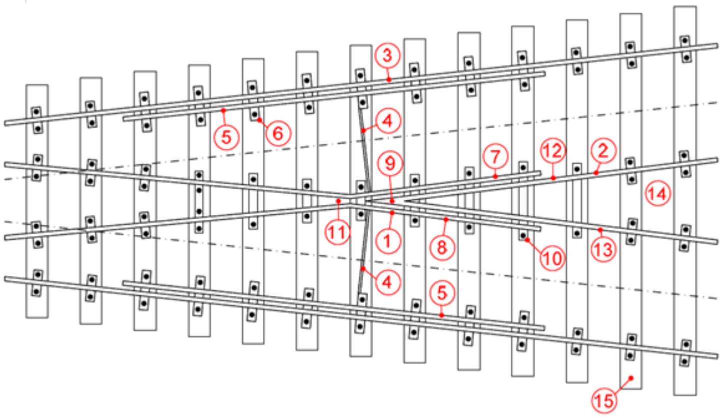


Figure 19: Precursors of accidents in the railway tracks systems of EU (source: UIC)

Switches and Crossing (S&C) are the most complicated and expensive parts of the railway infrastructure. They comprise three 'panels': The switch and crossing panels shown in Figure 20 are connected by a closure panel to form a set of points. The point motor/machine (actuator) moves the switch rails to select a path through the switch assembly; there may be several actuators for some types of lines with a long switch blade. The switch blade bends as a horizontal cantilever about the support at the heel.

The dynamic component of vertical wheel–rail contact forces, as induced by irregularities in track geometry (among other aspects due to S&C) and track stiffness, is an important source to ground-borne vibration and ground-borne noise. It can be affirmed that the longer the length of the train, the more vibratory activity will occur, generating greater fatigue to the different components of the S&C.

Contributions to railway induced ground-borne vibration are generated by both quasi-static and dynamic components of vehicle excitation. The quasi-static excitation is determined by the static component of the wheel loads, axle distances and vehicle speed, while the dynamic excitation is induced by wheel, rail and track irregularities as well as by irregularities in track support stiffness. For vehicle speeds well below the wave velocities in the soil, the quasi-static contribution dominates the track response whereas the free-field response is dominated by the dynamic contribution.

Switch	Crossing
	

Switch	Crossing
1. Left-hand half-set of switches 2. Right-hand half-set of switches 3. Left-hand curved switch rail 4. Right-hand straight switch rail 5. Left-hand straight stock rail 6. Right-hand curved stock rail 7. Heel baseplate 8. Block or heel block 9. Fishplate block 10. Stud/distance block 11. Slide baseplate 12. Stretcher bar bracket 13. Stretcher bar 14. Anti-creep device (not shown) 15. Switch toe/tip 16. Switch heel 17. Switch rail joint 18. Stock rail joint 19. Stock front joint 20. Soleplate	1. Common crossing 2. Crossing nose 3. Outside rail 4. Check rail strut 5. Check rail 6. Check rail support 7. Left hand wing (rail) 8. Right hand wing (rail) 9. Crossing vee 10. Crossing baseplate 11. Block 12. Point rail 13. Splice rail 14. Heel of crossing 15. Bearers

Figure 20: Parts of a switch (source: ADIF/Innotrack Project)

3.2.2 OCL

The system of transmission of electric power to the train (OCL or catenary) will not be affected by the circulation of long trains. However, it has been considered the case of circulating two locomotives, therefore with more than one pantograph rubbing the catenary. Considering the case of using a DC system, in which the electric arcs are more damaging (as there is greater intensity), it is possible that there is a greater affection on the contact wire of the catenary, as regards to greater wear. In addition the situation that occurs when there is a locomotive in the middle of the train (Figure 21) could produce that the pantograph of the second locomotive could have a worse energy catchment due to the mechanical oscillation produced by the first pantograph. In any case, these phenomena are initially theoretical and should be checked in future exploitation scenarios.

However this fact will be difficult to significantly affect the train. Currently this type of operation is accepted and it is normal to operate, for example, two trains of passengers coupled with the two pantographs distanced and in service. Normally, these are catenaries with counterweights that guarantee a constant mechanical tension and that improve the capture of energy in these situations.

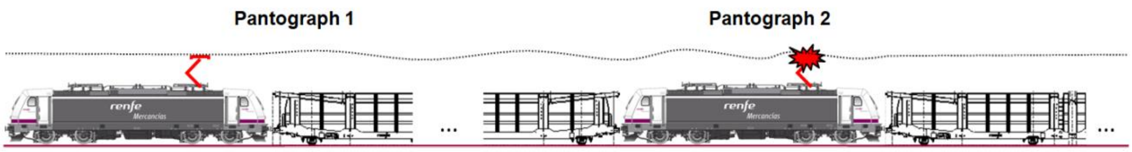


Figure 21: Problematic (possible) energy catchment with a long train (source: ADIF)

3.2.3 Power Supply System

The electric traction offers, against diesel traction, advantages such as the possibility of building vehicles of great power and speed, better efficiency from the point of view of energy consumption, and less environmental impact. Undoubtedly this traction is the traction of the present and the future in the railways, occupying the first place in the railway systems of the developed countries with the only important exception of the United States of America. In developing countries this type of traction is also the one that tends to be installed in all of its major railroads.

On the other hand electric traction requires large economic investments in its own facilities (electric power lines, substations and electric power transmission lines for train power), so it requires important economic studies. In any case in railway lines with high traffic speed and high traffic density, the use of electric traction is always necessary.

Railway Power Supply System can be distinguished between Direct Current (DC) and Alternating Current (AC) systems with different nominal voltages and power frequencies.

The use of Direct Current was motivated mainly by the ease of using the DC motor. On the other hand, the systems of alternating current allowed increasing the distances between the points of consumption of the railway (electric substations) to the being smaller the voltage drop to use greater electrical voltage.

The direct current is obtained in rectifying electric traction substations. These facilities are connected to a three-phase alternating current network and then perform two stages:

- Transformation process, through a transformer that reduces the voltage of the network to another working rectifier.

- Rectification process, by means of a diode rectifier (uncontrolled rectification) that conditions the voltage to the power supply of the train.

The output voltage of the rectifier (therefore the power supply to the train) has been very diverse, currently reaching up to 3.000 V nominal voltages. Other values currently standardized are 750 and 1.500 V.

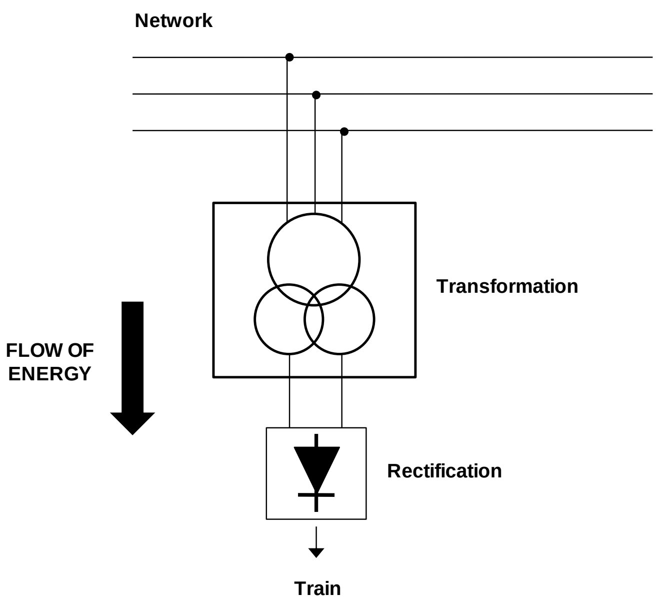


Figure 22: Stages of obtaining the direct current.
Rectification not controlled (source: ADIF)

The main advantage of the alternating current is that it allows the use of high voltage values, which allows a lower voltage drop. Although in the past there were railway electrifications with three-phase alternating current, currently only single-phase alternating current is used.

The single-phase alternating current is obtained in transformer electrical traction substations that are connected to a three-phase alternating current network to then perform a single transformation process. In this process, transformers that reduce the voltage of the network to the power supply of the train are used. These transformers are special because, precisely, the voltage of the secondary winding is single-phase and not three-phase, as in the case of transport and distribution systems.

As in DC systems, the output voltage of the transformer has also been very diverse, usually being 15.000 V (with a special frequency of 16,7 Hz) or 25.000 V of nominal voltage (often, in Europe, of 50 Hz).

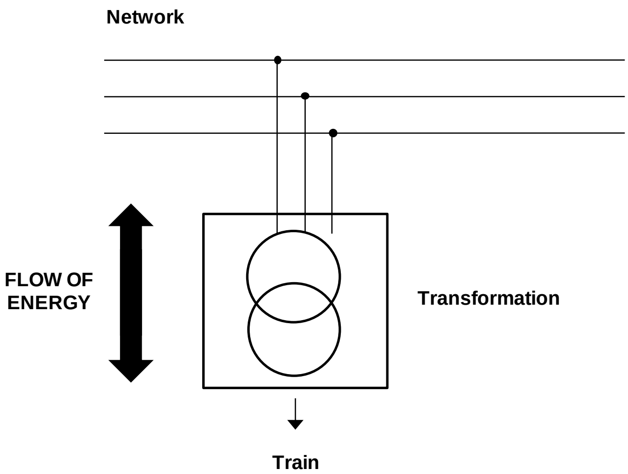


Figure 23: Stages of obtaining the alternating current. Transformation (source: ADIF)

Railway Power Supply System is a system in which it is possible to absorb or generate energy and distribute it to trains in an efficient and safe way. This system represents in itself a power electrical system with its own characteristics. In most cases the system is interconnected to the country's general electrical system (Figure 24). A common feature is that the electric energy, from its generation to its delivery to the trains, goes through different stages of adaptation and transformation. Considering the particular case of the Spanish network[6], it can be verified how the feeding of freight trains is done through rectifying substations that are connected to electrical distribution networks. There is only one case of power supply in the AC

[6]It would also be the case of railway networks in: France, Italy, Belgium, The Netherlands and Poland.

system in the high-speed section between Barcelona and the French border (Mediterranean Corridor); As discussed above, in this section the mixed operation of high-speed passenger trains and freight trains is possible.

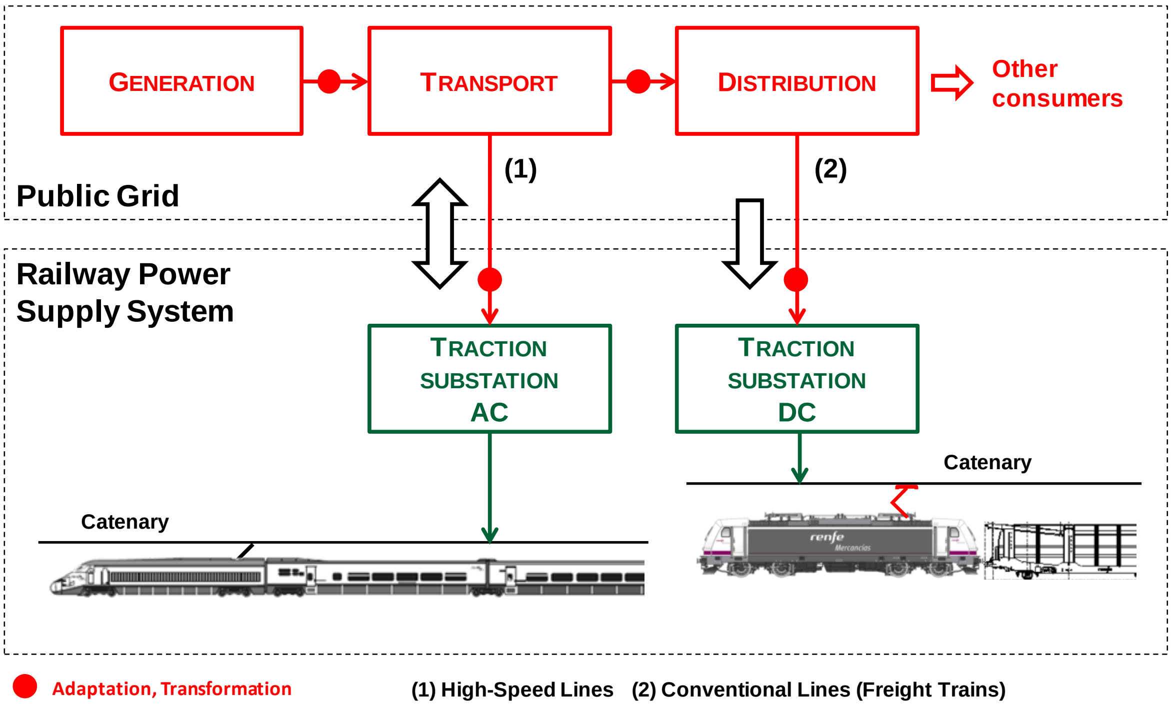


Figure 24: Basic diagram of a power electrical system (general and railway system). Diagram is represented by all the elements necessary for a train with electric traction to operate. In the most common case: 1) Generation sub-system (central of generation); 2) Sub-system Transport (transmission line); 3) Sub-system Distribution (distribution line); 4) High-Speed TPS (traction substation, single-phase electric transmission line to the train (catenary) and train); 5) DC Conventional TPS (traction substation, DC catenary and train) (Source: ADIF)

In **Appendix 3** you can consult the map of DC electrical substations in direct current of the Spanish network.

3.2.4 Signalling

The signalling system will be impacted by the train length in several circumstances according to the type of signalling system installed. As previously commented, the first check to be performed is to detect what the new stopping distance of the longer train is, as most of the safety installations are based on a maximum stopping distance to determine the signals and the preannouncement signals positioning. It might be necessary to move some of them.

The existing signalling and control command systems are very numerous but it is roughly possible to classify based on two fundamental criteria: If the transmission track/train is punctual or continuous; If the supervision of the movement of the train is punctual or continuous.

- Punctual systems: The transmission of information is received in specific points, usually through balyses installed on track. Supervision of train movement is only carried out in certain points on the line, usually in the vicinity of the light lateral signals. It consists in transferring to the driver automatisms that reproduce the indications of signals. These systems are very numerous in Europe and although they tend to have similar characteristics, they are all different.

- Punctual systems of continuous supervision: The transmission is punctual but nevertheless the supervision of the movement of the train is continuous, since data are transferred at the transmission points sufficient for such continuous supervision. In this group is the ERTMS Level 1 system

- Continuous systems: Both the transmission of information via track/train as the supervision of the movement of this is continuous. In this group are the ERTMS Level 2 and ERTMS Level 3 systems.

Usually the position of the train is only given by track circuits or axel counters system used for very low traffics and governing generally long segment of tracks. These elements are directly related to the blocking function of the system. Under normal conditions there can only be one train in each block section. This basic principle is the same throughout Europe, but systems vary in their technical layout and details.

Normally, after an analysis carried out in the case of the Spanish network, no great difficulties have been encountered. As long as the length of the train does not exceed the length of the block section, the parameters of the system will allow the circulation of this type of train. In any case, if the train must stop at a signal it is necessary to check if the extra length beyond the classical one does not occupy sensitive positions like a level crossing or like switches ensuring a track connection. It is also necessary to check the global elasticity of the train (according to the type of couplings) as the brakes release may induce a movement of the tail of the train linked to the buffers. This may mean some few tenths of meters.

With ERMS system the most important parameter to check is the acceptability of the train stopping distance by the euro-computer as this signalling system may allow a little shorter distance between the moving trains linked to the permanent radio connection to the control centre (this is referring to ERTMS Level2).In Spain, the ERTMS system has a maximum train length value of 4.000 m.

is important to note that the use of axle counters must be verified considering that these elements can be designed to work with a maximum number of axes detected.With exceeding the maximum countable vehicle axles (counter overflow), an incorrect track release has to be expected.

3.2.5 Structures

In principle, limitations associated with the circulation of long trains by bridges, tunnels or station areas have not been detected in Spanish networks. The increase in axle load of the wagons would have an impact to analyze in the case of bridges.

3.2.6 Telecommunications

No technical limitations regarding telecommunications systems have been detected

3.2.7 Others

The detectors used in the track for the supervision of different train parameters have been considered here. In the case of freight trains, in addition to measuring the temperature of the bearings (Hot Box detector), the vertical impact of the wheels is also measured (Impact Detector, Figure 25). Wheels of railway vehicles are subject to extreme stresses and strains, which inevitably lead to wear and tear. Flat patches as well as damage to the contact areas are typical indicators of wear and tear. The immediate result of such wear and tear is greater variation in the vertical forces between the wheel and the rail.

It is necessary to check that the detectors can absorb a much higher number of measurements to be transmitted to the control centre. It should be noted that in the case of the systems used by ADIF, it would be possible to send this information without problems.

Figure 25: Impact detector (source: ADIF)

3.3 IMPACT ON SAFETY

Since 2013, the railway sector has been affected by different European Directives that establish the need to apply a common safety method when a change in infrastructure or rolling stock is required. According to this change is *significant* or *not significant*, different actions must be carried out that can lead to a risk analysis of that change.

Commission Implementing Regulation (EU) 402/2013 (the Regulation on a common safety method (CSM) for risk evaluation and assessment [or “the CSM RA”]) is part of a wide-ranging programme of work by the ERA and the EC bring about a more open, competitive rail market while seeking to ensure that safety levels are maintained, and, if reasonably practicable, improved. In the past, safety requirements may have been used as a barrier to open competition across the EU. The intention of the CSM RA is to harmonise processes for risk evaluation and assessment and the evidence and documentation produced during the application of these processes. By applying a common process, it will be easier for an assessment undertaken in one EU Member State to be accepted in another with the minimum of further work. This is referred to as mutual recognition.

The CSM RA applies when any technical, operational or organisational change is being proposed to the railway system. A person making the change (known as ‘the proposer’) needs to firstly consider if a change has an impact on safety. If there is no impact on safety, the risk management process in the CSM RA need not be applied and the proposer must keep a record of how it arrived at its decision.

If the change has an impact on safety the proposer must decide on whether it is significant or not by using criteria in the CSM RA. If the change is significant the proposer must apply the risk management process. If the change is not significant, the proposer must keep a record of how it arrived at its decision. This process is summarised in Figure 26.

Technical changes are changes to a structural sub-system. Technical changes should also be reviewed to determine whether they introduce changes to the operation of the sub-system under consideration. Operational changes are changes to the operation of a structural sub-system; changes to the operation of the railway system; or changes to the operating rules of the railway system.

Table 10 shows the different criteria considered in the previous sections, having made an analysis of the impact that the CSM RA would have on each of them. In general terms, the operation of freight trains longer than 750 m would be a significant change with an impact on the safety of the infrastructure and the rolling stock. Analyzing each criterion separately, ADIF has concluded that around 34% of the criteria considered will be significant changes.

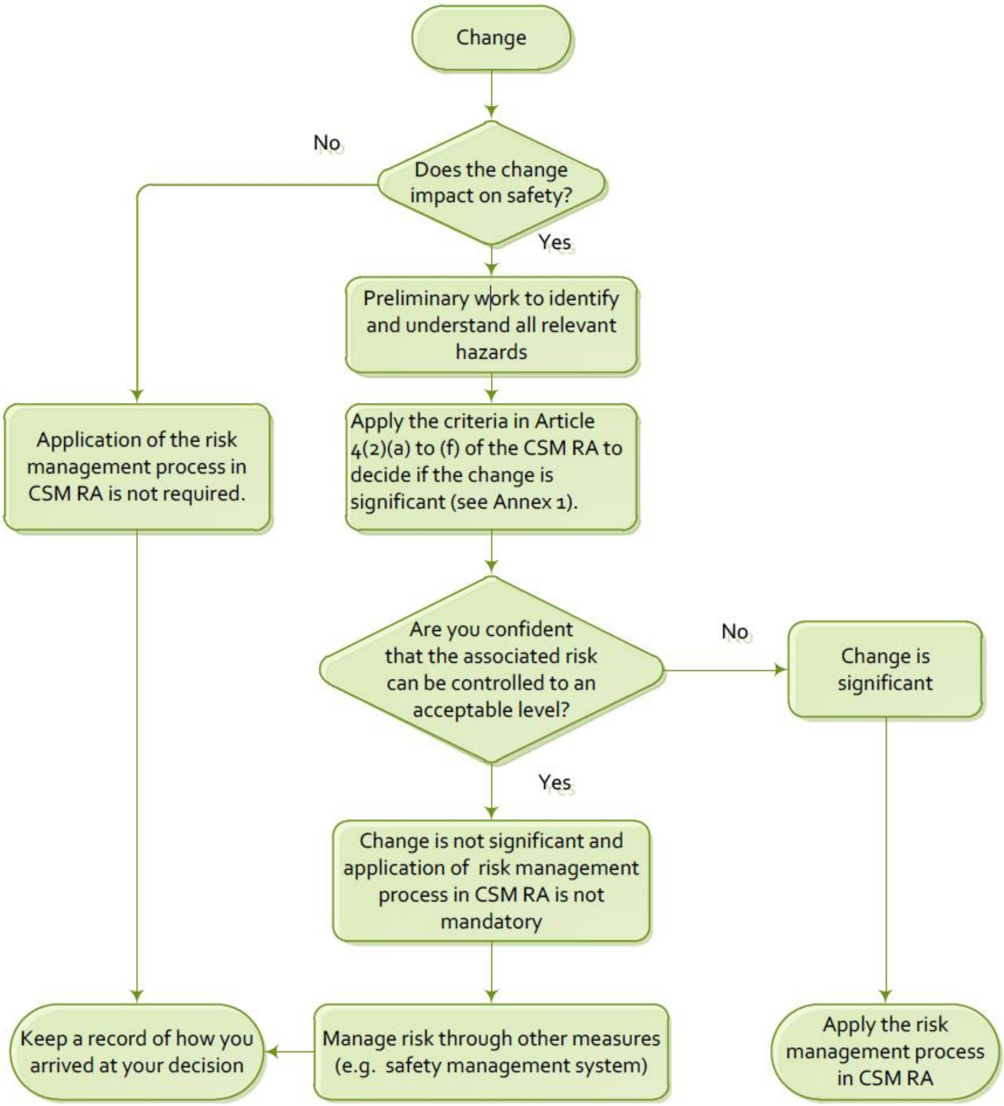


Figure 26: Applying the CSM RA for technical, operational or organisational change (source: ORR)

	Evaluation criteria	Previous impact on safety	Forecast significant change?
Operational conditions	Capacity	☑	☑
	Composing & Decomposing	☑	☑
	Train dynamic	☑	☑
	Braking	☑	☑
	Train aerodynamic (Cross Wind)	☑	
	Train aerodynamic (Crossing)		
	Gauge change	☑	☑
	Level crossing		
Assets	Track (Ballast)		
	Track (Dynamic)		
	Track (Geometry)	☑	
	Track (Fasteners)		
	Track (Joints)	☑	
	Track (Rail)	☑	
	Track (S&C)	☑	
	Track (Sleepers)		
	OCL (Dynamic)		
	OCL (Geometry)		
	OCL (Contac Wire)		
	PSS (Power)		
	Signalling (system class B)	☑	☑
	Signalling (ERTMS)	☑	☑
	Signalling (Block Section)	☑	☑
	Signalling (Interlocking)		
	Structures (Bridges)		
	Structures (Tunnels)		
	Structures (Platforms)		
	Telec. (Fixed)		
	Telec. (Radio system)	☑	☑

	Evaluation criteria	Previous impact on safety	Forecast significant change?
	Others (Hot Box Detector)	☑	☑
	Others (Impact Detector)	☑	☑
	Others (Change Gauge Facility)		

Table 10 – Impact on Safety. General analysis (source: ADIF)

3.4 Impact on Maintenance

The impact of the new freight trains on the maintenance of the infrastructure is a very interesting aspect to take into account. It should be noted that since there are no experiences with this type of traffic, only a series of theoretical estimates can be made according to the criteria analyzed above. This type of analysis would be similar to those already carried out on high-speed lines to analyze what is the impact on the maintenance of the infrastructure when the speed of trains is increased.

Again, and in order to have an overview, Table 11 analyzes the expected impact on the maintenance of the infrastructure. Unlike Table 10, the analysis focuses only on the assets of the infrastructure.

As has been mentioned in previous sections, it is foreseeable that the passage of longer freight trains will cause greater fatigue and wear on certain components of the infrastructure. That is why we must consider redefining, in each case, maintenance activities in order to offer operators a safe and optimal infrastructure. In general a well maintained track has fewer geometrical defects, and this limits instances of dynamic overloads and thus increases component lives.

As can be observed in the table, very few assets have been identified in which an impact of their life cycle is foreseen due to the circulation of long trains. Most of them are included in the track subsystem. Thus the geometry and the wear of its components will be the main identified condition. In the case of wear (joints, rails and S&C) it has been concluded that the current maintenance process has been altered, mainly by shortening the inspection times of these elements to prevent possible rail breaks. In the case of the catenary, a greater wear of the contact wire is also foreseen but it is not necessary to alter the current inspection process (it should be noted that unlike the track components, this element will not affect the safety).

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	Evaluation criteria	Previous impact on maintenance	Alteration of the current maintenance?
Assets	Track (Ballast)		
	Track (Dynamic)		
	Track (Geometry)	☑	
	Track (Fasteners)		
	Track (Joints)	☑	☑
	Track (Rail)	☑	☑
	Track (S&C)	☑	☑
	Track (Sleepers)		
	OCL (Dynamic)		
	OCL (Geometry)		
	OCL (Contac Wire)	☑	
	PSS (Power)		
	Signalling (system class B)		
	Signalling (ERTMS)		
	Signalling (Block Section)		
	Signalling (Interlocking)		
	Structures (Bridges)		
	Structures (Tunnels)		
	Structures (Platforms)		
	Telec. (Fixed)		
	Telec. (Radio system)		
	Others (Hot Box Detector)		
	Others (Impact Detector)		
	Others (Change Gauge Facility)	☑	☑

Table 11 – Impact on Maintenance. General analysis (source: ADIF)

There are two main auscultation techniques: Geometric auscultation methods and dynamic auscultation methods. Geometric auscultation methods are based on direct measurement of the track and catenary geometry. Dynamic auscultation methods are based on the measurement of accelerations in the interior of the vehicle or in a specific part thereof. This inspection would not in principle alter it in this case because the train speed will not be higher than 100 km/h.

Once the tracks have been auscultated, the quantification of the defects is obtained by the difference between the measured actual geometry and theoretical perfect track geometry. The intervention criteria (or the decision of performing maintenance work) mainly depend on three types of statistical quantifiers: the mean; the standard deviation and the extreme values. Both mean and standard deviation (of parameters such as alignment, longitudinal level, etc.) allow the assessment of the overall track quality. In contrast, the extreme values contribute to the detection of point defects. The current geometric inspection process will not be modified in principle because it meets all the guarantees necessary for the inspection.

Regarding the inspections carried out on the track, a general summary is given below:

- Track generally: obstructions of the line, including infringement of clearances; missing, inappropriate, defective or damaged components; condition of conductor rail equipment; permanent way materials interfering with signalling or other track mounted equipment; vegetation, particularly where this obstructs signals, sighting distances or positions of safety; buffer stops.

- Rails and rail joints: visible rail defects, including rolling contact fatigue and other cracks, breaks, rail head damage and significant corrosion; excessive sidewear; check rails, for security, wear and flange way obstruction; broken, cracked or defective fishplates; loose or missing fish bolts or multiple-groove locking pins; dipped joints; expansion gaps: joints in jointed track and adjustment switch settings in welded track; damaged end-posts and defective insulation at insulated rail joints, and lipping of rail ends; security of temporary rail clamping systems; loose or ineffective rail anchors; effectiveness of lubricators (is grease being applied correctly to the rails?); detached signalling or electrical bonds.

- Sleepers, bearers and fastenings: broken, cracked or ineffective, vertical or lateral movement of chairs or base plates; loose or missing fastenings, keys, pads or insulators; loose or damaged gauge tie bars.

- S&C: broken, cracked, defective or worn switch rails and crossings; obstructions in switches and flange ways; evidence of wheels striking the back of the open switch; longitudinal position of check rails, to confirm that crossing noses are covered; wide flange ways to, and security of, check rails; evidence of irregular running contact band on the switch, stock rails and crossing; wheel strikes at crossing noses; damaged or loose stretcher bars; loose or missing bolts or multiple groove locking pins or studs; security of points clipped out of use.

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- Track support: areas liable to subsidence or other earth movement, including by burrowing animals; collapsed catch pits; signs of ballast voiding, slurring or effects of inadequate drainage on ballast conditions; deficiencies in ballast provision or excessive ballast, track drainage (signs of flooding, damaged catchpit covers.) longitudinal rail-carrying bridge timbers and associated transoms, ties and packing.

The approach involves mainly reducing the frequency of rail inspection, using new inspection and control systems. Currently ADIF develops several annual campaigns to analyze the interior inspection of the lane using ultrasound technology. At this last moment a new system of its own to combine this inspection (internal) with a superficial inspection that can detect possible cracks. As will be discussed in the following section, also it is expected to use a system of continuous monitoring of the state of the rail to predict its possible breakage.

As can be seen in Table 11, the systems used to develop the gauge change operation for the wagons are also expected to have greater maintenance. It is an installation subjected to continuous wear so that the passage of a greater number of wagons will produce a greater degradation. It should be noted that ADIF is currently putting into operation a system in which the change in width is made under load (Figure 27). That is, the wagons automatically make the change of width with the wheels subject to 22,5 tons per axle.

Figure 27: Change gauge facility. System in tests (source: ADIF)

3.5 APPLICATION TO THE ATLANTIC CORRIDOR

Based on the information provided above this section will analyze the circulation of long trains in the section of line considered in the Atlantic Corridor (PS5, PS6 and PS7 sections). These sections of the Corridor run through the northern part of Spain, heading east towards the French border. According to the internal code of ADIF, it is Line 100. It is a conventional infrastructure, already with a certain age of the assets. It is expected that the future high-speed line to the Basque Country (from Madrid) will be put into service in the next few years, which means that it will suffer a significant reduction in traffic.

Figure 28: View of the PS6 section from the cockpit of a passenger train. You can see in a general way the characteristics of the infrastructur (source: ADIF)

Table 12 shows the main characteristics of the analysed route. Figures 29 to 32 show different schemes of the contemplated route. The situation of intermediate stations (sidings) has been outlined in yellow colour. Table 13 collects diverse information (length of the sidings, minimum curve radius, gradients and distribution of weekly traffic) distributed according to the kilometre of the section considered.

Aspect	Notes
Length	433 km
Track type	Double track (single track in some sections) 1.668 mm of gauge Ballast
Track geometry (see Table 13)	Straights Minimun radius curve: 285 m Gradient: ($^0/_{00}$): 8$^0/_{00}$ (average) – 18$^0/_{00}$ (maximum)
Sleeper type	Mono-block (possibility of equipping standard width without changing the sleeper) and Bi-block RS
Rail size	UIC 54
Track quality	Medium
OCL	Independent counterweight (contact wire/lift cable) Two contact wires
Power Supply System	3.000 V DC
Speed (freight trains)	100 km/h (maximum speed) 80 km/h (average)
Traffic (see Table 13)	Mainly regional passenger trains and freight trains. In section PS7 there are commuter services that significantly decrease the capacity of the line
Sidings (see Table 13)	There are 41 siding considering the extremes. The length of the tracks has an average of 575 m. In the **Appendix 4** the route scheme of all these sidings is collected
Signalling	ASFA (system class B) Block section: Track Circuit
Telecommunications (Radio System)	TREN-TIERRA (system class B)
Hot Box Detector	4
Level crossing	19
Impact Detector	2
Change Gauge Facilitie	1

Table 12 – Atlantic Corridor. PS5, PS6 and PS7 sections. Main features (source: ADIF)

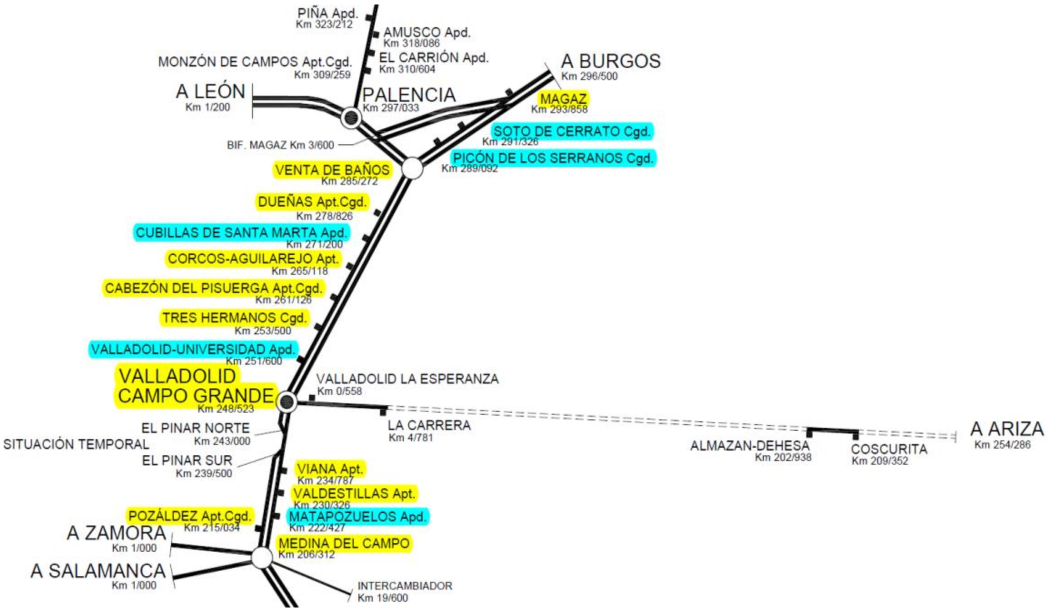

Figure 29: Atlantic Corridor (analysed route, part 1) (source: ADIF)

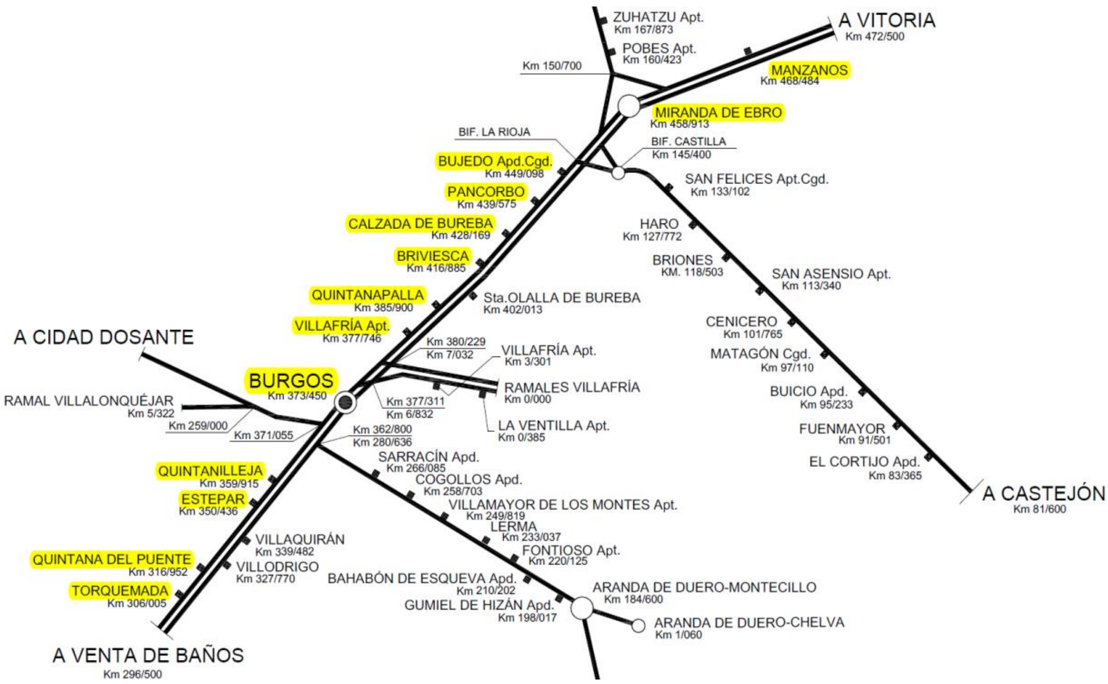

Figure 30: Atlantic Corridor (analysed route, part 2) (source: ADIF)

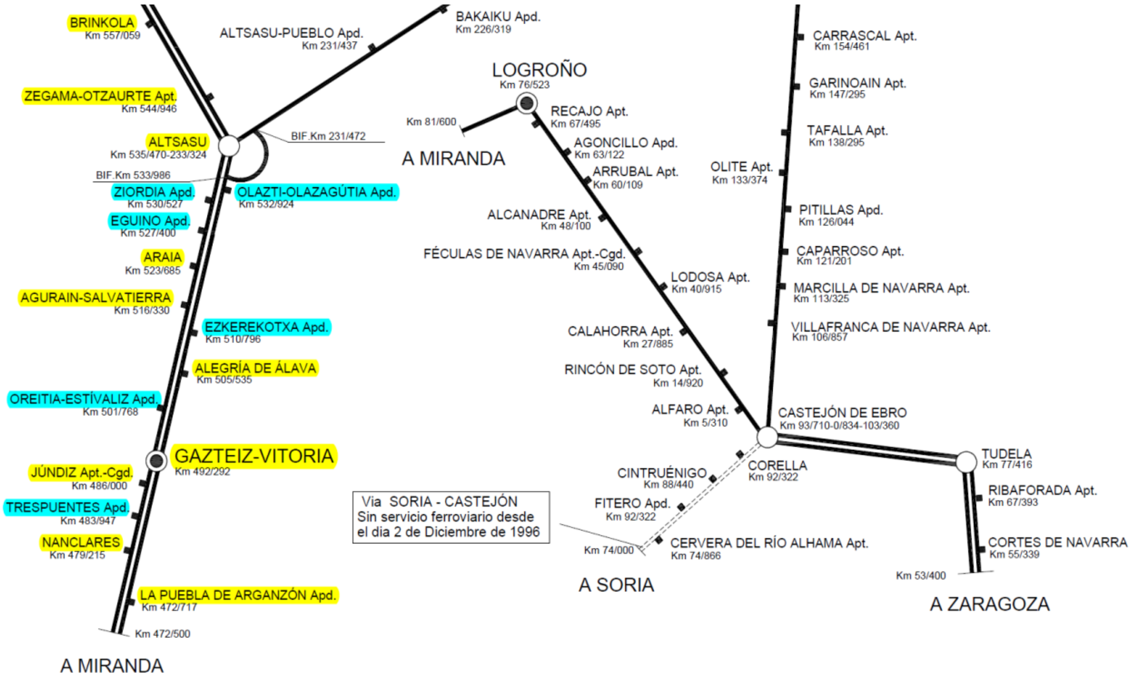

Figure 31: Atlantic Corridor (analysed route, part 3) (source: ADIF)

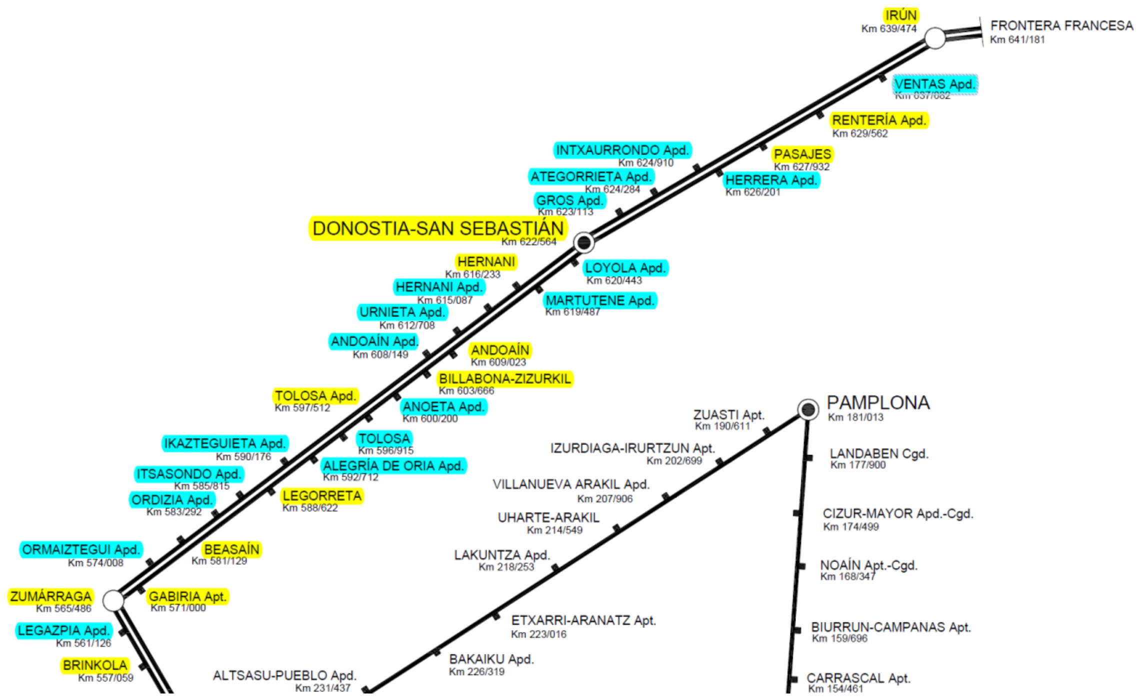

Figure 32: Atlantic Corridor (analysed route, part 3-4) (source: ADIF)

Section	No	Sidding	km	Max. Length → (m)	Max. Length ← (m)	Gradient → ($0/_{00}$)	Gradient ← ($0/_{00}$)	Radius (≤400 m) (m)	Notes	Number of trains (weekly average)	
										Total	Conmuter
PS5	1	*Medina del Campo*	206	630	630	10	0	303		419	0
	2	*Pozaldez*	215	568	568	0	9				
	3	*Valdestillas*	230	460	460						
	4	*Viana*	235	589	897	11					
	5	*Valladolid*	249	535	535	5	1		Single track		
	6	*Tres Hermanos*	253	559	559	2			Single track	330	0
	7	*Cabezon del Pisuerga*	261	540	540						
	8	*Corcos-Aguilarejo*	265	546	546						
	9	*Dueñas*	279	609	609	4					
	10	*Venta de Baños*	285	910	910	5	3				
PS6	11	*Magaz*	294	693	693					265	0
	12	*Torquemada*	306	598	598		2				
	13	*Quintana del Puente*	317	627	627						
	14	*Estepar*	350	612	612						
	15	*Quintanilleja*	360	568	568	15			Single track		
	16	*Burgos*	373	875	875	15	1				
	17	*Quintanapalla*	386	510	510	7	10			295	0
	18	*Briviesca*	417	591	591	4					
	19	*Calzada de Bureba*	428	513	513	0					
	20	*Pancorbo*	440	572	572						
	21	*Miranda de Ebro*	459	996	996	10	12				
PS7	22	*Manzanos*	468	587	587	7	11			234	0
	23	*Nanclares*	479	532	532		2				
	24	*Jundiz*	486	830	830						
	25	*Vitoria*	492	670	670	6	0				
	26	*Alegria*	506	584	584	9					
	27	*Agurain*	516	575	575						
	28	*Araia*	524	603	603	9					
	29	*Altsasu*	535	528	528	13	10	284			
	30	*Brinkola*	557	415	415			283			
	31	*Zumarraga*	565	290	290			295		664	436
	32	*Beasain*	581	566	566		18	274			
	33	*Legorreta*	589	476	476			393			
	34	*Tolosa*	597	378	378	2	8				
	35	*Billabona*	604	267	267			320			
	36	*Andoain*	609	361	361		6				
	37	*Hernani*	616	278	278		12				
	38	*San Sebastian*	623	476	444	12	5	387			
	39	*Pasajes*	628	551	551	7		380		51	0
	40	*Rentería*	630	680	680	12					
	41	*Irún*	639	618	618		13				

Table 13 – Atlantic Corridor. PS5, PS6 and PS7 sections. Sidings (lengths), gradients, radius and traffic (source: ADIF)

3.5.1 Capacity

As can be seen in Table 13, the analyzed route has a length of 433 kilometres, with 41 sidings including the extreme circulation dependencies. One of the first conclusions of the table is that the existing sidings would not allow the parking of a train over 1.000 m in any case (Figure 33). Even there are only around five sidings to park trains from 700 to 800 m. It should be noted that in the analysis it has been considered that parking can not be done in general tracks.

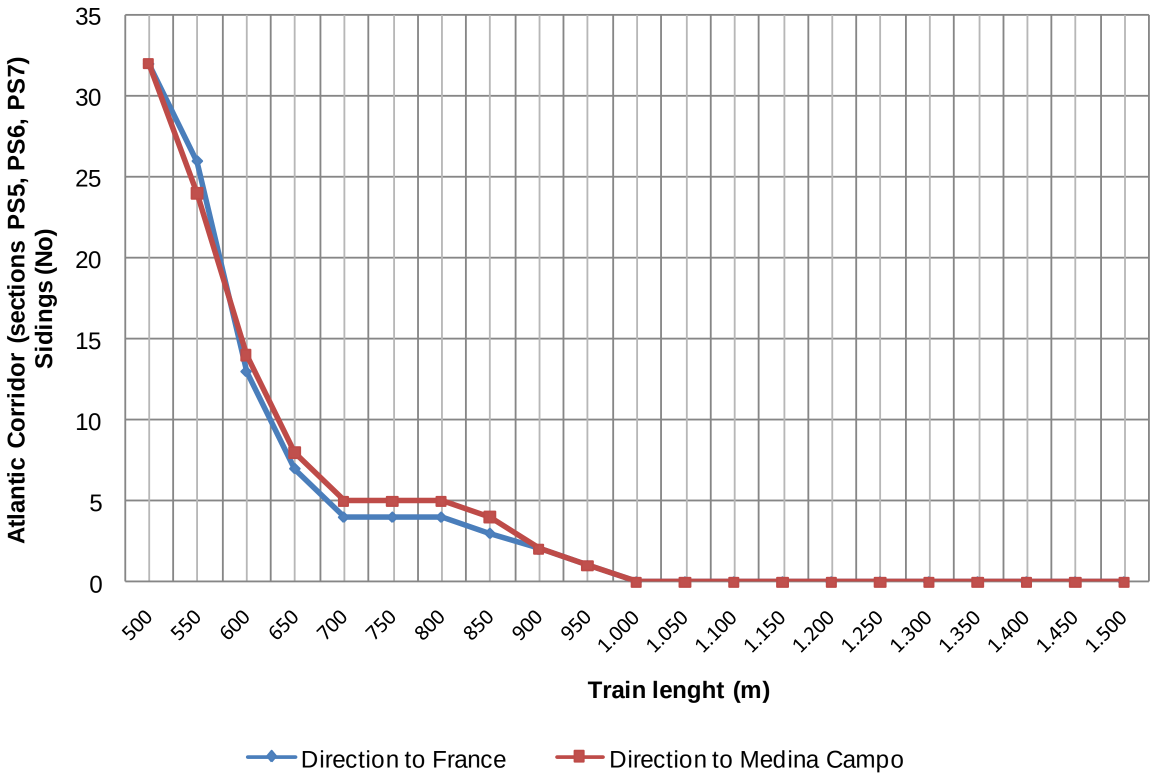

Figure 33: Sidings and train length (source: ADIF)

If the circulation of a train of more than 800 m was considered, and considering that it could not be parked in the 433 kilometres of the route, the following analysis is to check if its circulation is compatible with the rest of existing trains. Figures 34 to 38 represent a standard timetable in the analyzed section, divided into the different bands of traffic control regulation. Since there are commuter services in the final part of the section, the only possibility would be to assign the slots at night, always without interfering with possible maintenance works.

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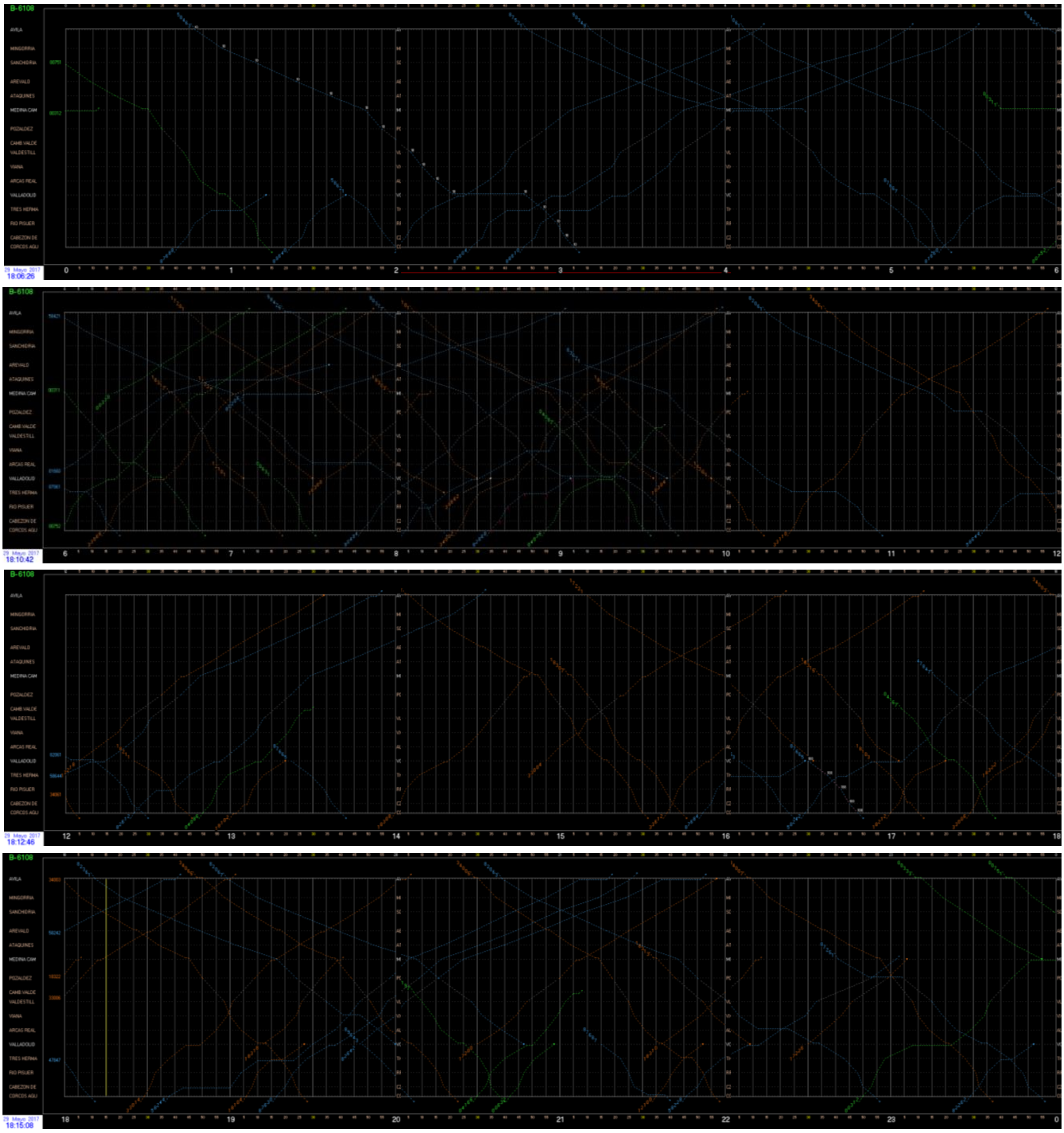

Figure 34: Atlantic Corridor. Standard Timetable (part 1) (source: ADIF)

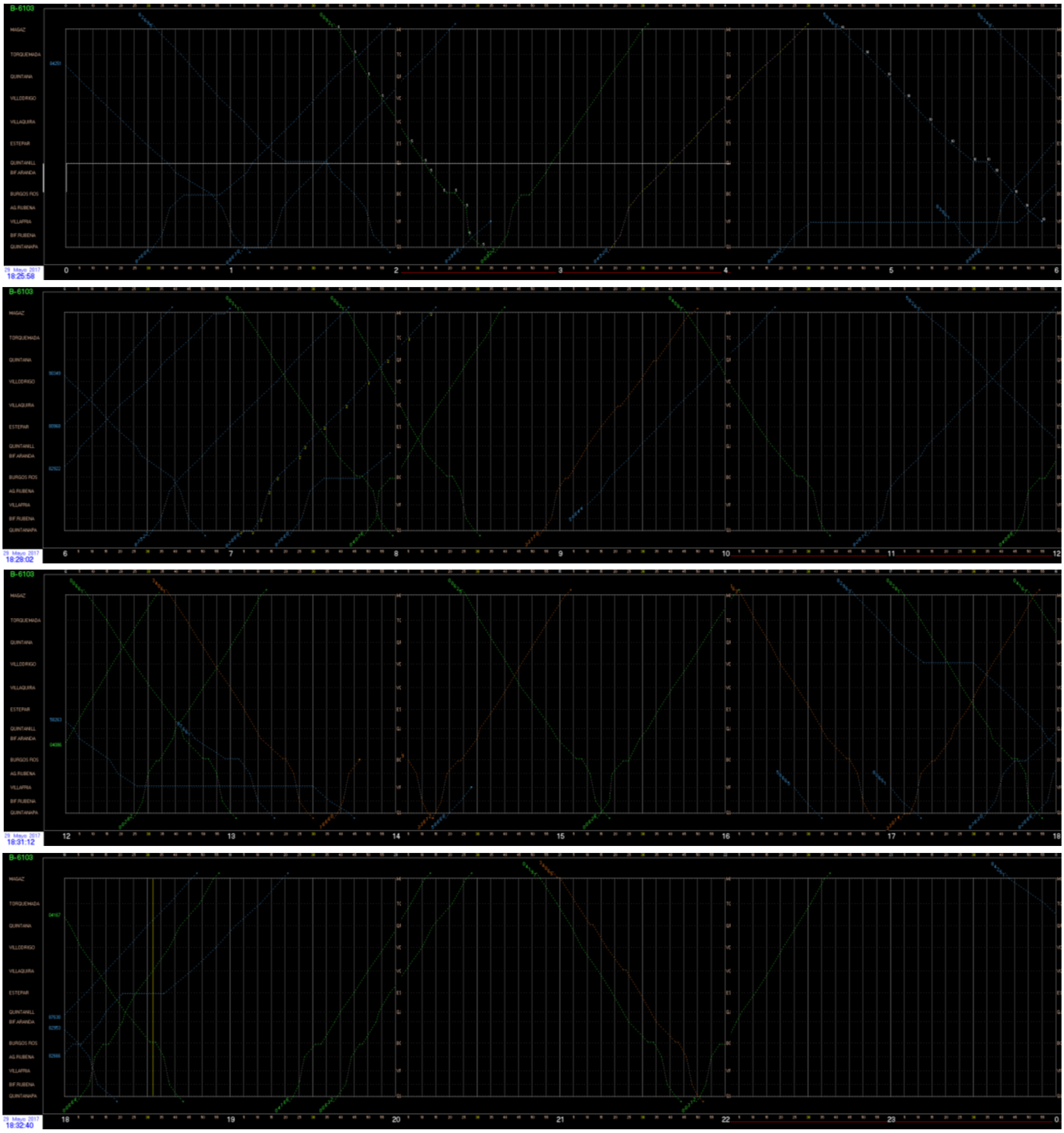

Figure 35: Atlantic Corridor. Standard Timetable (part 2) (source: ADIF)

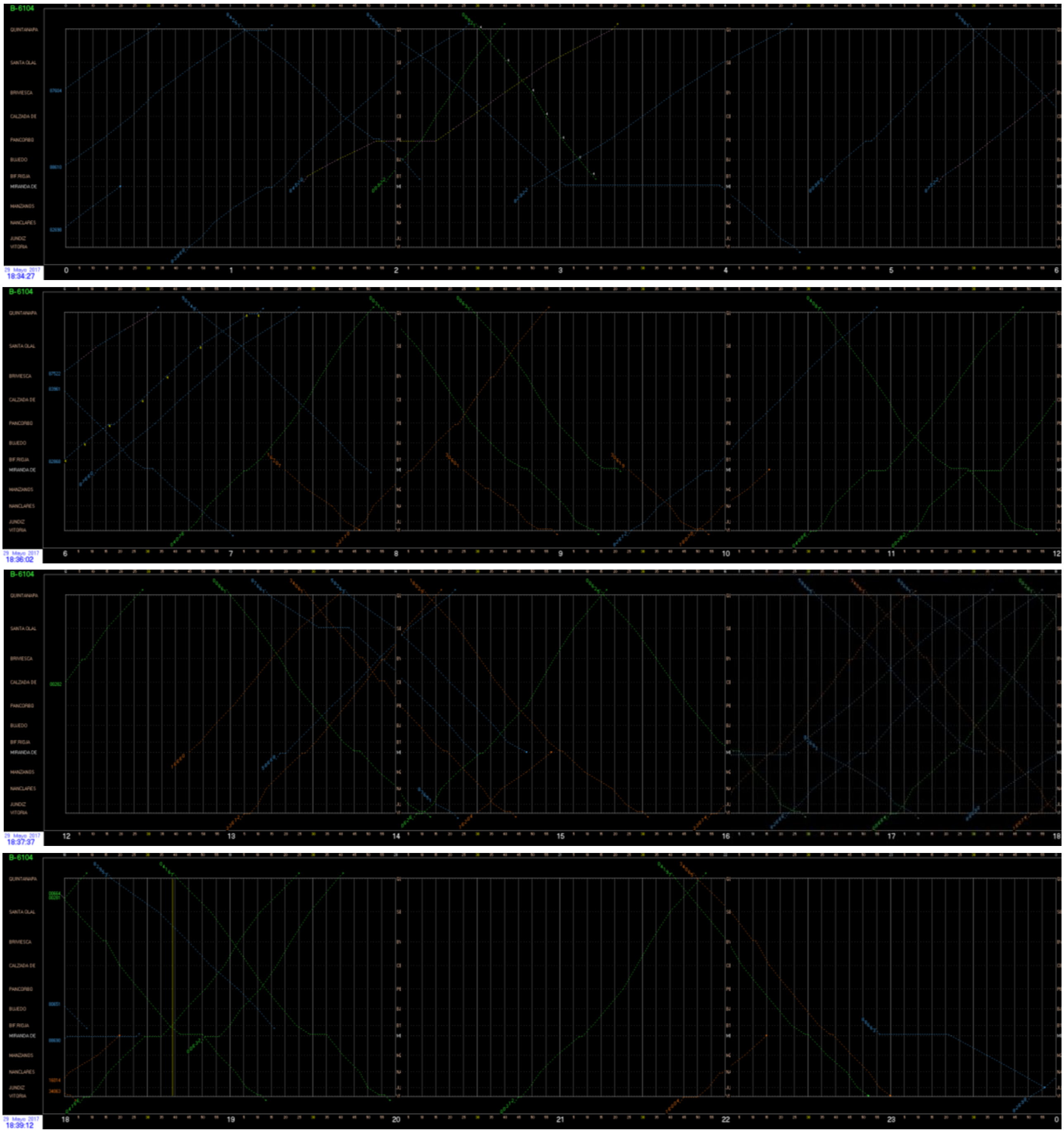

Figure 36: Atlantic Corridor. Standard Timetable (part 3) (source: ADIF)

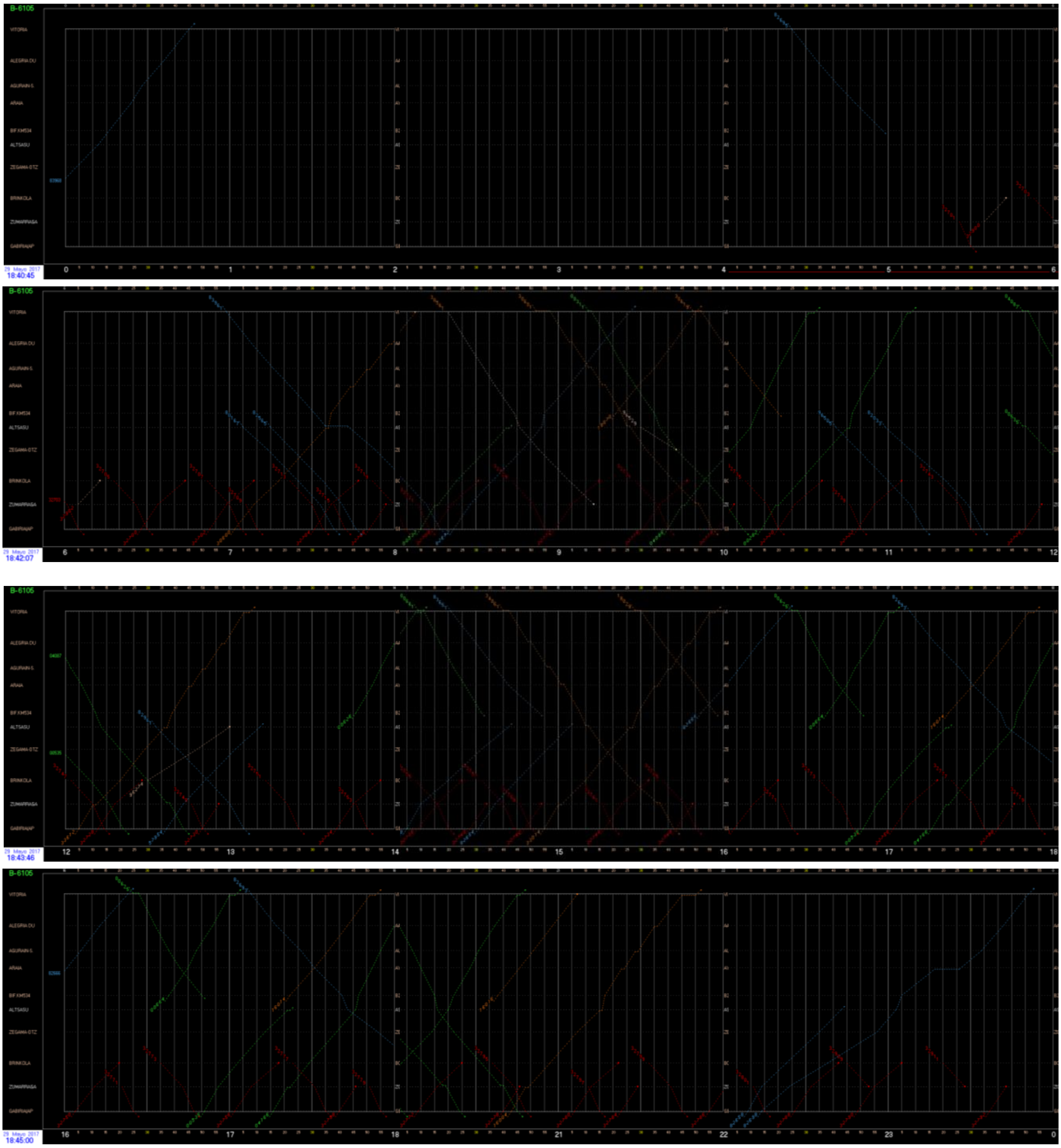

Figure 37: Atlantic Corridor. Standard Timetable (part 4) (source: ADIF)

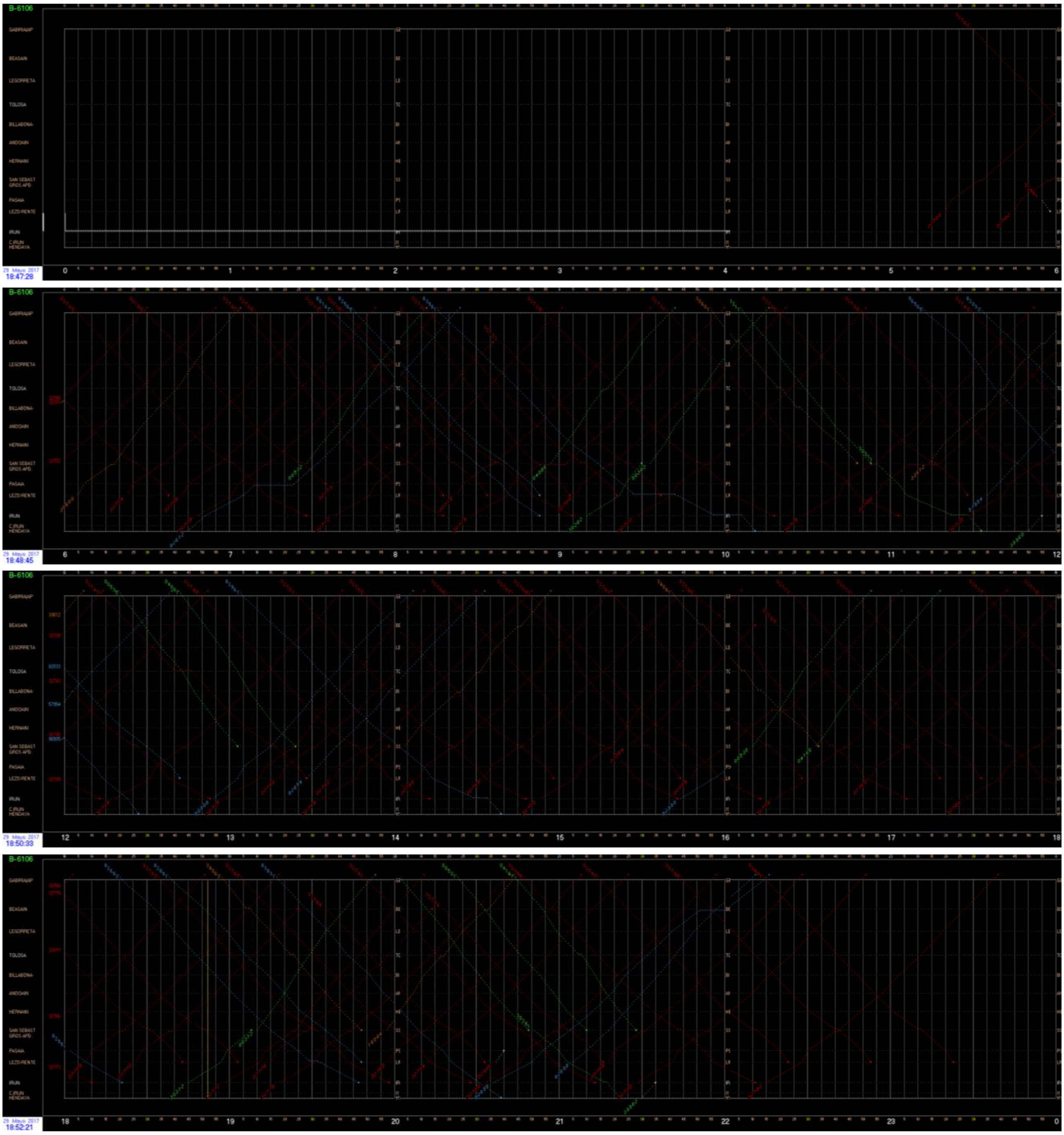

Figure 38: Atlantic Corridor. Standard Timetable (part 5) (source: ADIF)

Without a doubt the current situation that occurs in the Atlantic Corridor (analyzed route) does not allow the circulation of trains of more than 750 m without having to establish special operating guidelines: Continuous circulation in the 436 kilometres and at night. The main restriction, along with the length of the sidings, is the existence of commuter trains at the end of the route.

3.5.2 Composing & Decomposing

In principle, this operation will only be necessary in the final part of the route, at the moment of carrying out the operation of changing the gauge. This situation will be analyzed in section 5.

3.5.3 Train dynamic

Figures 39 and 40 show the existence of gradients and curves in the section analyzed. In the case of curves, only curves with a radius less than 400 m are considered.

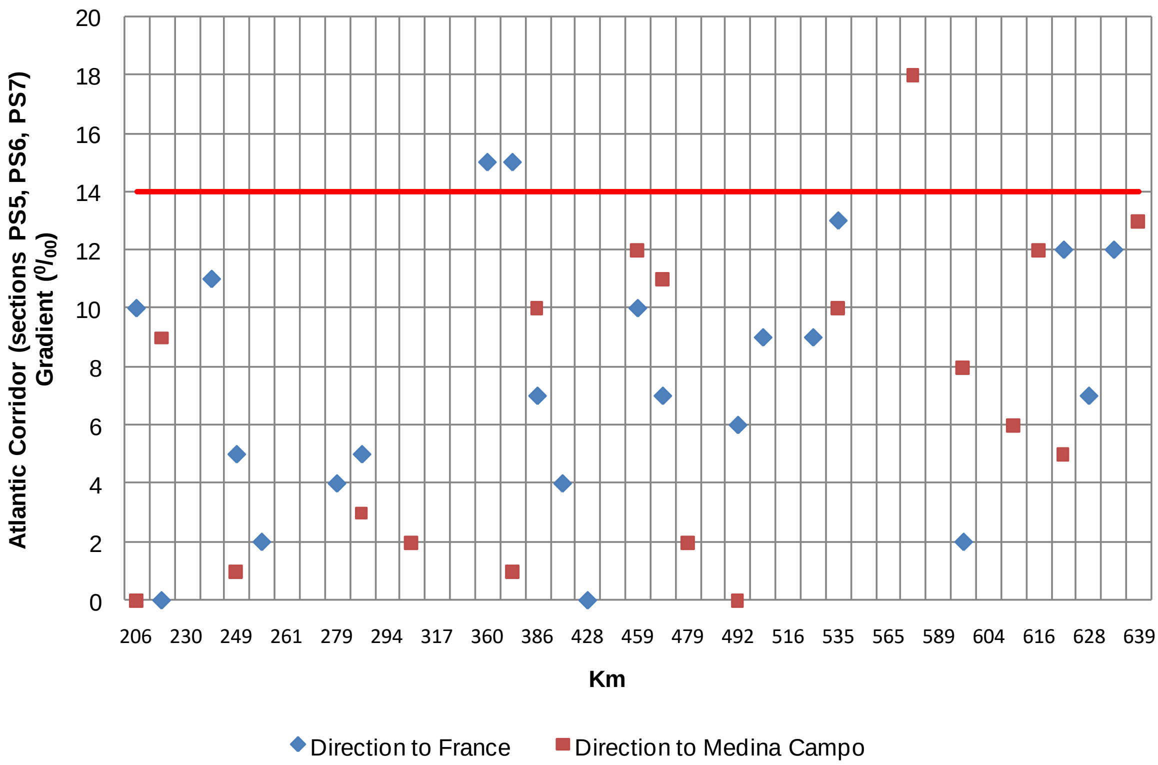

Figure 39: Distribution of gradients in the sector analyzed (source: ADIF)

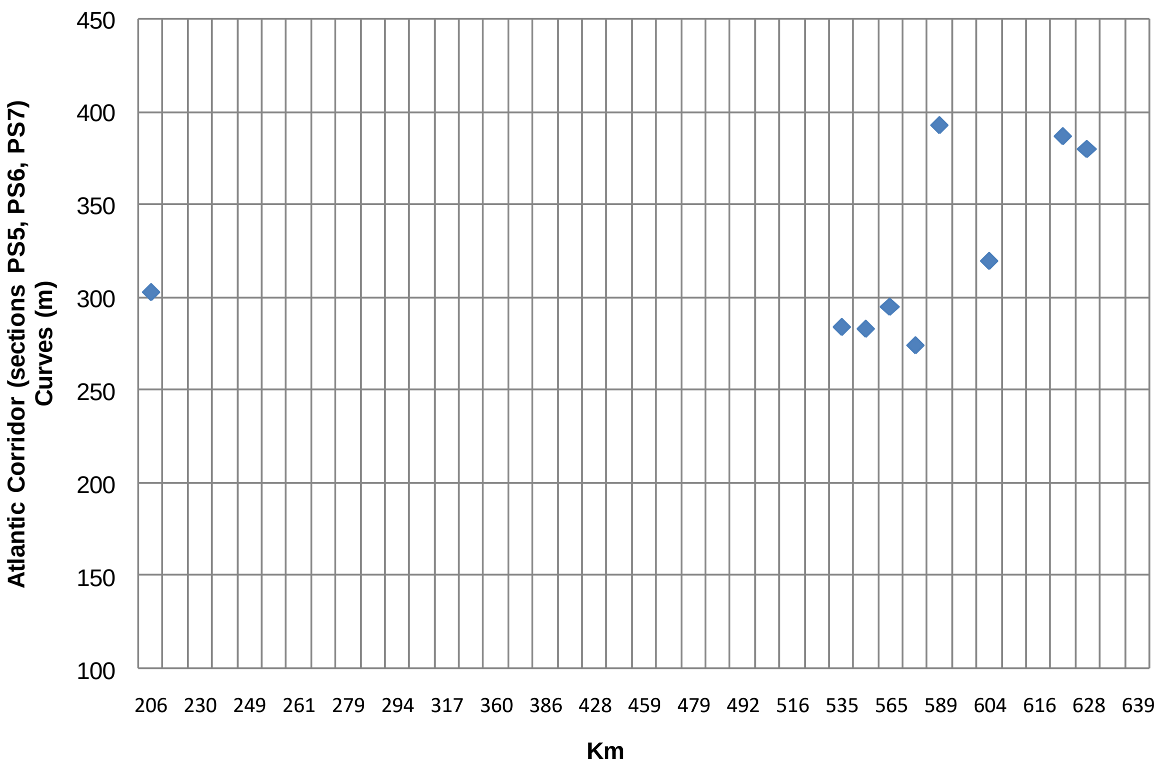

Figure 40: Distribution of curves in the sector analyzed (source: ADIF)

The gradients of the Atlantic Corridor in the Spanish part are below $14^{0}/_{00}$except for three points of the route (two points of $15^{0}/_{00}$and another point of $18^{0}/_{00}$). It should be noted that above these values, considering the locomotive used, it would be affecting the load capacity according to Figure 11. Considering the circulation of a train type TRc (100) for the gradient of $18^{0}/_{00}$, the maximum possible load it would be limited to 2.160 t, which means a train of 1.116 m and 36 wagons.

3.5.4 Braking

No comments in this point.

3.5.5 Train aerodynamic

Currently there is a support service to ADIF by the National Institute of Meteorology. If an inappropriate lateral wind is anticipated (above 90 km/h), the reduction of the speed of the freight trains is communicated to the traffic control centres. There are no other types of measures to reduce the effects of this wind.

3.5.6 Gauge change

At the moment the change gauge facility indicated in the Figure 27 is not installed, being foreseen to install it in the next years. As indicated in section 3.1.6, freight wagons that circulate to France are subjected to a process of replacement of the axle in other types of facilities. Section 5 will discuss how to perform the operation.

3.5.7 Level crossing

Without limitations and restrictions.

3.5.8 Track

An analysis of the existing track in the affected section has been developed. The objective was to analyze the evolution of incidents mainly associated with the rail. It should be noted that the most sensitive area is that which exists in the PS6 sector, especially in relation to defects and early breakages.

3.5.9 OCL

Without limitations and restrictions.

3.5.10 Power Supply System

An important restriction that has been detected is that the current DC power supply system is insufficient to supply the maximum power demanded by a train of 2.500 tons circulating in the PS7 sector. Precisely, the existence of a ramp in Medina del Campo direction of $18^{0}/_{00}$implies that the electrical system can not supply the necessary power. The problem is complicated taking into account that in this section commuters trains circulate in certain time periods.

For the realization of the simulations the tool SYCE has been used. SYCE is a simulation program for an electrified rail line in DC. The program uses a series of developed models that theoretically represent the electrical system under study. The SYCE application is owned by ADIF and has been validated in the CENELEC Working Group WGC20. In general, after entering the corresponding data, in each instant of time, SYCE solves the complete electrical timetable. For this, it has two algorithms, a Mechanical Algorithm and an Electric Algorithm.
As indicated, the affected substations (Zumarraga and Ordicia, Figure 41) are not capable of supplying the power demanded by the train, so it would not be possible to operate this type of

train if it is not making changes in the system. Considering a nominal voltage of 3.300 V that exists in the catenary, the simulator concludes that voltage drops of more than 1.500 V are obtained, which produces a voltage in catenary of about 1.900 V, unacceptable voltage for the correct operation of the system.

Although there are other ramps of $15^{0}/_{00}$in the PS6 zone, it is verified that in this case it could be operated even taking into account that yes values of voltage drop are produced that are above the average.

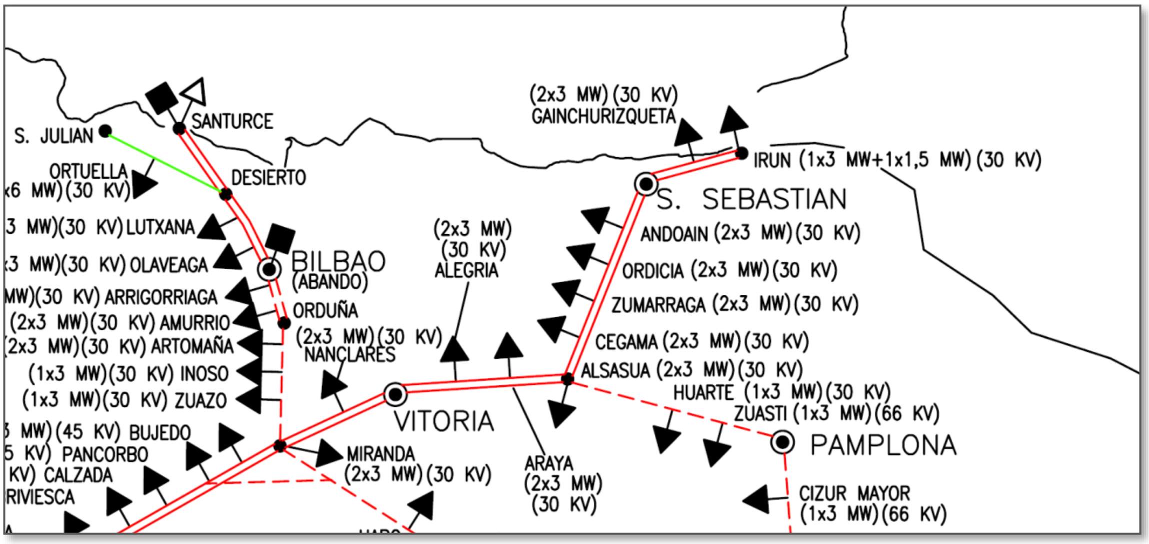

Figure 41: Electrical environment in the area of the sector PS7 (source: ADIF)

3.5.11 Signalling

An analysis has been made by checking all the stopping points of the route and it has been concluded that there are no restrictions on the part of the ASFA system and track circuits.

3.5.12 Structures

Without limitations and restrictions.

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3.5.13 Telecommunications

Without limitations and restrictions.

3.5.14 Others

Without limitations and restrictions.

3.5.15 Conclusions

Figure 42 shows the main conclusions obtained in the analysis carried out schematically.

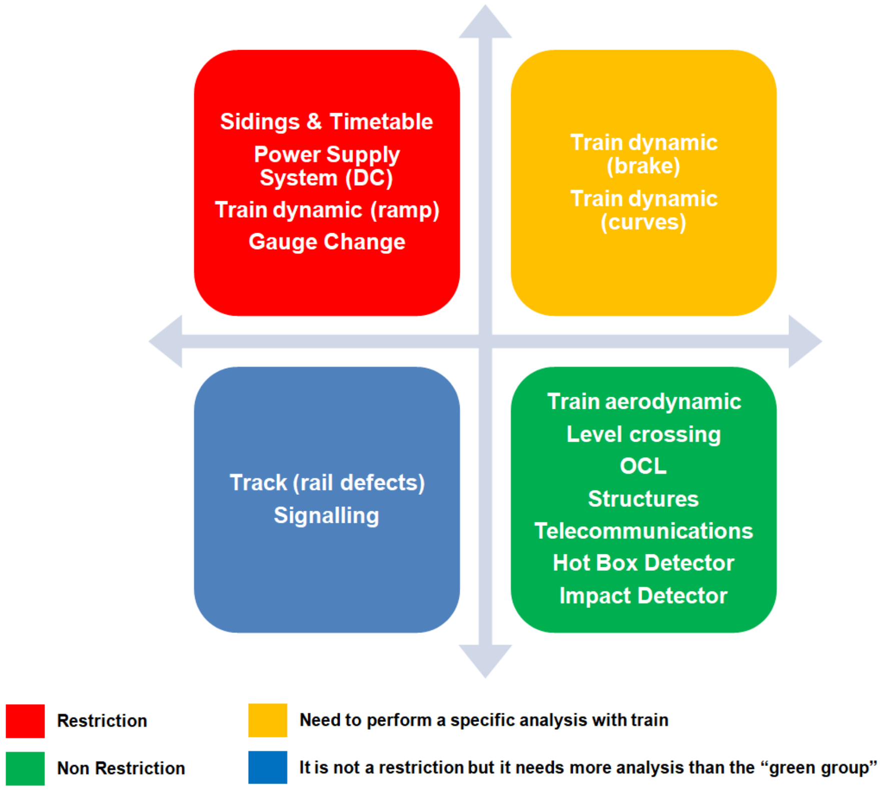

Figure 42: Main conclusions (source: ADIF)

4. DESIGN ASPECTS OF THE RAILWAY LINES

Considering the conclusions of the previous section, this section will analyze what aspects should be taken into account in the design and subsequent operation of long freight trains on a railway line. The approach followed takes into consideration the characteristics of the Spanish rail network. For example, while in other countries it is not appropriate to analyze the type of gauge to be used, in Spain this choice must be considered.

Since the approach can be complex, since the variability of cases would be practically unapproachable, the following exercise is proposed:

- Carry out the analysis on the same route considered in the previous section, taking into account that the layout can not be modified in any way by economically unviable. It should be noted that the most restrictive route is located in the area of the Basque Country, with a complex orography and a high population density next to the railway line.

- Carry out the analysis in a new line with characteristics similar to the previous one, but considering that there is a greater freedom of design.

In general terms, this approach has been transferred to Table 13. It shows, for each scenario considered, what would be the desirable characteristics in each one of them.

Aspect	Atlantic Corridor. PS5, PS6 and PS7 sections	New Line
Length	433 km	433 km
Track type	Double track (single track in some sections) 1.435 mm of gauge Ballast	Double track 1.435 mm of gauge Ballast
Track geometry	Straights Minimun radius curve: 285 m Gradient: ($^{0}/_{00}$): 8$^{0}/_{00}$ (average) – 18$^{0}/_{00}$ (maximum)	Straights Minimun radius curve: 400 m Gradient: 13$^{0}/_{00}$ (maximum)
Sleeper type	Mono-block	Mono-block
Rail size	UIC 54	UIC 60
Track quality	Medium	High

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Aspect	Atlantic Corridor. PS5, PS6 and PS7 sections	New Line
OCL	Poligonal. Independent counterweight (contact wire/lift cable) One contact wire Lightweight	Poligonal. Independent counterweight (contact wire/lift cable) One contact wire Lightweight
Power Supply System	25.000 V AC 50 Hz	25.000 V AC 50 Hz
Speed (freight trains)	100 km/h (maximum speed) 80 km/h (average)	120 km/h (maximum speed) 95 km/h (average)
Traffic	Mainly regional passenger trains and freight trains. In section PS7 there are commuter services that significantly decrease the capacity of the line	In the case of sections with commuter trains, install specific tracks for freight traffic
Sidings	Performance on several sidings in which the length of the track is increased	Every 40 km there will be a siding with at least one track of 1.750 m length
Signalling	ERTMS Block section: Track Circuit	ERTMS Block section: Track Circuit
Telecommunications (Radio System)	GSM-R or LTE	GSM-R or LTE
Hot Box Detector	4	Yes
Level crossing	19	No
Impact Detector	2	Yes
Change Gauge Facilitie	Dissapears	No
New equipment	Broken Rail Detector Dragged objects Detector Physical protections against cross wind Barriers against noise	Broken Rail Detector Dragged objects Detector Physical protections against cross wind Barriers against noise

Table 14 – Design aspects to consider (source: ADIF)

4.1 CAPACITY

As it has been seen, three (3) fundamental strategies will be implemented:

- Plan sidings of up to 1.750 m in length, approximately each 40 kilometers.
- Avoid single tracks. In the case of areas with high traffic (for example commuter services), consider the possibility of using one or two tracks only for long trains.

- Optimally design the schedule for long trains. Ideally, trains could perform the service without making stops.

It should be noted that in the case of the Atlantic Corridor, a brief analysis has been carried out, concluding that it would be feasible to modify the Corcos-Aguilarejo and Estepar sidings. Due to its complexity and orography, it would not be economically possible to modify the sidings from kilometer 360.

4.2 Composing & Decomposing

No comments in this point.

4.3 Train dynamic

Focusing the analysis on the value of the gradients and the radius of curves, in the first analysis the following are proposed:

- Maximum gradient: 13‰.

- Minimum radius: 400 m.

4.4 Braking

No comments in this point.

4.5 Train aerodynamic

Although it is proposed to continue operating in the same way as before, it is proposed to develop specific wind analysis as ADIF does at this time in the high speed lines. The key objective of “wind studies” is the assessment of the cross wind induced overturning risk in each section in which that freight line has been divided to be studied. Cross wind risk of each zone, Probability of Exceedance (POE), is compared with the safety target. If that risk is unacceptable, countermeasures should be installed. On the contrary, if the line zone can be considered as non sensitive zone and countermeasures are not necessary.

One of these measures consists in the installation of physical protections (protection barriers) in specially exposed places on the line (Figure 43).

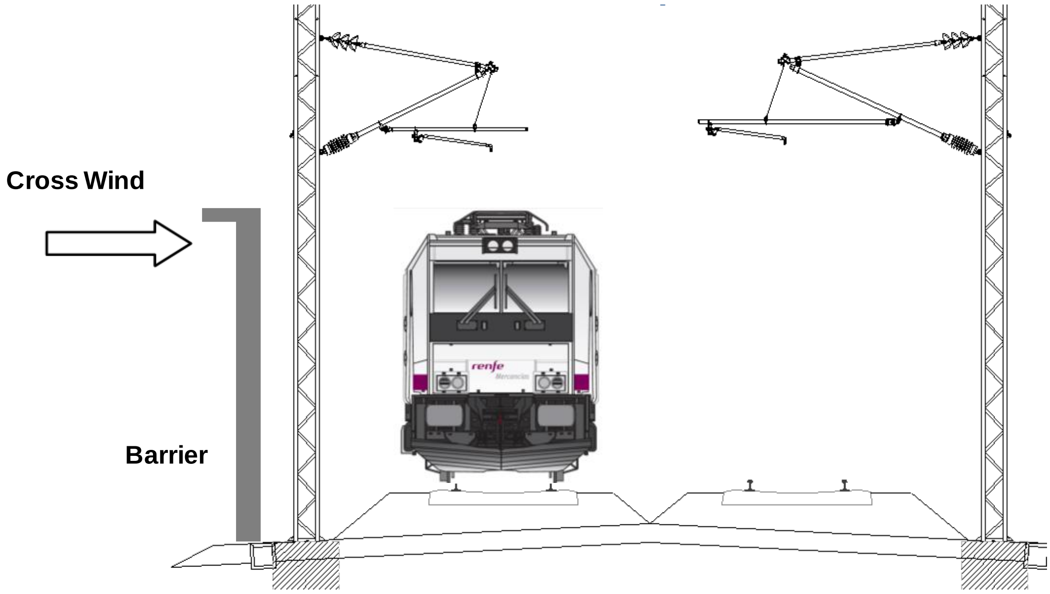

Figure 43: Schematic representation of a protection barrier of the freight train against the lateral wind (source: ADIF)

4.6 Gauge change

This condition does not need to be analyzed.

4.7 Level crossing

In the case of a new line, national regulations (for example in the case of Spain) usually regulate the construction of bridges above the track. Therefore, new level crossings will not be installed.

4.8 Track

The analysis carried out has focused on the detection of rail broken.

Vehicle-based inspections are currently being used to figure out faulty rails. However, such measurements can only take place periodically, mostly few times a year.Based on those measurements, the condition of the track is analyzed and rails will be replaced in case of damage or excessive wear. However, the causes of broken rail that may happen between the times of the periodic surveillances will not be detected. This has the consequence that trains could derail when they pass a broken rail. Hence, detection of rail breakage during the time between periodic inspections using permanent monitoring system on the railway track could minimize potential risks in the railway service. An additional value of such a broken rail detection system would then simultaneous collection and record of data on further track quality parameters.

Now a days advanced non-destructive test (NDT) techniques are being implemented for periodical track inspection. Track inspection systems utilize different techniques to capture rail defects and precisely locate rail defects along the track. Rail defects mainly include problems related to weld, internal defects, worn out rails, head checks, squats, spalling and shelling, surface cracks that are originated from rolling contact fatigue (RCF).

Broken rail detection methods can be distinguished in reactive and proactivesystems.Reactive systems identify a broken rail after it has occurred and pro-active systems find rail defects that can become broken rail in the future. In case of the reactive systems no information on the condition of the rail will be available ahead so that it is assumed that the rail is in a safe condition until the break happens. This means in case a slight break of rail has already occurred, no warning signals will be available for the next train that passes over the damaged rail which lead the rail to be completely broken. In case of proactive systems, the rail condition is periodically monitored. As a result, changes in the track are already detected.Emanating from these changes it is possible to infer the further development of the track.

In general, it can be said that vehicle-based measurement methods have a proactive character (ultrasound, induction, etc.). In the past, track-based measurement methods, e.g. track circuits are usually reactive systems. However, the evolutionary progress of the track-bound measurement methods is leading to the proactive character of those systems. For instance, it is currently possible to detect the tensions in the railby means of glass fiber sensors that are attached to anticipate the probable breakage of the rail. As a further example, a track-bonded ultrasound method could be mentioned, because such systems could nowadays also detect large cracks in the rail.

One of the most promising technologies to detect problems in the lane is based on the use of fiber optics. Fibre optics transmit information over a large distance through light waveguides. They can also be used as sensors.The basic idea for this sensor system is the fact that mechanical influences change the light signal in the fibre optic.Those deviations can be measured and enable to make statements about the mechanical influences in the glass fibre.

The simplest application of a fibre optic sensor for broken rail detection is to install them on the rail web. The glass fibre is flooded by light pulses that are generated by a laser, the wavelength of the pulses is commonly 1.550nm.At the other end of the fibre optic cable, a receiver is installed to evaluate those signals. If the rail breaks, the monitored section is interrupted and the receiver cannot detect any light pulses. When this happens, an alert message will be generated and the trains could be warned that a rail break has occurred. In the case of a slightly broken rail, where the fibre optic is not completely broken the receiver could also detect the rail break, by the drop of the signal strength. If the transmitter is equipped with an optical time domain reflectometry (OTDR), it is also possible to localise the geographical position of the breakage.

In recent years the fibre sensor technology has developed strongly and currently it is possible to detect further parameters. However, some of these new technologies are still at development stage and have not yet been tested in the field. The most important and also promising technologies are briefly listed below.

A DAS sometimes referred as DVS measurement system is based on the fact that materials get minimal changes in their dimensions under influence of sound waves, temperature or mechanical vibrations. In case of glass fibre, the glass molecules are stimulated to oscillate during the length variation, triggered by mechanical waves. When a laser pulse passes through the glass fibre, it will be partially reflected by the oscillating molecules. Depending on the oscillation intensity of the glass molecules, the reflected laser pulse gets a spectrum shift. This spectral shift can be detected (Rayleigh scattering) and the position of the reflection in the optical fibre can be detected by the signal running time (Figure 44).

This technology allows measurement distance up to 40 kilometres with a virtual sensor interval of one meter. Measureable sizes for this system are mechanical waves and temperature, consequently a change in the rail oscillation may indicate a rail break. This system is mainly used in geophysics to detect seismic activities. Furthermore, DAS systems are used in real-time monitoring on oil and gas pipelines. Such system may be interesting for track monitoring, because the fibre optic does not need to be located directly on the rail and would be better protected during track maintenance works.

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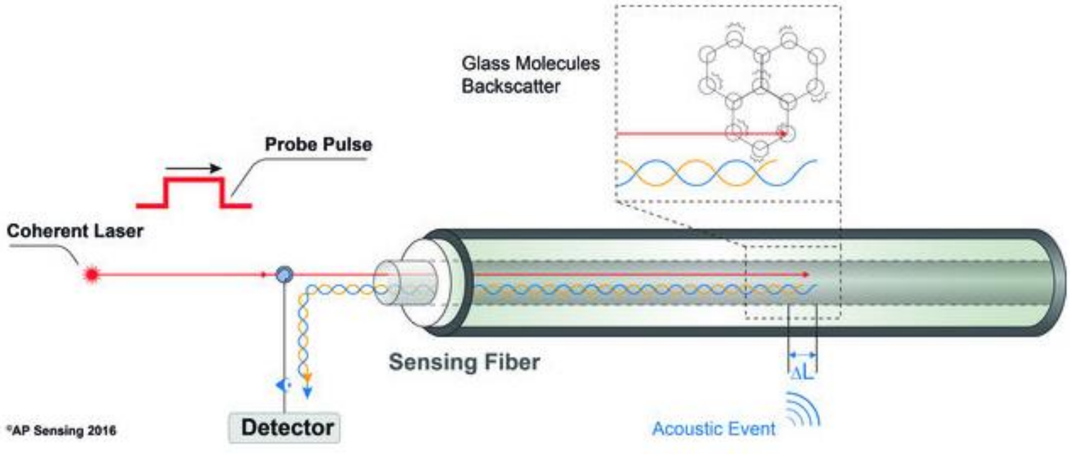

Figure 44: Schematic illustration of a DAS sensor (source: UIC)

It should be noted that ADIF, due to the analysis carried out in the Dynafreight Project, has installed a DAS system under test in the sector PS6.

4.9 OCL

As you will see in the following section, when using an AC electric system, it will be necessary to perform actions in the catenary. If the catenary is already installed, a large number of elements can be used. In general terms, the insulation should be modified (replacement of insulators), so that the rest of the elements can be used.

In the case of a new line, a catenary with unique specifications of alternating current will be installed.

4.10 Power Supply System

All new electrifications will use the AC system. In case of renewal of the infrastructure, this system will also be used.

As discussed in the previous section, the use of the AC system has a large number of advantages over the DC system. By using more voltage and less electrical current, higher power can be transported with less number of substations and lower voltage drops.

While in the case of a new line the equipment is very well defined, if the transformation of the Atlantic Corridor to an alternating current line is planned, it will be interesting to take advantage of the existing substations. In this case it should be considered that low power lines are used (distribution network according to Figure 24) so if high power requirements of the network are required, imbalances may occur. Imbalances of currents and voltages at different points in the network, due to the character of the single-phase load, are the most important disturbance.

Trains that operate with AC system are a source of disturbances in the power lines and the own railway environment. It is a load powered by single-phase alternating current, variable in space and time, and power electronics of locomotives. This electronics produces harmonic components of the traction current that flows through the catenary and then returns to the nearby terrain. This fact complicates the operational scenario, taking into account that the rest of the railway systems require electrical cables for their operation.

Although the single-phase alternating current offers an important advantage over the direct current as is its ease of transformation, as a disadvantage is its property of inducing voltages in parallel conductors. Note that in the normal use of alternating current in three-phase systems, the inductions of each phase are compensated by the inductions of the other phases. This fact does not occur in single-phase electrification as there is an electromagnetic disturbance that may be important for other railway installations.

For all of the above it can be said that electrification causes disturbances in the electrical environment of the railway line. These disturbances occur both on the distribution line (as a consequence of being connected to it) and in all the electrical and electronic installations of the railway line.

In the case of a line like the Atlantic Corridor, power electronics applications can be used to actively reduce the voltage unbalance in the public grid. For this purpose different technologies and applications are introduced. Furthermore other advantages can be achieved like reduced voltage drop at the TPS. For example static VAR compensators (SVCs) connected to the three-phase grid in parallel to the TPS reduces the voltage unbalance imbalance but require large harmonic filters due to the switching of the thyristors. Then synchronous static converters (STATCOMs) connected to the three-phase or single-phase traction network were used where they also allow to filter the harmonics produced by the traction loads.

Static frequency converters have also been used to provide the total power required by the substation, although in a smaller number due to the lower cost of the SVC or STATCOM since these are dimensioned for a fraction of the total power of the substation. These frequency converters have evolved from back-to-back converters to the current modular multi-level converters (MMC).

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A very interesting feature of the use of an AC system is due to the possible recovery of braking energy. In a line with many slopes, the braking of a train of great length (therefore with a lot of mass) can be very efficient from an energy point of view. The management of the electric power regenerated in the braking of the trains has great incidence in the energetic improvement with respect to a line with DC system. The braking process a train has to carry out, either to make a stop or to lower the existing slopes along the path, or even to succeed in reaching the speed limits imposed, may lead to important consequences in the final calculation of the energy required by an electric railway line. Indeed, energy is dissipated in the braking process, some of it is lost in friction brakes (pneumatic brakes), that has no useful use, and some of it is dissipated in the dynamic brakes.

For the dynamic brakes in particular, in the case of having an electric traction train (or a diesel-electric traction one), the braking process involves the generation of electricity. At present, the electricity generated in this type of brake can have multiple destinations:

- Provided the train incorporates regenerative braking, energy is dissipated as heat into electrical resistors provided on board (rheostat brake).

- Provided the train does not incorporate regenerative braking, energy is returned to the catenary. In this case, if there is another train being fed from the same power sector requiring energy, the train may consume the returned energy. This particular example constitutes an optimal process from an energy standpoint. In the case there are no trains demanding energy, two additional cases arise:

    - In case of having a single phase AC power, the energy generated is returned to the national grid and can be used by other consumers connected to it.

    - In the case of having DC power, thus existing a rectifier group in the substation (Figure 22), energy is dissipated in the resistors of the rheostat brake provided in the train.

That is, in DC electrifications, energy cannot be returned to the national grid taking into account the current situation, since the substations are equipped with rectifier groups that do not allow current flow into the grid. It also should be noted that the energy is regenerated to the catenary when the train that is stopping has previously fed its auxiliary services (heating, air conditioning).

In summary, the migration to an AC system will allow trains to be fed more efficiently (especially in areas with a strong gradient) and the system's energy efficiency will be improved.

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4.11 Signalling

In new lines the ERTMS system will be installed (in a freight line, normally Level 1). As can be seen in Table 14, in the case of the Atlantic Corridor there would be no need to modify the current system (ASFA system).

4.12 Structures

No comments in this point.

4.13 Telecommunications

No comments in this point.

4.14 Others

In addition to the types of detectors already indicated above, it is proposed to use a detector of dragged objects.

Dragged objects and wagons with derailed axles cause major damage to the infrastructure and entail a high risk of derailments. The system consists of vertical bands located on both sides of the rails, which detect possible trailed objects and derailed axles that could affect the operation (Figure 45). This information is sent to an electronic equipment installed in the nearest technical building or booth, from where the information is sent to the control center. By means of this measurement it is possible to act on the trains that present some derailed axis or drag an object, making them reduce their speed conveniently and even stopping them in the next station, siding or dependence of circulation.

Figure 45: Dragged objects detector in a Spanish high-speed line (source: ADIF)

5. DESIGN AND OPERATIONAL ASPECTS IN TERMINALS

In this section we analyze in general terms what should be the technical aspects to be taken into account in the freight terminals that receive trains with a maximum length of 1.500 m. The analysis is really complex because of its great variability, having to establish a series of previous criteria that limit development. In this sense, a very preliminary analysis is presented here that should be complemented in the future in other projects.

On the other hand, considering the Spanish problems (which can also be extrapolated to other European countries and borders), the conditions that would occur in the case of carrying out a change of gauge operation in a terminal of this type have also been contemplated here. In the case of the Atlantic Corridor, this terminal is located in Irun and in the Mediterranean Corridor it is located in Port-Bou.

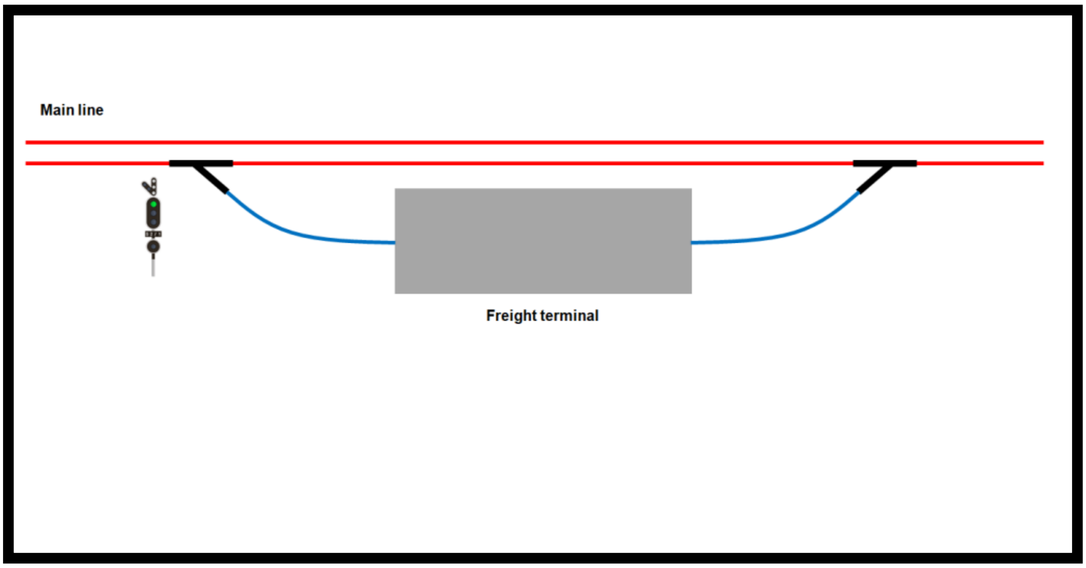
5.1 Freight Terminals

As indicated in section 2, the existing merchandise terminals in the Spanish part of the Mediterranean Corridor have been considered. These terminals are very different, although two different general types can be established:

- Terminal (A) that has access on both sides to the main line (this would be the case, for example, of the Valencia-Fuente de San Luis terminal).

- Terminal (B) that only has access on one side of the main line (for example, it would be the case of the Silla terminal, in the vicinity of city of Valencia).

Figures 46 and 47show a general scheme of each type of terminal.



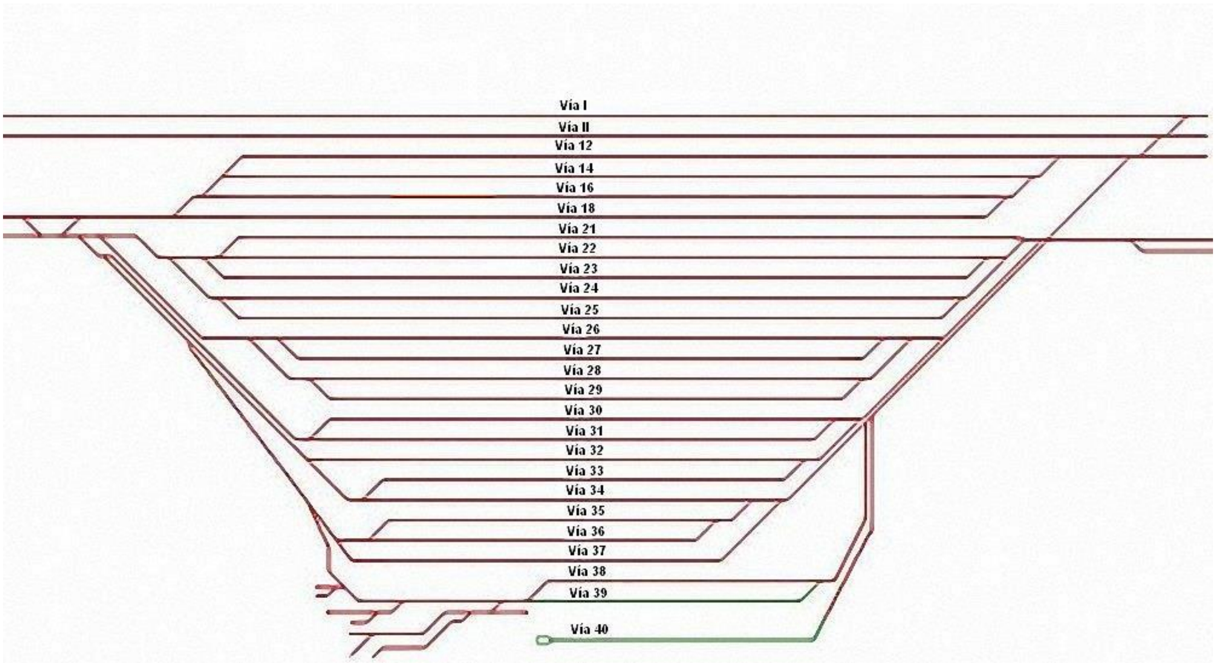


Figure 46: Terminal type A (Below, scheme of the terminal of Valencia-Fuente de San Luis) (source: ADIF)

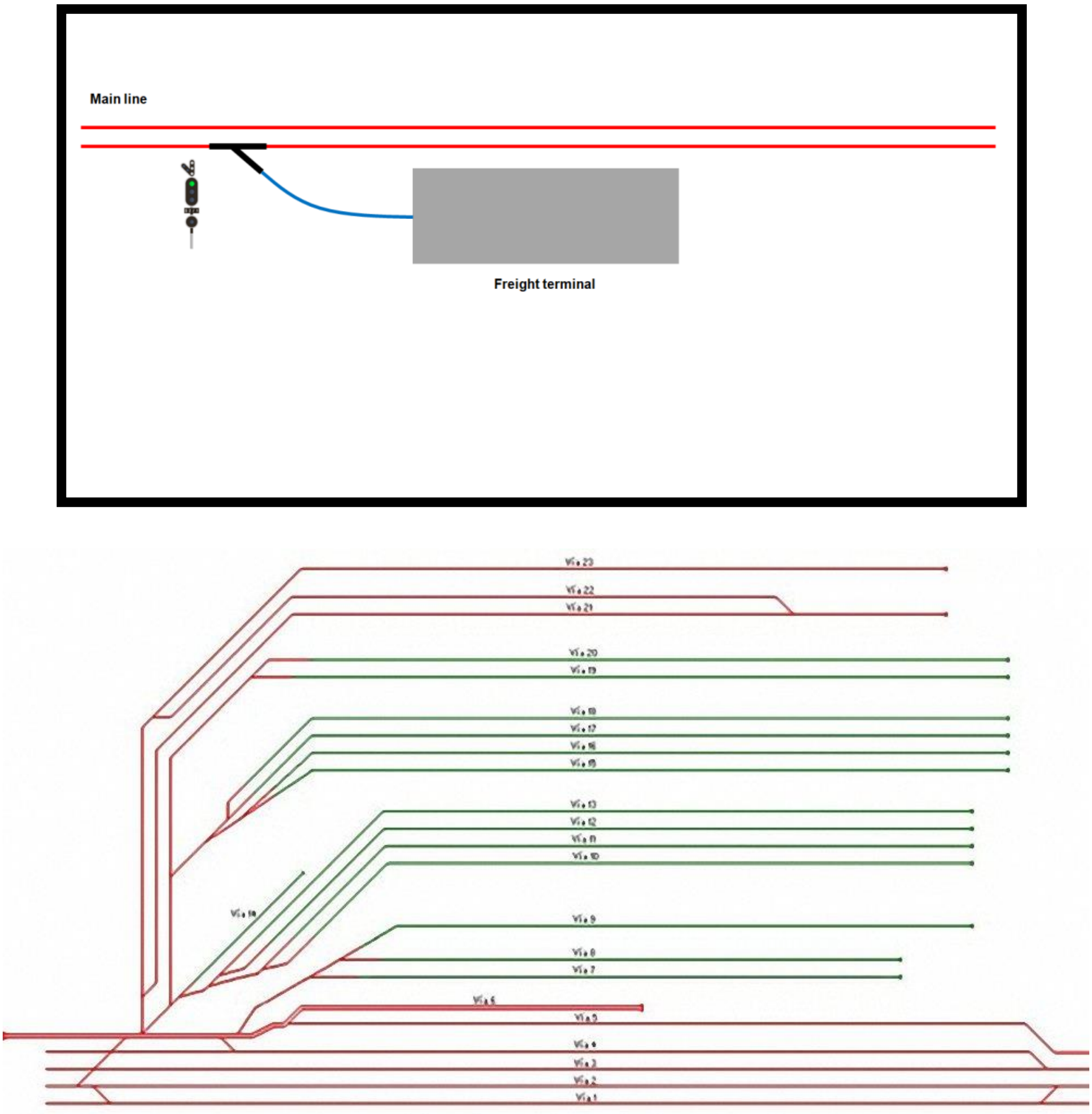


Figure 47: Terminal type B (Below, scheme of the terminal of Silla) (source: ADIF)

5.1.1 Terminal type A

Figure 48 represents in a general way the typical configuration of this type of installation (only three tracks have been represented, with a length greater than 750 meters). Currently, it is not possible, for space, to design tracks higher than 900 m in these terminals.

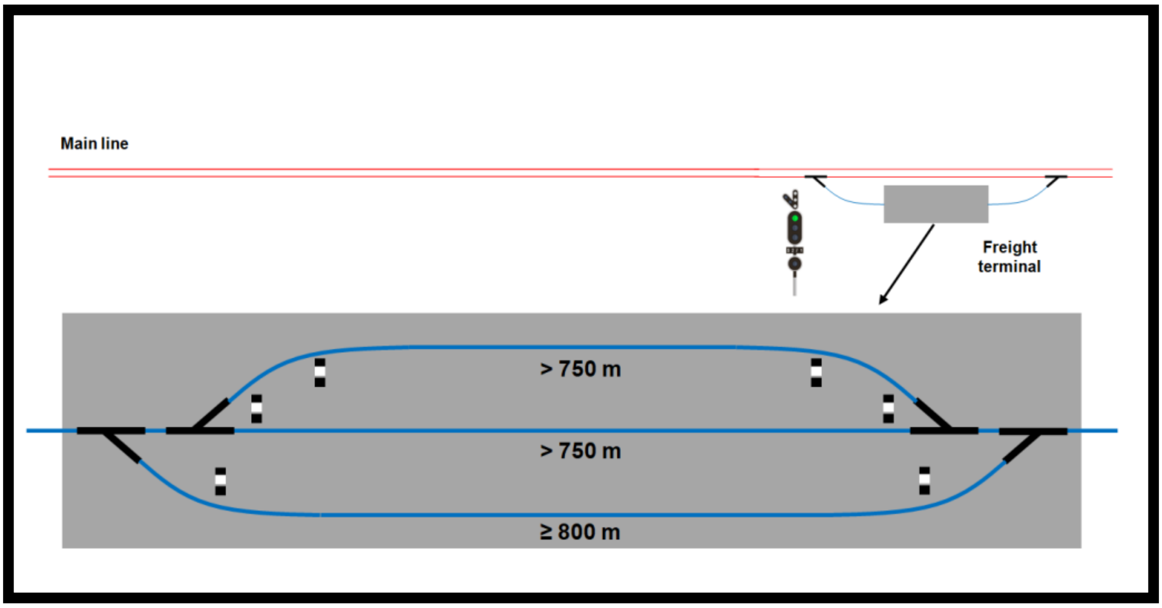


Figure 48: Terminal type A (Scheme) (source: ADIF)

Figures 49 to 53 represent, sequentially, a possible proposal for the reception of a 1.500 m freight train (formed by two trains of 750 m). This train arrives on the main line and stops before taking the switch to the terminal (Figure 49).

The objective is therefore to divide the two trains; First will access the front train (train B) (Figures 50 and 51) and then the rear train (train B) (Figures 52 and 53).The locomotives can be uncoupled and exit on the opposite side of the entrance.

It should be noted that the necessary resources must be considered to be able to carry out the division of the train on the main line (here not contemplated now).

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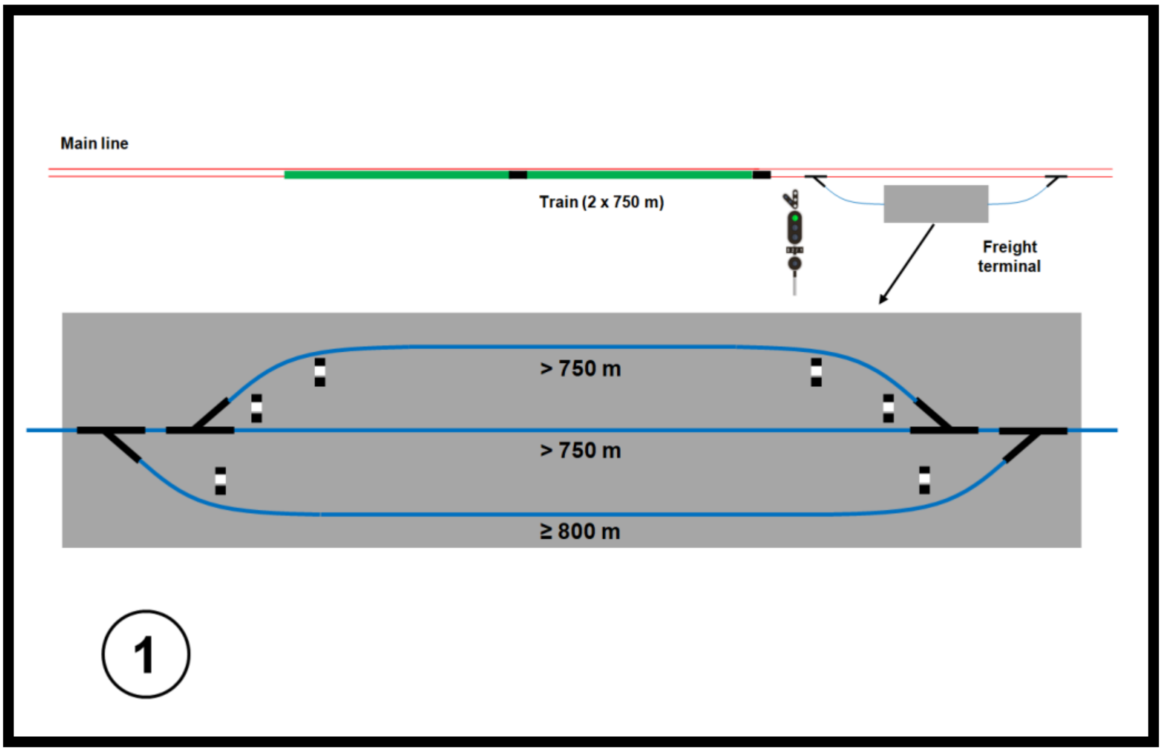

Figure 49: Terminal type A (Sequence 1) (source: ADIF)

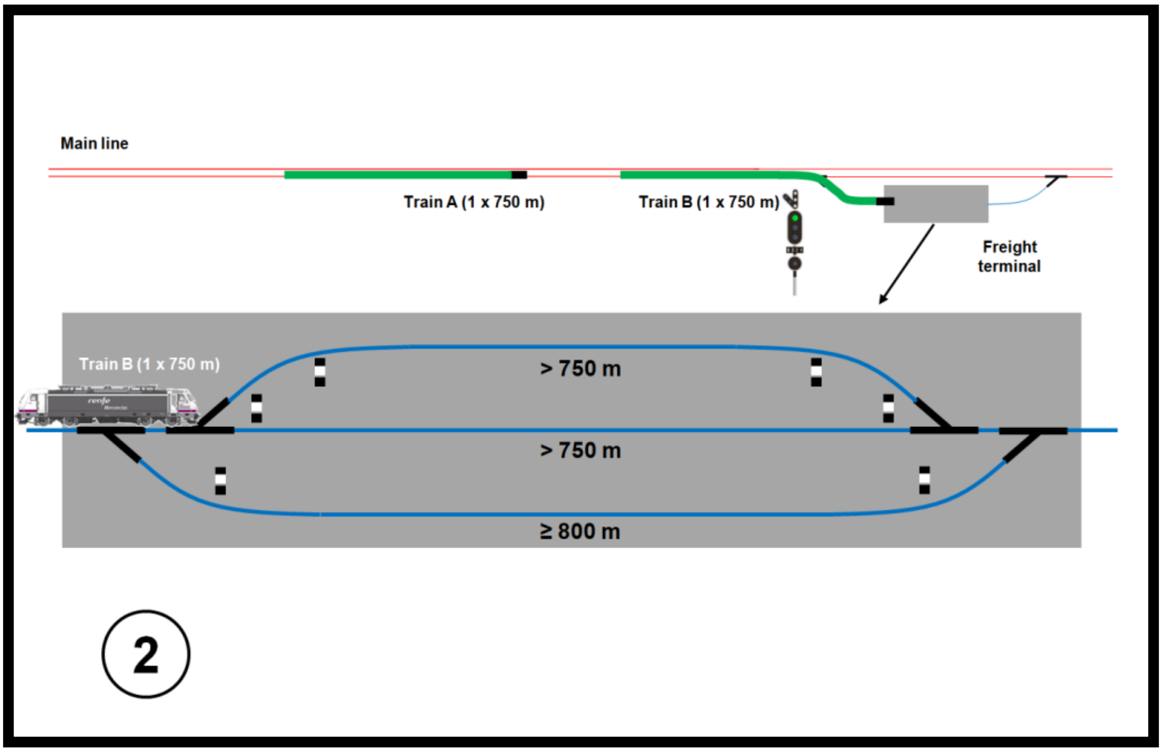

Figure 50: Terminal type A (Sequence 2) (source: ADIF)

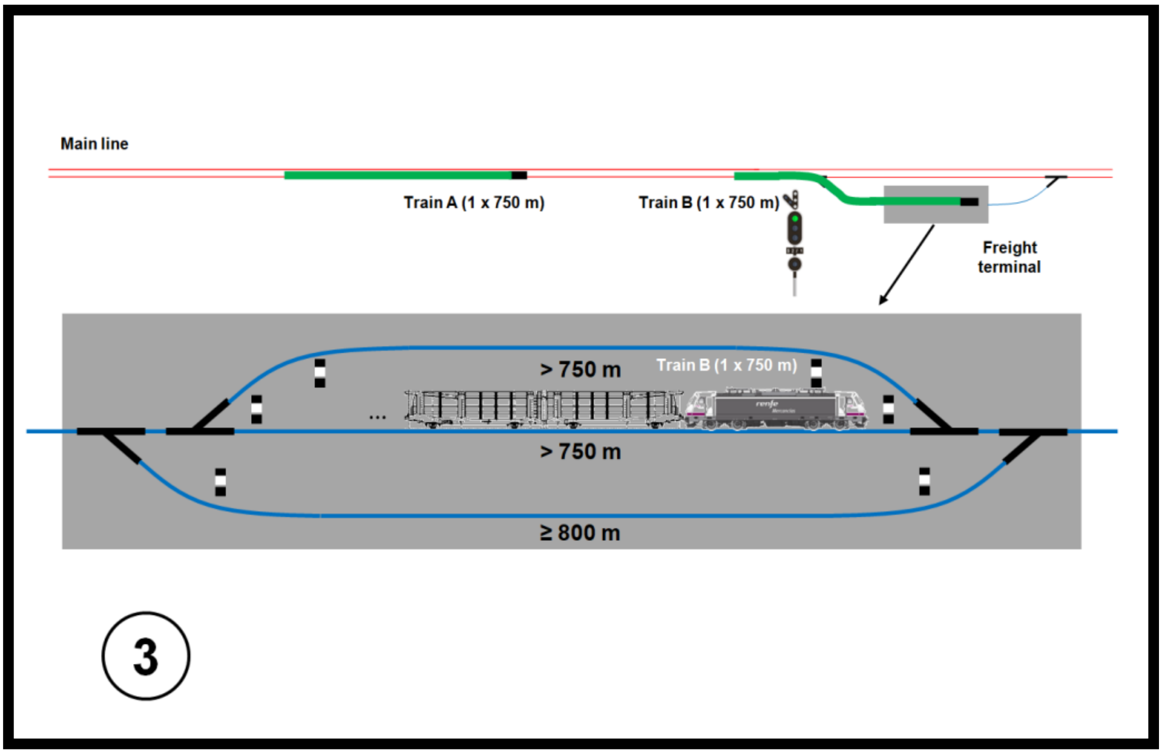

Figure 51: Terminal type A (Sequence 3) (source: ADIF)

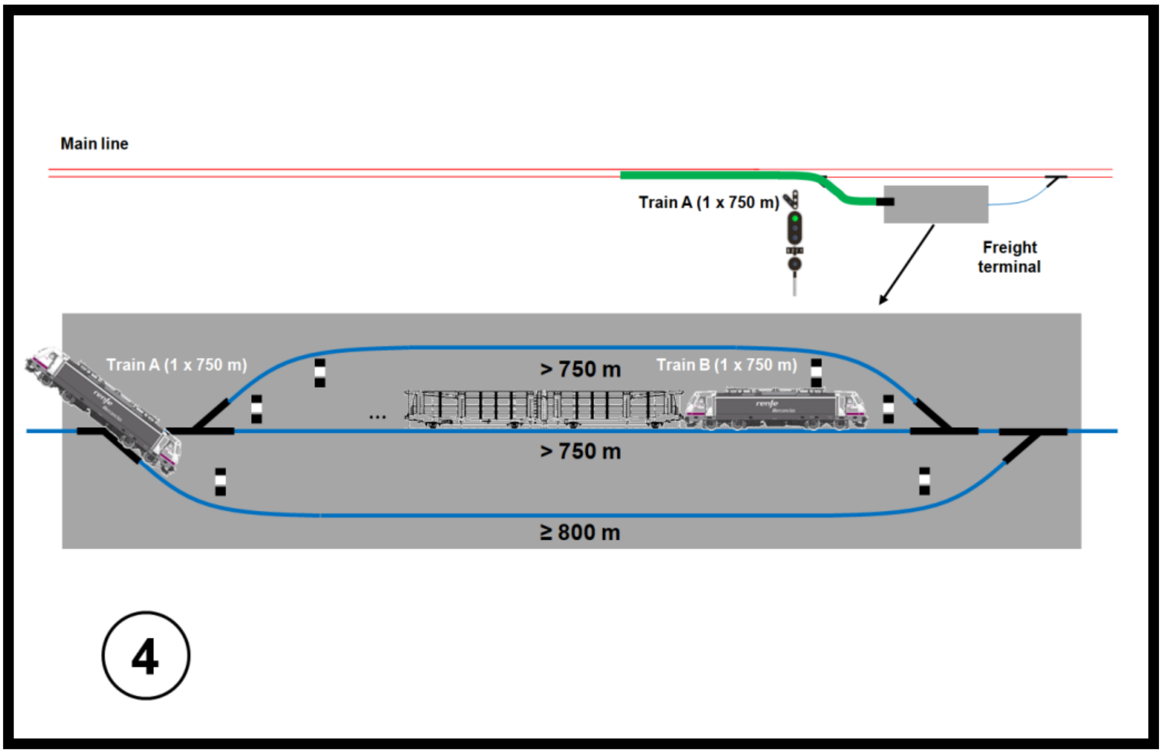

Figure 52: Terminal type A (Sequence 4) (source: ADIF)

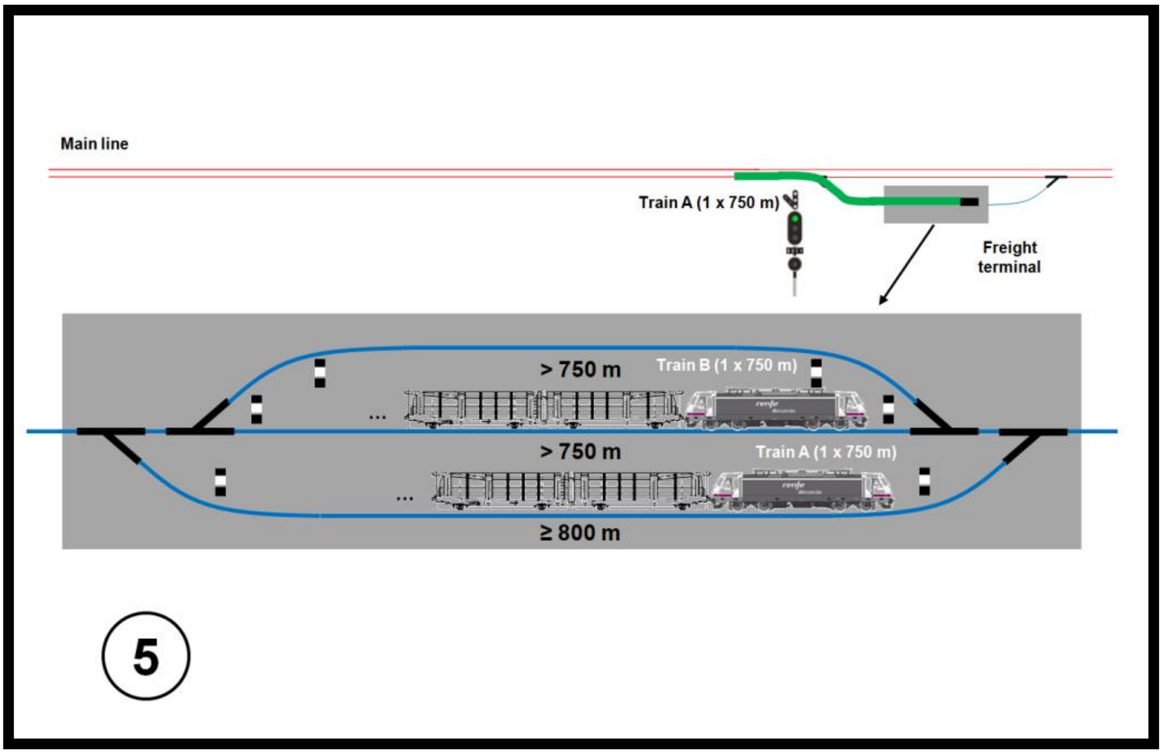

Figure 53: Terminal type A (Sequence 5) (source: ADIF)

5.1.2 Terminal type B

Figure 54 represents in a general way the typical configuration of this type of installation (only three tracks have been represented, with a length greater than 750 meters). Currently, it is not possible, for space, to design tracks higher than 900 m in these terminals. As will be seen below, new switches must be installed (in yellow in the figure) to release the locomotives.

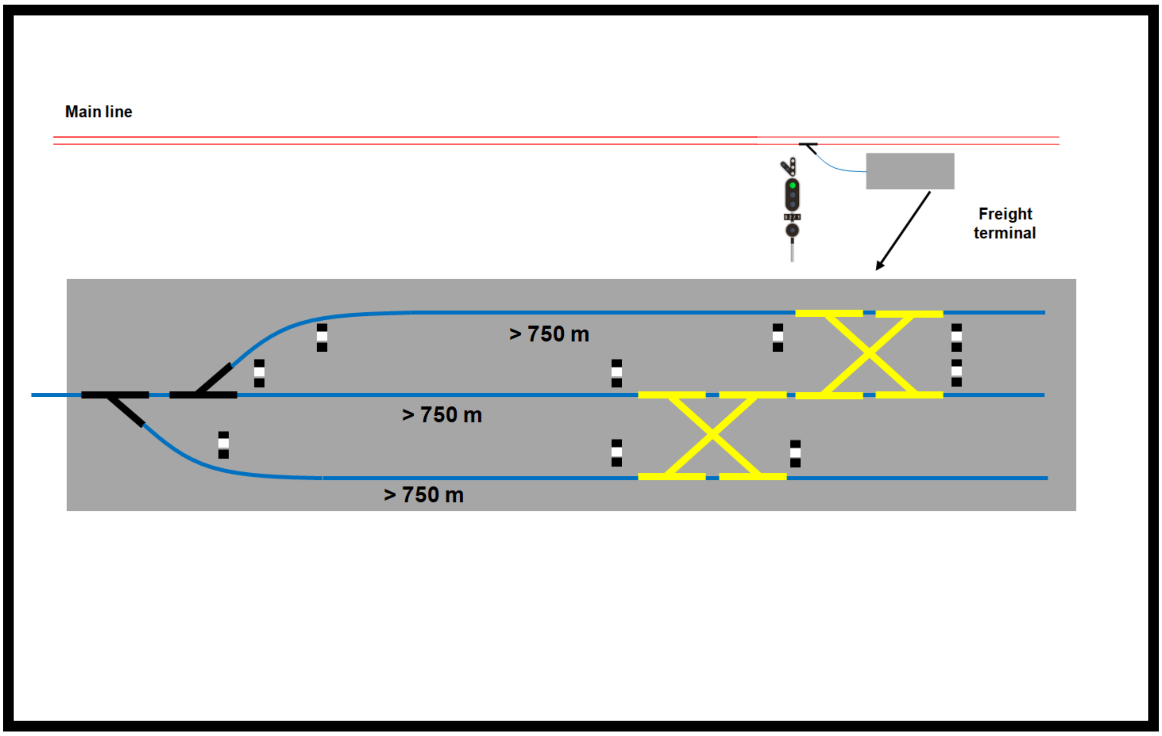

Figure 54: Terminal type B (Scheme) (source: ADIF)

Figures 55 to 59 represent, sequentially, a possible proposal for the reception of a 1.500 m freight train (formed by two trains of 750 m).This train arrives on the main line and stops before taking the switch to the terminal (Figure 55).

As before the objective is therefore to divide the two trains; First will access the front train (train B) (Figures 56 and 57) and then the rear train (train B) (Figures 58 and 59).Unlike the terminal type A, it is necessary to release the locomotives using a new system of switches.

It should be noted that the necessary resources must be considered to be able to carry out the division of the train on the main line (here not contemplated now).

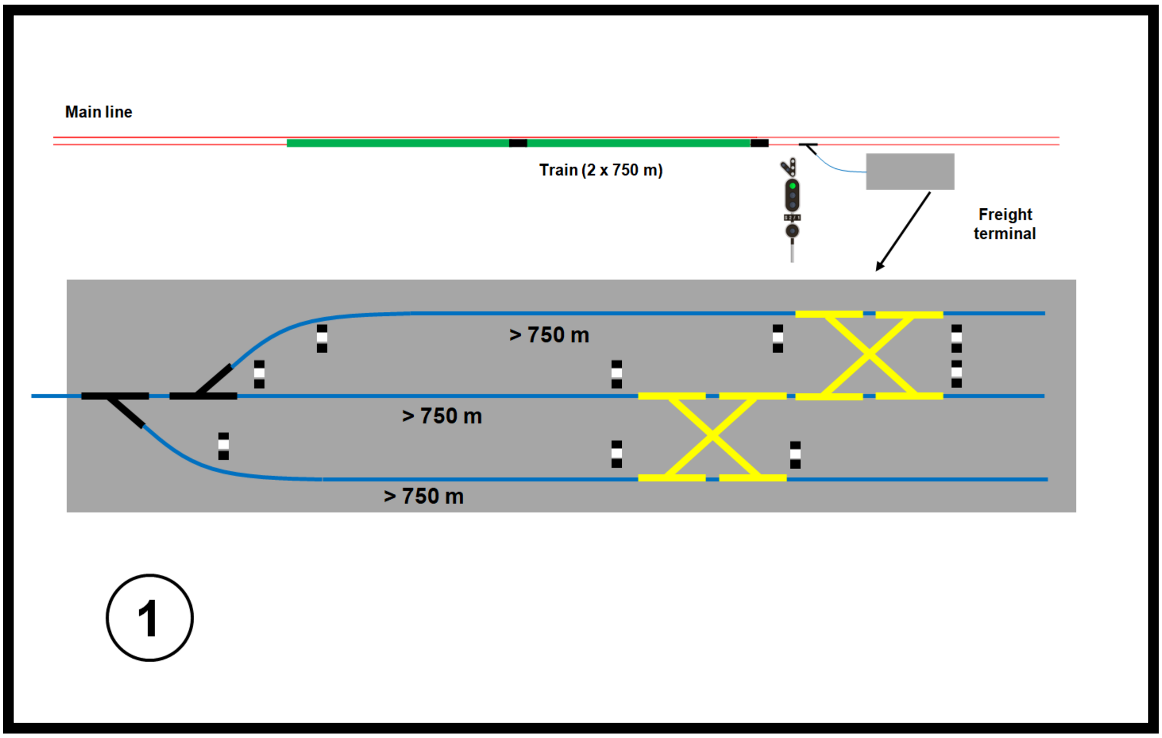

Figure 55: Terminal type B (Sequence 1) (source: ADIF)

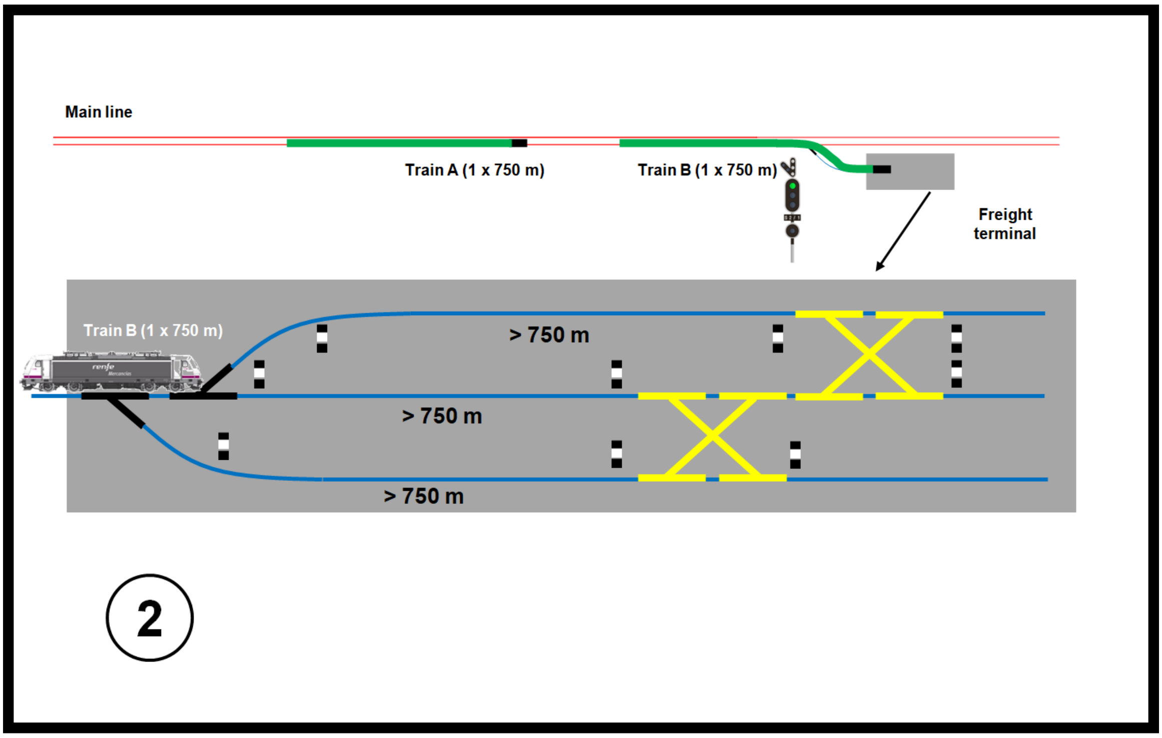

Figure 56: Terminal type B (Sequence 2) (source: ADIF)

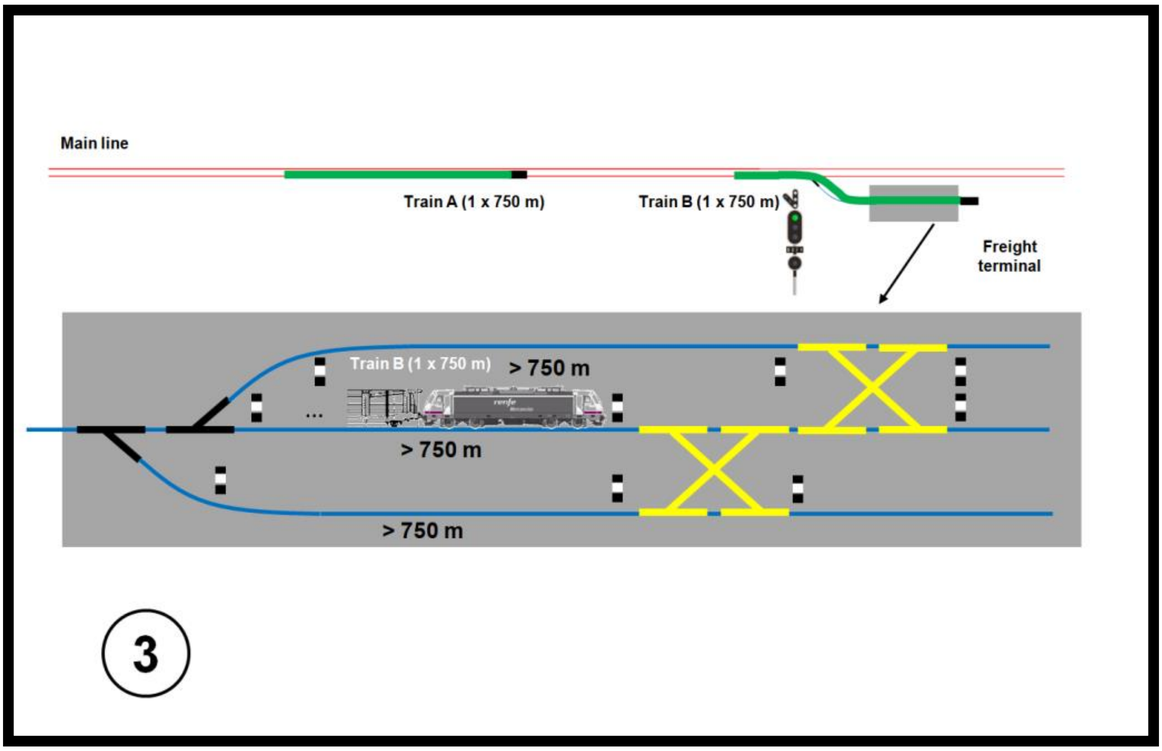

Figure 57: Terminal type B (Sequence 3) (source: ADIF)

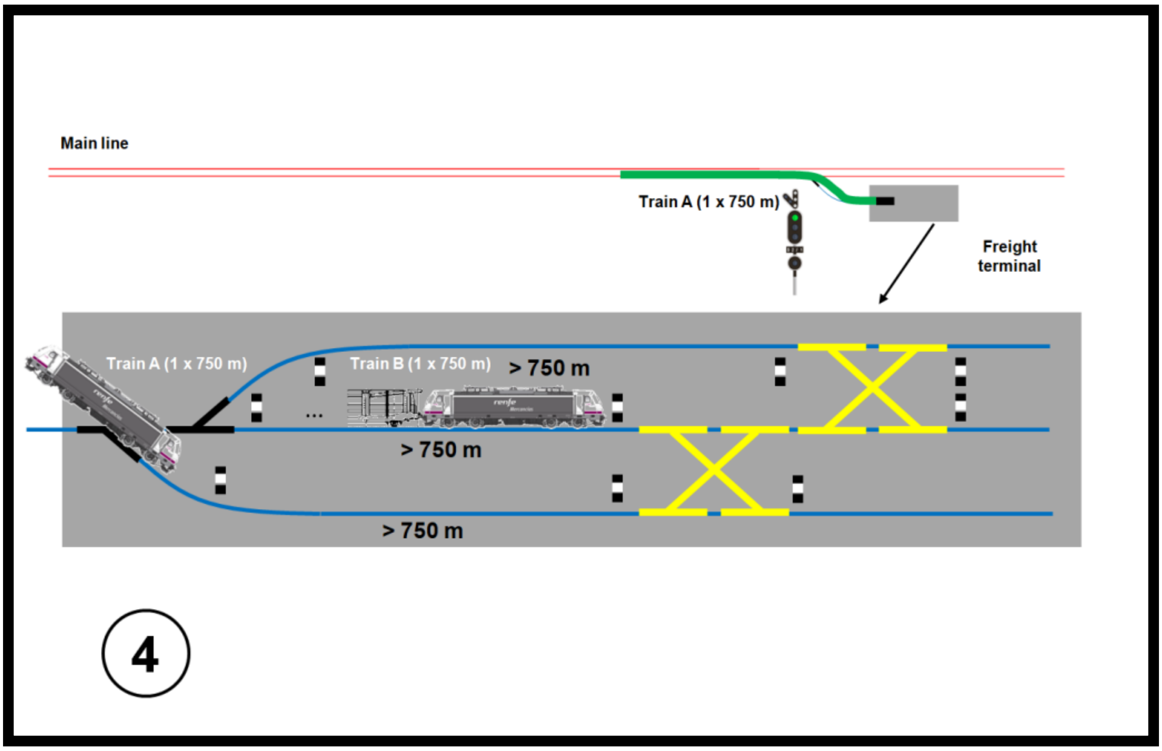

Figure 58: Terminal type B (Sequence 4) (source: ADIF)

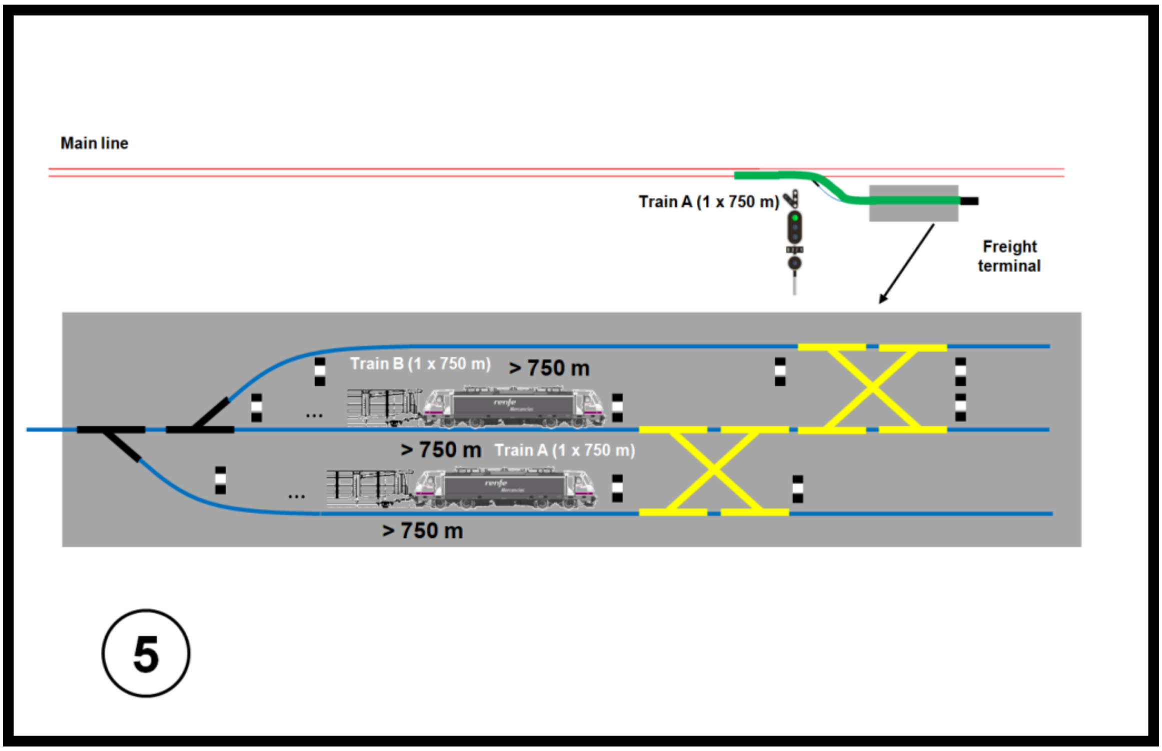

Figure 59: Terminal type B (Sequence 5) (source: ADIF)

5.2 Change Gauge Terminals

Figure 60 represents in a general way the configuration of this type of installation (there may be an exchange axle facility or a change gauge facility). At both ends there are two auxiliary lines, one gauge 1.668 mm and another gauge 1.435 mm. There are parking track on both lines.

There is another parking track about 800 m from the terminal. On this track an auxiliary machine is parked to support the operation.

Figures 61 to 75 represent, sequentially, a possible proposal for the operation of a 1.500 m freight train (formed by two trains of 750 m).This train arrives on the main line and stops before taking the switch to the terminal (Figure 61).

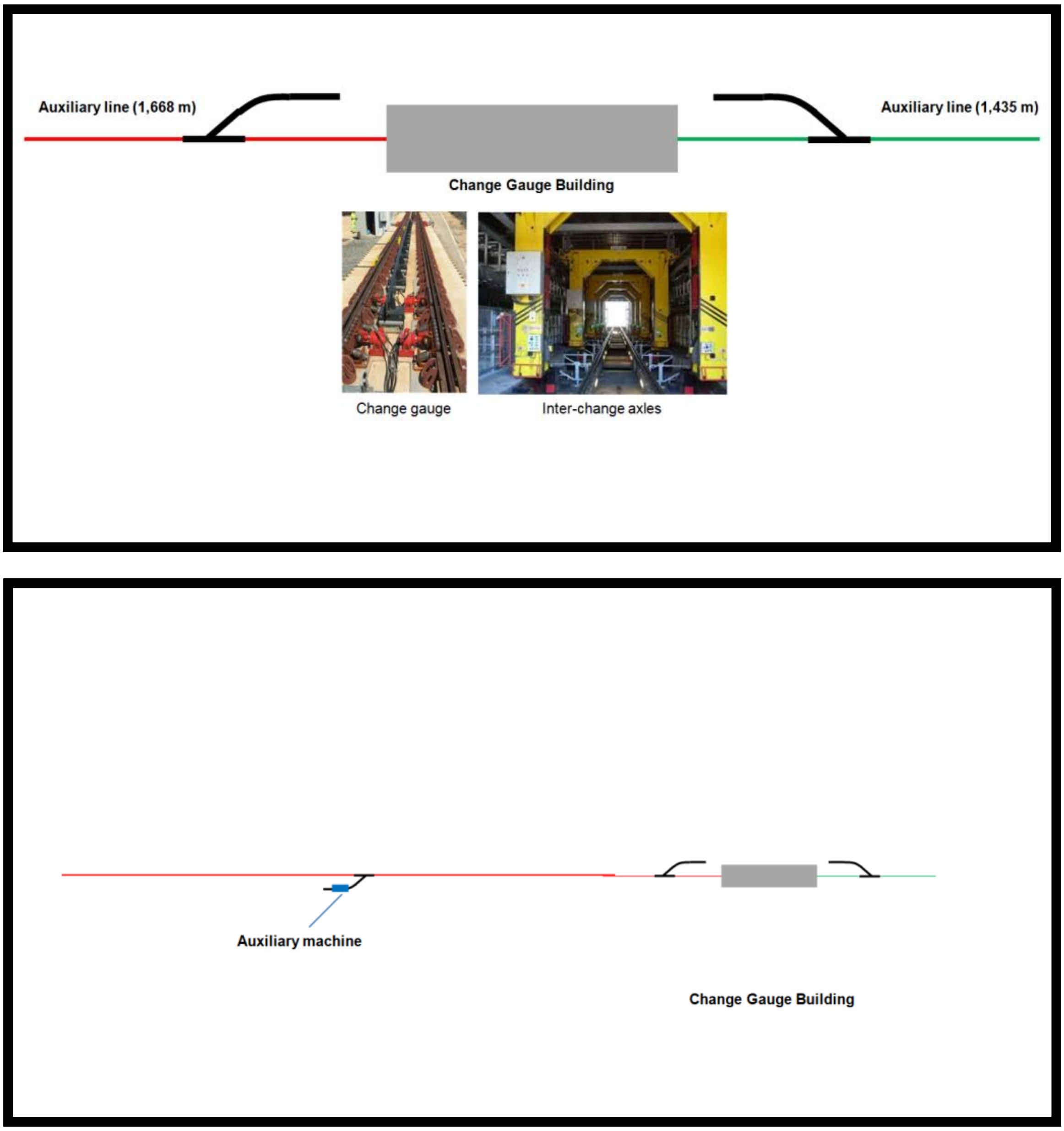

Figure 60: Change gauge terminal (Scheme) (source: ADIF)

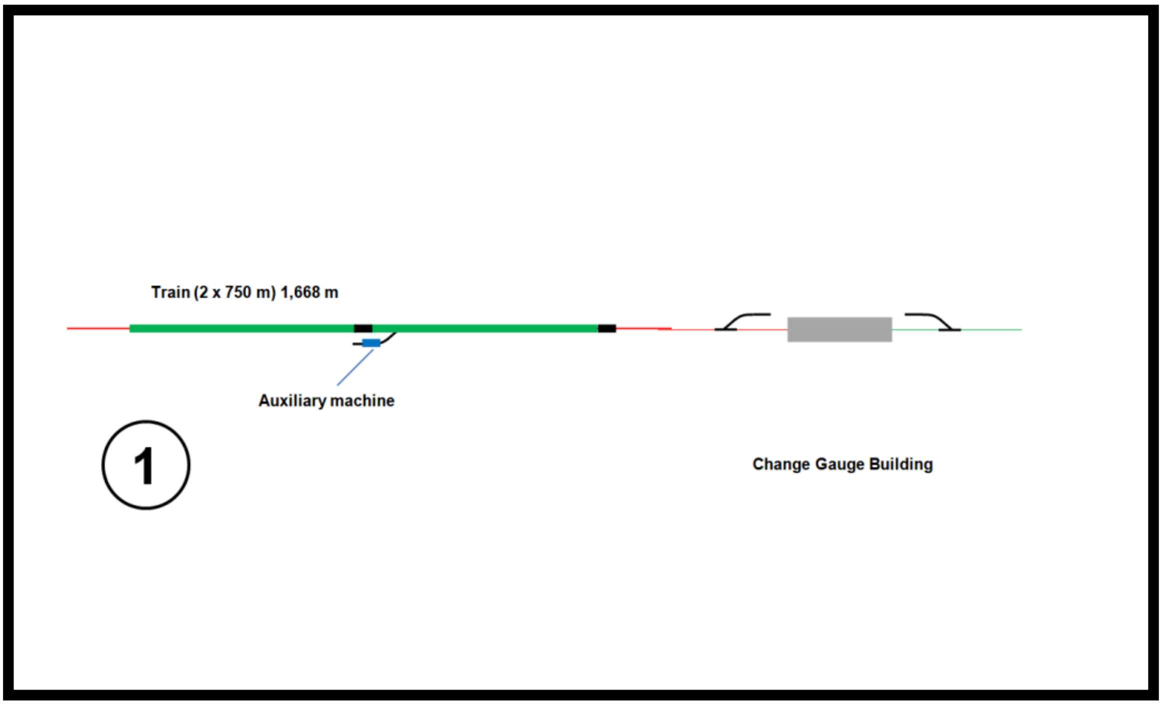

Figure 61: Change gauge terminal (Sequence 1) (source: ADIF)

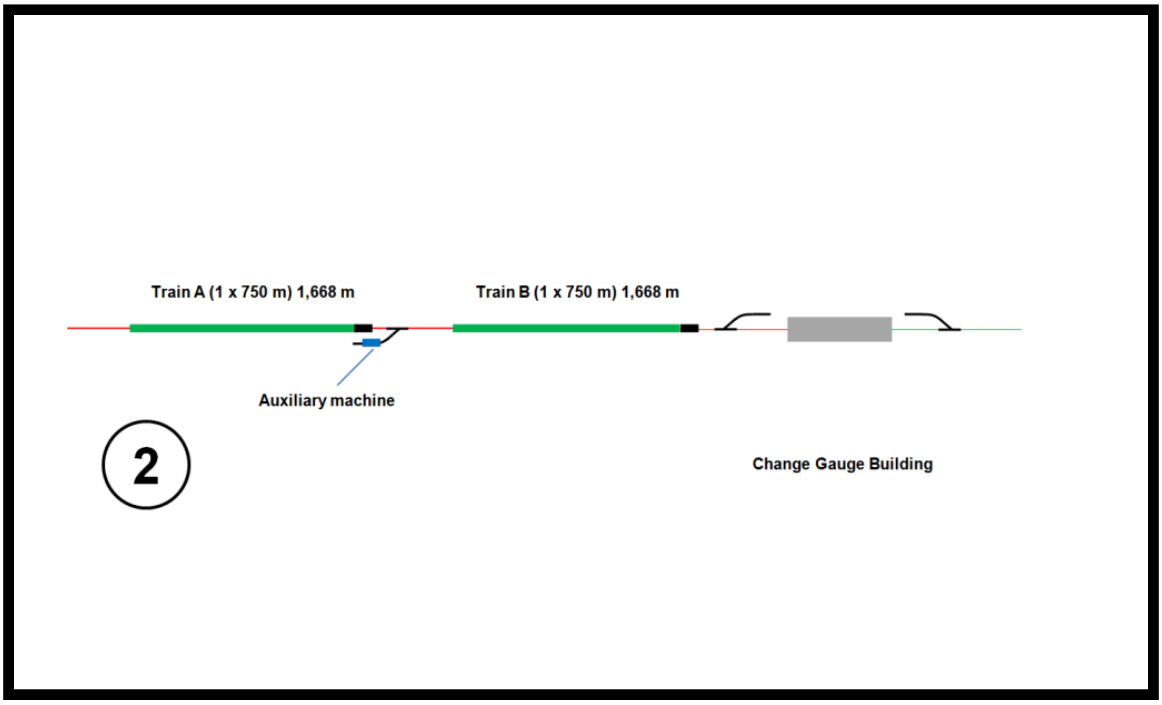

Figure 62: Change gauge terminal (Sequence 2) (source: ADIF)

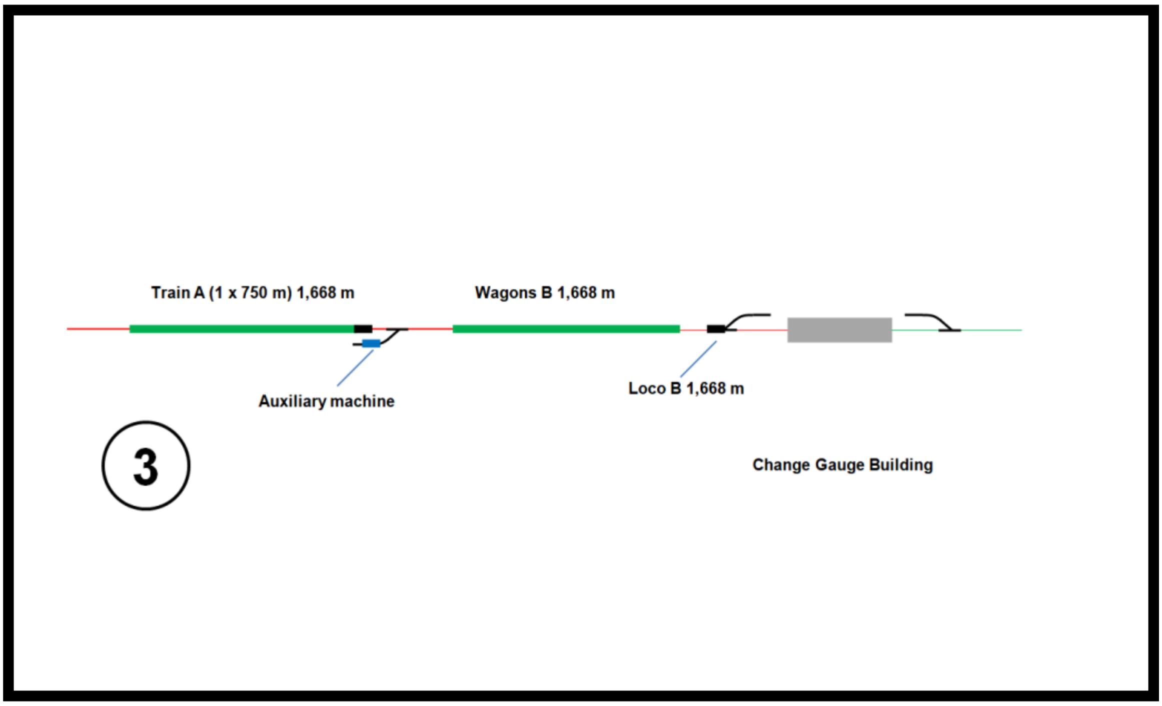

Figure 63: Change gauge terminal (Sequence 3) (source: ADIF)

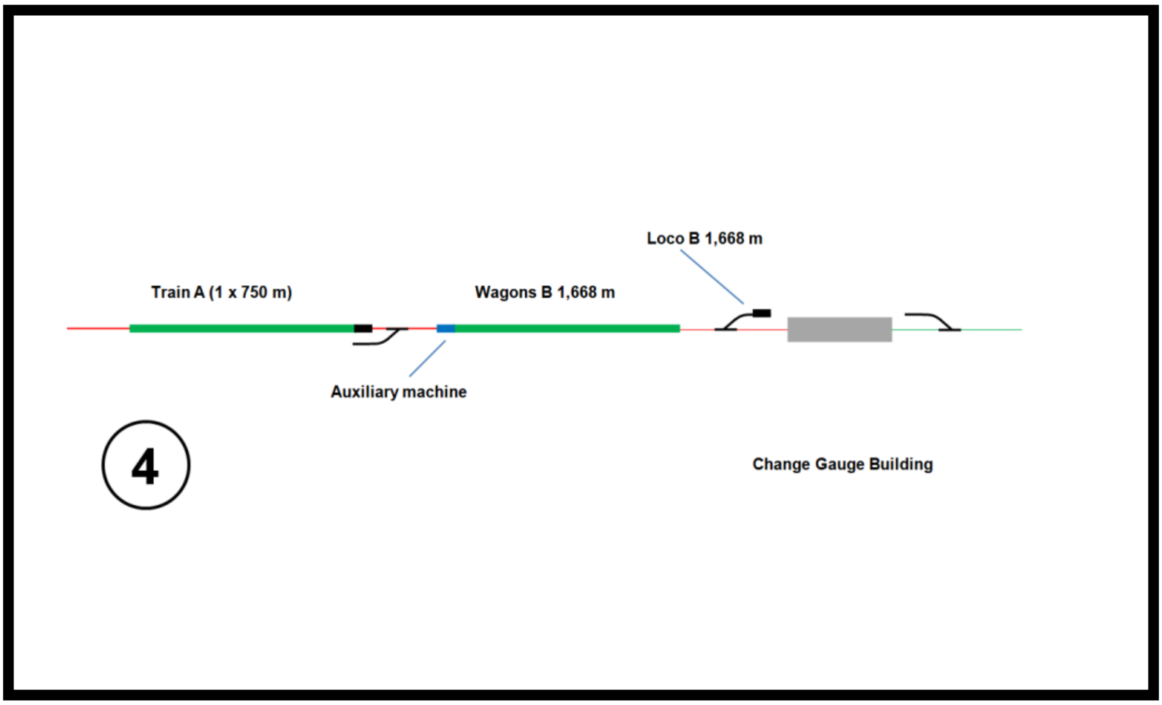

Figure 64: Change gauge terminal (Sequence 4) (source: ADIF)

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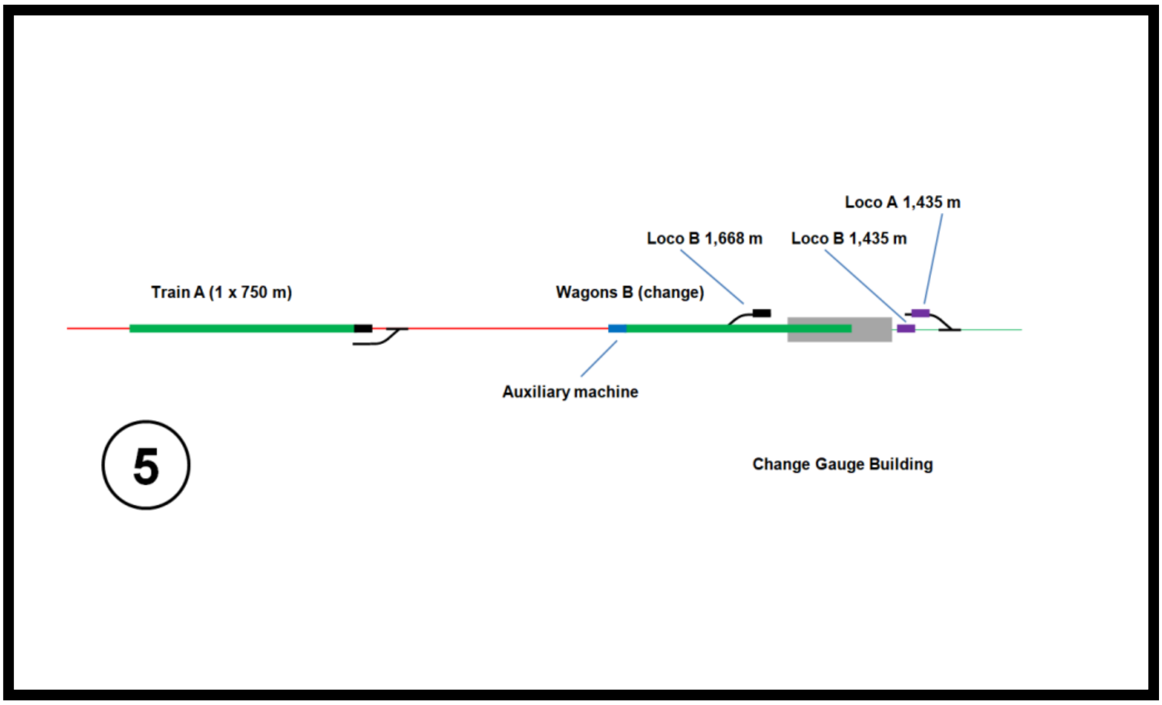

Figure 65: Change gauge terminal (Sequence 5) (source: ADIF)

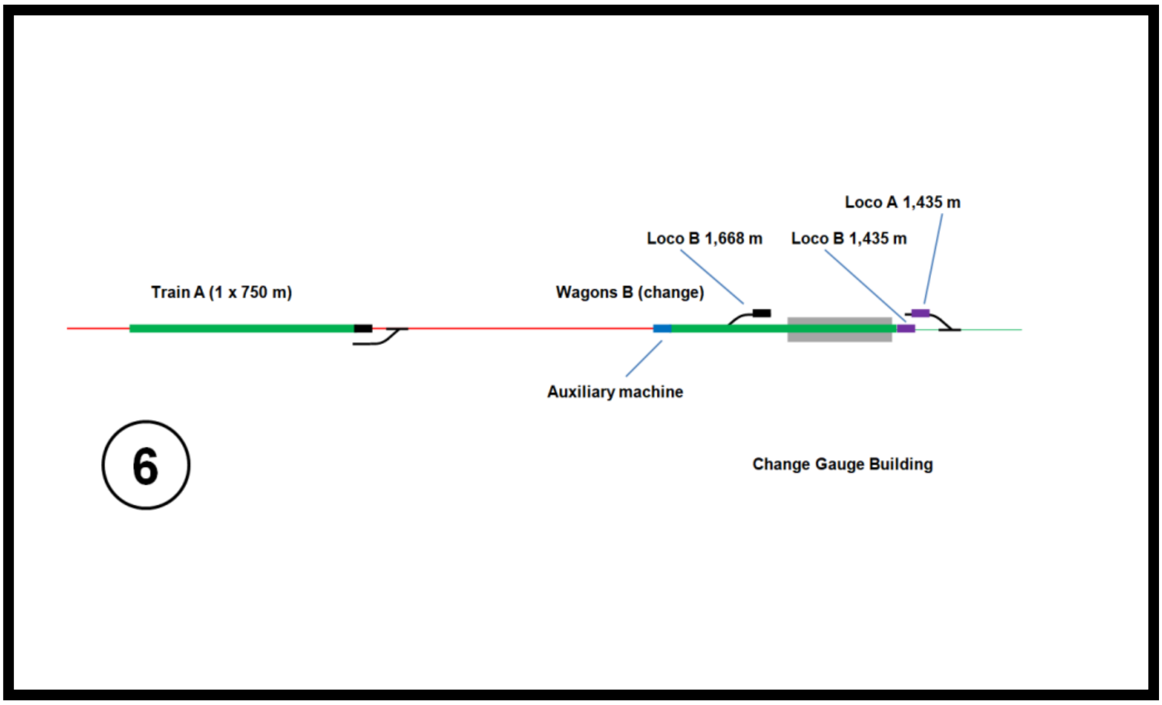

Figure 66: Change gauge terminal (Sequence 6) (source: ADIF)

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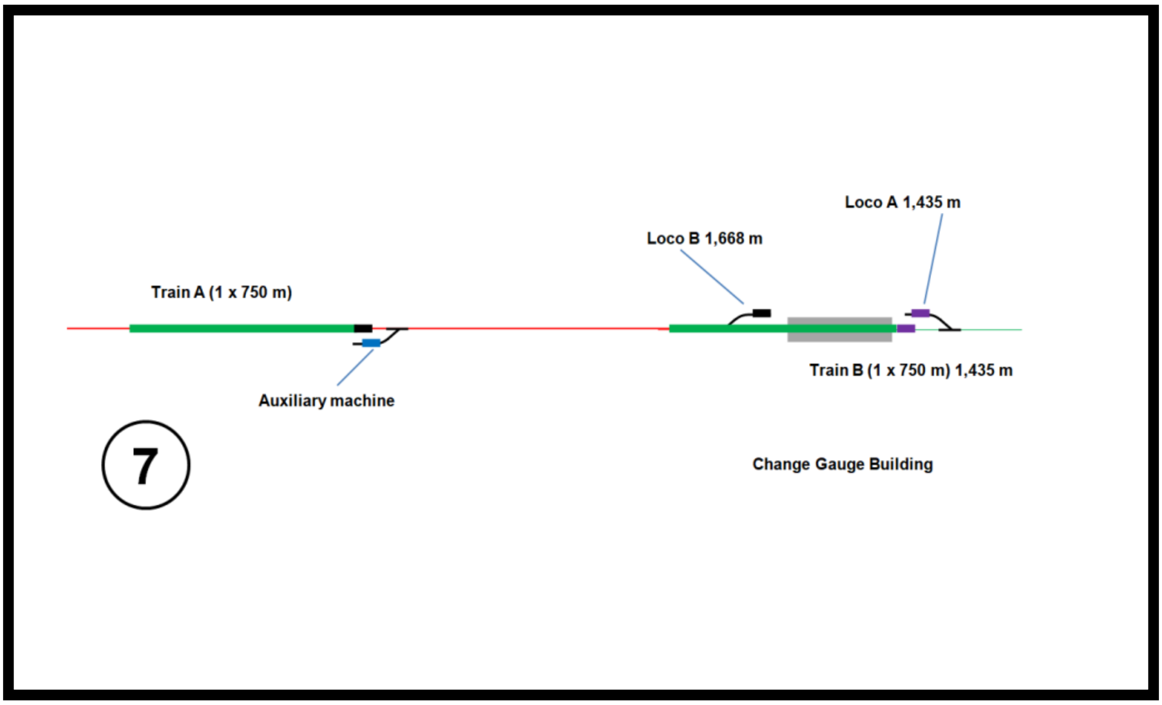


Figure 67: Change gauge terminal (Sequence 7) (source: ADIF)

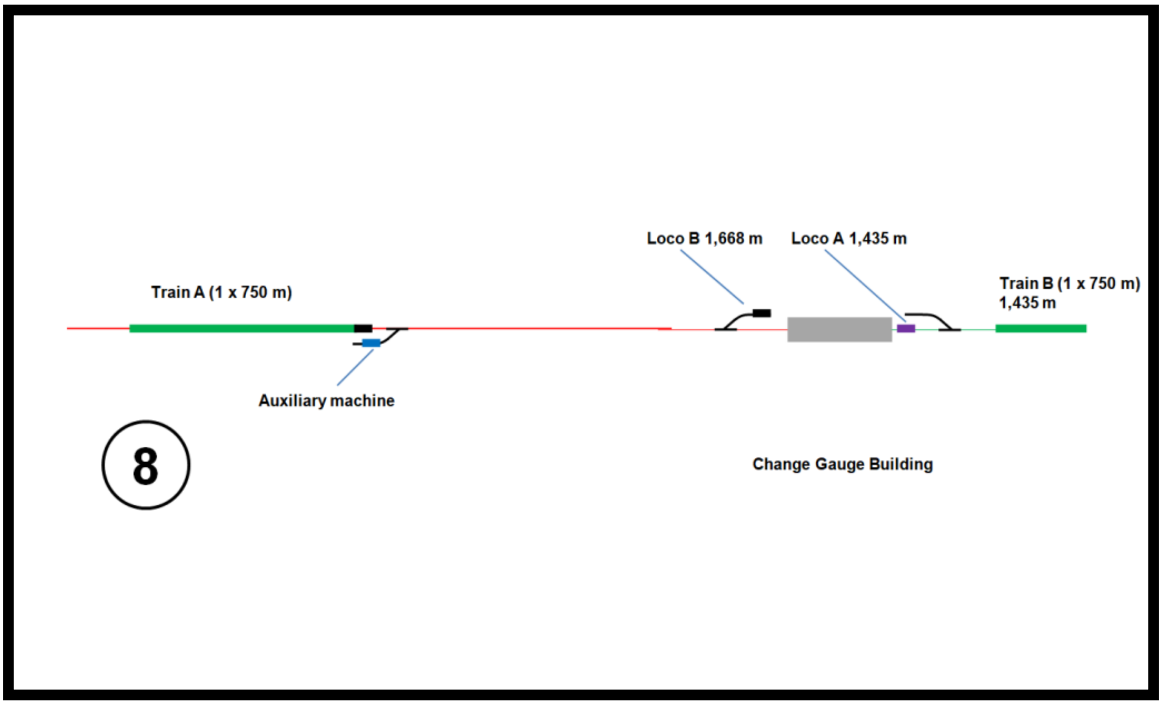


Figure 68: Change gauge terminal (Sequence 8) (source: ADIF)

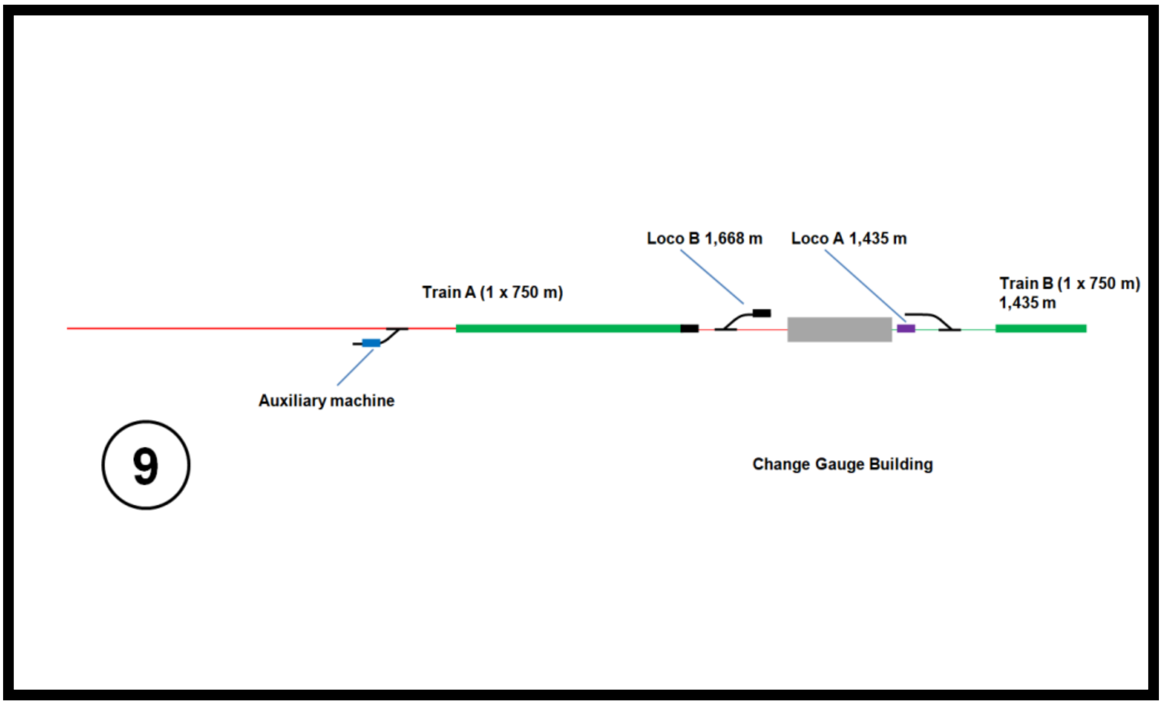


Figure 69: Change gauge terminal (Sequence 9) (source: ADIF)

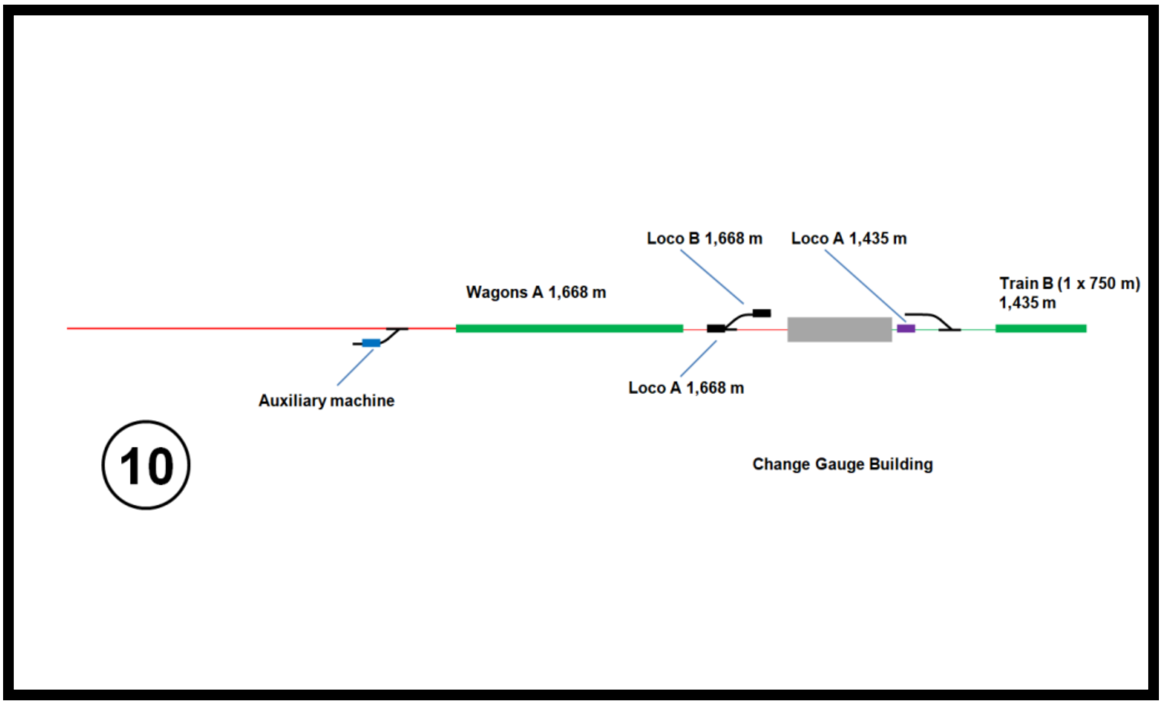


Figure 70: Change gauge terminal (Sequence 10) (source: ADIF)

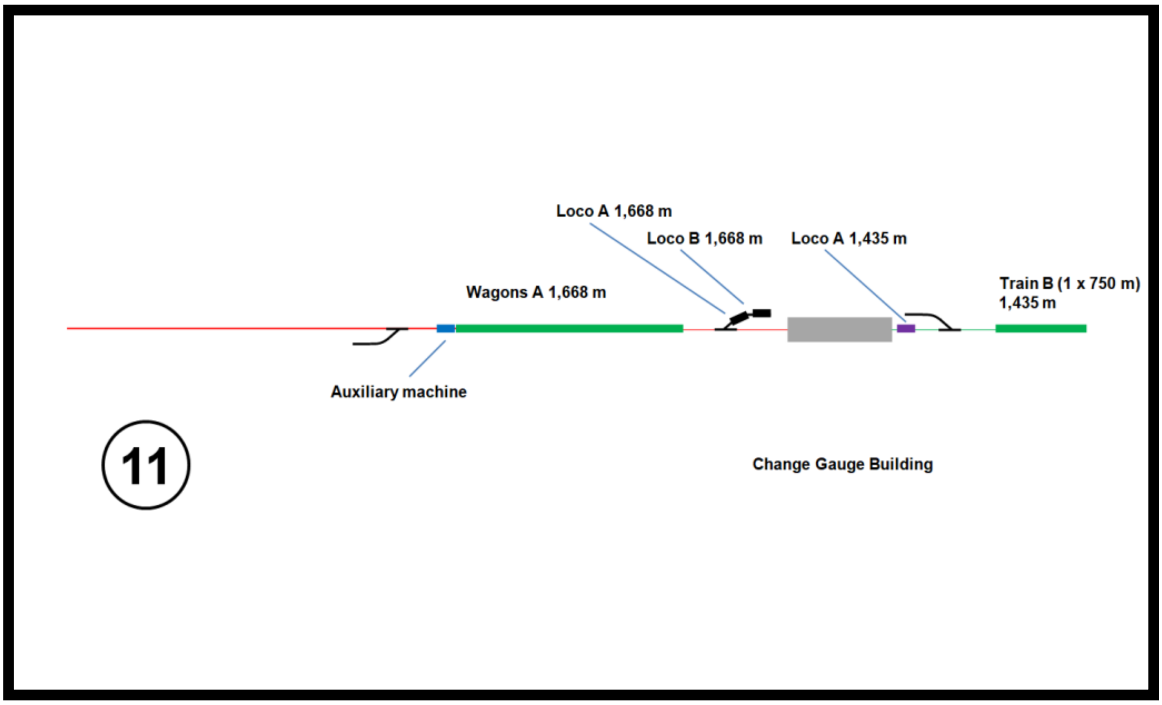


Figure 71: Change gauge terminal (Sequence 11) (source: ADIF)

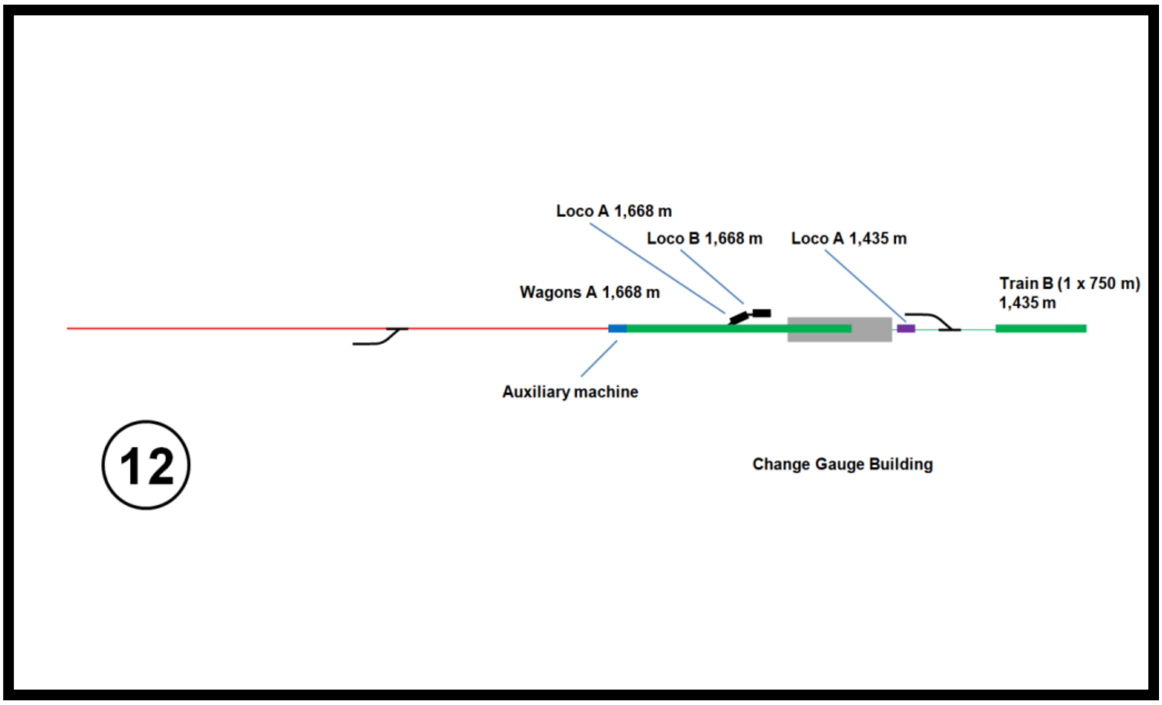


Figure 72: Change gauge terminal (Sequence 12) (source: ADIF)

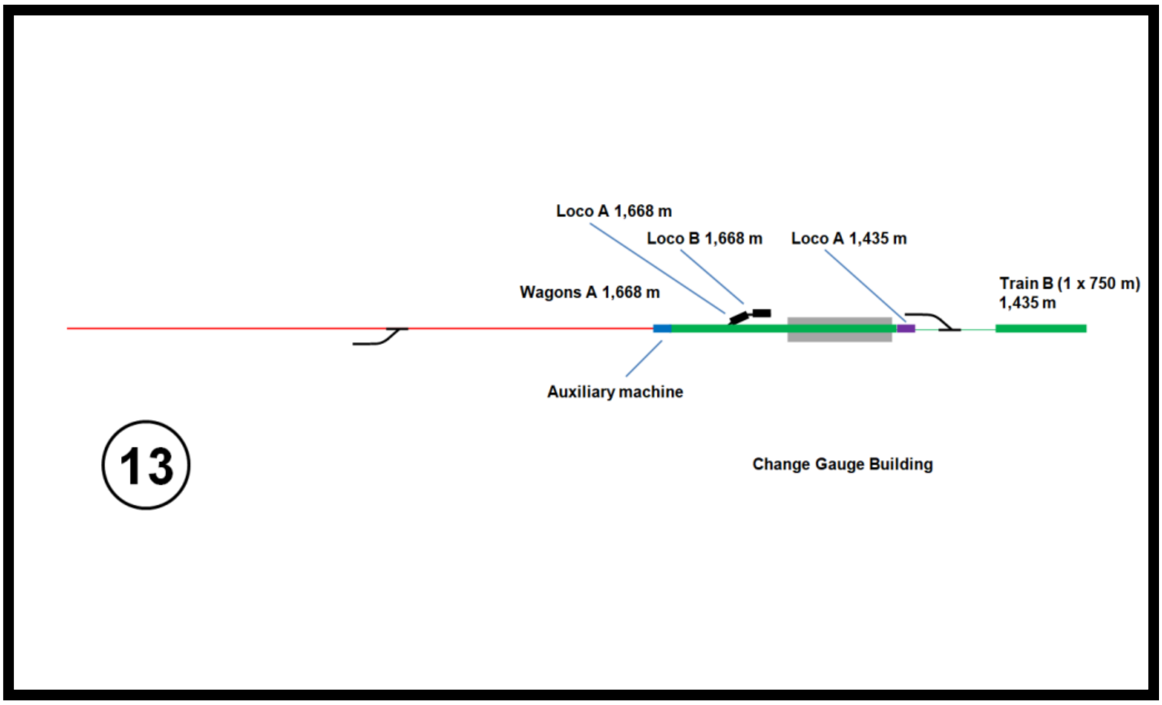


Figure 73: Change gauge terminal (Sequence 13) (source: ADIF)

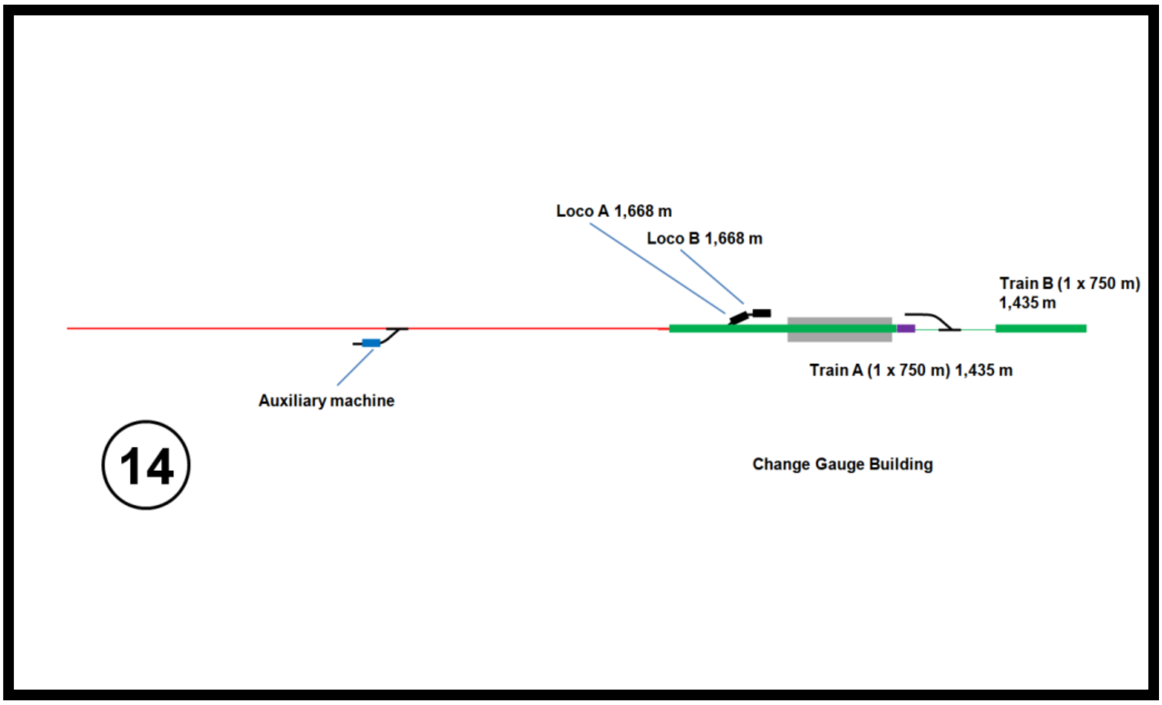


Figure 74: Change gauge terminal (Sequence 14) (source: ADIF)

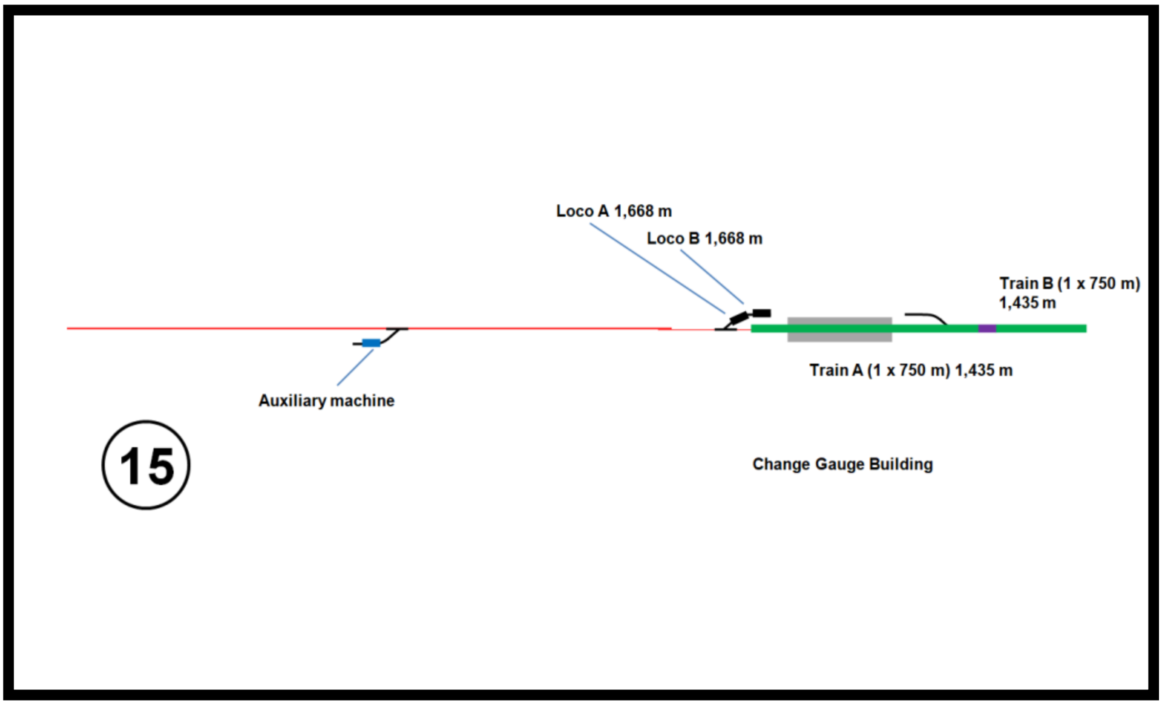


Figure 75: Change gauge terminal (Sequence 15) (source: ADIF)

6. CONCLUSIONS

- Currently it is more interesting to increase the length of freight trains instead of their axle load. In the case of old lines, there may be technical restrictions that impede the circulation of trains with higher load per axle than the standard one. In the case of new lines, these restrictions would not exist but maintenance would be generally greater.

- The increase in the length of the trains does have greater effects on traffic management, although in this case, adequate operation strategies can be applied.

- From a point of view of affection to the infrastructure, the interaction with long trains is more interesting in the Atlantic Corridor than in the Mediterranean Corridor. In this way the analysis is done in the first one, being totally extrapolated to the rest of the lines (if the trains of these characteristics can circulate in this Atlantic Corridor, they can do it in the Mediterranean Corridor).

- The train length is limited with given train parameters by: National regulations; Gradients on the line sections; and tracklength limitations combined with operational guidelines of the IM.Generally, the national regulations of all countries allow long trains up to 740 m. In Spain, national regulation limits trains to 750 m and 2.500 t maximum train weight. The maximum speed of freight trains is 100 km/h.

- It has been considered that in no case should the maximum weight value (2.500 t) currently regulated by national regulations be exceeded. In this way it is intended that the results of the present analysis can be realistic, establishing only the value of the train length as variable.

- There are two different kinds of long trains: One or two locomotives with more wagons than standard; Two locomotives connected over remote control. Connecting two trains with one locomotive in the front and one in the middle over remote control is not regularly used yet and has to be studied.

- Specifically, it is proposed to carry out a general analysis of the condition, considering four (4) main sections: Operational conditions; Assets (components of the infrastructure itself); Safety (impact); and Maintenance (impact).

- Operation conditions with impact: Capacity, Composing & Decomposing, Train dynamic, Braking,Train aerodynamic (Cross Wind) and Gauge change.

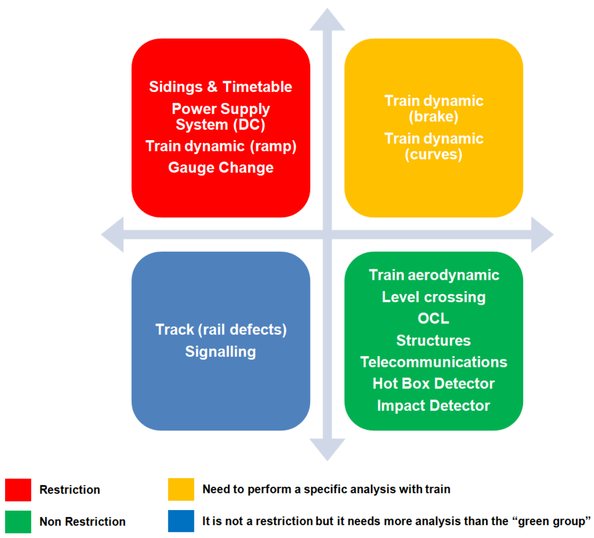
- Assets with impact: Track geometry, Joints, Rails, S&C, Contact Wire, Power, Signalling systems, Block sections, Radio system and Detectors.

  - Since 2013, the railway sector has been affected by different European Directives that establish the need to apply a common safety method when a change in infrastructure or rolling stock is required. According to this change is significant or not significant, different actions must be carried out that can lead to a risk analysis of that change. In general terms, the operation of freight trains longer than 750 m would be a significant change with an impact on the safety of the infrastructure and the rolling stock. Analyzing each criterion separately, ADIF has concluded that around 34% of the criteria considered will be significant changes.

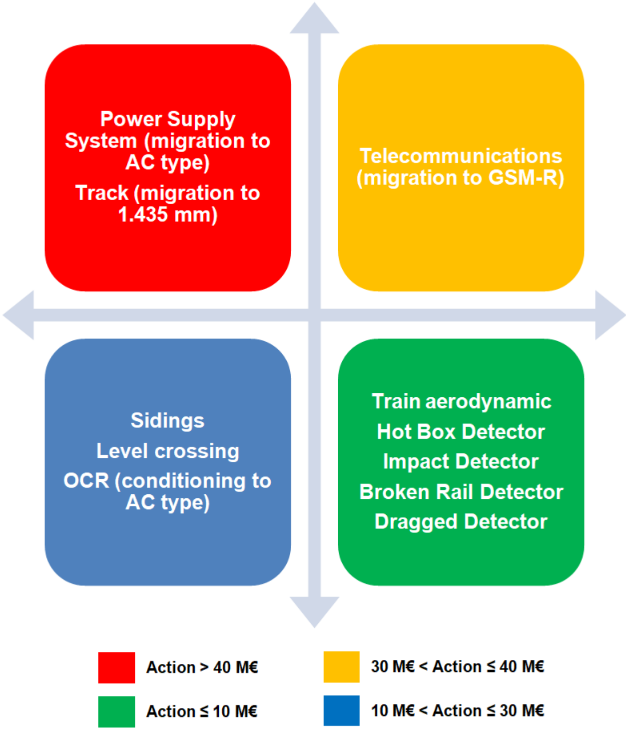
- The impact of the new freight trains on the maintenance of the infrastructure is a very interesting aspect to take into account. It should be noted that since there are no experiences with this type of traffic, only a series of theoretical estimates can be made according to the criteria analyzed above. This type of analysis would be similar to those already carried out on high-speed lines to analyze what is the impact on the maintenance of the infrastructure when the speed of trains is increased.

- Assets with impact on maintenance: Track (Geometry), Joints, Rail, S&C, Contac Wire and Change Gauge Facility.

- It's analyzed the circulation of long trains in the section of line considered in the Atlantic Corridor (PS5, PS6 and PS7 sections). The main conclusions obtained in the analysis carried out schematically:



- It´s analyzed what aspects should be taken into account in the design and subsequent operation of long freight trains on a railway line. Since the approach can be complex, since the variability of cases would be practically unapproachable, the following exercise is proposed: Carry out the analysis on the same route considered in the Atlantic Corridor, taking into account that the layout can not be modified in any way by economically unviable; Carry out the analysis in a new line with characteristics similar to the previous one, but considering that there is a greater freedom of design.



- It’s analyzed what should be the technical aspects to be taken into account in the freight terminals that receive trains with a maximum length of 1.500 m. The analysis is really complex because of its great variability, having to establish a series of previous criteria that limit development. In this sense, a very preliminary analysis is presented here that should be complemented in the future in other projects. On the other hand, considering the Spanish problems (which can also be extrapolated to other European countries and borders), the conditions that would occur in the case of carrying out a change of gauge operation in a terminal of this type have also been contemplated here.

- In general, the operation of changing gauge with long trains is very complex. In the case of freight terminals, in principle it can be carried out.

7. REFERENCES

A. Marqueteeken, A. Van Leuven, and F. Kopf, “Rail wear in curves and special trackwork for trams,” URBAN TRACK Deliverable D2.8, European Commission 6th Framework Programme, 2008.

A. Toubol, F. Castagnetti, B. Olsson, “CAPACITY4RAIL project. The wagon load activity technology innovations: new freight wagons and trains”. Transport Research Arena 2014, Paris.

C4R. Deliverable 24.3. August 2017.

CEN: European Committee for Standardization, “Railway applications. Switches and crossings.Crossing components made of cast austenitic manganese steel,” British Standard BS EN 15689:2009, British Standards Institution. February 2009.

CER, “Longer trains. Facts & Experiences in Europe. Results of the CER working group on longer and heavier trains”. CER. May 2016.
EEIG Corridor Rotterdam–Genoa EWIV,“Study Long Trains (740m) on Corridor Rotterdam-Genoa. Final public report”. EEIG Corridor Rotterdam–Genoa EWIV (Members: ProRail B.V., DB Netz AG, RFI S.p.A.; Associates: Infrabel S.A., SBB AG, BLS Netz AG, Trasse Schweiz).

European Commission, “Mediterranean Core Network Corridor Study. Final report”. European Commision. December 2014.

European Commission, “Atlantic Core Network Corridor Study. Final report”. European Commision. December 2014.

H. A. Aglan, “Fatigue crack growth and fracture behavior of bainitic rail steels,” Tech. Rep. DOT/FRA/ORD-11/17, Federal Railroad Administration, U.S. Department Of Transportation. September 2011.

INNOTRACK Consortium, “Deliverable overview,” summary, European Commission 6th Framework Programme. April 2010.

INNOTRACK Consortium, “Quantification of benefit available from switch and crossing monitoring,” Tech. Rep. Deliverable D3.3.6, European Commission 6th Framework Programme. October 2009.

INNOTRACK Consortium, “Recommendation of, and scientific basis for, optimisation of switches & crossings - part 1,” Innotrack Guideline Deliverable D3.1.6: Part 1, European Commission 6th Framework Programme, 2009. October 2017.

INNOTRACK Consortium, “Recommendation of, and scientific basis for, optimisation of switches & crossings - part 2,” Innotrack Guideline Deliverable D3.1.6, European Commission 6th Framework Programme, 2009.

INNOTRACK Consortium, “Report on cost drivers for goal-directed innovation,” Deliverable D3.1.2, European Commission 6th Framework Programme. July 2008.

INNOTRACK Consortium, “Summary of results from simulations and optimisation of switches,” Deliverable D3.1.4, European Commission 6th Framework Programme. February 2009.

NR, “Inspection and maintenance of permanent way - specific requirements for switches and crossings,” Network Rail Company standard NR/L2/TRK/001/D01, Issue 4, Network Rail. December 2009.

ORR,“Common Safety Method for risk evaluation and assessment. Guidance on the application of Commission Regulation (EU) 402/2013”.ORR. March 2015.

R. Buda, “Long-term effects of interaction between rolling stock and track/turnout components regarding maintenance intervals and durability,” in World Congress on Railway Research, Montreal, 2006.

RIVAS. Definition of wheel maintenance measures for reducing ground vibration. Deliverable D2.7. November 2013.

RIVAS. Guideline for Design of Vehicles Generating Reduced Ground Vibration. Deliverable D5.5. December 2013.

RIVAS. Overview of Methods for Measurement of Track Irregularities. Important for Ground-Borne Vibration. Deliverable D2.5. July 2013.

UIC Project: Broken Rail Detection Systems. WP1: State of the art analysis. Report. Carl Ritter von Ghega Institute forIntegrated Mobility ResearchUniversity of Applied Sciences, St. Pölten. Authors: Hirut Grossberger, Martin Kalteis, Frank Michelberger.

8. APPENDICES

8.1 Appendix 1 (Maximum length of freight trains in Spain (Map))

Annex attached to the Deliverable

8.2 Appendix 2 (Characteristics of the Atlantic corridor (Maps))

Annex attached to the Deliverable

8.3 Appendix 3 (DC Electrical Substations in Spain (Map))

Annex attached to the Deliverable

8.4 Appendix 4 (Siding in Atlantic Corridor (Schemes))

Annex attached to the Deliverable

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