Annex 9 – Identification of the rail infrastructure investment cost drivers

The REGIO Rail Unit Cost Benchmarking Tool (RRUCBT) is designed to perform a benchmark analysis and verify whether the investment cost of a rail infrastructure project is comparable to the investment cost of similar projects. These projects are identified based on their similarity in terms of endogenous (e.g. design speed, technical specifications, etc.) and exogenous factors (e.g. presence of urban environment, presence of mountainous terrain, etc.) impacting on the investment cost of rail infrastructure projects.

The RRUCBT translates these factors into filters applied to the data background to select sample of projects to consider for the benchmark. In case the sample matching all the characteristics of the investment under assessment results to be too limited, the information related to the least relevant factor is discarded in the selection of the clusters. The process is reiterated until a sufficient sample can be identified (see figure below).

Therefore, to define the logic of the RRUCBT it was preliminarily necessary to:

- identify the cost-drivers impacting on rail infrastructure projects,
- assess the relevance of these cost-drivers to define the prioritisation logic.

Figure 1 – The creation of the clusters for the benchmark analysis

	Project under assessment	Sample 1	Sample 2	Sample 3
Type of works	New line	New line	New line	New line
Infrastructure category	High-speed	High-speed	High-speed	High-speed
Design speed	301 km/h – 350 km/h	301 km/h – 350 km/h	301 km/h – 350 km/h	301 km/h – 350 km/h
Environment	Rural	Rural	Rural	Rural
Terrain	Flat	Flat	Flat	Flat
Line category	Passenger	Passenger	Passenger	
Axial load	> 8,5 ton/m	> 8,5 ton/m		
		12 projects	**20 projects**	**41 projects**

The cost-drivers of rail infrastructure projects as well as the relevance of their impact on investment cost were defined with the involvement of **rail infrastructure experts** and were validated by the analysis of the **relevant literature** on the matter (mentioned in this annex and fully presented in Annex 5). Additionally, in case a sufficient number of projects presenting determined characteristics was included in the database, the impact of each cost driver has been assessed **empirically** through analysis performed on the database. It should be noted that the analysis performed were designed to assess the impact of the cost drivers in order to proceed with the prioritisation, while the actual magnitude of the impact will be evaluated on the basis of the benchmark results provided by the REGIO Rail Unit Cost Benchmarking Tool itself.

Further, it shall be noted that the exercise has been performed considering the trade-off between the usability of the REGIO Rail Unit Cost Benchmarking Tool and the need to include as many drivers as necessary to reach sufficiently detailed results. As a result, the list of drivers hereunder presented does not include all the possible elements, but is limited to the main ones that contribute the most to differentiate one project to another in terms of unit costs.

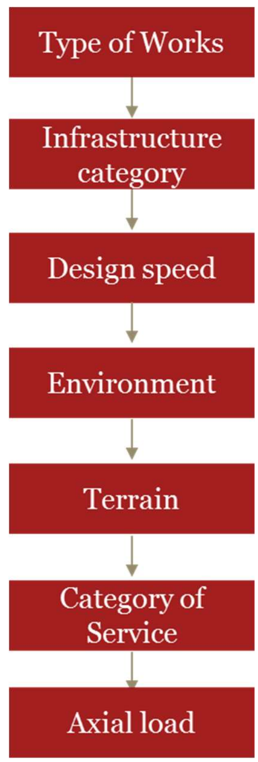
The relevance and the type of external factors which have an impact on unit cost varies depending on the level of detail on which the analysis on unit cost is performed i.e. the type of works included in the project is not a cost-driver for the analysis of cost on Tier 3 which concerns single works.

The cost drivers identified for the categorisation on Tier 1 and 2 and for the categorisation on Tier 3 are presented the following paragraphs.

1.1. Drivers affecting Tier 1 and 2 categorisation

Tier 1 and Tier 2 refer to a level of detail that does not entail specific work categories, but rather refers to whole infrastructure works. The drivers impacting on the different infrastructure and cost categories in this case is rather wide and concerns both technical features (which impact on the technical standards the infrastructure must meet, and it does at a cost) as well as external factors.

Figure 2 – Prioritisation of the cost drivers impacting on investment cost of new lines, rehabilitation and upgrade[1]



TYPE OF WORKS

The primary factor that impacts on the investment cost of a rail infrastructure project is the type of intervention which can be categorised in new line, rehabilitation, upgrade, signalling electrification and telecommunication. The construction of a new railway lines usually require a number of different works, from the deployment of the substructure to the installation of each element of the equipment. Whereas, upgrade investments can be focused on a specific aspect of an existing railway line (e.g. replacement of the permanent way) and require less interventions.

Therefore, the type of works is the first discriminating factor considered to create and analyse uniform cluster of projects as it can drive the overall project costs. Specifically, four clusters, outlined in the following table, have been analysed separately.

Table 1 – Clusters identified on the basis of the railway infrastructure works

Project category	Description
New lines	Construction works mainly related to the deployment of a new railway line.
Rehabilitation	Construction works mainly related to improvement work that are conducted to reinstall the design characteristics of an existing line (e.g. design speed, capacity, etc.) which has worsened in quality due to a lack of sufficient maintenance. Rehabilitation can also

[1] For what concerns works in signalling, electrification and telecommunication, the classification is deemed relevant only until the level of infrastructure category. Further drivers are then applied at Tier 3 level, as reported below.

	refer to works that are executed to make an existing line compliant with new EU regulations.
Upgrade	Construction works related to improving the original design parameters of an existing line, usually in terms of capacity or speed.
Signalling, telecommunication and electrification	Construction works related to the deployment of a signalling, telecommunication and/or electrification system along a railway line.

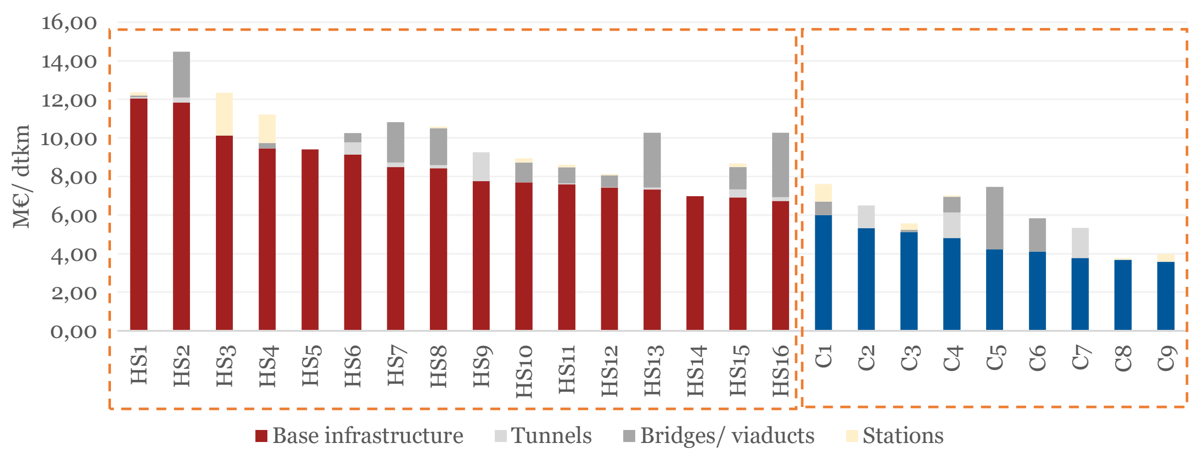
Clustering investment cost based on the type of works included is obviously not relevant in case each work is analysed separately.

Infrastructure category

The second factor affecting Tier 1 and 2 categorisation is the infrastructure category of the railway lines, as conventional or high-speed[2] projects present significant cost differences. Indeed, a high speed railway line requires higher quality, safety standards and technical aspects[3] than a conventional one, which translate into higher investment cost[4].

This is confirmed by the analysis of the projects included in the final database. For instance, the comparison of the base infrastructure unit cost of new lines highlights as the average unit cost of high-speed lines is approximately 4 M€/km higher than that of conventional lines (i.e. 8.6 M€/km vs. 4.5 M€/km).

Figure 3 – Base infrastructure cost of high-speed and conventional lines (new lines)



<u>The infrastructure category affects the single elements of the infrastructure, thus remain relevant for the analysis carried out on the single intervention.</u>

Design speed

The design speed, which is the maximum speed allowed in a specific railway line, can vary significantly and therefore has a considerable impact on costs. With the support of rail experts, different speed ranges have been identified and are reported in the table below.

Table 2 – Clusters identified on the basis of the maximum design speed

Conventional lines	High-speed lines
up to 120 km/h	From 201 km/h to 250 km/h[5]

[2] The differentiation used in the study follows the definition of Directive 2004/50/EC of the European Parliament and of the Council of 29 April 2004: high-speed is classified as newly built infrastructure that can be operated at a speed higher than 250 km/h or that results from an upgrade of a pre-existing line which can then be operated at 200 km/h; conventional is classified as the newly built infrastructure that can be operated at a speed lower than 250 km/h or an existing line that can be operated at a speed lower than 200 km/h.
[3] See Decision 2012/462/EU
[4] Competitive interaction between airports, airlines and high-speed rail, OECD, 2009.
[5] Only in the case of upgraded lines.

From 121 km/h to 160 km/h	From 251 km/h to 300 km/h
From 161 km/h to 200 km/h	From 301 km/h to 350 km/h
From 201 km/h to 250 km/h[6]	More than 351 km/h.

The possibility to achieve a higher maximum high speed translates into slightly higher investments, as confirmed by rail experts and the analysis of the relevant literature[7]. The analysis of the projects included in the database validates this statement. Indeed, comparing the base infrastructure unit cost of rehabilitation and upgrade interventions carried out on lines with different design speed, it is observed that the average unit cost is higher for lines achieving higher speed (i.e. the average unit cost of a conventional line with a maximum design speed of 200 km/h is approximately 30% higher than the unit cost of a line with a design speed lower than 120 km/h).

Topography (Environment and Terrain)

The natural and artificial features of the area where a rail infrastructure project is carried out impact on its investment cost, because of the necessary measures and structures to tackle the external conditions. Such phenomenon has been widely recognised in the relevant literature: e.g. Baumgartner[8] identified different unit cost ranges of the rail infrastructure depending on their topography. The same applies to the reference unit cost ranges defined by the Spanish Ministry. [9,10]

The two main topographical aspects considered for the assessment of rail infrastructure project costs are: the presence of urban areas (environment) and the orography of the line (terrain). Their characteristics mainly reflect in the presence of structures (e.g. tunnels, bridges, overpasses, underpasses, etc.) which drive up the cost of a railway infrastructure. Therefore, the unit construction cost of railway projects passing through urban environment/ mountainous terrain is higher than that of projects facing easier topographical conditions.

When the base infrastructure unit cost is analysed, the cost of big structures (i.e. tunnels and bridges) is subtracted from the overall construction cost. As a result, the impact of the orography results less relevant. This is confirmed by the analysis carried out within the study. The unit cost range for high speed projects is between 6.98 M€/km and 25.21 M€/km; whilst when the cost of big structures is subtracted to the overall construction cost, it is possible to identify a narrower unit cost range (between 6.73 M€/km and 12.05 M€/km). Nonetheless, setting a building site in a mountainous area requires higher cost, due to e.g. the necessity to bring equipment and machineries on the site. Thus, the base infrastructure unit cost of projects built in mountainous areas results slightly higher than that on project passing through flat terrain.

The presence of an urban environment requires to build several elements which are included in the base infrastructure cost (e.g. noise barriers, mitigation measures, minor structures, interfaces, etc.). Therefore, this factor impacts also on the base infrastructure unit cost.

The topography impacts mainly on the number of major and minor structures included in the rail infrastructure, thus can be neglected when the cost of the single elements is analysed (with the exception of earthworks).

Category of service (and axial load)

A railway infrastructure can be designed to be operated by passenger trains, freight trains or both of them. Passenger and mixed-service railways are usually operated at higher speed and requiring higher curve radius (see above); oppositely, freight (and mixed-service) infrastructure usually require infrastructure to sustain higher stress, caused by the higher weight of rolling stock[11]. Indeed, the maximum axial load allowed on a specific rail line affects the characteristics of its superstructure, and the related cost.

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[6] Only in the case of new lines.
[7] González Franco I., (2015). Effect of the design speed on the construction cost of the infrastructure
[8] Baumgartner J.P., (2001). Prices and Costs in the Railway Sector
[9] Ministerio de Fomento (2010). Boletín Oficial del Estado
[10] See also Tsamboulas D., (2014), Estimating and Benchmarking Transport Infrastructure Costs; Campos J., de Rus G., Barrón I., (2006). Some stylized facts about high speed rail around the world: an empirical approach; Gattuso D., Restuccia A., (2014). A tool for railway transport cost evaluation.
[11] Pyrgidis C., Christogiannis E. (2012). The problems of the presence of passenger and freight trains on the same track.

1.2. Drivers affecting Tier 3 categorisation

SIGNALLING

Signalling works concern the implementation and deployment of signalling systems on railway lines. Their investment cost can increase or decrease based on:

- **Level of ERTMS**. As detailed in the case study, a difference can be encountered in the unit cost of the different ERTMS levels, due to the heterogeneity of software and hardware requirements that each level demand. Therefore, an increasing level of ERTMS results in a slightly higher investment cost.

- **Performing software upgrading work.** Signalling works can consist in an upgrade of the software of the signalling system already deployed on a line. In this case, the unit cost of signalling is considerably lower than that encountered when a whole signalling system is deployed. Software upgrading works should not be considered in the scope of the study (not being infrastructure works); nonetheless, as they can be included in wider intervention, it was deemed necessary to include them into the analyses.

- **Signalling structures.** Signalling works might include the deployment of signalling structures and spot interventions e.g. installation of radio block centres, key Management System and other interventions specific on small areas. The deployment of signalling structures contributes, *ceteris paribus*, to higher the unit cost of the work. As an example, the average unit cost for conventional line with signalling structures is 0.9 M€/km while the average unit cost of project without this intervention 0.4 M€/km.

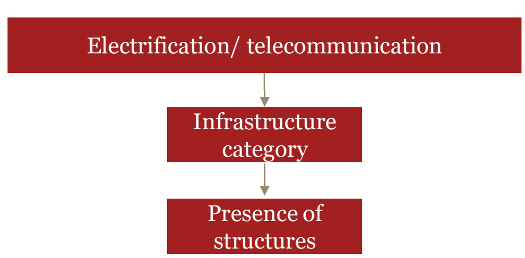
- **Signalling works within a station.** In case works to deploy the signalling system include the deployment of the system within a station, the unit cost of the interventions increases. Indeed, in this case the works include the installation of specific equipment e.g. electronic central management system which drive up the investment cost. This is confirmed by the analysis of the database. The unit cost of signalling works performed on conventional lines including the deployment of the signalling system in a station is approximately 1.3 M€/km, compared to the 0.5 M€/km average unit cost calculated for project not including signalling works in stations.

TELECOMMUNICATION AND ELECTRIFICATION

The deployment of specific substructures increases the unit cost of telecommunication and electrification works. This phenomenon has been confirmed analysing the observations included in the database: e.g. electrification works including structures have an average unit cost of 1.0 M€/km, compared to the unit cost of 0.6 M€/km without structures. The reason is simply explained by works in structures representing an additional cost item to the mere works on the lines.

Being somewhat detached from works made on the *hard* infrastructure (earthworks, permanent way), the cost is not impacted by the different categories of speed, axial load that the infrastructure must sustain, etc. Electrifications works would not be present in case the line is operated by diesel powered trains only.

Figure 4 – Prioritisation of the cost drivers impacting on the cost of telecommunication and electrification works

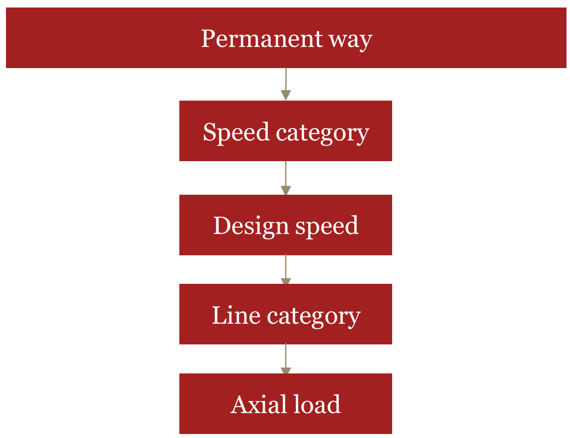


Hard infrastructure: permanent way and Earthworks

The specific tier 3 components presented before refer to works that are not performed on tracks. They therefore tend to be less impacted by the type of operation that the infrastructure has to guarantee as well as by the environmental conditions.[12] Oppositely, the works relative to the construction of the *hard* infrastructure are highly dependent on such factors. In particular, earthworks are relative to excavations and works relative to preparing the ground, therefore are overall more dependent on the conditions of the environment, while the permanent way tends to be more dependent on the technical specifications that the infrastructure ought to respond to.

The different technical characteristics of a railway line affect the overall cost of the permanent way, which quality should enable the line to be operated at determined conditions. Therefore, the unit cost of the permanent way is primarily affected by the cost drivers that relate to the type of infrastructure and the factors that determine the operational standards of the line. These are presented in the figure below:

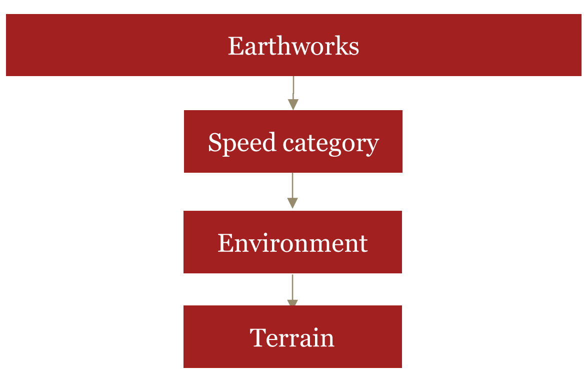
Figure 5 – Prioritisation of the cost drivers impacting on the cost of works on the permanent way



Moreover, the installation of permanent ways within a station may impact the cost of the work as tracks that are deployed do not need to sustain stress of high speed trains operating – and therefore are often of somewhat lower-quality.

As anticipated, the cost of earthworks depends on the topographical characteristics of the project; e.g. performing construction works in mountainous terrain requires an additional amount of earthworks to reduce the slope of the line, etc. [13] These complexities tend to result in higher unit cost of the earthworks. Figure hereunder presents the different drivers considered.

Figure 6 – Prioritisation of the cost drivers impacting on the cost of earthworks



[12] As outlined before, the drivers considered are not the <u>only</u> ones that impact on the unit cost, but are those that have been identified as the most relevant in differentiating among projects when assessing the unit cost. Would all elements be included, the list would most likely be extremely long and would compromise the usability of the REGIO Rail Unit Cost Benchmarking Tool.

[13] Shafahi Y., Shahbazi M.J. (2010). Optimum railway alignment.