NeTIRail

Needs Tailored Interoperable Railway Infrastructure

Deliverable 2.1

Analysis of "big data": geospatial analysis of costs, drivers of failure and life of track infrastructure

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Executive Summary

The research within this deliverable starts with an overview of the most commonly used methods applied in different European countries for the classification of infrastructure expenditures and the methods used to estimate capital costs. We looked at modalities for classification of infrastructure expenditures, and progressed towards infrastructure expenditures components to monitor infrastructure expenditures and costs and ultimately to the consideration of whole life cycle and whole system costs. These in turn acted as a stepping stone which allowed us to look at RAMS and LCC concepts from two distinct perspectives:

1) a general overlook of the concepts and
2) their detailed application into practice.

Although we observed that both RAMS and LCC are considered powerful tools these are not fully understood hence their development is slower than anticipated. We highlighted the fact that due to the limited number of available databases containing RAMS indicators, progress towards a unified European/ International system is still slow. Furthermore, lacking a clear RAMS programme plan, RAMS analyses are not carried out in all life cycle phases hence, lacking full RAMS-LCC integration. Generally speaking, there is higher propensity to consider inputs deriving from either track tests, meetings and questionnaires and past faults to carry out RAMS analyses which leads to a need to fully systemise RAMS in railway infrastructure.

Undeniably a RAMS and LCC analysis allows the optimisation of the maintenance strategy and allows to shorten decision times regarding maintenance/renewal. Even more interesting is the fact that any RAMS-LCC analysis indicates the consequences of under budgeting maintenance and renewal. This is why we conceptualised our own database starting from cost components to define the database structure and RAMS-LCC integration to define some database relations.

This data analysis task builds on existing rail industry datasets in two ways: (i) Addition of data from NeTIRail-INFRA countries and line types that have not been collected previously, and (ii) Through application of Geographic Information System (GIS) mapping to the failure data to reveal correlations and underlying drivers of cost and maintenance which have not been previously visible.

Based on the data collected and available so far in the database we provide several basic descriptions of the data by presenting the main statistics in terms of costs, failures and traffic volume. Various cost categories, failure type and incidence and, traffic volume information are presented in a comparative manner across case study lines. These first level analyses are accompanied by a correlation analysis performed on an aggregated country level and individual line level.

Table of contents

Abbreviations and acronyms

Abbreviation / Acronym	Description
ABC	Activity Based Costing
CFR	Romanian National Railway Company
EU	European Union
EP	European Parliament
FMEA	Failure Modes and Effects Analysis
GHG	Greenhouse Gases
ICT	Information and Communications Technology
ICE	InterCityExpress
IEC	International Electrotechnical Commission
IM	Infrastructure Manager
LCA	Life-Cycle Assessment
LCC	Life-Cycle Costing / Life-Cycle Cost
M&R	Maintenance and Renewal
MAD	Mean Administrative Delay
MLD	Mean Logistic Delay
MPH	Miles Per Hour
MRT	Mean Repair Time
MTTF	Mean Time To Failure
RAM	Reliability, Availability and Maintainability
RAMS	Reliability, Availability, Maintainability and Safety
SZ	Slovenske železnice
TGV	Train à Grande Vitesse (High Speed Train)
UIC	Union Internationale des Chemins (International Union of Railways)
USA	United States of America

1 Railway transport infrastructure overview

1.1 Railway transport infrastructure challenge

In this modernized and globalised world, the mobility of people and goods has been increasing, and in some regions mobility has even increased faster than economic growth. Millions of people all around the world commute in urban transport networks, millions of products move throughout complex logistic chains. Railway transport infrastructure as a mode of transport plays an important role and has changed radically, not only in terms of design, manufacturing, etc; but also in terms of its image in society.

In the 20th century, the railway transport infrastructure sector faced a serious financial crisis due to a societal burden, losing its attractiveness, and the introduction of more competitive modes like the car and the plane etc. After the Second World War, nationalized railway transport infrastructure companies represented a valuable asset to society, operating in a monopoly industry with non-profitable purposes.

In the period 1960 -1970, the railway transport infrastructure lost market share to road and air, and annual losses increased in such a dramatic way that revitalizing the railway transport infrastructure sector worldwide became necessary. Adopted solutions mostly consisted of privatization of the entire railway transport infrastructure system or parts of it. The United States and Japan took the lead, and soon the European Union followed this trend.

The relationship between the different stakeholders involved in the railway transport infrastructure sector changed after the introduction of the EU directive 91/440 which aim to facilitate the adoption of common railway transport infrastructure standards to the needs of the Single Market and to increase efficiency.

In this context the provision of transport services and the operation of infrastructure in the railway transport systems were separated, while improving the financial structure of infrastructure managers by introducing separate accounts between both activities and the state. This separation of accounts was compulsory, whilst organizational and institutional separation was optional.

This directive also highlights the importance for member states to retain general responsibility for the development of the appropriate railway transport infrastructure. With separate accounts, the infrastructure manager (IM) had to charge a fee to railway transport infrastructure operators for using that infrastructure.

The calculation of this fee is still controversial, demanding more knowledge on life-cycle cost of the railway transport infrastructure. It is considered reasonable that this fee to take into account mileage, the composition of the train, specific requirements as speed, axle load, degree or even the time period of utilization. The methods of calculating the fee can also create perverse incentives for the different organisations which in some cases may reduce the costs for one organisation, but may increase the costs for the overall railway system.

1.2 Railway transport infrastructure - European policy and network

For a more cost-competitive system, European railway transport infrastructures have concentrated on standardisation and knowledge sharing in order to improve and the competitiveness of rail.

There are many opinions which consider that asymmetric regulation in the transport sector is needed since the so-called internalization of external costs in the roadway transport is not implemented, this results in consumers paying much less than its real cost.

To become more competitive than road transport, interoperability between national systems must be achieved, improving the seamless movement of trains across Europe, while reducing delays at border crossings and extra costs associated.

The 2001 White Paper emphasized the importance of safeguarding efficient mobility for people and goods as the central element of a competitive EU internal market and includes the EU‟s strategy on transport policy which proposes measures to break the link between economic and traffic growth, to promote modal shift and combat the unequal growth of the various modes of transport, underlying that rail transport is the key to achieve modal rebalance and mitigate the dependency on road transport, particularly in the case of passengers.

The EU has tried to create a network of railway transport infrastructure lines dedicated exclusively to the service of goods (Figure 1-1), while partly transferring passenger traffic to „new‟ high performance high-speed rail networks. The new high-speed lines will contribute to the alignment of the gauge, improving the links between all the countries into an European network.

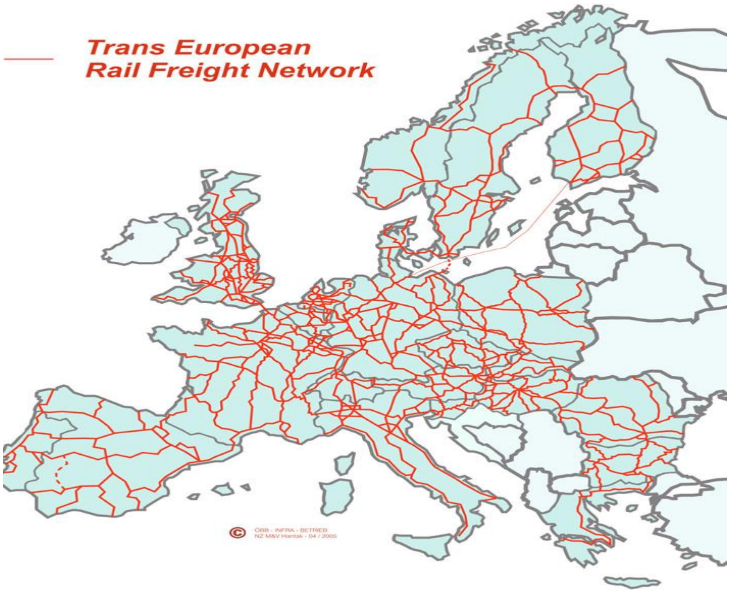

Figure 1-1 Trans European Rail Freight Network

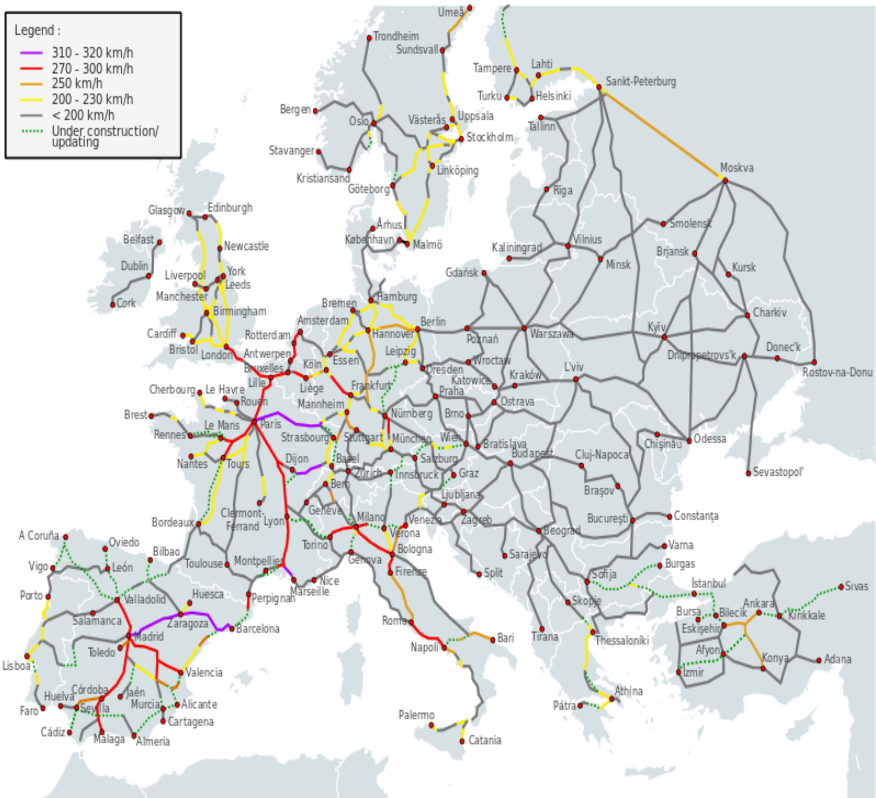

Figure 1-2 High speed railway transport infrastructure map in Europe[1,2]

[1] http://revolve.media/europe-train-transport/
[2] http://www.projectmapping.co.uk/Reviews/Resources/pic_map_big.jpg

Important strategic goals in the European transport policy include sustainability, interoperability and increasing competitiveness of intermodal transport, a genuine market in rail transport, optimum use of infrastructure while guaranteeing rail safety standards and assuring the necessary modernisation of services, considering energy and environmental aspects.

The effective utilisation of the existing railway transport infrastructure is an essential element to invert the status quo. Some measures proposed to the European railway transport infrastructure sector are included in the table below.

	Measures	Descriptions
Railway transport infrastructures	Rail interoperability	Improve seamless movement of trains across Europe
	Harmonised regulation systems	Provide fair competition for rail operators
	Rail efficiency	Increase technical unit efficiency of rail travel
	Rail passenger service quality	Increase quality (rolling stock, ICT)
	Passenger/ freight Intermodal facility	Develop service integration (operating facilities)
	Rail capacity	Improve rail capacity in key corridors/rail bottlenecks

Figure 1-3 Measures for long-distance travel (passenger and freight)[3].

2 Railway transport infrastructure expenditures and costs

The research within this deliverable was based on an overview of the most commonly used methods applied in different European countries for the classification of infrastructure expenditures and the methods used to estimate capital costs. The subchapters below include:

- Modalities for classification of infrastructure expenditures;
- Infrastructure expenditures components to monitor infrastructure expenditures and costs;
- Methods to move from annual series of expenditures to the consideration of whole life cycle and whole system costs.

2.1 Railway transport infrastructure expenditures

2.1.1 Infrastructure expenditures classification

Rail transport infrastructure expenditures consist of the amount of money that has been spent by infrastructure managers and can be considered from two points of view.

[3] ECORYS Transport, CE Delft (NL), 2005, Infrastructure expenditures and costs. Practical guidelines to calculate total infrastructure costs for five modes of transport, Adopted by the European Parliament (2008)

- Asset related: expenditures on investment, renewal, maintenance and operations of infrastructure;
- Usage related: fixed and variable expenditures on infrastructure.

Infrastructure expenditures can be classified based on these criteria as is presented below.

Infrastructure expenditures can be classified according to the way they enhance the functionality and/or lifetime of infrastructure (asset approach) in the following types of expenditures:

- Investment expenditures - expenditures on:
  - new infrastructure with a specified functionality and lifetime;
  - expansion of existing infrastructure with respect to functionality and/or lifetime.
- Renewal expenditures - expenditures on replacing existing infrastructure, prolonging the lifetime without adding new functionalities;
- Maintenance expenditures - expenditures for maintaining the functionality of existing infrastructure within its original lifetime;
- Operational expenditures - expenditures not relating to enhancing or maintaining lifetime and/or functionality of infrastructure.

Expenditures on infrastructure can also be classified according to the way they are influenced by the infrastructure usage (usage approach) in connection with transport volume as follow:

- Variable expenditures - expenditures that vary with transport volume while the functionality of the infrastructure remains unchanged;
- Fixed expenditures - expenditures that do not vary with transport volume while the functionality of infrastructure remains unchanged, or expenditures that enhance the functionality or lifetime of the infrastructure.

The distinction between fixed and variable expenditures enables an efficient allocation of infrastructure expenditures.

2.1.2 Methods to distinguish fixed and variable expenditures

There are two formal methods which support to distinguish fixed and variable expenditures:

- The econometric approach - where the total expenditure is considered to be the dependent variable and transport outputs. An econometric analysis can be used to determine and estimate a total expenditure function from which variable expenditures may be derived (based on railway infrastructure costs using a top down approach);
- The engineering approach - where total expenditures are disaggregated into subcategories, and for each categories exist separate variable expenditures (based on LCC (Life Cycle Cost) and RAMS (Reliability, Availability, Maintainability, Safety) using a bottom up approach).

The engineering approach it is a bottom up approach, which typically analyses single infrastructure sections or lines, and subsequently generalises the results. In contrast, the econometric approach it is a top down approach, which start from the total expenditures or total expenditure components, and it is functional oriented explaining the variation in total expenditures for different line segments of time periods. From the parameters can be derived in this expenditure function approximations of variable expenditures.

Expenditure functions can be derived in both approaches by using either cross section analysis or regression analysis based on time series. From a theoretical point of view, the econometric and the engineering approach are valid methods usable to estimate fixed and variable expenditures. The econometric approach has been applied for rail transport infrastructure.

The econometric approach is generally preferred, because it provides objective evidence of expenditures causes, being based on real figures on specific cost drivers. The engineering approach is more subjective being based on relationships between inputs.

The available statistics do not offer the possibility that these methods to be used at the parameters that these can offer, in order to be relevant and complete a very large dataset of all the expenditures performed for the rail transport infrastructure would need to be gathered. In some studies performed these methods analysed small segments of a rail infrastructure and the obtained results were extrapolated to larger parts of the infrastructure.

Another method based on practical experiences, simple calculations and/or expert judgments to establish the variability of each expenditure category that can be used to differentiate between fixed and variable expenditures and which uses the available statistics, is a method which applies a cost allocation approach.

2.1.3 Drivers for infrastructure expenditures

Expenditures for rail transport infrastructure with the same functionality can be different amongst countries in relation with infrastructure managers.

A list of expenditure drivers[4] for such differences is the following:

- Construction standards (legal obligations for safety, degree of technical progress applied to infrastructure construction, special standards for mountainous areas or ecological sensitive areas, different soil types and substructure);
- Type of infrastructure: construction and maintenance (motorways/other, high-speed train lines/other, tunnels/bridges, underground system/above ground system, canals);
- Access to infrastructure during construction and maintenance phases

[4] UNITE - UNIfication of accounts and marginal costs for Transport Efficiency Deliverable 2: The Accounts Approach, 2000

- Levels of wages and prices per country;
- Expected traffic mix and occupancy;
- Weather and climate;
- Population density (land costs).

Differences which can exist are related to the social and natural factors (such as population density, climate, hydrology or topography) that influence the level and composition of the capital stock in transport infrastructure.

In practice infrastructure expenditures can be relative to investment, renewal and / or maintenance activities. Infrastructure managers plan these activities to be executed in an efficient way to improve rail transport infrastructure functionality, to extend its lifetime, to minimise total expenditures and to attract more infrastructure users.

Analyses of how an asset is used in current or prospective projects to invest, renew or maintain rail infrastructure, an asset can be assessed from two points of view:

- Assess with specific use only for a project (or expenditure category) then the investment, renewal or maintenance expenditure will be assigned to that project;
- Assess which different percentage use in many projects (or expenditure category) then percent from considered investment, renewal or maintenance expenditure will be assigned to each project in which is used.

Both approaches have to make use of the expert judgments to be able to make the required and correct distinction.

2.2 Railway transport infrastructure costs

2.2.1 Method for calculating total infrastructure costs

The infrastructure expenditures are related to the creation/investment, renewal and maintenance of infrastructure assets and in majority of cases have an expected lifetime of more than 1 year. The share of the infrastructure expenditures is related to those expenditures of infrastructure assets with an expected lifetime of more than 1 year. This means that the expenditures made in year X are not equal with the infrastructure cost allocated for year X, the yearly value for the use of the infrastructure assets.

The infrastructure costs which represent the periodic (yearly) value for the use of infrastructure assets consist of:

- Capital costs:
  - Yearly depreciation costs related to investments, renewals and maintenance of the infrastructure assets;
  - Yearly interest expenditures.
- Running costs:
  - Yearly recurring (other) maintenance and operational expenditures.

There are many different types of railways, from dedicated freight lines to high speed passenger lines. We will make distinction between the different types of lines and in consequence the data corresponding to each type of like will be collected and analysed separately. The types of lines considered in the project are the following

- Busy passenger;
- Low density rural/secondary line;
- Freight dominated route.

The method proposed for the registration of the infrastructure cost will be based, as possible, on the current cost registration practice in the different countries. The calculation of cost will be performed in steps as follow and is based of expenditures performed and associated to each type of action:

- Calculation of costs related to the investment expenditures;
- Calculation of costs related to the renewal expenditures;
- Calculation of costs related to the maintenance expenditures:
- Calculation of costs related to the operational expenditures

as these are registered by the infrastructure administrators in each country.

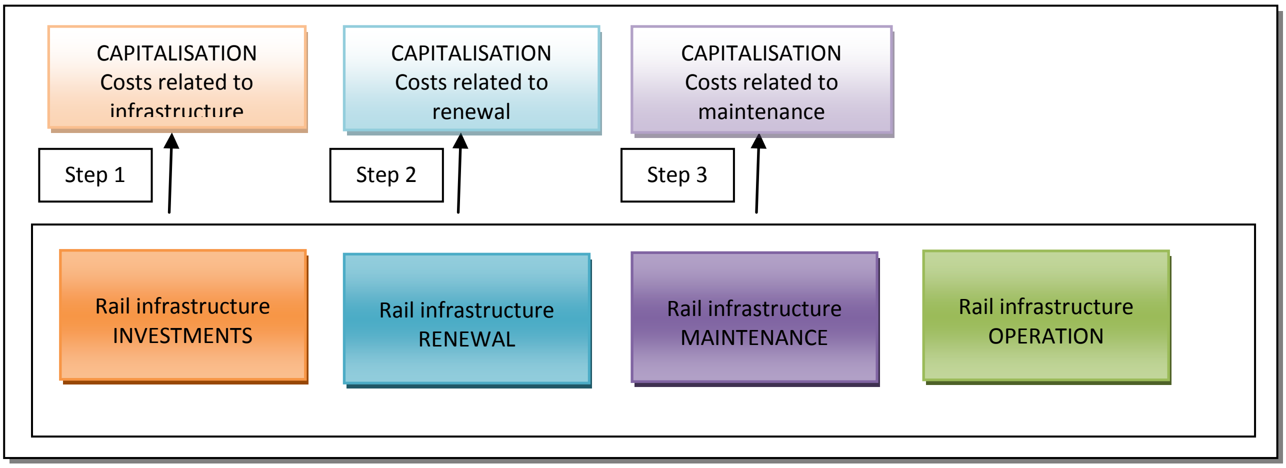

Figure 2-1 Method to calculate costs starting from infrastructure expenditures[5]

Step 1 Investment expenditures

✓ Investment expenditures made in the current year

In order to determine the total investment costs on a yearly level, and not the investment expenditures, capital costs should be taken into account which means that we considered all the expenditures that were made in connection with respective investment and all these should be capitalized.

[5] Adaptation from ECORYS Transport, CE Delft (NL), 2005, Infrastructure expenditures and costs. Practical guidelines to calculate total infrastructure costs for five modes of transport, Adopted by the European Parliament (2008)

The annual capital costs can be calculated based on the asset value, asset service life and interest rate utilising an equal payment series (meaning a linear depreciation function) discount formula[6]:

$$(Annual\ capital\ costs) = (Asset\ value) * \frac{Interest\ Rate}{\left(1-(1+Interest\ Rate)\right)^{\wedge-(Service\ life\ of Asset)}}$$

Since most countries use linear depreciation functions it is advised to use linear depreciation.

Interest rates vary with time and from country to country. For long term investments we could use an interest rate of 5%, the same interest rate as that used in Cost Benefit Analysis for EU-projects.

- ✓ Investment expenditures made in the past years

The capital costs must be calculated not only for new investments in the current year but also the capital costs of previous investments in the infrastructure, using the PIM method. For each subsequent year the investments have to be divided according to their life expectancy. The countries often use the same average lifetime for all or most asset categories and there is a large variation of lifetimes across countries. It should be noted that railways have little or no alternative use for the abovementioned investments, meaning that there are very few historical investments in railway infrastructure that should make a difference for decisions of today.

Step 2 Renewal expenditures

Infrastructure renewal expenditures are the expenditures made to replace existing infrastructure, prolonging its lifetime without adding new functionalities. These renewal expenditures lead to an extension of life time of assets. Where a component of the infrastructure asset is replaced or restored the expenditures should be capitalised, since the expected lifetime will be more than 1 year and for this is used the formula[7]:

$$Annual\ capital\ costs\ of\ renewal\ expenditures\ = = Renewal\ expenditures * \frac{Interest\ Rate}{\left(1-(1+\ Interest\ Rate)\right)^{\wedge-(Service\ life\ of\ Renewal\ work)}}$$

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[6] Infrastructure expenditures and costs, Practical guidelines to calculate total infrastructure costs for five modes of transport, Final report, Client: European Commission – DG TREN ECORYS Transport (NL) CE Delft (NL), Rotterdam, 30 November 2005

[7] Infrastructure expenditures and costs, Practical guidelines to calculate total infrastructure costs for five modes of transport, Final report, Client: European Commission – DG TREN ECORYS Transport (NL) CE Delft (NL), Rotterdam, 30 November 2005

For renewal expenditures are follow the same steps as those performed for investment expenditures:

- Expenditures in the current year;
- Expenditures in the past years should be applied.

Step 3 Operational and maintenance expenditures

The operational and maintenance expenditures comprise the expenditures to keep the infrastructure in working order and these do not lead to an extension of life time of parts of the infrastructure.

The operational and maintenance expenditures that have a life time expectancy greater than 1 year should be capitalized, if the life time expectancy is 1 year or less the expenditures have to be taken into account for the specific year in which the expenditure was made without any capitalisation. The capitalisation of operational and maintenance expenditures is done using the formula[8]:

$$\begin{aligned} &Annual\ capital\ costs\ of\ operational\ and\ maintenance\ expenditures\ with\ life\ time \\ &> 1\ year \\ &= Maintenance\ expenditures \\ &* \frac{Interest\ Rate}{\left(1 - (1 + Interest\ Rate)\right)^{\wedge -(Service\ life\ of\ Maintenance\ work)}} \end{aligned}$$

For maintenance expenditures with life time > 1 year the same steps are performed as for investment expenditures:

- Expenditures in the current year;
- Expenditures in the past years.

For each year the total infrastructure costs is the sum of all the capitalised expenditures related to investments, renewal, operational and maintenance.

2.2.2 Collection and processing of infrastructure costs data

Infrastructure costs are available from the business accounts. They are the sum of depreciation and capital costs. All infrastructure managers collect information on infrastructure costs. However, the different cost figures may not be comparable, due to differing accounting standards.

[8] Infrastructure expenditures and costs, Practical guidelines to calculate total infrastructure costs for five modes of transport, Final report, Client: European Commission – DG TREN ECORYS Transport (NL) CE Delft (NL), Rotterdam, 30 November 2005

In order to enhance the consistency of the reported costs is recommended to be used the same method to calculate costs as those presented before and proposed by IAS/IFRS, which is the only international standards available. A number of railway companies already use these standards.

By using IAS/IFRS most inconsistencies between reported infrastructure costs can be eliminated. In the calculation of infrastructure costs, IAS/IFRS accept several methods like:

- Depreciation base: historical prices or replacement value;
- Depreciation method: linear or other;
- Lifetimes of asset categories.

Linear depreciation methods has the advantage of considering in each year the same level of depreciation in relation with non-linear depreciation method which changes the distribution of depreciation over time. In the presence of inflation, the use of different depreciation methods would yield different real (inflation-adjusted) cost figures. This decreases their comparability.

Considering the life-time of assets, some studies[9] advise not to issue standard lifetimes. There are reasons why lifetimes vary (variance in quality, environmental and climatologically circumstances, infrastructure use, etc.). Uniform lifetimes would lead to a distorted view on infrastructure costs. We therefore propose to adhere to the lifetime of assets as reported in the business accounts.

2.2.3 Fixed and variable infrastructure costs

To represent fixed and variable infrastructure costs. It is suggesting a matrix structure in the table below. In the table are included the categories of expenditures - investments, renewal, maintenance and operational – and the cost categorisation related to the different parts of railway transport infrastructure.

	Investment expenditure		Current expenditure			
	Investments	Renewal	Maintenance		Operational	Total
	Capital costs		Capital costs	Running costs	Running costs	
	%fixed / %variable	%fixed / %variable	%fixed / %variable	%fixed / %variable	%fixed / %variable	
Buildings / Railway stations						
Civil engineering works						
Superstructure						
New construction in progress						

[9] Infrastructure expenditures and costs, Practical guidelines to calculate total infrastructure costs for five modes of transport, Final report, Client: European Commission – DG TREN ECORYS Transport (NL) CE Delft (NL), Rotterdam, 30 November 2005

	Investment expenditure		Current expenditure			
	Investments	Renewal	Maintenance		Operational	Total
	Capital costs		Capital costs	Running costs	Running costs	
	%fixed / %variable	%fixed / %variable	%fixed / %variable	%fixed / %variable	%fixed / %variable	
Transmission lines						
Signalling equipment						
Telecommunications Equipment						
Safety installations						
Vehicles / rolling stock						
Plant and machinery						
Other fixed assets						
Interest						
Management of traffic, control and safety systems						
Train running diagRAMS						
Unallocated overhead						
Total						

Table 2-1 Structure for rail transport infrastructure expenditure and cost categories

Based on IFRS advices, the new construction in progress of the investment properties is reported in business accounts under the category ‘new construction in progress’ at the cost incurred until the new investment has been completed and at that moment it is reclassified as investment property under one of the other categories.

Blue cells indicate non-existent combinations (e.g. interest is always capital costs).

From a theoretical point of view[10], it is wrong to calculate costs by using both replacement values and nominal interest payments. Interest is considered to be a reward for lending capital and a compensation for inflation. Replacement values are adjusted for inflation.

Hence, when calculating costs, replacement values should be used in combination with real interest rates. Interest payments that are available from the profit and loss account should be adjusted for inflation. All these adjustments use arbitrary methods and parameters. Therefore, it is better to use historical cost prices and nominal interest rates.

If the infrastructure managers are able to provide detailed expenditure figures for most of the parameters included in the cells of this matrix, then a more complex analyses can be done and this approach to distinguish between fixed and variable expenditures could be a better support for political and decision makers.

[10] Infrastructure expenditures and costs, Practical guidelines to calculate total infrastructure costs for five modes of transport, Final report, Client: European Commission – DG TREN ECORYS Transport (NL) CE Delft (NL), Rotterdam, 30 November 2005

2.2.4 Infrastructure cost drivers

The infrastructure cost drivers influence infrastructure costs. In the table below is presented a list of specific drivers that can lead to major differences in the calculation of infrastructure costs between countries from the point of view of the infrastructure managers.

Infrastructure costs	Cost drivers
Depreciation	Life-expectancy of assets
	Valuation at historical costs versus replacement costs
	Linear versus non-linear depreciation
	Time span between maintenance expenditures
Interest	Interest rates

Table 2-2 Example of cost drivers for infrastructure costs[11]

The meaning of each cost driver is presented below:

- Life-time expectancy: the life-time expectancy of infrastructure assets as well as the components of specific assets can be different. To determine a correct value for the depreciation costs the differences in lifetimes should be accounted and should ideally be based on data analyses.;
- Historical costs versus replacement costs: assets valuation can be done using historical costs or replacement costs. The replacement costs are regarding the future value of the asset;
- Linear versus non-linear depreciation: when historical costs are used to determine the value of assets, depreciation costs can be calculated by different types of depreciation functions (linear or non-linear). To can compare these values between countries the same depreciation method should be applied;
- Time span between maintenance expenditures: maintenance expenditures are made to maintain the original functionality of infrastructure. These maintenance expenditures – or at least part of them - are not made on an even basis every year, but in 'waves'. To establish the yearly costs, maintenance expenditures should be capitalized.
- Interest rate: In order to determine a common interest rate, an interest rate of 5% could be used, as that is specified for use in EU-projects.

2.2.5 Method for classification of capital costs

For railway transport infrastructure, the capital stock and corresponding capital costs can be derived based on the business accounts of each infrastructure manager.

✓ The Perpetual Inventory Method

The Perpetual Inventory Method (PIM)[12] is one used by most OECD-countries to support the calculation of the asset value by cumulating the annual investments and subtracting either

[11] UNITE - UNIfication of accounts and marginal costs for Transport Efficiency D2: The Accounts Approach, 2000

the value of those assets that exceeded their life-expectancy (referred below as written down assets) or the depreciation.

The perpetual inventory concept is based on the capitalization of the time series of annual investment expenditures by cumulating the annual investments and by subtracting the value of those assets which exceeded their life-expectancy (referred below as written down assets) as is indicated by the equations below:

- VG t+1 = VG t + It,t+1 - At,t+1;
- VN t+1 = VN t + It,t+1 - Dt,t+1;

where:

- VG t : Gross value of assets at time t;
- VN t : Net value of assets at time t;
- It,t+1 : Investments during t, t+1;
- At,t+1 : Written down assets during t, t+1 (assets which exceeded life-expectancy);
- Dt,t+1 : Depreciation during t, t+1.

The perpetual inventory method can be applied for estimating the gross value (gross concept) and the net value (net concept) of infrastructure assets. The gross value contains the value of all assets which still exist physically in the considered year, e.g. which have not yet exceeded their life expectancy. Thus, At,t+1 refer to those assets which could not be used any longer or which were shut down. It is assumed that the assets are properly maintained and can be used until they exceed their defined life-expectancy.

Within the net-concept the annual depreciation Dt,t+1 are considered. The net value of assets describes the time-value of all assets which have not yet exceeded life-expectancy. According to the international conventions of the System of National Accounts (SNA) most countries use a linear depreciation method.

The general principle as described above can be refined by more sophisticated approaches which use probability functions for the written down assets. In contrast to simple perpetual inventory models, the refined models assume that the life expectancies of assets within an investment vintage are dispersed over the mean value. This approach considers the fact that the investment spent for an asset group consists of parts with different life expectancies which are dispersed within an interval around the mean.

The perpetual inventory model requires, in general, long time series on annual investment expenditures, information on life expectancies of assets, and initial values of the capital stock (except when the investment time series is as long as the life expectancy).

Due to the fact that the use of probability functions in the refined concept implies no single assets, there are considered technically homogeneous groups of assets (earthworks,

[12] UNITE - UNIfication of accounts and marginal costs for Transport EfficiencyD5 – Annex 1: German Pilot Accounts, 2002

bridges/tunnels, terminal buildings, pavement and equipment) and the investment time series for asset groups (for example pavement, tunnels/bridges, equipment) have to be available.

To estimate more accurately capital stock, PIM uses the following information:

- Long investment expenditure time series for each mode (30-40 years). These comprises expenditures on new construction, extension, reconstruction and renewals. Non-transport related capital costs must be excluded;
- Life expectancy of the infrastructure as a whole or of infrastructure components (for the investments per infrastructure component over time need to be known);
- Depreciation over time (linear, geometric);
- Interest rate (opportunity cost).

If the long investment time series does not exist but there available a cross-sectional database for one year then a synthetic method could be applied for capital valuation, capital costs can be calculated by using annuities. If does not exist a perpetual inventory approach and the synthetic method cannot be applied, then can be used indicators like capital values per km.

✓ Synthetic method

The synthetic method is a method to value an existing infrastructure network and it does this by estimating what it would cost to replace the relevant network with assets of equivalent quality.

The method measures the existing physical assets and calculates how much cost to construct an infrastructure with the same physical characteristics as the existing one.

2.2.6 Total infrastructure costs

Total infrastructure costs consist of capital costs (concerning depreciation and interest of previous investments, renewals and non-yearly maintenance) and running costs. For the calculation of costs must be considered the investment, renewal, maintenance and operational expenditures as registered by the administrators. In the figure below are illustrate interdependencies between all the elements described above.

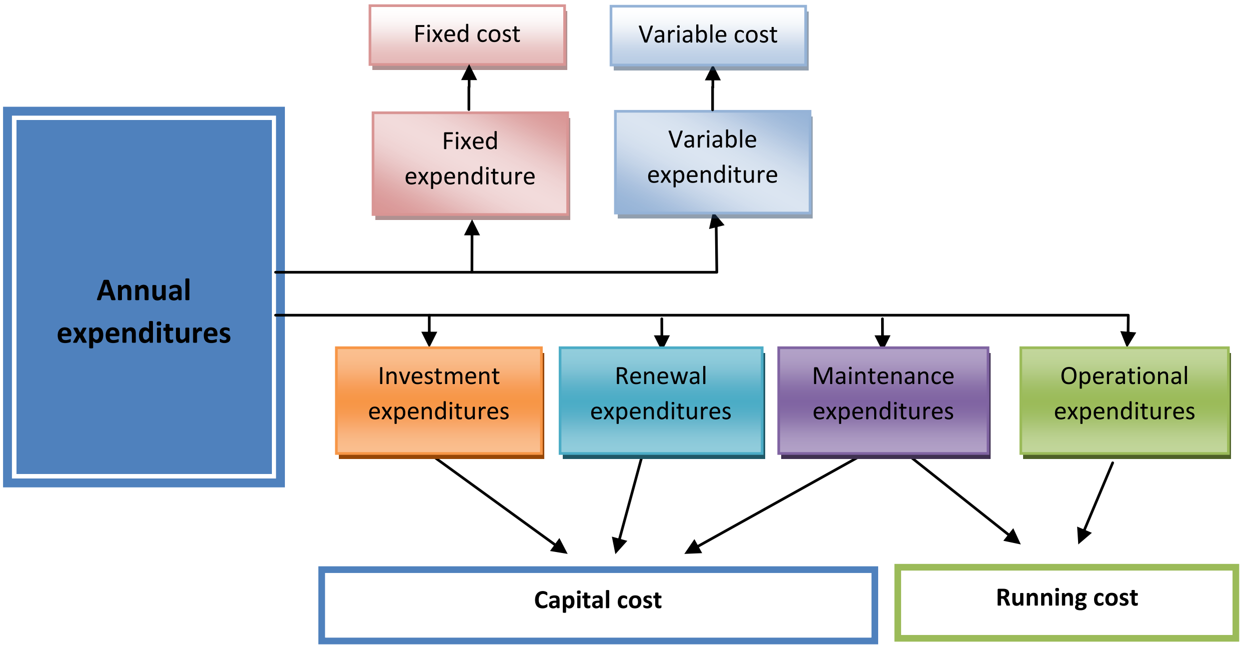


Figure 2-2 Total infrastructure cost components

2.2.7 Sustainability of costs

It is understood that infrastructure managers will go through cycles of high investment in infrastructure and maintenance where the quality of the infrastructure is enhanced raising the standards and reliability. Likewise there will be periods where investment is reduced below sustainable levels, and in the future enhanced investment will be required to raise the standards up to a safe and reliable levels. These cycles are heavily dependent upon the availability of finance and political policy. However, when comparing the costs of one organisation to another it is important to consider where they are in this cycle of investment. The UIC project LICB (Lasting Infrastructure Cost Benchmark) has considered this aspect in their benchmarking process and compensated for investment cycle, comparing costs as if all infrastructure managers were maintaining their infrastructure on the balance of sustainability.

3 RAMS&LCC in railway transport infrastructure

Looking at RAMS and LCC concepts from two distinct perspectives - general understanding of the concepts and detailed application into practice, we can clearly observe that although both RAMS and LCC are considered powerful tools these are not fully understood hence their development is slower than anticipated. This is why RAMS is relatively still in an early stage of implementation for railway infrastructure. One noteworthy aspect is the relative low number of RAMS standards with some notable examples being the EN 50126, CP-DDE-134 or DIN 40041. The real underlying issue is the way RAMS methodologies are being used inpractice due to the fact that there is a limited number of RAMS databases and that most users use ad-hoc self-developed databases to store datasets. These mostly include traffic volume, axle load, type of rail, availability in percentage, repair time, numbers of failures, delays on track works by suppliers and other factors that affect RAMS and LCC values Furthermore, lacking a clear RAMS programme plan, RAMS analyses are not carried out in all life cycle phases hence, lacking full RAMS-LCC integration. Generally speaking, there is higher propensity to consider inputs deriving from either track tests, meetings and questionnaires and past faults to carry out RAMS analyses which leads to a need to fully systemise RAMS in railway infrastructure. Undeniably a RAMS and LCC analysis allows the optimisation of the maintenance strategy and allows to shorten decision times regarding maintenance/renewal. Even more interesting is the fact that any RAMS-LCC analysis indicates the consequences of under budgeting maintenance and renewal.

However, progress is inevitable due to the fact that the needs for better maintenance management lead infrastructure managers to include RAMS parameters in contracts with manufacturers in order to get highly reliable and cost-effective products from them. On the other hand, it is important to maintain RAMS and LCC as core methodologies for validation, after the installation of the infrastructure in order to check if it is in line with RAMS and LCC targets laid in the design phase. Unfortunately, we don't yet have a staple tested methodology for validation and these are currently being performed ad-hoc via small samples or simulation. In addition, the service life time for the infrastructure is computed from both technical and economical perspectives, with no clear rationale for one or the other. Overall, the biggest issue faced by LCC is the selection of the discount rates. As seen previously the discount rates are an important element of TPV/ NPV however, highly overlooked. Indeed, it is difficult to always identify the adequate discount rate but deviations lead to over/ under representing costs due to downtime, unavailability, traffic disruption, etc.

One positive aspect of LCC and RAMS modelling in current practice resides in the use of historical data to estimate reliability parameters of the track. However, manufacturers and contractors are often at a disadvantage due to lack of information and data from infrastructure managers. For example, failure distributions of track components are still unknown to them mostly because they do not have enough data for the analysis or sufficient information for the systematic approach. From a reliability perspective, sufficient data is available for the most common failures (broken rails, track buckles, track twist, switches failures). In terms of availability, targets are fixed based on train delay minutes, number of speed restrictions and these are the product of simulations based on the number of speed restrictions, allowed time for repair and individual component reliability data. In general, the periodicity of preventive maintenance actions is calculated via engineering judgments, past experience, RCM analysis, deterioration rates derived from regular track recordings and inspection.

The safety element of RAMS is the most advanced in terms of methods and data. Safety Risk Models based on fault trees and event trees are used to model a wide range of safety hazards on the railway alongside powerful tools to monitor the trend in precursor events e.g. broken rails and how this trend translates into the risk profile of serious train accidents. However, risk analyses are not considered as widely as needed in modelling LCC. Risks are captured through the predictions of future track conditions while exogenous factors such as environmental costs are not explicitly considered in the LCC calculation except for noise barrier or pads.

Some important issues with RAMS and LCC in practice are also related to data quality and data availability. Meeting RAMS and LCC targets will be faced with problems are linking between inputs and outputs to RAMS and LCC, long lifespan of the system, lack of financial means for renewal/maintenance. Returning to the issues that there is no clear procedure to get RAMS and LCC data in case of maintenance being outsourced, sharing information with the contractors should be of utmost importance. Such a system would allow all participants to adhere to single database containing regular observations of the infrastructure and where all major maintenance/ renewal actions taken by the participants will be based on RAMS characteristics and lead to reduced LCC.

3.1 Definition of concepts

RAMS is a staple tool in the railway transport field due to the need for better and cheaper services that can only exist on the basic premise of safety. Although railways have a generally good record for safety compared to other modes of transport, a brief analysis of the major developments and advancements of safety solutions and regulations are the consequence of unwanted events. One key element that leads to changes (read: improvements) of safety is the basic societal acceptance of risks. Even though in any market environment risk is normal and even accepted and transferred (e.g. insurance companies), changes to legislation and increasing complexity of the railway systems call for a very proactive approach to identifying, accessing and mitigating risk[13].

The significance of RAMS can be better illustrated by defining each component individually[14]:

[13] Railway Safety Directorate. 2013, Policy statement on the relationship between the CSM for Risk Evaluation and Assessment and other risk assessment requirements

[14] EN 50126 (1999) The Specification and Demonstration of Reliability, Availability, Maintainability and Safety (RAMS) for Railways Application, Comité Européen de Normalisation Electrotechnique (CENELEC), Brussels, Belgium.

Reliability	• can be basically described as "the ability of a component or system to perform required functions under stated conditions for a stated period of time"
Availability	• represents the ability of a component to "perform its required function at a stated instant of time or over a stated period of time" or rather the "ability of a product to be in a state to perform a required function under given conditions"
Maintainability	• represents in basic terms "the probability that a given maintenance action, under given conditions of use, can be carried out within a stated time interval"
Safety	• can simply be expressed as "freedom from unacceptable risk"

Figure 3-1 RAMS components[15]

It is relatively easy to spot that a common thread can be drawn through all four components of RAMS, namely *risk*. Although there is a considerable number of definitions and illustrations of risk, we simply mention that it represents the probable rate of occurrence of a hazard causing harm, alongside the degree of severity of that harm. One disambiguation we stress is important regarding the meaning of risk is that we refer as risks the probability of *hazards causing harm* not *hazards alone,* making a clear distinction between occurrence of hazards and occurrence of harm. In its most basic mathematical representation:

$$Risk = Rate\ of\ accidents * Degree\ of\ severity$$

Additionally, Avizienis (2001) proposes a reference system based on four techniques that encompass risks in the concept of *faults*:

[15] Adapted from EN 50126 (1999) The Specification and Demonstration of Reliability, Availability, Maintainability and Safety (RAMS) for Railways Application, Comité Européen de Normalisation Electrotechnique (CENELEC), Brussels, Belgium.

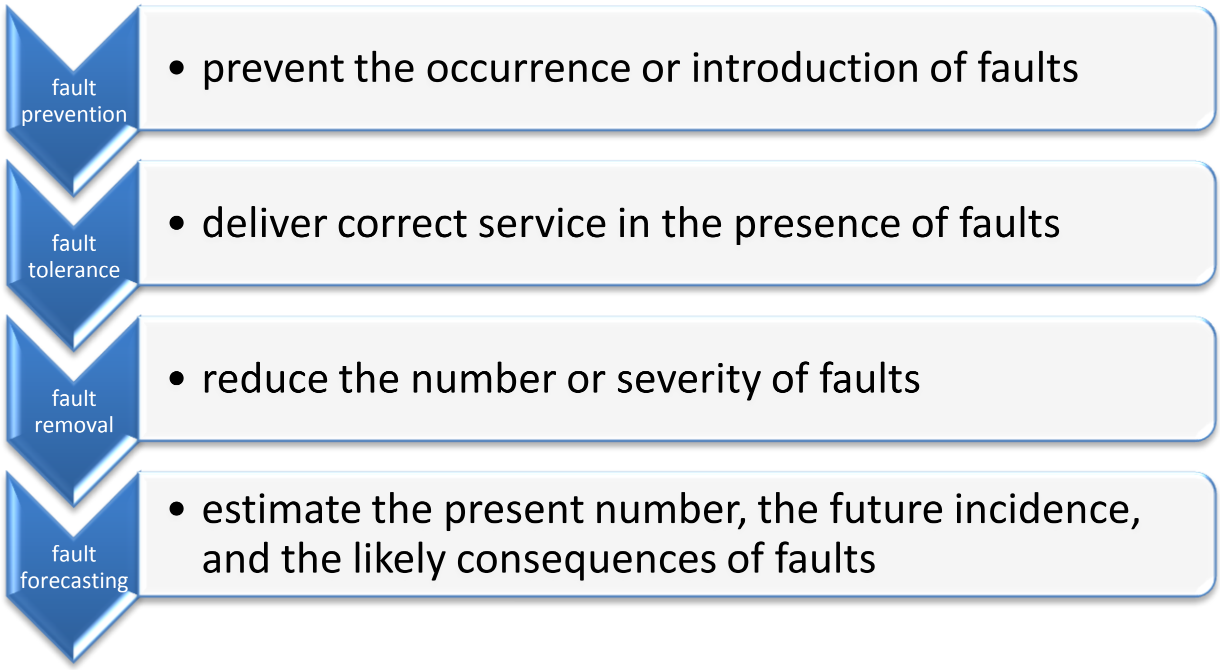


Figure 3-2 Reference system for risks

The basic description of a fault based prevention-tolerance-removal and forecasting system is based on quality control techniques employed during design and manufacturing stages and verification, diagnosis and correction during the operational life of the system. It is obvious that a life cycle approach is embedded within the concept especially since fault forecasting is based on the evaluation of the system behaviour with respect to fault occurrence or activation by classifying failures and compute probabilities that some parameters of dependability are satisfied.

Railway transportation systems are one of the most commonly used modes of transports and their importance and utility is high for the society as a whole. It is easy to understand that the advancement of the technology, ever changing environment and increasing customers' demands pressure railways have to continuously upgrade their services. However, as stated earlier, no improvements are possible except in a safe and reliable environment with sufficient capacity and availability. In this regard, it is impossible to argue against the fact that the railway infrastructure represents a major systemic component in the sense that tracks form an essential part of the railway infrastructure which in return consists of components such as: rail, fasteners, switches, all of these having a degradation rate, hence a different life cycle. By simply looking at the various track components with their various life cycles, we need to consider the phases of their life cycle such as: *inception, design, manufacturing, installation, operation and maintenance, and disposal*. The issue becomes even more relevant when considering that it is very difficult/ costly to modify the initial design of the infrastructure hence, a very important aspect can be highlighted at this early stage: *the performance of the infrastructure depends largely on the maintenance and renewal decisions taken during its life cycle*. This is why even from the earliest stages of design we need to consider cost and aspects such as: *Reliability, Availability, Maintainability, and Safety (RAMS)*

In the later stages, during the operation and maintenance, Life Cycle Costs (LCC) besides RAMS represent a reliable duo for making effective decisions. Each of the track components having varying life and degrading conditions will obviously influence the quality and operability of the track. In order to maintain the quality of infrastructure at a level considered acceptable, two aspects of track quality need to be considered:

object of measurement of track quality

- service reliability
- track utilisation and accessibility
- track safety
- cost-effectiveness.

methodologies

- means to achieve required track quality
- continuous measurements
- metrics

It is easy to understand that high operation and maintenance costs act as a significant barrier for achieving financial performance in railway operation. Obviously, with increasing track requirements (axle load, gross tonnage, speed,) it is easy to envision that the system is prone to more failures. Additionally, the extra pressure of maintenance activities on track availability is even more acute in increased traffic conditions. Hence, more performance demands more maintenance which in turn requires more budget and other resources. Such basic reasons lead to the necessity to optimise maintenance activities in terms of costs and RAMS, based on a systematic approach. Overall, infrastructure managers have to cope with the increased demand for performance alongside budget optimisations all while reliability and availability have to be increased without endangering traffic safety.

Since in practice most of the maintenance and renewal decisions are based on past experience and expert estimations, we focus on a systematic LCC approach in combination with RAMS that aims to provide a way to optimise the maintenance strategy, considering the short term budget restrictions as well as long term costs of ownership.

3.2 RAMS Parameterisation and Interrelation

In order to perform any track analysis a deep understanding of the technical description of the system is necessary since different track components is prone to varying degradation cycles and, furthermore, degradation of one component usually leads to the degradation/ accelerated degradation of other components. These critical inter-correlation factors need to be considered when estimating RAMS of the track system. Hence, in order to estimate the RAMS at an infrastructure system level, one must evaluate the RAMS characteristics at sub-system and component level.

RAMS - Reliability Parameters

The reliability on a system level is defined based on failure categories explained bellow. Meeting required performance levels of the infrastructure signifies that based on various failures types, a higher reliability target is put for higher significance failures while lower targets are put for decreasingly significant failures. In a nutshell, this approach leads infrastructure managers to better identify which component failures should be given more attention in order to achieve higher reliability at the system level.

Failure category	Definition
Significant (immobilizing failure)	A failure that usually prevents train movement or causes a delay to service greater than specified threshold or generates a cost greater than a specified level
Major (service failure)	A failure that must be rectified for the system to achieve its specified performance but does not cause a delay or cost greater than an accepted level
Minor	A failure that does not prevent a system achieving its specified performance and does not meet criteria for significant or major failures

Table 3-1 RAMS reliability parameters[16]

One of the ways to represent reliability is via a function of time where the time unit for the track is generally considered in Million Gross Tonnes (MGT). MGT (in Metric Tonne) is expressed as the cumulative tonnage passed over a track section in one year. This approach is based on the fact that train operation accounts for more degradation of the track than train free periods however, it does not consider the ageing factor. Among other factors which have an important influence on reliability are 1) period of use and 2) environment of use. Typically, some widely used infrastructure reliability parameters are the:

Mean Time To Failure (MTTF) or Mean Time Between Failure (MTBF)

Mean Distance To Failure (MDTF)or Mean Distance Between Failure (MDBF)[17]

R**A**MS - Availability Parameters

Overall, reliability and maintainability on a component level determine the availability of systems which can be measured in three ways[18]:

[16] EN 50126 (1999) The Specification and Demonstration of Reliability, Availability, Maintainability and Safety (RAMS) for Railways Application, Comité Européen de Normalisation Electrotechnique (CENELEC), Brussels, Belgium.
[17] Ebeling, C.E. (1997) An introduction to reliability and maintainability engineering, Mc Graw-Hill, New York.

Inherent availability - the ideal state for analysing availability which is the probability that a system or equipment, when used under stated conditions, in an ideal support environment (i.e. readily available tools, spares, maintenance personnel, etc.), will operate satisfactorily at any point in time as required

Achieved availability - more realistic in nature as it considers both preventive maintenance as well as corrective maintenance which is probability that a system or equipment, when used under stated conditions in a maximum available support environment will operate satisfactorily at any point in time

Operational availability - is the probability that a system or equipment, when used under stated conditions in an actual operational environment, will operate satisfactorily when called upon. Operational availability takes into account that maintenance response is not instantaneous rather it considers logistic issues related to repair.

RA**M**S Maintainability Parameters

In principle, maintainability is a design related function that must be developed during the initial stages of the infrastructure life cycle as early as the design stage. Maintainability is performed due to the following main rationales:

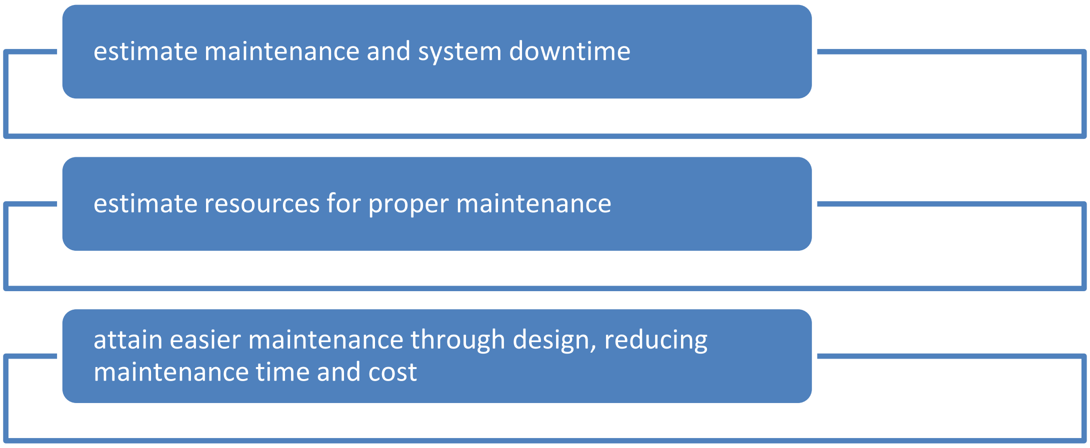


Figure 3-3 Maintainability parameterisation[19]

Two metrics are commonly employed and in this regard, maintainability is most commonly measured by *Mean Time to Repair (MTTR)* and *Mean Time Between Maintenance (MTBM)*

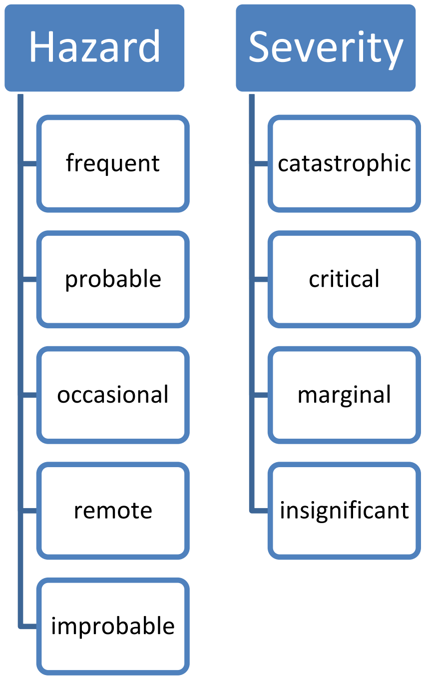
[18] Blanchard, B.S. and Fabrycky, W.J. (1998) Systems Engineering and Analysis, 3rd ed., Upper Saddle River, NJ: Prentice-Hall.

[19] Adapred from EN 50126 (1999) The Specification and Demonstration of Reliability, Availability, Maintainability and Safety (RAMS) for Railways Application, Comité Européen de Normalisation Electrotechnique (CENELEC), Brussels, Belgium.

or *Mean Distance Between Maintenance (MDBM),* which consider both unscheduled and preventive maintenance.

RAM**S** - Safety Parameters

Safety analyses deal with categories and severity levels of hazardous events that can negatively impact train operation through infrastructure failures. Hazard identification is the first step in the safety analysis and these events can be categorized as frequent, probable, occasional, remote, improbable and incredible. Additionally, the severity level can be divided into four categories - catastrophic, critical, marginal and insignificant. Hence, safety can be defined as a subset of reliability with consideration of severity of failure modes. Typical safety metrics that that are being used are:



Mean Time Between Hazardous Failure (MTBHF)

Mean Time Between Safety System Failure (MTBSF)

In terms of RAMS component interconnectivity, safety and availability are considered as the output of any RAMS analysis and any conflicts between safety and availability requirements may prevent in achieving a dependable system from being achieved. Hence, attainment of in-service safety and availability targets can only be achieved by meeting all reliability and maintainability requirements and controlling long-term maintenance and operational activities. The interrelationship between RAMS components is shown below and illustrates that failures in a system will always have some effect on the behaviour and performance of the system either via system reliability or safety of the system.

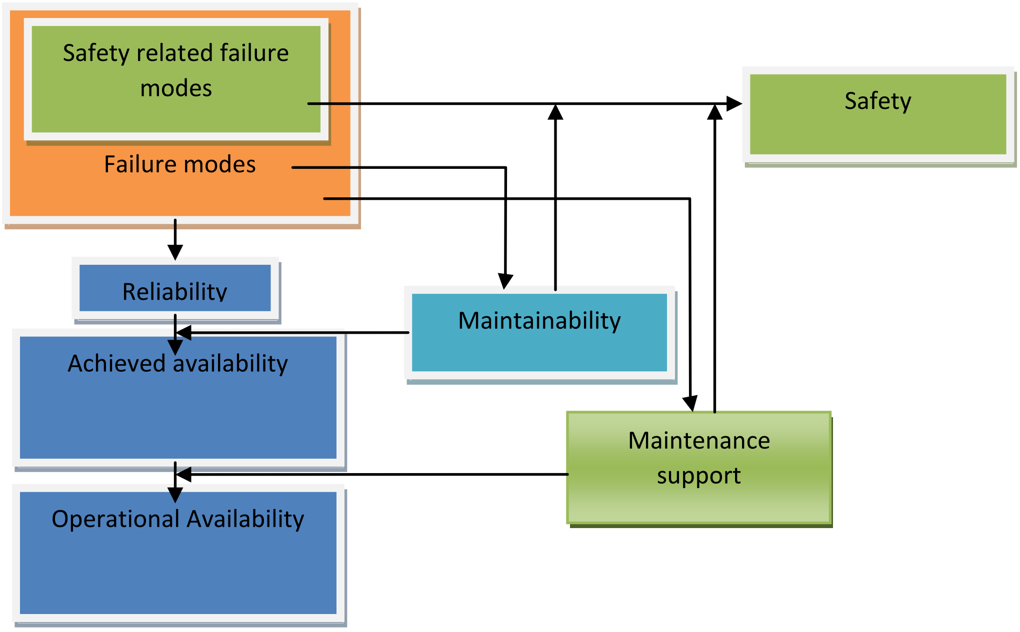


Figure 3-4 RAMS interrelations[20]

Based on the failure modes, various tools and methods are used to calculate reliability and maintainability of the system, for example, FMEA (Failure Mode and Effects Analysis), FMECA (Failure Mode, Effects and Criticality Analysis), FTA (Fault Tree Analysis), Failure Block Diagram Analysis, CCA (Cause Consequence Analysis) (**Markeset and Kumar, 2001**). One highly relevant aspect is that failure modes directly affect reliability (in terms of probability of occurrence), maintainability (in terms of the number of failures occurring in a period of time) and supportability (in terms of probability and criticality of failure modes). Overall, the safety of the system can be considered as the sub-set of reliability of the system, when the severity of the failure consequences is taken into account and also depends on maintainability of the system in terms of ease of performing maintenance of safety related failure modes, time to restore the system into a safe mode.

3.3 RAMS -factors of influence

Even though it is fairly difficult to create a balanced RAMS system in which all four components are optimised, in order to transition from a theoretical approach to a close-to-real operation approach at least some factors which could influence the RAMS need to be identified, their effect need to be assessed and the causes of these effects need to be managed throughout the lifecycle of the system. In brief, RAMS factors of a railway system are influenced in three ways:

- System conditions: sources of failures introduced internally within the system at any phase of system lifecycle

[20] Adapted from EN 50126 (1999) The Specification and Demonstration of Reliability, Availability, Maintainability and Safety (RAMS) for Railways Application, Comité Européen de Normalisation Electrotechnique (CENELEC), Brussels, Belgium.

- Operating conditions: sources of failures connected due to system operations
- Maintenance conditions: sources of failures introduced during maintenance actions

	Physical parameters	Technical parameters
System conditions	Track gradients (start, end, value	Quasi-static stress
	Track curvature (transient curve in, transient curve out, radius)	Quasi-static stress
	Rail (rail type, jointed or welded	Yield stress
	Ballast (ballast type, ballast size	Stiffness, Damping
	Sleeper (sleeper type, sleeper spacing	Stiffness, Damping, Bending stress
	Fastener (fastener type)	Damping
Operating conditions	Loads (annual MGT, maximum axle load)	Bending stress, Shear stress, Contact stress
	Environment (temperature)	Thermal stress
	Speed of train	Vertical stress
	Vehicle condition (hollow wheel)	Dynamic stress
Maintenance conditions	Grinding	Wear rate
	Tamping	Change in track stifness
	Lubrication	Change in friction co-efficient
	Renewal of track components	Interval of renewal
	Corrective replacements of track components	Failure rate of track components

Table 3-2 Relationship of RAMS parameters with maintenance support[21]

The generic factors illustrated above that influence RAMS can be applied to achieve a dependable infrastructure system. We herewith identify some specific factors that affect the infrastructure RAMS taking into account that the quality of RAMS data affects the correctness of RAMS estimation. Hence, many types of data are relevant to the estimation however, not all are collected in many instances, making the lack of information, sometimes, a serious problem[22]. As seen in the table above, different physical parameters that affect RAMS have associated technical characteristics. In this regard, technical parameters are the causes of the physical parameters which directly affect infrastructure RAMS. The system condition mostly deals with the design and manufacturing of the components whereas the operating condition deals with the rolling stock operations. In most of the cases it is difficult to change the system conditions and operating conditions of the system in the operation and maintenance phase of the infrastructure though sometimes operating condition (e.g. change in axle load) can/ must change because of change in railway regulations. However, changes in maintenance conditions are quite possible to enhance RAMS of the infrastructure system.

One particularly noteworthy aspect is the fact that even though a RAMS system is relatively easy to conceptualise, in order to assess the effects of maintenance conditions on the

[21] IEV 191-01-07 (2007) International Electrotechnical Vocabulary
[22] Blischke, W.R. and Murthy, D.N.P. (2003) Case Studies in Reliability and Maintenance, John Wiley & Sons, USA

reliability of the track system, for example, it is necessary to consider a combined effect[23]. Knowing that grinding affects the reliability of the rail, performing an effective reliability analysis must consider the combined effects of other maintenance conditions e.g. lubrication, rail replacements. Basically, lubrication reduces the rail wear especially in the curves and thereby increases the reliability of the rail however it is also a factor for rolling contact fatigue defects which is removed by grinding thus, an estimation of the combined effects of different conditions is necessary in order to measure their influence on the RAMS of the track system[24].

3.4 Life-Cycle Costing in railway transport infrastructure

It is important to mention right from the beginning that although a multitude of cost models are used in the field of railway infrastructure, the usage of Life Cycle Cost (LCC), although generally regarded as a powerful tool, is quite limited. The aforementioned cost models while supporting decisions on maintenance and renewal actions, rarely consider the whole life cycle perspective of the infrastructure. Perhaps the key aspect of a life cycle cost analysis is to understand the factors that influence LCC and the parameters that are needed to estimate it. Due to these facts we approach the railway infrastructure's need for LCC and the current models used in practice.

Any asset that has a long amortisation period is prone to be better analysed using a life cycle approach. Indeed the more complex the system the more difficult is to performs such an analysis, however, once bottlenecks are sorted, the unlocked value is considerable. Railway infrastructure is in fact a large and complex system with a long useful life. Therefore, as stated earlier, once installed, it is very difficult and costly to modify the initial design. Thus, the performance of the infrastructure depends on the maintenance and renewal decisions taken during its life cycle. In many countries restructuring of railways and increasing efficiency and effectiveness requirements cause a changing environment for infrastructure management. Responsibilities for parts of the railway system are often handed over to different actors which beyond confusions, create an environment where costs cannot be optimises in a systemic manner. In order to guarantee optimal long-term results for the railway systems the effects of decision should be systematically evaluated by the infrastructure manager which is responsible for the design, construction, maintenance, *renewal* and upgrading of the infrastructure[25]. Since the pressure for more reliability and availability affects budgets, a systematic approach is needed to make sure all stakeholders are up to the challenge.

[23] Diamond, S. and Wolf, E (2002) Transportation for the 21st century, TracGlide Top-of-Rail Lubrication System, Report from Department of Energy, USA.
[24] Ringsberg, J.W. (2001) Life prediction of rolling contact fatigue crack initiation, International Journal of Fatigue, Vol. 23, pp. 575-586.
[25] Zoeteman, A. and Esveld, C. (1999) Evaluating Track Structures: Life Cycle Cost Analysis as Structured Approach,WCRR, Tokyo, Japan, Session on Infrastructure.

Putallaz (2003) proposes a very simple tri-factor model that illustrates the competing needs for: 1. investments, 2. maintenance and 3. renewal and the pressure these put on the overall available budget. Hence, without systemic cost optimisations, any disequilibrium in any one factor reverberates leading to appreciate costs and suboptimal budget allocations. The theoretical framework of LCC is clearly defined as all costs associated with the system life cycle and includes:

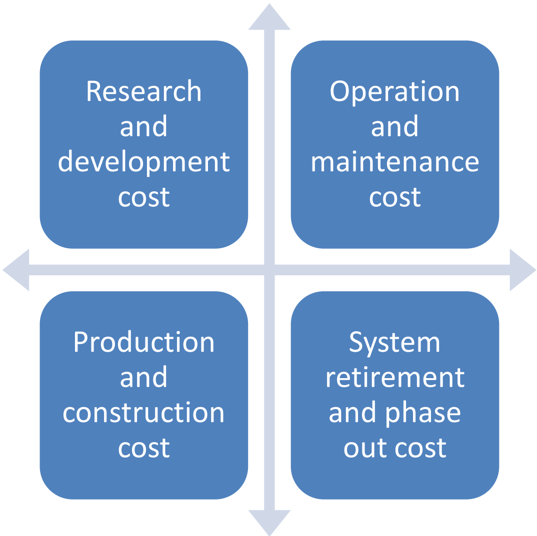


Figure 3-5 LCC factors[26]

These costs can be viewed from diverse points of view i.e. from the viewpoint of the system's supplier or of the system's user or owner, or even more broadly from the point of view of society. A basic assumption providing motivation for the LCC approach is that it is usually possible to affect the future costs of a product beforehand, either by planning its use or by improving the product or asset itself[27]. Additionally, Asiedu and Gu (1998) stated that LCC analysis should not only be seen as an approach for determining the cost of the system but as an aid to decision making in design, maintenance, etc. The use of life cycle cost analysis should therefore be restricted to the cost that we can control. In order to be able to estimate life cycle costs of the rail infrastructure, the factors influencing the performance of the railway infrastructure and their relationship need to be identified. In this regard, an obvious cause and effect path must be taken which would explain, for example, that track degradation depends on the initial quality of construction, the quality of the substructure and the loads on the track. Additionally, there are also RAMS factors that influence LCC such as the amount of preventive maintenance, market prices of labour, materials and machines, and the operational characteristics of the line. Some of these factors can be managed for

[26] Adapted from Blanchard, B.S., Verma, D. and Peterson, E.L. (1995) Maintainability: A Key to Effective Serviceability and Maintenance Management, New York, John Willeyand Sons Inc.
[27] Markeset, T., and Kumar, U. (2003), Integration of RAMS and risk analysis in product design and development work processes: A case study, Journal of Quality in Maintenance Engineering, Vol. 9, no 4, p. 393-410

example the infrastructure manager can cooperate with the transport operators and influence the quality of rolling stock however, some exogenous factors, such as the condition of the soil and the interest rate, will also influence life cycle costs[28]. One noteworthy aspect concerning rail infrastructure is that physical design influences the asset degradation together with other conditions, such as traffic intensities and axle loads, the quality of substructure and the effectiveness of performed maintenance. The quality of the geometric structure determines the required volume of maintenance and renewal (M&R) alongside the chosen maintenance strategy.

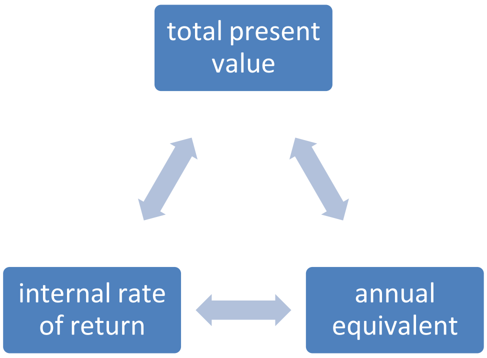


Figure 3-6 Life Cycle Cost measures[29]

Generally speaking, cost models used in the decision support systems or maintenance management systems should be able to provide means to evaluate and compare the costs and benefits of different maintenance strategies and options. In order to carry out an economic analysis, it is necessary to make adjustments to costs to ensure that they are all measured in the same units and represent real resources' costs. According to Zoeteman (2001), life cycle costs can be presented in three different ways, i) total present value (TPV), ii) internal rate of return (IRR), and iii) annual equivalent or annuity (ANN).

Total Present Value (TPV)

Is a measure of accrual which involves the sum of all discounted cash flows. Since the LCC methodology mostly concerns costs, one can consider that incomes are nothing more than negative costs. Hence, the larger the TPV, the less attractive is the investment compared to other alternative investments or maintenance. The importance of discounting techniques is that investments made at different intervals have different economic values and in order to take these into account, all future costs are discounted to convert them to present values. Total Present Value (TPV) is given by:

$$TPV = \sum_{i=1}^{n} \frac{c_i}{(1+r)^i}$$

[28] Zoeteman, A. (2006) Asset maintenance management: State of the art in the European railways, International Journal of Critical Infrastructures, Vol. 2, No. 2-3, pp 171-186, ISSN: 1475-3219.
[29] Adapted from Zoeteman, A. (2001) Life cycle cost analysis for managing rail infrastructure, Concept of a decision support system for railway design and maintenance, EJTIR, Vol. 1, No. 4 , pp. 391 – 413.

where

c_i = the sum of all costs incurred in year i

r = discount rate

i = year of analysis

Discount rates vary greatly from company to company for example the InnoTrack project in 2010 found the following variation between different railway infrastructure managers.

Ban Verket (now Trafik Verket) – Sweden	r=4.0%
Deutsche Bahn Netz – Germany	r=5.9%
Network Rail – UK	r=6.5%
ProRail – Netherlands	r=4.0%

Additionally, we can compute a Net present value (NPV) is the difference between the discounted benefits and costs over the analysis period. A positive NPV indicates that the investment is justified at a given discount rate.

NPV is given by:

$$NPV = \sum_{i=1}^{n-1} \frac{b_i - c_i}{(1+r)^i}$$

where

b_i = sum of all benefits incurred in year i

Internal Rate of Return (IRR)

The internal rate of return (IRR) is a comparative method defined as the percentage earned on the amount of capital invested in each year of the life of the project after allowing for the repayment of the sum originally invested. It shows the profitability of an investment compared to alternative investments or maintenance strategies. The IRR is the discounting rate at which the present values of costs and benefits are equal, i.e. NPV = 0. This signifies that the higher the IRR, the better is the investment. If an investment yields higher than the discounting rate, then the investment is economically justified.

Annual Equivalent or Annuity (ANN)

ANN is the sum of interest and amortisation, which has to be paid every year to finance the investments and maintenance. With the annuity, projects of different life spans can be compared.

$$ANN = \frac{(i+1)^n \times i}{(i+1)^n - 1} \times TPV$$

Framework for LCC Models

For the maintenance management of the railway assets, cost modelling has three major purposes:

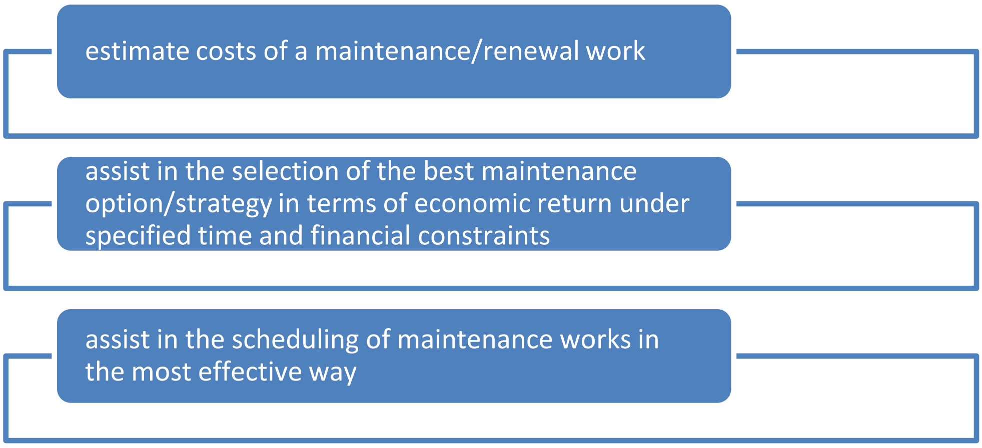


Figure 3-7 Basic LCC model[30]

Several cost models are available which can be applied to infrastructure maintenance and renewal. Since 1997, the rule based expert system 'ECOTRACK' was developed to aid infrastructure managers to plan maintenance and renewal on the basis of well-defined technical and financial rules. ECOTRACK defines a five step process for generating a maintenance and renewal work plan. Inputs are track measurements, maintenance histories and a rule base. The first three steps are based on an analysis of the track condition with a gradually increasing level of detail. In the initial diagnosis the rough maintenance and repair needs are calculated, while the system points the user at desirable, additional data for more detailed diagnosis. Finally, the preliminary work programme is improved in terms of clustering renewal works, which are close in time and space. Finally, the fifth level allows a number of statistical analyses.

Zoeteman (2001) developed and applied a decision support system named LifeCycleCostPlan in several case studies. Inevitably, expert judgement is an important part of the input and in LCC models. The LCCRailTrack model is based on a Markov multistate

[30] Adapted from Zaalberg H. (1998) Economising Track Renewal and Maintenance with ECOTRACK, Conference on Cost Effectiveness and Safety Aspects of Railway Track, ERRI and UIC, Paris 1998.

model where the possible states of railway track as well as the chances of transfer from a less worse to a worse deterioration state need to be estimated by users. Estimation and minimisation of traffic disruption can be considered as a special area of railway research, requiring mathematical algorithms and simulation models.

Overall, studies have been undertaken in the last years to develop:

- Optimal maintenance execution plans, i.e. scheduling consecutive MR machine runs in order to minimise integrated costs of track works and possessions.
- Optimal clustering and timing of small MR works into regular maintenance slots

In this regard, the life cycle cost model developed by Vatn (2002) considers the punctuality cost in the model. The basic punctuality information entered is the ordinary speed of the line and any speed restrictions due to degradation. The program then calculates the corresponding increase in travelling time. The model also calculates the economic gain due to the increase in life length brought about by maintenance actions. It can be noticed that most of the existing models in railways are not taking into account all aspects especially the risk aspects of life cycle costing. Cost modelling on traffic disruption, train punctuality, environmental cost (noise, vibration etc), and customer (end user) dissatisfaction is still in developing stages, which can have a major impact on the maintenance and renewal decisions.

3.5 EU and international practices in the use of RAMS and LCC

The International Electrotechnical Commission (IEC) is a worldwide organization which promotes international co-operation concerning standardization in the electrical and electronic fields. The International Standard IEC 60300-3-3, "Application guide – Life-Cycle Costing (2004) includes many important aspects support to build up an LCC model for the railway transport infrastructure with the main goal that the products to be designed and developed are reliable and safe, easy to maintain throughout their useful lives. In the procurement phase of a product it is essential to consider not only the product's initial cost (acquisition cost), but also the product's expected operating and maintenance cost over its life (ownership cost) and the disposal cost.

Life-Cycle Costing (LCC) performs represents an economic analysis to assess the total cost of acquisition, ownership and disposal of a product and provides important inputs in the decision-making process for different life phases of the product. LCC can be optimized and a cost-effective solution achieved by evaluating different design, operating, maintenance and disposal strategies. LCC can be also used[31] to assess the costs associated with a particular activity to cover a specific part of a product or to cover only a selected phase or phases of a product life-cycle. In literature this is referred also as Activity Based Costing (ABC) and is integrated in a life-cycle analysis. The performing LCC only for a particular activity can be

[31] Ramos Andrade, Renewal decisions from a Life-cycle Cost (LCC) Perspective in Railway Infrastructure: An integrative approach using separate LCC models for rail and ballast components M.Sc Thesis in: Civil Engineering, Supervisor: Prof. Paulo Manuel da Fonseca Teixeira, September 2008

very helpful depending on the actors involved. In the railway transport infrastructure, the managers may be only interested in assuring the lowest operation and maintenance cost, while obeying to safety and availability restrictions defined by the regulatory entity.

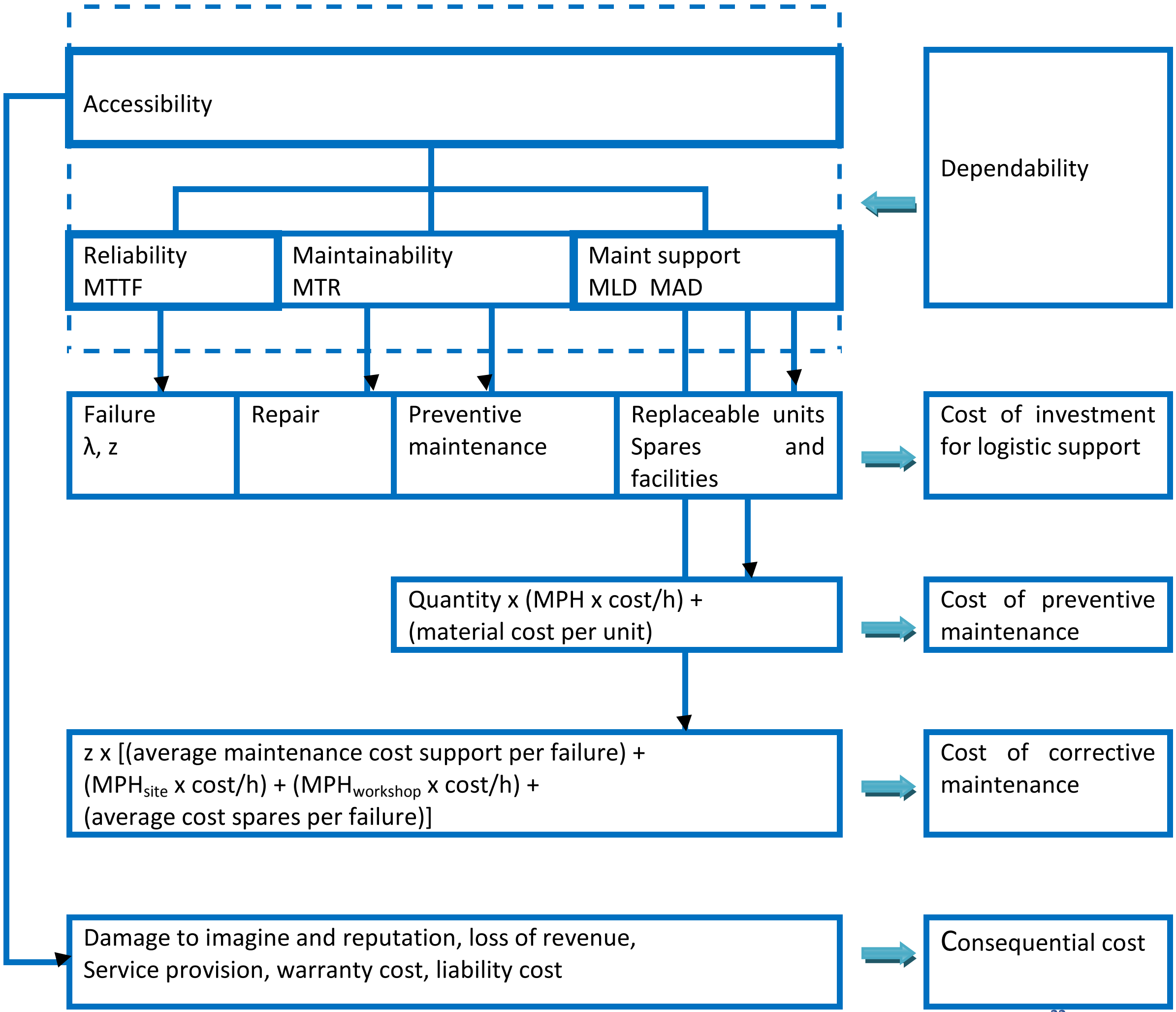


Figure 3-8 Relationship between dependability and LCC during operation and maintenance processes[32]

The standard defines dependability as a term used to describe the product availability performance. The costs related to dependability features should include system recovery cost, preventive maintenance cost and consequential cost. The figure below presents the relationship between dependability and LCC during operation and maintenance processes. Dependability is mainly composed by Reliability, Availability and Maintainability (RAM). Safety is included in this group of three aspects, forming RAMS and in railway transport infrastructures it is considered an a-priori condition and indirectly assured by good performance levels of the other components of RAMS.

Dependability performance is conditioned by failures, which may be mitigated or removed through preventive or corrective maintenance with associated costs that should be included

[32] The International Standard IEC 60300-3-3, 2004 "Application guide – Life-Cycle Costing

in LCC. Maintenance activities may require investments in logistic support. The consequential costs are those which occur when a product is unavailable. These costs include warranty cost, liability cost, cost due to loss of revenue and costs for providing an alternative service and can be analysed also by their impact on the company image, reputation and prestige, which may be more difficult to estimate. The performance payment regimes contracted between the infrastructure manager and the regulator entity are mainly the consequential costs considered in LCC. Life-Cycle Costing analysis contributes to achieve optimal product reliability, corresponding to the lowest Life-Cycle Costing, evaluating the trade-off between higher acquisition costs and lower maintenance and support costs.

A useful LCC model should represent in the best manner the characteristics of the product, its intended use environment, maintenance policy, the constraints or limitations (one possible limitation is related to financial aspects) and must be comprehensive, including every factor relevant to LCC, useful to support quick decision making, easy updated to any future modification, flexible and designed to permit the evaluation of the specific elements of LCC independent from the others.

The considered cost elements have to be categorised in function of the work/product category, the life-cycle phase and the applicable resource(s) and in this perspective life-cycle cost can be divided in recurring and non-recurring costs or in fixed and variable costs. Recurring costs are regular costs incurred for each item produced or each service performed, while non-recurring costs are unusual costs, unlikely to occur again, also called extraordinary costs.

The estimation of the costs may be done via three methods which can be used separately or together:

- Engineering cost methods;
- Analogous methods;
- Parametric methods

The engineering cost method is based on the examination of the product components, considering each specific components or the consideration of the products parts analysing each of them using standard established cost factors such as manufacturing estimates updated to the present time by the use of appropriate factors (e.g. consumer price index components).

The analogous cost method may be the quickest and simplest way to estimate costs, because ii uses the historical data related to a similar product, updated to reflect cost escalation. An analogous cost method can be improved by using time-series forecasting as an example, decomposing it in different trend lines. LCC should be seen as a multidisciplinary activity.

The parametric cost method uses parameters and variables in order to develop cost estimation relationships in form of equations. Some assumptions are made on the values of the system considering the historical data or expert opinion. A parameter is the rate of failures in a system and is used to estimate the cost of corrective maintenance of that system. This method, if it desires to reflect much better the complexity of the referred system or product can include typical stochastic processes analysis, assuming some randomness in the parameters and variables used.

By using the maximum and minimum values, providing in this way a set of boundaries in the total life-cycle cost, this approach could offer a much flexibility and adaptability of the model to different conditions, some of them which have not been identified or not considered. To deal with uncertainty, more accurate and complex analyses can be performed as that offered by the Monte Carlo simulation.

There are many factors which contribute to uncertainty and risk, such as lack of information, introduction of new technology, or even political and economic circumstances (including legislative changes), predicted inflation rates, labour, material and overhead costs

A well-presented and coherent LCC analysis and easily understood by decision-making actors should include a plan addressing the purpose and scope of the analysis, the analysis objectives in order that LCC to become for a specific product a support for the planning, contracting, budgeting or similar needs; to can evaluate the impact of different alternatives, such as design options or maintenance policies or even to identify major contributors to the LCC of a product. LCC is particularly important in order to develop an optimal maintenance strategy, as the infrastructure manager, which is responsible for ensuring a certain RAMS level, to can perform the needed maintenance operations, otherwise it will be penalised by the regulatory entity, based on a performance payment scheme.

In order to have a clearer picture on the requirement and structure of our database, it is important to mention that on a EU level several models and tools being used in the estimation of RAMS parameters and LCC components. These are used by infrastructure managers to analyse either components or the system as a whole. Patra (2007) presents an interesting compilation of the LCC and RAMS tools used across various infrastructure managers.

LCC Models/Tools

Track Strategic Planning Application known as T-SPA developed by Serco is a decision support tool designed to provide an analysis of a broad range of renewal and maintenance options and provides connections from the effort and cost of the work to the performance of the railway infrastructure. The main objective of T-SPA is to aid in the development of robust long term plans, critical to the future funding of the infrastructure maintenance and renewal. Overall the tool:

- Enables user to specify a comprehensive range of scenarios constructed around future train service patterns, varying maintenance regimes and renewal options
- Provides a form of quantification of the condition of the assets during their time in service

- Draws from various data sources (historical and forecasted) to provide accurate input for prediction models
- Allows analyses to be performed at different levels of detail ranging from single routes to the whole railway infrastructure comprising almost 32,187 track kilometres.

D-LCC was developed by Advanced Logistics Developments (A.L.D) group it a tool that provides bottom-up cost estimations with the aim to perform detailed examinations of costs and parameters affecting LCC. It computes discounts and annuities of costs with a much focused life cycle approach. The tool allows users to apply pre-defined LCC models as well as to create new cost breakdown structures and models. Any cost structure can be used as long as the structure remains consistent along all investment options. D- LCC supports detailed examination of the dynamics of future cash flows over multiple time periods with the following functionalities:

- Evaluation and comparison of alternative design approaches
- Identification of cost-effective improvements
- Budget viability assessment

Life Cycle Management (LCM) aids determining the cost-effectiveness of alternative maintenance actions. LCM calculations include the following stages:

- Project definition and time frame
- Definition of maintenance alternatives via expert groups
- Project description (brief)
- Identification of maintenance inputs - costs, failure rates and actual data input.
- Output of total costs for different alternatives broken down in different cost categories
- Graphical representation of results
- Sensitivity analysis

RAMS Models/Tools

TRAIL is a discrete event simulation model used to estimate availability based on individual component reliability data. Some of the important features of TRAIL include:

- The level of detail is user definable down to the level of individual track circuits or other assets. This allows the reliability of each track circuit to be incorporated into the overall model.
- When a failure is generated, train services operating on the faulty section between the failure time and the end of the repair are subjected to the effects characterized by the failure modes. The delays are applied to each train delayed and the sum of the delay is attributed to the faulty section for the final statistics.
- Accepts that failure rates to be entered as a function of time or usage.

- The final aspect of availability is the illustration of down time or performance loss that occurs between the start of the failure and the commencement of the repair and total performance loss of an asset that occurs during the repair.
- By providing a target performance, the model lists either asset categories or individual assets that make the largest contribution to delay

RailSys is a simulation tool developed by Rail Management Consultants GmbH (RMCon). The tool computes time of the traffic for both planned and unplanned situations resulting in calculating delay time per train, which is multiplied by delay cost per minute. Finally, the costs for non-availability are calculated on the possession time according to the track standard. Some features of RailSys are:

- Modular design of the simulation area
- Simulation of new technologies of train protection on systems
- Conflict recognition by means of occupation time steps
- Timetable construction and planning for new or existing lines, nodes and networks
- Elaboration of complete operation programmes in consideration of marginal conditions
- Simulation of non-disrupted and disrupted operation to judge the timetable stability/quality

Optimizer+ is a simulation tool which determines the relationship between maintenance costs and performance - in terms of availability, reliability and safety. It was developed by MaintControl BV in conjunction with Baas & Roost Maintenance. The following steps are taken by the tool to the end result:

- Collecting information on failure mode, failure cause, failure condition etc for each component and introduced to the library database
- Systems can be modelled in Optimizer+ using the building blocks. For each system, a risk analysis is carried out, in which the specific failure behaviour is described at the component level. Within the model, all possible risks with regard to the company goals are mapped out. The goal of the model is to make the risks posed to the company goals by component failure more transparent, so that maintenance can be modified accordingly.
- Formulating risk analysis to formulate a concrete relationship between failure behaviour, its effect on company goals and the frequency with which this effect repeats itself. This determines the risk (probability multiplied by effect). The company goals with regard to costs, availability and safety form the point of departure for the risk analysis.
- On the basis of the results of the risk analysis, the existing maintenance plan is modified for several building blocks. With the help of Optimizer+, preventive maintenance actions are determined for the critical components as well as the frequency with which they are to be carried out.

- With the help of the simulation module, the quantitative relationship is determined between failure behaviour on the one hand and availability, reliability and maintenance costs on the other. Based on the risk analysis, several simulation models are created and calculated.

3.6 RAMS/ LCC bottlenecks and potential areas of improvement

As seen in the sections above although progress was made during the recent years in terms of RAMS/ LCC modelling and use to optimise railway infrastructure, some improvements are still needed.

One of the first areas that need to be addressed is the inclusion of environmental costs in LCC models. Indeed, all externalities need to be included so that the LCC reflect more than the effort for the infrastructure manager but also have a societal perspective. Since there is a strong trend towards clean transportation, it is necessary to adjust the expected impact of maintenance/ investment paths. Additionally, more diverse risk analyses need considered in LCC/ RAMS models. This aspect goes beyond the rationale that under/ over estimation of risks hurts the overall outcome of the model to the degree that risk estimations make or break the entire model which make systemic approaches almost impossible. In the same line of thought, infrastructure managers should define achievable RAMS targets and lay out a procedure to attain those targets due to the fact that unforeseen costs like reduction of passengers, loss of good will due to train delays should be modelled.

On another note, there is also a need to ease the use of databases and repositories and to allow better information sharing between infrastructure managers and contractors. In order to carry out reliable RAMS and LCC analyses from early phases of the system life cycle, manufacturers and contractors should be aware of the RAMS and LCC specifications and targets they need to meet and infrastructure managers need to provide as much background data as possible.

The InnoTrack project identified in 2010 the key costs for railway infrastructure managers which require innovation to address. The innotrack project just considered track and S&C problems and did not consider overhead line failures. These ten most important track issues listed in terms of cost importance were:

- Track: bad geometry
- Rail: cracks and fatigue
- Switches and crossing (S&C): switch wear
- Substructure: unstable ground
- Joints: insulating block joint failure
- Rail: corrugation
- Rail: wear
- Structures
- Fasteners: worn /missing pads
- Sleepers: renewal optimisation

- Culverts/pipes: flooding
- Ballast: stone spray on passing axles
- Ballast: ballast wear
- Rail: low friction/adhesion
- Joints: weld quality
- S&C: common crossings
- S&C: manganese crossings
- S&C: geometry maintenance
- S&C: loss of detection

4 Design of data repository support for data and geographical analysis

One of the outcomes of the research activity performed was the physical design for a Web-GIS application based on open source tools and libraries according to Open Geospatial Consortium (OGC) specifications.

The application will provide the needed functionalities which supports users to make a comparative analysis of costs specific to the actions from a life cycle approach of the railway infrastructure in different geographic areas.

The proposed approach towards interoperability is an adoption of service-based architecture for implementation of a multi-tier Web GIS application. This architecture has a deployment style when functionality is separated into layers where each segment can be located on a physically separate computer.

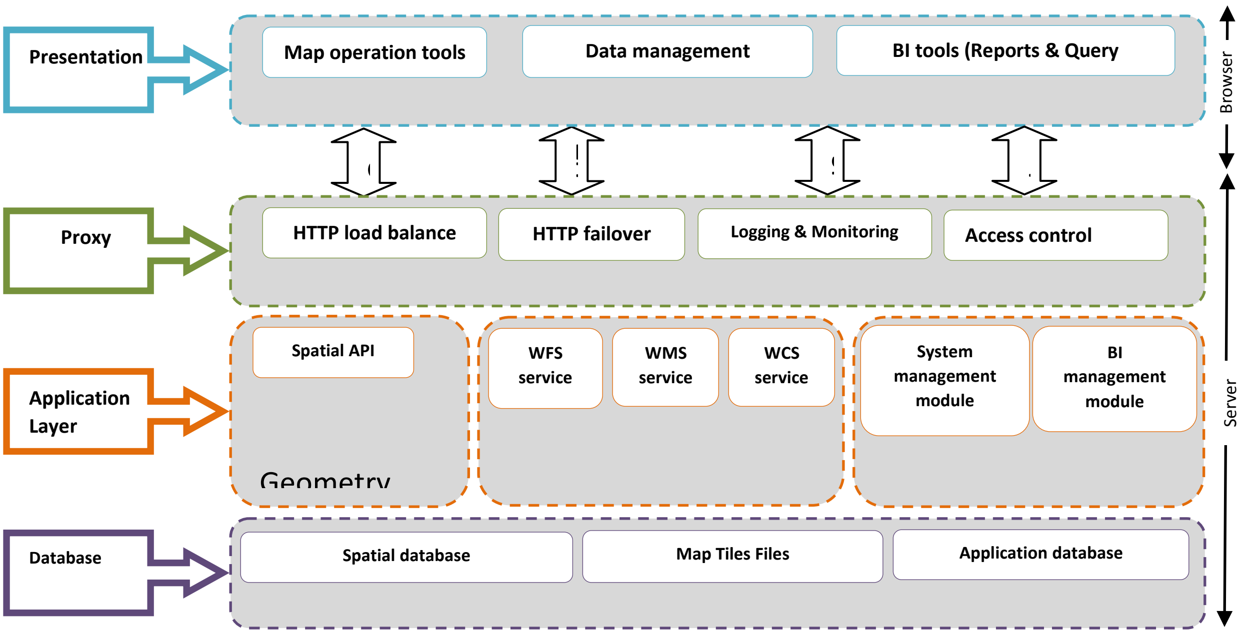


Figure 4-1 Architecture of a system for geographical comparative analysis

In fact, this type of architecture is considered to meet the requirements of availability, stability, interoperability and portability.

This architecture (see in the Figure 4-1) includes the following layers: presentation, proxy, application and database & model.

The presentation, proxy and application layers shall be in WP 6 (detailed architecture will be presented in the task 6.2), only the database layer is made in task 2.1.

The Presentation Layer provides a graphic user interface, which is accessible via the browsers of many devices, for users to perform system management, map operations, spatial and attribute information retrieval, specific railway data management, and so on.

The map viewer is achieved by the Openlayers[33] component, which communicates with map services to retrieve the grid or vector map through Asynchronous JavaScript and XML (AJAX) and to render the map in the browser. Thus, it provides operation experience approximate to a desktop GIS tool.

For Business intelligence (BI) component is used JasperReports Library[34], for presenting the specific railway data analysis results, due to its dynamic and excellent chart functionalities.

The Proxy Layer consists in open-source web server (Nginx, Apache etc.), which lies the presentation and application layers and acts as a communication agent for these two layers.

The deployment and configuration of such web servers provides useful functionalities like: load balancing, failover, access control, logging, monitoring, etc. Thus when the system exceeds the workload limit of the system, the system administrator can add more background services and a simple configuration of web server to scale up the system. Therefore, the proxy tier is very important for enhancing the performance and improving the stability of the system.

The Application Layer consists of two components: map service (geo-services and geometry application services) and application services.

The geo-services component uses an open source Web GIS tool (Geoserver, MapServer etc.), which is in compliance with the Open Geospatial Consortium (OGC) standards, such as Web Map Service (WMS[35]), Web Feature Service/Web Feature Service-Transaction (WFS/WFS-T[36]) and Web Coverage Service (WCS[37]). Additionally we used external Web GIS

[33] **OpenLayers** - is an opensource javascript library to load, display and render maps from multiple sources on web pages. (for more information see http://openlayers.org/)
[34] **JasperReports Library** - is the most popular open source reporting engine. It is a Java reporting tool that can write to a variety of targets, such as: screen, a printer, into PDF, HTML, Microsoft Excel, RTF, ODT, Comma-separated values or XML files. (for more information see http://community.jaspersoft.com/)
[35] **WMS** - Web Map Service - provides map images
[36] **WFS** - Web Feature Service - provides an interface allowing requests for geographical features across the web using platform-independent calls
[37] **WCS** - Web Coverage Service - provides access to coverage data in forms that are useful for client-side rendering, as input into scientific models, and for other clients

tools like OpenStreetMap or Google Maps in order to provide a thematic map. OpenStreetMap is a free and editable map of the world built by a community of mappers that contribute and maintain data about roads, trails, railway stations, and much more, all over the world.

The geometry application services component uses open source libraries like Java Topology Suite and Hibernate Spatial in order to implement the fundamental algorithms for processing linear geometry on the 2-dimensional Cartesian plane and also for handling geographic data. These components are used to extract and/or manipulate the geographic data (geometry like point, line, multilines, polygon and multipolygons) in different open dialects and provide the results in SFS specifications[38] in order to be inserted into relational database.

The application services provide functionalities for railway data management, such as CRUD operation (Create, Read, Update and Delete) and also to provide support for dynamic queries and to display their results. These components are standard compliant and service oriented, making them scalable and interoperable.

The Database Layer is the most important level of this architecture and is located on the bottom of the architecture. The databases store and manage attribute data, spatial data and map tiles via a spatial database, an object-relational database and a file system.

The spatial data can be stored in the PostgreSQL database with the use of the PostGIS library or in MySQL database with the use of the MySQL Spatial extension, which adds support for the use and management of geographic objects. Spatial and other regular indices are created for every map layer stored in the spatial database to increase the speed of retrieval. Map tiles are pre-generated and stored in the map tile repository. This will accelerate the mapping processes, as WMS can directly deliver the caching map tiles to the client when a map request is sent to it.

A detailed description of the object-relational database is given in the ANNEX 4: Design of data repository.

4.1 Design of conceptual model for integration of database with GIS

The design of data structure with fields which make possible GIS mapping to the failure data to reveal correlations and underlying drivers of cost and maintenance which have not been previously visible is presented below.

The development of GIS application involves the following activity:

- Data input;
- Data management;
- Data manipulation and analyses;

[38] SFS specification - defines a set of functions on geometries and is implemented in most RDBMS with spatial data support.

- Data output.

The information consists from nonspatial and geographical (spatial) data. For example in the railway activity domain, data about infrastructure managers (name, address, contact person etc.) will be modelled, and when the geographic system in considered, other additional data must be taken into account (railway geometry, node and hub location, station location, asset location etc.) since it strongly defines the functionality of the system.

In this regard the conceptual model helps to produce consistent and clear design of GIS application. The conceptual model is a type of abstraction that uses logical concepts and hides the details of implementation and data storage. The conceptual models offer powerful concepts to the designers that provide getting the most complete specification from the real world.

By realizing such model, the existing spatial data (digitalized in other projects) or created using GIS systems, can be integrated in the geodatabase with options for an efficient administration, for a reutilisation within various applications developed in the project or for a future development within an integrated database.

The spatial database model contains especially the following main components:

- Objectives, existing data analysis and entities establishing;
- Realizing the database model;
- Establishing the database integrity rules (relations, topology, subtypes, and domains).

The analysis of the data of the rail infrastructure map content provides a series of elements, which are separated in data sets and layers, organized within a map sheet:

- Country area;
- Railway networks;
    - interoperable and secondary lines
    - simple and double
    - by type of gouge
    - by type of signal systems
    - by type the power supply system
- Station and node location
- Asset location

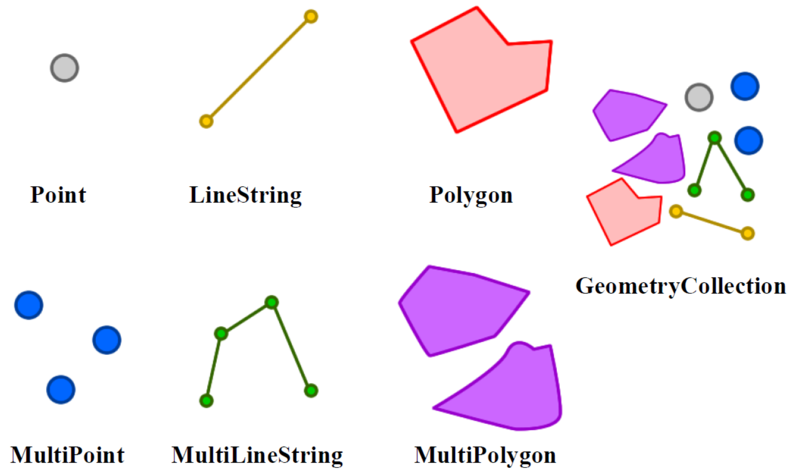


Figure 4-2 Geometry types defined in the OGC Simple Features for SQL specification

The database modelling establishes a set of rules and instructions, necessary for the representation of the real objects as spatial and logically represented objects, characterized by geometry (see Figure 4-2) and attributes.

The data sets contain grouped layers which have the same spatial reference, associated with rules that establish the relations and the topology:

- main data sets (geographic and topographic elements): Basemap, Country, Railway networks etc.
- associated data sets (the components associated with the geographical map): Legend, Sources etc.

Geographical data analyses define a set of operation for the manipulation of objects, such as calculation distance among objects. These operations depend on the geometry objects and on the reference system in which the location has been defined. For example there is difference in computing a distance between a pint and line or between a line and a polygon.

For manipulation of spatial objects we will use Hibernate Spatial and Java Topology Suite (JTS).

Hibernate is the most popular Object Relational Mapping (ORM) for Java. Relational databases can be used to store Java objects by translating object state information to and from SQL and transmitting the SQL commands over a JDBC connection. Because SQL is a non-object-oriented text format, maintenance of direct SQL conversion software is tedious and error-prone. An Object Relational Mapping (ORM) system such as Hibernate automates this process, emitting SQL to define, store, and query objects in a relational database.

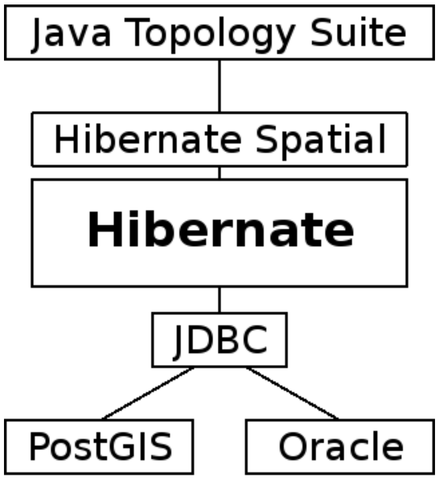


Figure 4-3 Hibernate Spatial is a layer on top of Hibernate that adds support for the Geometry types of the Java Topology Suite (JTS)[39]

Hibernate Spatial (see Figure 4-3) enabling Hibernate to store and query OpenGIS Simple Features in a spatial database. Hibernate spatial supports PostGIS and MySQL spatial databases.

The Java Topology Suite (JTS) provides Geometry types that implement the OpenGIS Simple Features Specification. JTS provides a complete, consistent, robust implementation of fundamental algorithms for processing linear geometry on the 2-dimensional Cartesian plane.

An important application of JTS is computing the spatial relationships between Geometries. Various methods of computing relationships are provided. Most relationships of interest can be specified as a pattern which matches a set of intersection matrices. JTS also provides a set of Boolean predicates which compute common spatial relationships directly.

The Java Topology Suite (JTS) provides the following Spatial Functions and Predicates:

- Buffer
- Contains
- ConvexHull
- CoveredBy
- Covers
- Crosses
- Difference
- Disjoint
- Distance
- Equals

[39] Source: AuScope – An organization for a National Earth Science infrastructure Program - https://twiki.auscope.org/wiki/Grid/HibernateSpatial

- Area
- Boundary
- Centroid
- Envelope
- EnvelopeInternal
- Length
- Intersection
- Intersects
- Is Empty
- Is Simple
- Is Valid
- Is Within Distance
- Normalize
- Overlaps
- Relate (DE-9IM Intersection Matrix)
- SymDifference
- Touches
- Union
- Within

The Java Topology Suite (JTS) provides the following Algorithms:

- Validation
- Line Merging
- Polygonization
- Spatial Indexes (Quad Tree, STRtree, BinTree…)
- Linear Referencing
- Planar graphs
- Simplification (Douglas Peucker, Topology Preserving)

Also the Java Topology Suite (JTS) provide a function for reading and writing to and from JTS Geometry Objects and geometry string formats in other neogeography/Web 2.0 geometry string formats: KML, GeoJSON, GeoRSS, GML, GPX and WKT.

5 Methodology for collecting spatial, cost, maintenance and failure

One of the aims of the T2.1 task is identifying the type of geographic railway information available at level of country partners involved in this task, as well data collection, at level of railway and regions, regarding cost, maintenance and failure.

The data collected will be used to understand the variability of information relating to railway infrastructure maintenance costs and to make comparisons at the geographical level.

Also the data collected will provide a matrix of issues identified in each country involved in the project and will provide input to the work packages WP1 and WP6.

In order to collect data from each partner, has built an Excel file template based on the database structure and that consists in the following categories of information:

- Common catalogues;
    - Countries;
    - Region;
    - Type of rail station;
    - Type railway lines;
    - Type of interlocking system
    - Type of power supply;
    - Type of switch crossing;
    - Type of track circuits;
    - Type of track railway;
    - Railway and S&C components
    - LCC phases;
    - LCC cost categories;
    - Failure modes;
    - Type of traffic volume;
    - Traffic indicators;
    - Type of operators;
    - Type of rolling stock;
- Geographical and descriptive characteristics of the rail structure;
    - Rail Stations;
    - Railway lines;
    - Gauge of lines;
    - Track of lines;
    - Power supply of lines;
    - Track circuit of lines;
    - Switch & Crossing;
    - Switch & Crossing at railway level;

- Economic, maintenance and traffic characteristics to the rail structure;
  - Railway LCC at railway level or regional level;
  - LCC at S&C level;
  - Failure at railway level;
  - Failure at S&C level;
  - Traffic volume at railway level;
- Catalogue of infrastructure managers, railway operators and rolling stock at railway operator level;
  - Infrastructure Managers;
  - Railway infrastructure managers;
  - Rail Operators;
  - Railway Rail Operators;
  - Rolling stock;

For further analyses, for spatial or economic aspects, was imposed the utilisation of common nomenclatures especially for LCC phases, cost category and failure modes.

In this respect have been used the nomenclatures developed in the projects InnoTrack and Capacity4Rail, and these lists are presented below:

- Failure modes:
  - (Track) -> Flooding of track
  - (Track) -> Rail defect identified - clamp and/or speed limits applied
  - (Track) -> Derailment/delays - Rail break
  - (Track) -> Derailment/delays - track alignment fault
  - (Track) -> Derailment/delays - wheel profile/rolling stock failure
  - (Track) -> Derailment/delays - landslide
  - (Track) -> Derailment/delays - hitting object./animal on track
  - (Track) -> Earthwork failure
  - (S&C) -> Flooding
  - (S&C) -> Signalling/electrical failures
  - (S&C) -> Ice, ballast or other object between switch and stock rail preventing switch locking
  - (S&C) -> Damage to switch drive from flying ballast, ice falling from vehicles
  - (S&C) -> Stretcher bar failure
  - (S&C) -> Derailment due to switch rail wear
  - (S&C) -> Crossing failure
  - (S&C sensor) -> Cost of unavailability due to sensor failure
  - (S&C sensor) -> Repair of sensors damaged due to flying ballast, ice, moisture, fatigue, high acceleration forces,
  - (Bridge failures) -> Road vehicle collision with bridge
  - (Bridge failures) -> Bridge scour due to flooding
  - (Bridge failures) -> Corrosion failure
  - (Bridge failures) -> Masonry deterioration

    - (Operational/signalling) -> Train collision - Signal passed at danger - driver error
    - (Operational/signalling) -> Train collision - Signalling failure/S&C/traffic management system failure
    - (Rolling stock) -> Traction power failure
    - (Rolling stock) -> Other rolling stock failures
- LCC phases:
    - R&D - Investment
    - R&D - Disposal
    - Operation
    - Maintenance
    - Decommissioning
- LCC cost categories:
    - Project preparation
    - Inputted Residual value
    - Ground preparation - geotechnical and civil (Site investigation)
    - Ground preparation - geotechnical and civil (Soil substitution)
    - Ground preparation - geotechnical and civil (Reinforcement)
    - Ground preparation - geotechnical and civil (Subgrade layers)
    - Ground preparation - geotechnical and civil (Drainage)
    - Slab positioning - Civil work (Concrete sublayer)
    - Slab positioning - Civil work (Connector / stoppers)
    - Slab positioning - Civil work (Slab laying)
    - Slab positioning - Civil work (Positioning)
    - Slab positioning - Civil work (Mortar / Fix the slab)
    - Slab positioning - Civil work (Inspection / Quality control)
    - Track laying - track work (Ballast)
    - Track laying - track work (Rail laying)
    - Track laying - track work (Pads)
    - Track laying - track work (Sleepers)
    - Track laying - track work (Fastenings)
    - Track laying - track work (Rail)
    - Track laying - track work (Clip/screw fastenings)
    - Track laying - track work (Welding)
    - Track laying - track work (Tamping)
    - Switch installation (Removal of existing switch)
    - Switch installation (Transport costs and logistics of delivering new switch layout)
    - Switch installation (Welding)
    - Switch installation (Tamping/geometry)
    - Switch installation costs (Signalling and electrical)
    - Inspection/quality control

- Decommission costs
- Removal costs
- Disposal costs/recycled value (rail and ballast recycling)
- Facilities
- Residual value
- Energy
- Personnel
- Training
- Facilities
- Fees
- Communications
- Communications - operating costs of use of mobile networks for communication of data
- Data processing/analysis of data
- Facilities
- Inspection - Visual Inspection
- Inspection - Ultrasonic - Manual
- Inspection - Ultrasonic - Train based
- Inspection - Eddy current inspection - Train based
- Inspection - Track geometry - train based
- Inspection - Slab monitoring for cracks and movement
- Inspection - Noise monitoring
- Inspection - Train based high speed image capture inspection
- Preventative - Rail Change
- Preventative - Rail Transpose
- Preventative - Grinding
- Preventative - Lubrication
- Preventative - Fish Plate lubrication
- Preventative - IBJ replacement
- Preventative - Re-sleeper
- Preventative - Replace sleeper pads and insulators
- Preventative - Noise abatement
- Preventative - S&C adjustment
- Preventative - Tighten/adjust stretcher bars
- Preventative - Adjust drive
- Corrective - Rail Change - defects
- Corrective - Weld change - defects
- Corrective - Rail adjustment
- Corrective - Ballast reprofile
- Corrective - Wet bed removal
- Corrective - Tactical reballast
- Corrective - Plain line tamping

- Corrective - Stoneblowing
- Corrective - Geometry manual
- Corrective - replacement of pads and fasteners
- Corrective - Correct cracks in slab -> Replace slab - in case of derailment or accident (major damage)
- Corrective - Correct cracks in slab -> Inject resin to protect steel
- Corrective - Correct settlement of slab -> Inject cement or other products under slab
- Corrective - Correct settlement of slab -> Expansive foam treatment
- Corrective - Correct settlement of slab -> Micro piles
- Corrective - Half set replacement
- Corrective - Crossing replacement
- Corrective - Crossing weld repair
- Corrective - Replace bearers
- Corrective - S&C tactical reballast
- Corrective - S&C tamping
- Corrective - Manual S&C geometry correction
- Corrective - Repair/replace switch motor and drive mechanisms
- Corrective - Repair/replace locking mechanisms
- Corrective - Repair electrical/signalling/interlocking failures
- Corrective - Repair of sensors damaged due to flying ballast, ice, moisture, fatigue, high acceleration forces,
- Renewals - Rail, sleeper and Ballast renewal
- Renewals - Sleeper and ballast renewal
- Renewals - Tactical resleeper
- Renewals - Ballast cleaning
- Renewals - Slab replacement
- Renewals - Rail+pad+fasteners replacement
- Renewals - Rail + pad replacement only
- Renewals - Replace drainage system
- Renewals - S&C renewal
- Off Track maintenance - Drainage
- Off Track maintenance - Fencing
- Off Track maintenance - Vegetation
- Other maintenance of sensor equipment - Battery replacement
- Other maintenance of sensor equipment - Sensor position and realignment
- Other maintenance of sensor equipment - Data retrieval
- Cost of non-availability during normal railway maintenance activities - Planned maintenance
- Cost of non-availability during normal railway maintenance activities - Unplanned maintenance

- Cost of non-availability and damage due to failures - Cost of unavailability due to sensor failure
- Cost of non-availability and damage due to failures - Repair of sensors damaged due to flying ballast, ice, moisture, fatigue, high acceleration forces,
- Cost of non-availability and damage due to failures - Flooding
- Cost of non-availability and damage due to failures- Signalling/electrical failures
- Cost of non-availability and damage due to failures - Ice, ballast or other object between switch and stock rail preventing switch locking
- Cost of non-availability and damage due to failures - Damage to switch drive from flying ballast, ice falling from vehicles
- Cost of non-availability and damage due to failures - Stretcher bar failure
- Cost of non-availability and damage due to failures - Derailment due to switch rail wear
- Cost of non-availability during maintenance activities - Planned maintenance
- Cost of non-availability during maintenance activities - Unplanned maintenance

6 Availability of spatial data and data relative to costs, maintenance and failure

This section presents the details about availability of spatial data and data relative to costs, maintenance and failure.

Over the timeframe of Task 2.1, partners had several online meetings to discuss and decide on the structure of the database and the information available at the level of each partner.

To identify availability and utility of data to be collected in the database, it was created survey template in Excel format, and that was sent to each partner for filling. The table illustrates the survey template.

Table 6-1 Survey template for data collection

Category	Table	Table field	Is it available? (YES/NO/Maybe)	Is this data useful? (YES/NO)	Comment
Rail Stations +Interlocking	Rail Stations	name			
		type rail stations			
		type interlocking			
		location (WKT format)			
		status			
Railway (gauge & track)	railway lines	railway name			
		country			
		type (RINF classification)			

Category	Table	Table field	Is it available? (YES/NO/Maybe)	Is this data useful? (YES/NO)	Comment
		geometry (WKT format)			
	gauge lines	railway name			
		gauge type			
		start rail station			
		end rail station			
	track lines	railway name			
		track type			
		start rail station			
		end rail station			
Railway + Power supply	power supply lines	railway name			
		power supply type			
		start rail station			
		end rail station			
Railway + Track Circuits	Track circuit lines	railway name			
		track circuit type			
		start rail station			
		end rail station			
Switch & Crossing	switch & crossing	type switch crossing			
		year of manufacture			
		location (WKT format)			
		description			
	railway switch & crossing	switch indentifier			
		railway name			
LCC	Railway LCC	LCC phase			
		Cost category			
		Railway component			
		LCC date (year)			
		Cost (thousand EURO)			
	S&C LCC	LCC phase			
		Cost category			
		S&C component			
		LCC date (year)			
		Cost (thousand EURO)			
Failure	Railway	railway name			

Category	Table	Table field	Is it available? (YES/NO/Maybe)	Is this data useful? (YES/NO)	Comment
		failure mode			
		component			
		number of failures			
		year			
	S&C failure	railway name			
		failure mode			
		component			
		number of failures			
		year			
Traffic volume	Traffic volume	railway name			
		traffic indicator			
		traffic volume			
		year			
Infrastructure Managers	Infrastructure Managers	infrastructure manager name			
		country			
		infrastructure manager address			
		infrastructure manager contact			
	Railway infrastructure managers	infrastructure manager name			
		railway name			
		start rail station			
		end rail station			
		description			
Rail Operators	Rail Operators	rail operator name			
		type rail operator			
		country			
		infrastructure manager address			
		infrastructure manager contact			
	Railway Rail Operators	rail operator name			
		railway name			
		start rail station			
		end rail station			
		description			
Rolli ng stock	Rolli ng stock	rail operator name			

Category	Table	Table field	Is it available? (YES/NO/Maybe)	Is this data useful? (YES/NO)	Comment
		type rolling stock			
		number of rolling stock			
		description			

6.1 Availability of spatial data

In task T2.1 was identified the type of geographic railway information available at level of country partners involved in this task.

The data collected have been transposed via tools QGIS in OGR shape format and also in WKT format.

The following shows the geographic railway information available at UK, Nederland, Slovenian, Turkey and Romanian level.

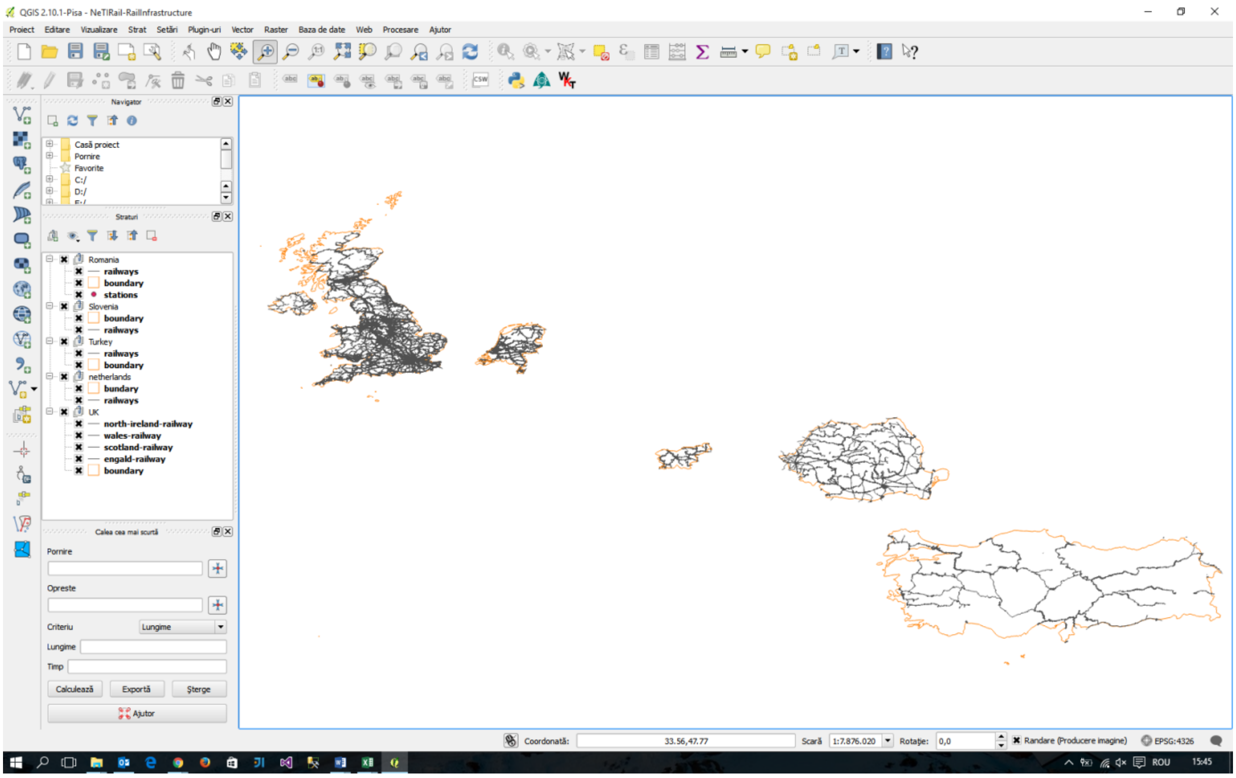


Figure 6-1 Spatial representation of UK, Nederland, Slovenian, Turkey and Romanian railways network

For UK the collected geographic information consists in following layers: UK boundary, England railway network, Scotland railway network, Wales railway network, North Ireland railway network and Over the 2540 rail stations.

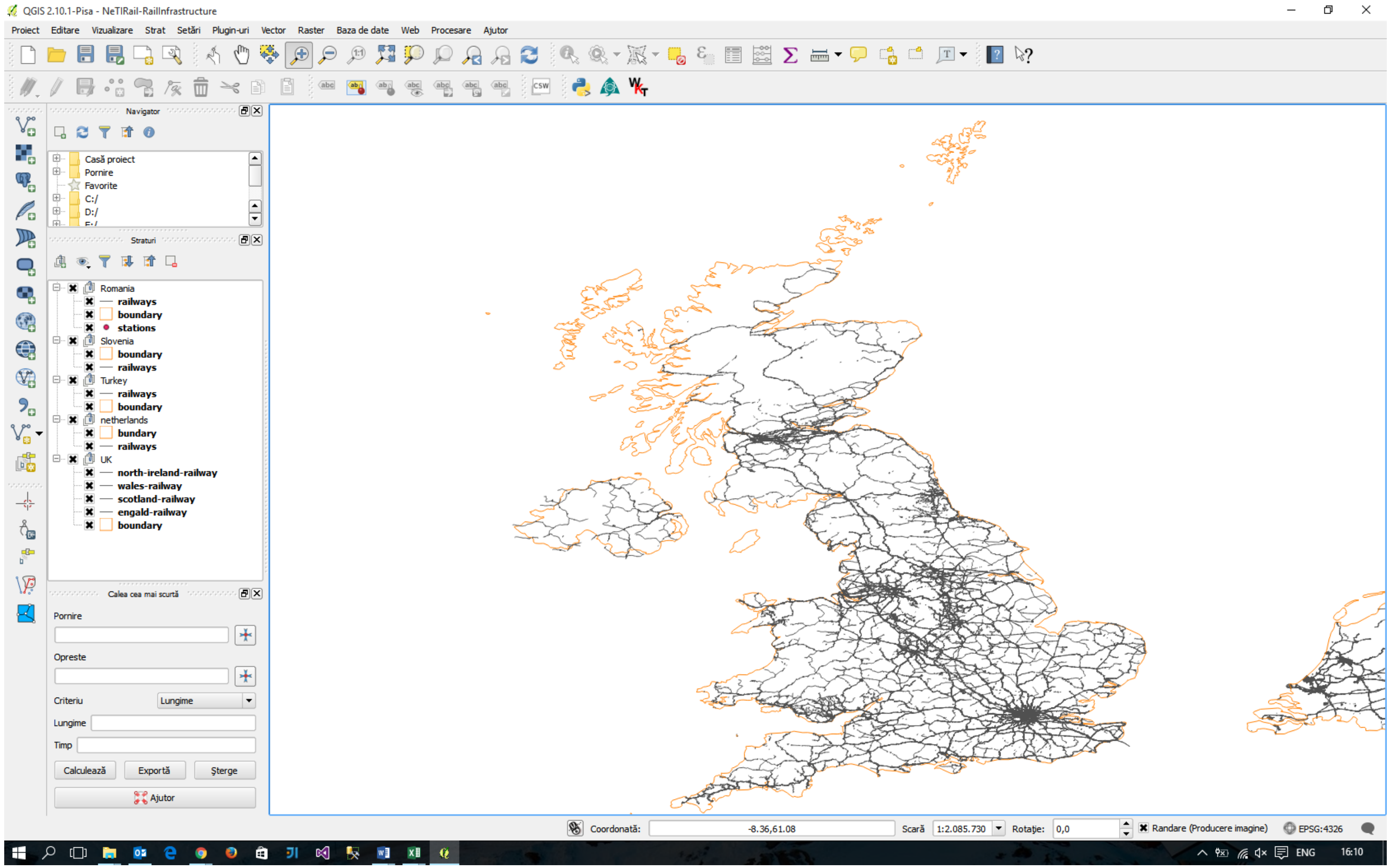


Figure 6-2 Spatial representation of UK railway networks

For Nederland the collected geographic information consists in following layers: Nederland boundary, Nederland railway network.

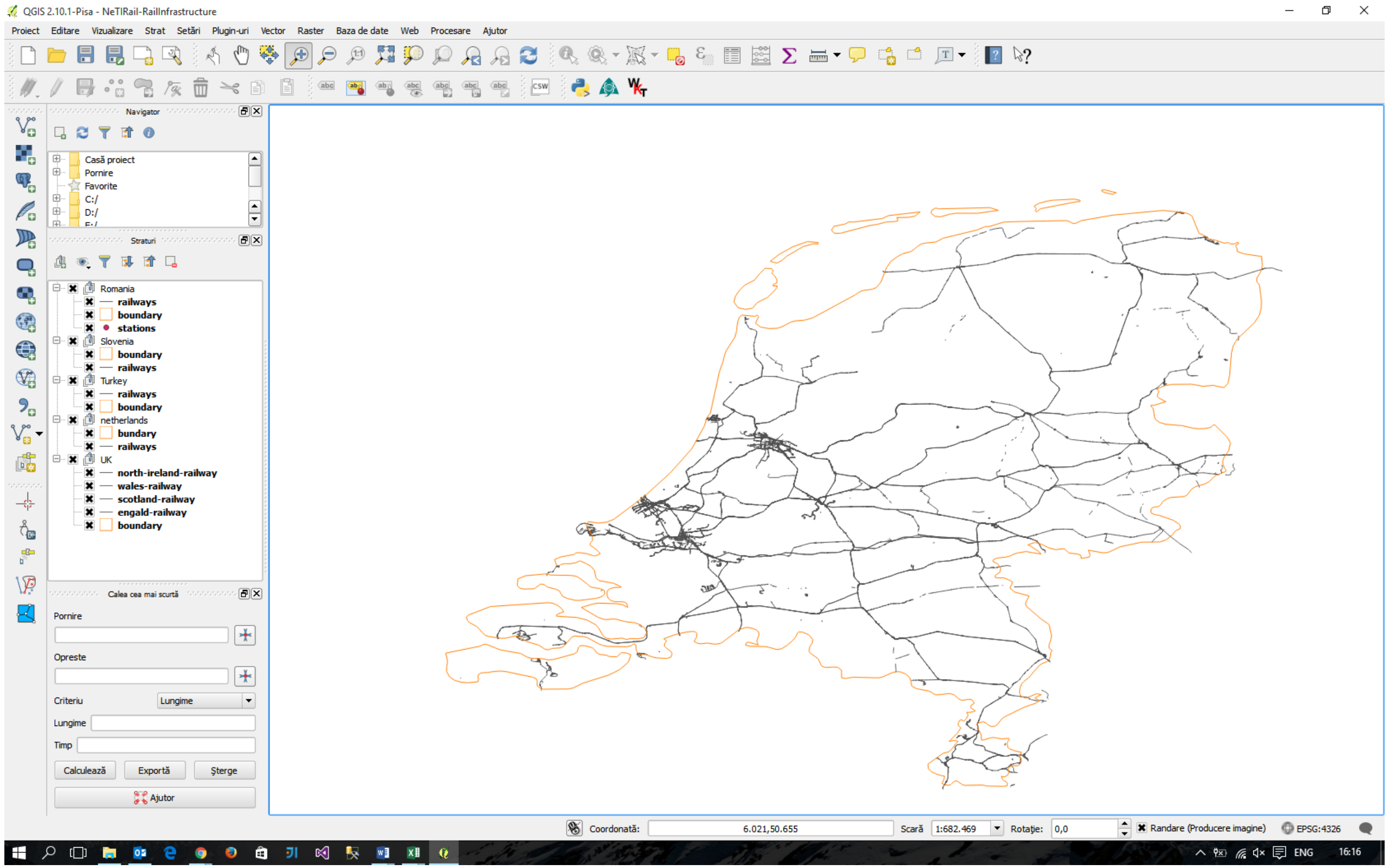


Figure 6-3 Spatial representation of Netherland railway network

For Slovenia the collected geographic information consists in following layers: Slovenian boundary, Slovenian railway network.

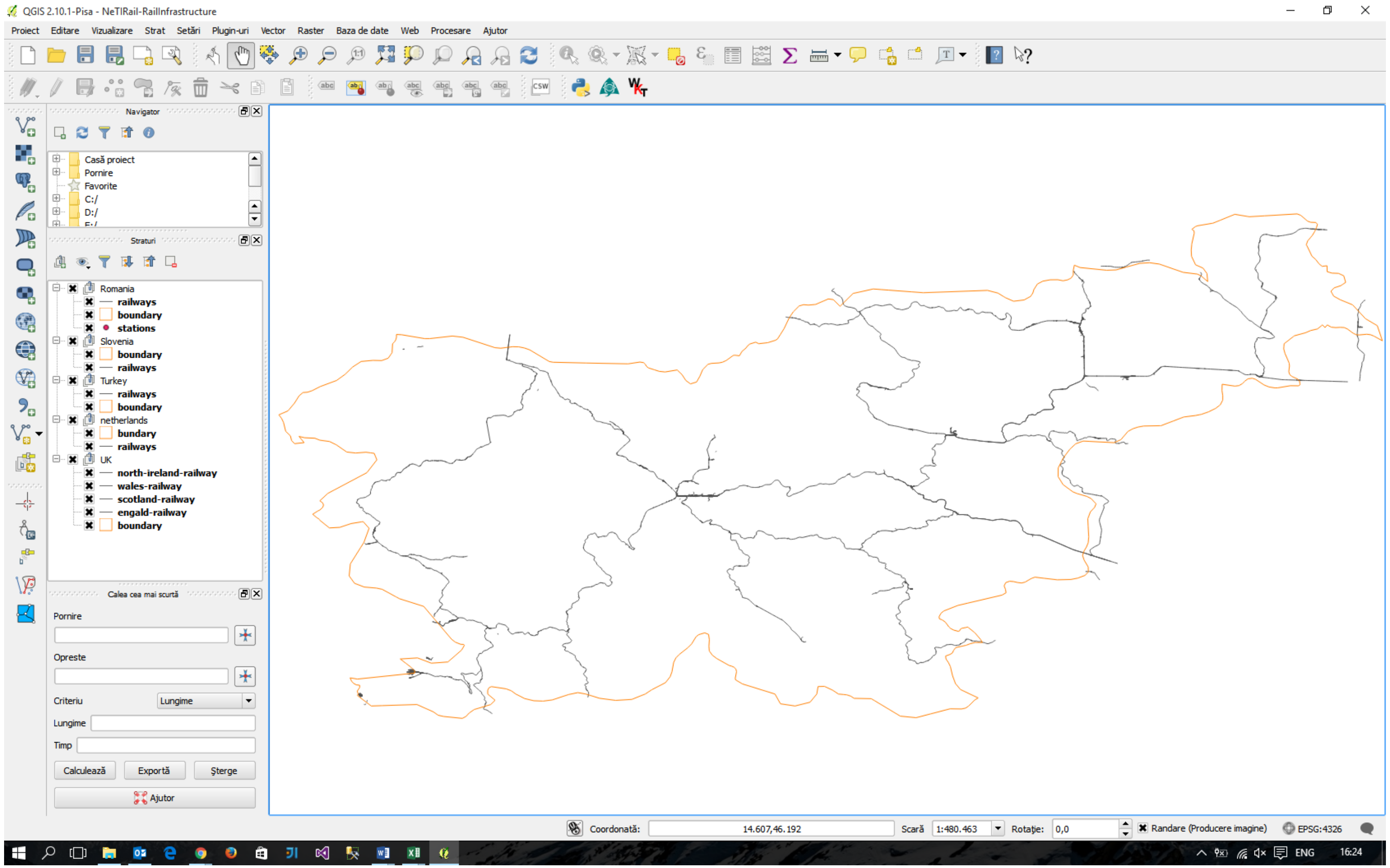


Figure 6-4 Spatial representation of Slovenian railway network

For Turkey the collected geographic information consists in following layers: Turkey boundary, Turkey railway network.

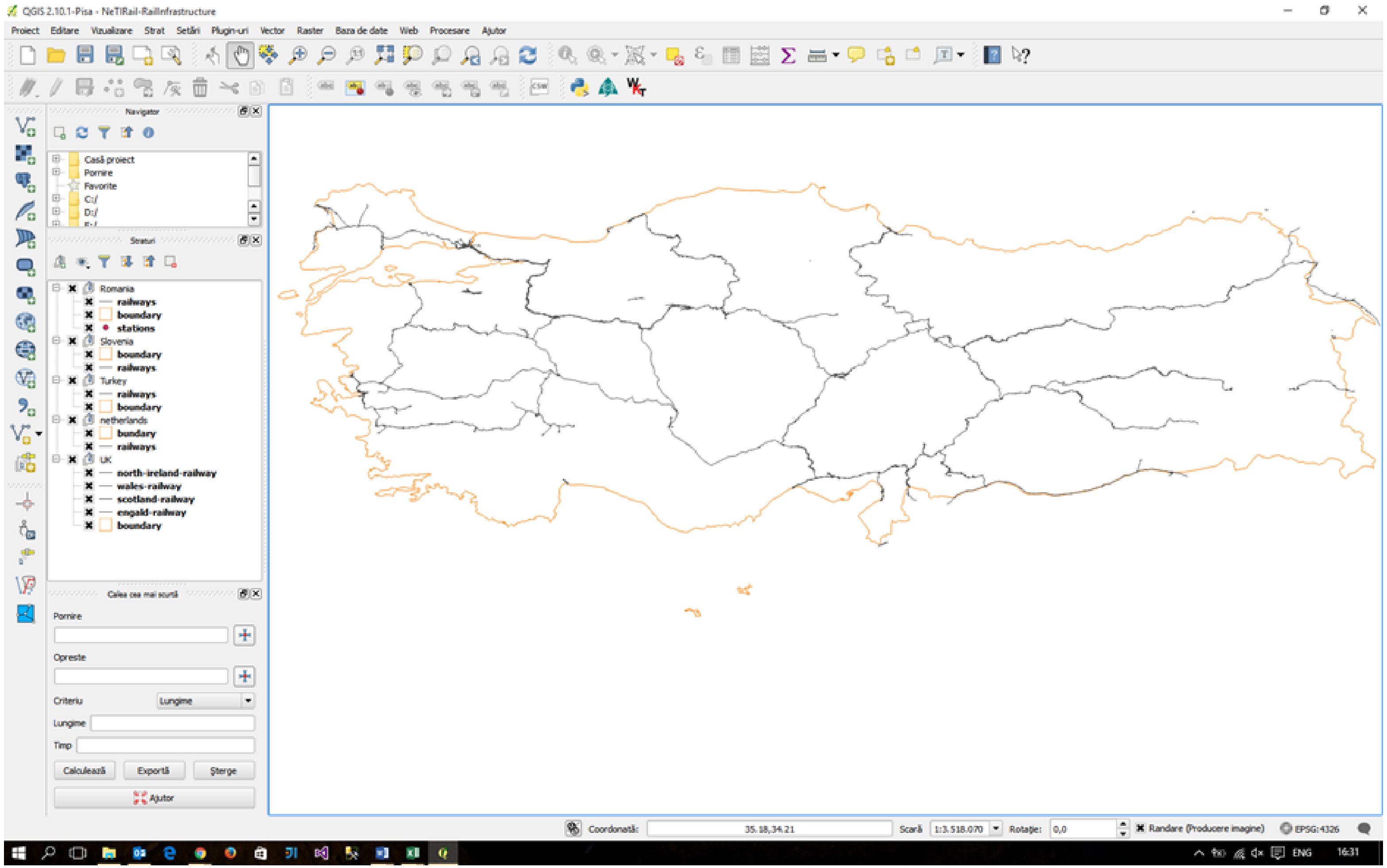


Figure 6-5 Spatial representation of Turkey railway network

For Romania the collected geographic information consists in following layers: Romanian boundary, Romanian railway network and Over the 2100 rail stations.

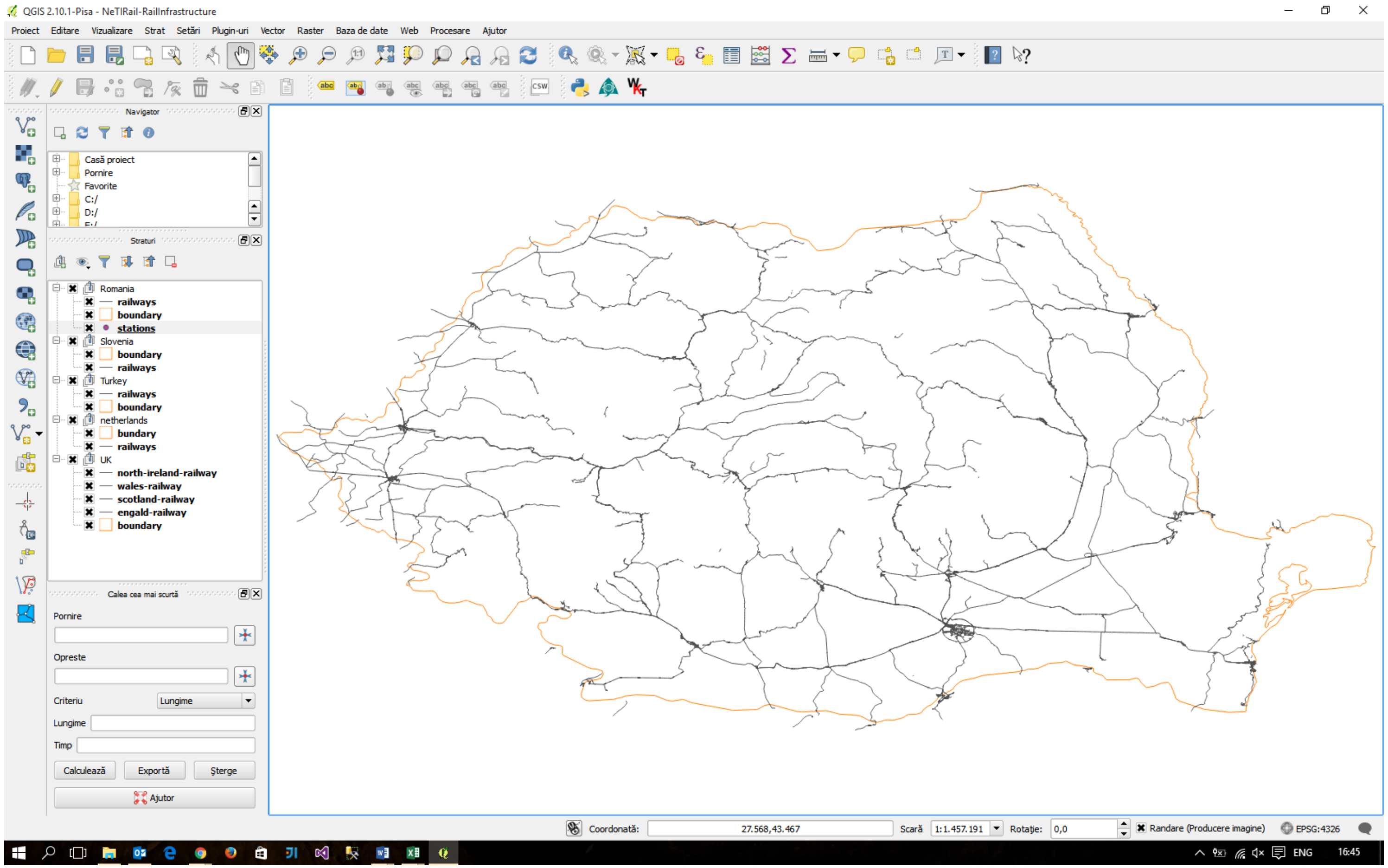


Figure 6-6 Spatial representation of Romanian railway network

6.2 Availability of general railway information

In this section are presented the general railway information available at level of country partners involved in this task.

The data collected have been transposed via SQL scripting from Excel spreadsheet into MySql relational database.

Below we present the most important data collected for the study areas:

- **UK**

For UK the collected information consists in fallowing data category:

- Overview of Network infrastructure;
- Activity volumes;
  - Track renewals
  - Rail renewed
  - Sleepers renewed
  - Ballast renewed
  - Switches and crossings renewed
  - Track drainage renewals
  - Signalling renewed
  - Level crossing renewals
  - Telecom renewals

In the following tables are presenting information regarding UK network asset measures and in period 2008 -2013.

Measure	2008/09	2009/10	2010/11	2011/12	2012/13
Good track geometry	137,9	137,7	137	136,5	138,1
Poor track geometry	2,18	2,38	2,48	2,58	2,38
Intervention/ Immediate action geometry faults per 100km	38,2	40,3	39,7	41,3	40,3
Broken rails (No.)	165	152	171	127	178
Rail breaks and immediate action defects per 100km	6,8	5,8	4,49	3,8	4,14
Immediate action rail defects per 100km	6,27	5,31	3,94	3,39	3,48
Condition of asset TSRs (No.)*	4436	1729	1348	1864	1958
Civils - Assets subject to additional inspections (No.)	889	844	810	789	801
Earthworks failures (No.)	61	56	42	28	144
Bridge condition score	2,09	2,09	2,09	2,1	2,25
Signalling failures causing delays of more than 10 mins. (No.)	19607	18324	16501	15638	15023
Signalling asset condition	2,39	2,37	2,41	2,38	2,37

Measure	2008/09	2009/10	2010/11	2011/12	2012/13
AC power incidents causing >500 minute train delays (No.)	66	46	61	50	52
DC power incidents causing >500 minute train delays (No.)	14	14	14	16	8
AC traction feeder stations and track sectioning points condition	2,78	2,7	2,56	2,57	2,29
DC traction feeder stations and track sectioning points condition	2,53	2,32	2,36	2,45	2,38
AC contact systems condition	1,6	1,6	1,6	1,6	1,4
DC contact systems condition	1,9	1,9	1,9	2	2
Telecoms condition	0,89	0,92	0,94	0,95	0,96
Points failures	8048	7130	5815	5166	5053
Train Detection failures	6470	6061	5226	4923	4608
Track failures	7748	6670	5887	5501	5335
Power incidents causing train delays of more than 300 minutes	103	75	100	71	65
Telecom failures causing train delays of more than 10 minutes	817	770	689	698	697
Station stewardship measure:					
- **Category A**	2,44	2,38	2,3	2,26	2,21
- **Category B**	2,47	2,46	2,4	2,37	2,34
- **Category C**	2,52	2,52	2,47	2,43	2,4
- **Category D**	2,52	2,54	2,47	2,41	2,39
- **Category E**	2,57	2,58	2,5	2,43	2,39
- **Category F**	2,55	2,56	2,5	2,47	2,47
Scotland (all categories)	2,39	2,39	2,33	2,28	2,33
Light maintenance depot stewardship measure (network)	2,52	2,5	2,48	2,43	2,39
Asset reliability (no. of infrastructure incidents causing delay)	52270	46091	42135	40415	39365

Table 6-2 Comparison of UK network asset measures between 2008 and 2013[40]

In terms of activity volumes, the evolution between 2008 and 2013 the general information are presented in the in following table.

[40] Network Rail - Annual Return 2013 - http://www.networkrail.co.uk/publications/Annual-return/

Activity volumes	2008/09	2009/10	2010/11	2011/12	2012/13
Rail (km of track renewed)	1206	810	587	774	699
Sleeper (km of track renewed)	735	438	445	567	501
Ballast (km of track renewed)	763	509	525	573	522
Switch & crossings (No. of full units replaced)	419	231	269	285	264
Signalling (SEUs)	981	813	802	1,266	978
Bridge renewals (No.)	358	248	340	261	214
Culvert renewals (No.)	33	25	25	31	16
Retaining wall renewals (No.)	15	5	11	10	10
Earthwork renewals (No.)	157	113	103	117	148
Tunnel renewals (No.)	44	24	49	48	30

Table 6-3 Comparison activity volumes of UK network between 2008 and 2013

- **Slovenia**

The rail network of the Republic of Slovenia is 1,208 km long, of which 875 km are single-track and 332 km double-track lines. In accordance with the national classification of lines, Slovenia has 607 km of main lines and 601 km of regional lines.

In terms of traction power supply, all electrified lines of SZ are electrified by a one-way system with a rated voltage of 3 kV, only in near-border sections are the systems of neighbouring Austria (15 kV, 16.67 Hz) and Croatia (25 Hz, 50 Hz) built in.

Electric power system	Characteristic
Length of electrified lines	503,5 km
- **double-track lines**	330,9 km
- **single-track lines**	172,6 km
Number of power supply stations	17

Table 6-4 Traction power supply of SZ rail network

In terms of railway signalling and safety devices of SZ, the general information are presented in the following table.

Elements	Characteristic
Lines equipped with signalling devices in km	668
Electronic interlocking, electronic relay interlocking, mechanical interlocking, automatic rail block, in km	230
Block in km	132
AS devices-line in km	668
Type of station security:	168 stations
- **electronic SV devices**	6
- **electronic relay SV devices**	80
- **electro-mechanical SV devices**	11
- **mechanical SV devices**	15
- **combined SV devices**	62
Automatic rail block (APB) in km	240
Block (MO) in km	96
Remote traffic control (DVP) in km	108
AS devices (ASN) in km	668
Level crossings in SŽ:	972
- **secured level crossings**	315
- **automatically secured level crossings**	272
- **mechanically secured level crossings**	43
- **non-secured level crossings, marked by road traffic signs**	652

Table 6-5 Railway signaling and safety devices of SZ rail network

The following tables are presenting general statistics information regarding Slovenian rail networks.

Statistical data	km
Total length of lines:	1.228,10
- **Double-track**	330,4
- **Single-track**	897,7
- **for freight transport**	106,1
- **for passenger transport**	2,2
- **for combined transport**	1.119,80
Length of electrified lines	502,8
Length of tracks	1.558,40
All bridges, viaducts and culverts (number)	3.348
All bridges, viaducts and culverts (km)	17
Tunnels and galleries (number)	93
Tunnels and galleries (km)	37,4
Stations (number)	128
- **for freight transport**	11
- **for passenger transport**	8
- **for combined transport**	108

Table 6-6 General statistical information for SZ rail network

- **Turkey**

For Turkey the collected information consists in following data category:

- Evolution of TCDD networks (development on railway transportation)
- Information and evaluation about passenger transportation according to Railway Industry Report 2013.
- Information and evaluation about freight transportation according to Railway Industry Report 2013.

In the following tables are presented general information regarding Turkey networks.

Characteristics of railway transportation	2011	2012	2013
Ridership in high speed trains (million passengers)	2,56	3,35	4,20
Conventional network (km)	11112	11120	11209
Conventional line electrified (km)	2271	2328	2416
Conventional line signalized (km)	3020	3128	3147

Table 6-7 Evolution of turkey rail networks between 2011 and 2013

The average age of the rail infrastructure equipment is younger in Turkey. About 27.8 percent of rail is under 10 years of age; 25.2 percent is between 11 and 20 years; 24.7 percent is between 21 and 30 years of age; and 22.3 percent is over 30 years. In 2009, 423 km of lines and 226 switches were renewed. Meanwhile, rail infrastructure equipment is more recent, with over 75 percent of the telecommunications installations, catenary system, and signalling system under 20 years old (see Figure 6-7).

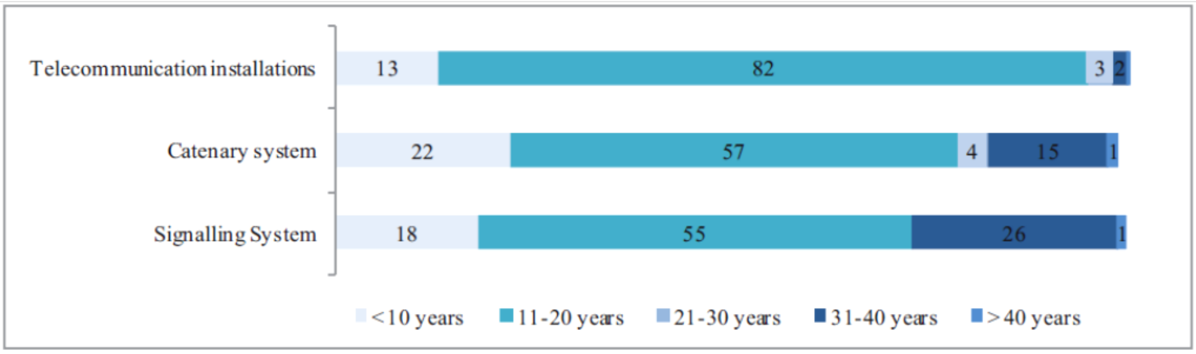


Figure 6-7 Turkish Railways - Age Structure of Rail Infrastructure Equipment[41]

According to Railway Industry Report 2013, some notes about passenger transportation are presented below:

[41] Source: Turkish Railways

- There's a very slight increase in ridership of main passenger trains. 16.7 million Passengers transported by rail in 2013
- Occupancy rate is 76%, on-time departures are 95% in high speed trains.
- Incomes of TCDD decreased by 1% where expenses increased by 11%. Net loss is 1.3 billion TL (46% increase compared to 2012).

According to Railway Industry Report 2013, some notes about freight transportation are presented below:

- Tonnage of freight by rail reached to 26.2 million to. It was 25.7 million to in 2012.
- Exports by rail is 578k to in 2013 (35% decrease compared to 2012). 419k is in European direction and rest in Asian direction.
- Import by rail is 1.11 million to (9% decrease compared to previous year). Almost all is from Europe (1.02 million to).
- Transit loads by rail increased from 11k to to 21k to.

- **Romania**

According to CFR statistics[42], on March 01, 2013, the length of the Interoperable and Non-Interoperable Railway Infrastructure is structured as follows:

- length of the route of the Interoperable Railway Infrastructure Network: 7 370 km;
- length of the route of the Non-Interoperable Railway Infrastructure Network: 3 268 km (92 traffic sections), out of which:
  - no. of km managed by CFR: 438 km (15 sections);
  - no. of km rented by Infrastructure Managers: 2 830 km (78 sections);

The map of the railway stations and of the interoperable and non-interoperable railway lines highlighting the Infrastructure Managers that have rented non-interoperable lines from the CFR is presented in Annex 1.

From the point of view of *track typology*, Romanian railway network is as follows:

a) in terms of the traffic capacity, out of the 10 637 km of the CFR Railway Network:
   - 2 908 km are equipped with double line;
   - 729 km are equipped with simple line.

   These lines are highlighted on the map presented in Annex 2.

b) in terms of the track superstructure equipment of the CFR Network, the total line length of 20,077 km is divided as follows:
   - 4 474 km are equipped with rail superstructure Type 65
   - 2 292 km with rail superstructure Type 60,

[42] CFR Network Statement, Version 5.3, September 01, 2015

- 496 km with rail superstructure Type 54,
- 8 030 km with rail superstructure Type 49,
- 4 785 km with rail superstructure Type below 49.

From the point of view of *track gauge*, Railway Network has the European (normal) gauge of 1 435 mm.

Nevertheless, there are some short sections at the railway border with the Ukraine (UZ) and the Republic of Moldavia (CFM), where the line with normal gauge is doubled by a line with wide gauge of 1520 mm on the distance from the CFR border station to the neighbouring railway administration.

Moreover, a 44 km long line with wide gauge (1 520 mm) is situated on the Romanian territory between the stations Teresya (UZ) – Campulung la Tisa (CFR) and Valea Viseului (CFR) – Berlibas (UZ).

From the point of view of traction power supply, the characteristics of the electrification system are presented below:

- the power supply voltage of the contact line :25 KV
- the frequency of the contact line: 50 Hz.
- the height of the contact line as to the head of the track: 5 750 mm
- the contact pressure of the pantograph on the contact line: between 5 and 7 daN in accordance with EN 50119
- zig-zag +/- 200 mm

The map containing the electrified lines is presented in Annex 2.

In point of view *signalling systems*, the Romanian Railway Infrastructure is equipped with two-speed step signalling systems and multiple-speed step signalling systems, both types being equipped with additional signalling devices, as necessary.

The indications of reduced and set speeds are sent by the traffic lights, light signals and indicators that are preceded by warning beacons, as necessary.

The *traffic control* is performed with the help of the switch control systems that ensure the switch operation according to the necessary train traffic route.

The CFR Network is equipped with 26 524 switches and points, 20 305 of them being placed on the public Railway Infrastructure and 6 219 on the private infrastructure.

Most of the railway stations are equipped with interlocking systems, but there are also stations which are situated on low traffic sections and are equipped with key-operated switch and signal control systems.

Their classification is the following:

– Interlocking systems that include o 33 electronic interlocking systems

  - 13 electromechanical interlocking systems with computer-assisted control station
  - 594 electrodynamic interlocking systems
  - 63 electromechanical interlocking systems
  - 18 shunting hump mechanisation and automation systems
- other systems
  - 178 systems with interlock
  - 166 systems without interlock

The summarising table of the characteristics of the CFR network are presenting following:

Element	Characteristic
Network length	10.629 km
Total network length	19.997 km
Double line	2.909 km
Simple line	7.720 km
Electrified line	4.028 km
Non-electrified line	6.601 km
Number of stations	930
Electronic interlocking systems	34
Electrodynamic interlocking systems with computerized control station	15
Electrodynamic interlocking systems	586
Electromechanical interlocking installations	62
Marshalling hump mechanization and automation installations	18
Installations without interlocking	315
Automatic block signals	1.014
Automatic barriers	1.090
Number of tunnels	171
Length of tunnels	67,1 km
Number of bridges and culverts	18.032
European gauge	1.435 mm
Wide gauge	1.520 mm
Length of interoperable km network	6.874,9 km
Length of non-interoperable km network	3.754,1 km

Table 6-8 Characteristics of the CFR rail network

7 Analyses of costs, maintenance and failure data

Based on the data collected in the database we are able to provide a first level analysis if the data by presenting the main statistics in terms of costs, failures and traffic volume. The figures bellow represent the most relevant findings which illustrate together the situation in all three test sites.

The first description of our data sample is given by the various costs incurred for each line available, over the course of 2014, split into various categories (see Table 7-1). A quick observation reveals that costs in Romania are generally lower and split into a multitude of categories while in Turkey, for all three lines, these are higher and generally clustered.

	Romania / Bartolomeu - Zarnesti	Turkey / SİNCAN -KAYAŞ	Turkey / MALT-İSKEND.	Turkey /Malatya-Divriği
Operation -> Facilities	3,00	0	0	0
Operation -> Fees	12,00	0	0	0
Operation -> Energy	10,00	0	0	0
Operation -> Personnel	240,00	0	0	0
Operation -> Training	2,00	0	0	0
Operation -> Communications	1,00	0	0	0
Operation -> Communications - operating costs of use of mobile networks for communication of data	1,00	0	0	0
Maintenance -> Personnel	54,00	0	0	0
Maintenance -> Training	2,00	0	0	0
Maintenance -> Inspection - Visual Inspection	5,00	0	0	0
Maintenance -> Inspection - Ultrasonic - Manual	2,00	0	0	0
Maintenance -> Inspection - Track geometry - train based	5,00	0	0	0
Maintenance -> Inspection - Slab monitoring for cracks and movement	2,00	0	0	0
Maintenance -> Preventative - Lubrication	1,00	0	0	0
Maintenance -> Preventative - Re-sleeper	10,00	0	0	0
Maintenance -> Corrective - Rail Change - defects	45,00	0	0	0
Maintenance -> Corrective - Weld change - defects	8,00	0	0	0
Maintenance -> Corrective - Rail adjustment	8,00	0	0	0
Maintenance -> Corrective - Ballast reprofile	6,00	0	0	0
Maintenance -> Corrective - Tactical reballast	12,00	0	0	0
Maintenance -> Corrective - Plain line tamping	16,00	0	0	0
Maintenance -> Corrective - Geometry manual	4,00	0	0	0
Maintenance -> Corrective - replacement of pads and fasteners	32,00	0	0	0
Maintenance -> Corrective - Repair/replace locking mechanisms	2,00	0	0	0
Maintenance -> Off Track maintenance - Drainage	4,00	0	0	0
Maintenance -> Off Track maintenance - Vegetation	8,00	0	0	0
Maintenance -> Track laying - track work (Ballast)	0	127,34	108,27	810,01

	Romania / Bartolomeu - Zarnesti	Turkey / SİNCAN -KAYAŞ	Turkey / MALT-İSKEND.	Turkey /Malatya-Divriği
Maintenance -> Track laying - track work (Rail laying)	0	1612,34	4,67	356,50
Maintenance -> Track laying - track work (Sleepers)	0	172,06	35,23	1,29
Maintenance -> Track laying - track work (Fastenings)	0	5,20	4,35	19,85
Maintenance -> Track laying - track work (Welding)	0	13,11	12,39	30,47
Maintenance -> Track laying - track work (Tamping)	0	80,70	64,84	49,97
Maintenance -> Switch installation (Tamping/geometry)	0	9,96	0	0
Maintenance -> Track laying - track work (Clip/screw fastenings)	0	4,84	0	0

Table 7-1 LCC categories by case study line

The figure bellow shows the weight of individual track and S&C costs for Romania and Turkey relative to the total costs. We can determine that in Romania the most relevant cost are personnel costs both in the operation phase as well as in the maintenance phase, followed by preventive and corrective maintenance. For Turkish lines, track maintenance costs with ballast and track laying have the greatest weight.

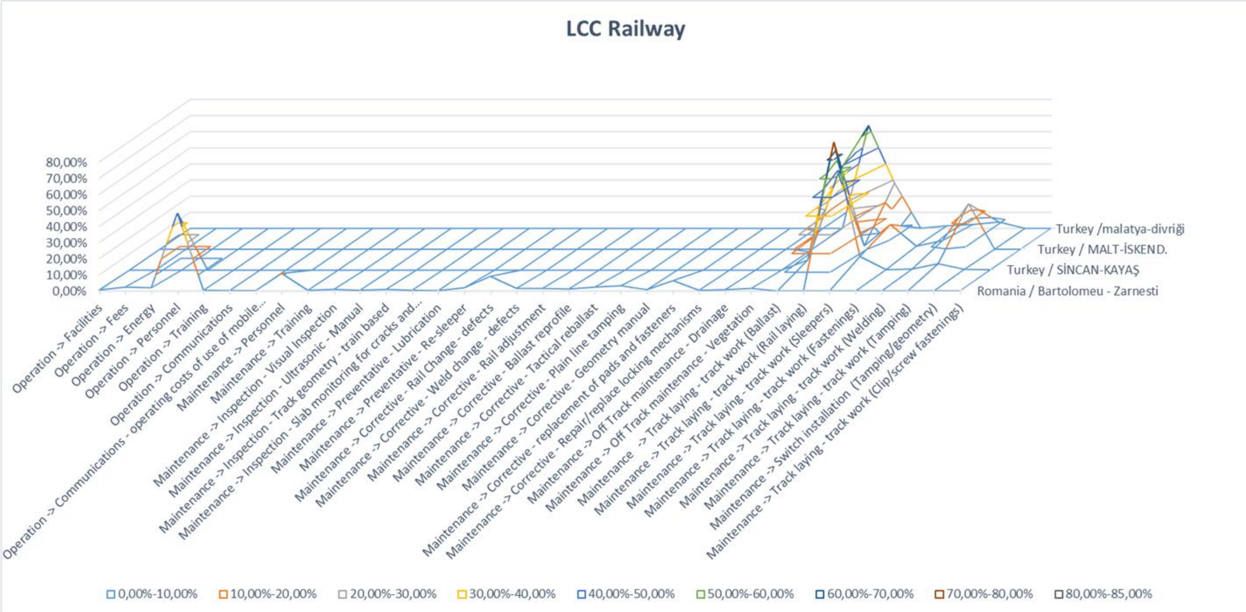


Figure 7-1 Relative LCC weight by test track

Strictly referring to switches and crossing costs we can see in the figure bellow that corrective maintenance costs with geometry correction and re-ballasting are prevalent in Romania while in Turkey mainly switch installation costs are highlighted.

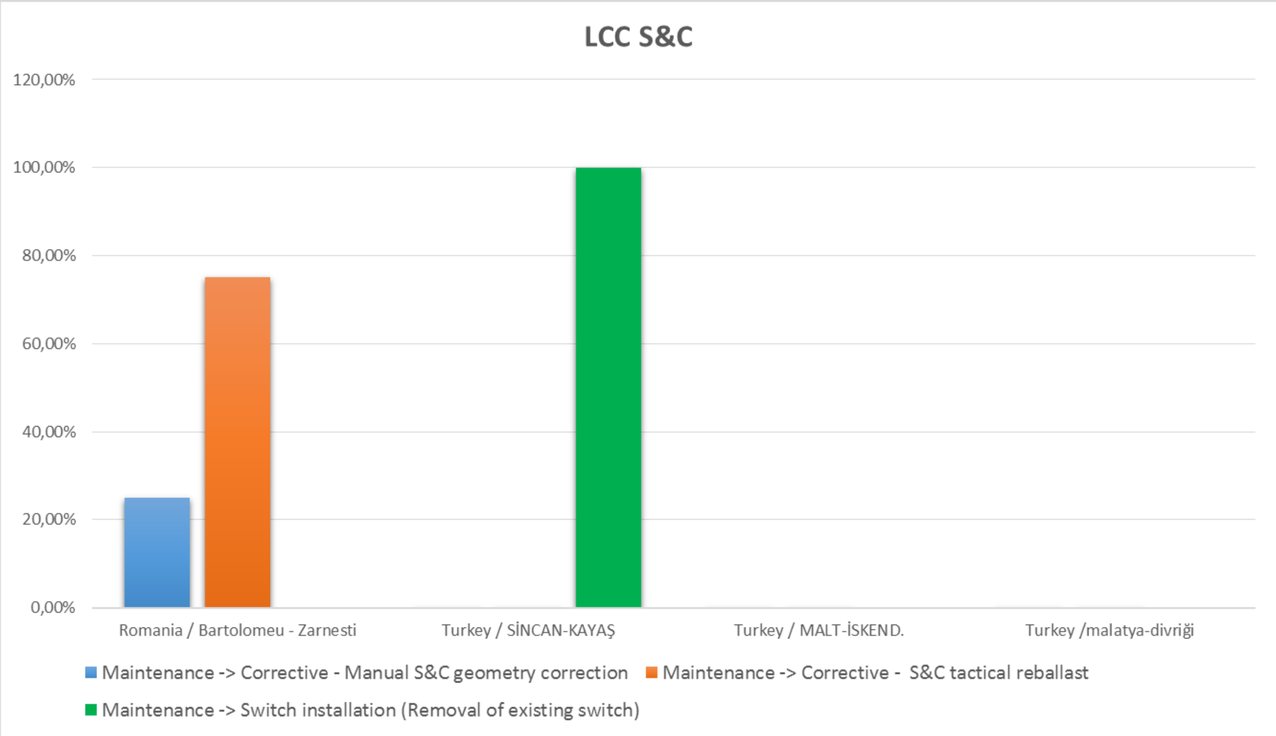


Figure 7-2 S&C cost structure by case study line

Moving on to failures, we can easily describe the situation in all three countries and all case study lines by providing an overview of various failure types and their incidence. In the figure bellow, we presented the number of track failures in 2014 for the following case study lines: Romania / Bartolomeu – Zarnesti; Slovenia / Cepišče Prešnica-Koper; Slovenia / Divača-cepišče Prešnica; Turkey / SİNCAN-KAYAŞ; Turkey / İskend-Malatya; Turkey / Malatya-Divriği. As it can be clearly observed, Sleeper level failures are more prevalent as well as Ballast faults.

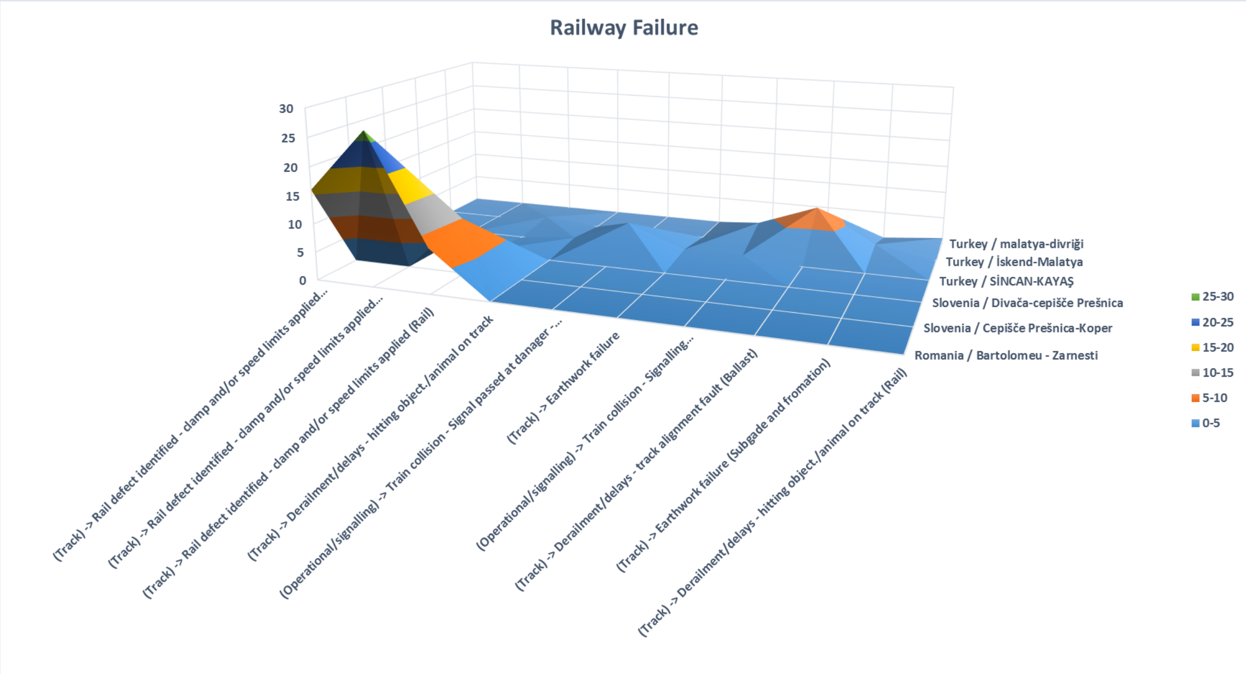


Figure 7-3 Number of track failures by type and test track

In terms of S&C failures, we can observe in the figure bellow that the most widespread S&C failures are electrical in nature more prevalent in Slovenia.

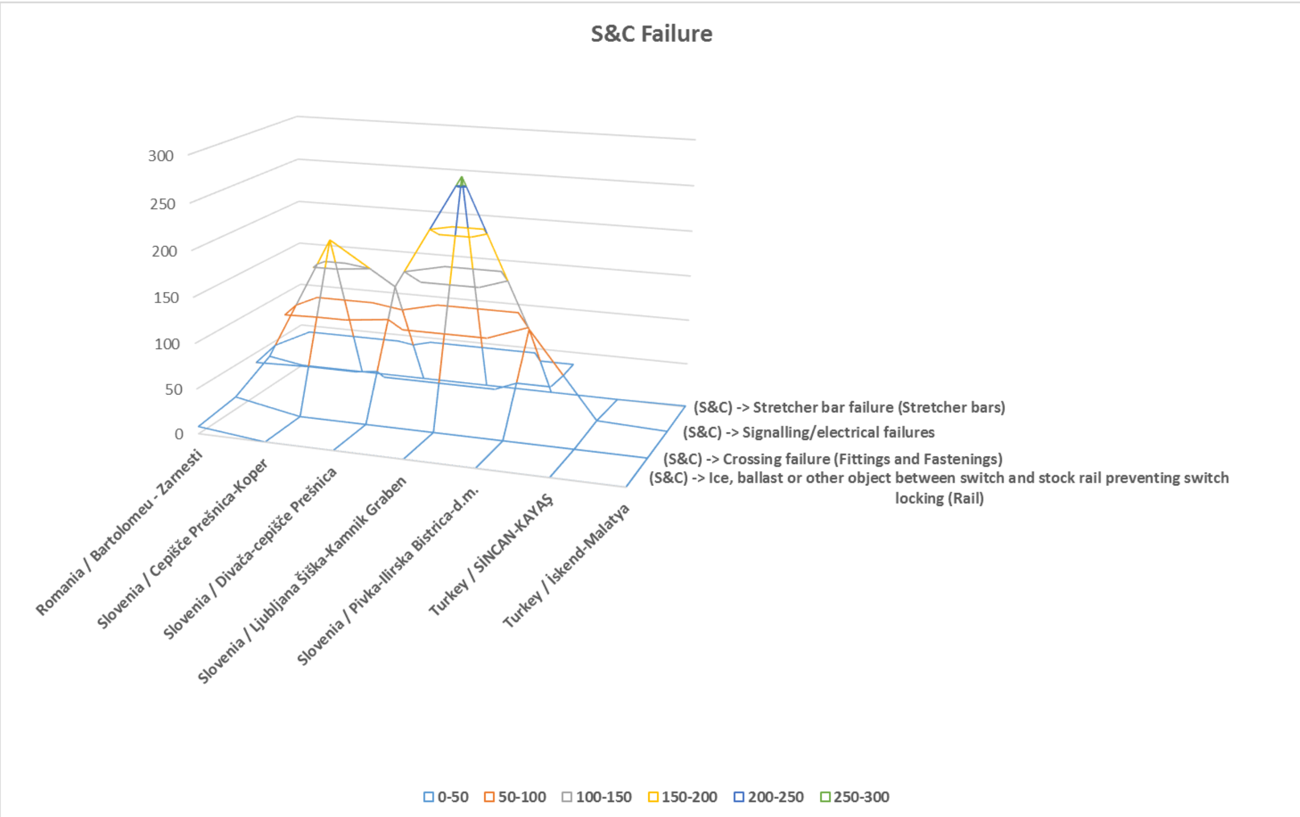


Figure 7-4 Number of S&C failures by type and case study line

The third descriptive element is the traffic volume for which we used five metrics overall for passenger traffic and freight combined. Bellow we present only two of these metrics due to the fact that all findings are consistent. Hence, the figures bellow show comparatively the number of passenger train-km and freight train-km for all case study lines.

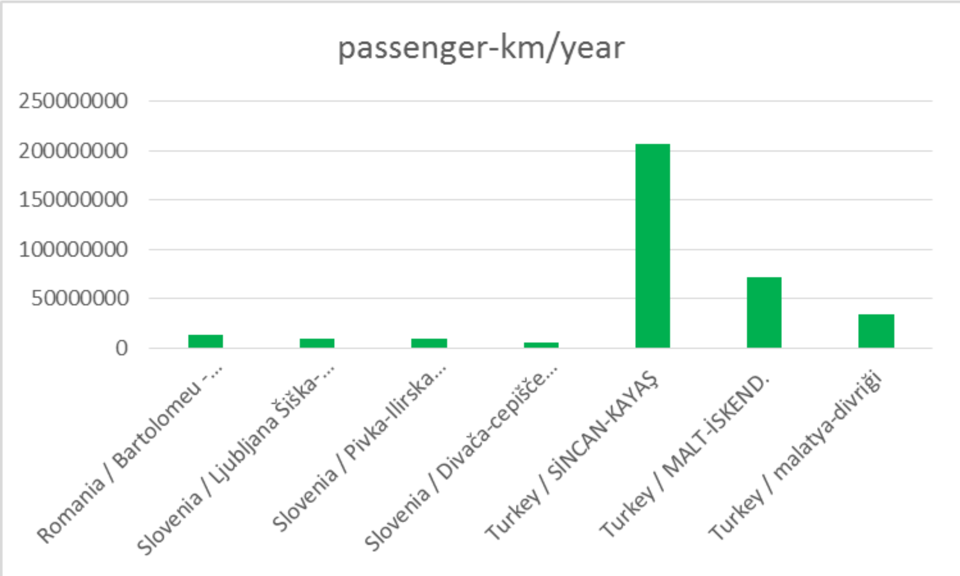


Figure 7-5 Passenger traffic by case study line

Figure 7-6 Freight traffic by case study line

Alongside the characteristics presented above we can also draw some conclusions and provide an analysis at an aggregate level (for all case study lines). In this regard, we aimed to identify whether or not there is any correlation between costs, failures and traffic on a combined level (all case study lines) or individual lines, starting from the hypothesis that increased traffic may lead to increased failures which leads to more costs. In order to reach a level of understanding of the phenomenon, based on the available data, we opted to compute the correlation coefficient between pairs of Costs, Failures and Traffic in order to illustrate the basic connection between these. We highlight the fact that correlation is not causality meaning that it measures the strength and the direction of a linear relationship between two variables not the influence one bears over the other.

The first correlation was made between Costs (two categories), number of failures (2 categories) and traffic on an aggregated level in each of the three test countries. The results aim to present in the most aggregated way possible the correlation on a whole dataset level. As the table below indicates a strong positive correlation can be observed between cost and traffic and weak but negative correlations between the number of failures and traffic and number of failures and costs. Even though these correlations are weak, it is still interesting that these are negative meaning that failures happen irrespective of traffic and are disproportionate relative to the cost of fixing them. These initial results led us to expand the analysis and consider each line individually and observe the same correlations between costs, failures and traffic.

	LCC	Failures	Traffic
LCC	1,00		
Failures	-0,42	1,00	
Traffic	0,73	-0,24	1,00

Table 7-2 Correlation coefficients on an aggregated level

The table below illustrates the correlation of datasets on an individual line level. In this instance all correlations are relatively weak, however a similar observation can be made where failures are negatively correlated with costs and traffic, respectively. Although the observations apply strictly to the dataset used (no generalisations are possible) and are currently based on a small number of data points, this gives a rationale to further investigate this relationship which is one branch that leads to cost optimisation and traffic optimisation in a safety and availability framework.

	LCC	Failures	Traffic
LCC	1,00		
Failures	-0,55	1,00	
Traffic	0,58	-0,51	1,00

Table 7-3 Correlation coefficients on an individual track level

8 Conclusions

This section summarises the results of the research activities and analysis which have been carried out in this Task 2.1.

In section 2 the research was based on an overview of the most commonly used methods applied in different European countries for the classification of infrastructure expenditures and the methods used to estimate capital costs. The analyses were focused on:

- Modalities for classification of infrastructure expenditures;
- Infrastructure expenditures components to monitor infrastructure expenditures and costs;
- Methods to move from annual series of expenditures to the consideration of whole life cycle and whole system costs.

In section 3 the analyses that have been carried out in this report have highlighted the inherent complexity of the RAMS and LCC analysis, by allowing the optimisation of the maintenance strategy and allowing to shorten decision times regarding maintenance/renewal. This is also reflected on the variety of topics. We highlighted the fact that due to the limited number of available databases containing RAMS indicators, progress towards a unified European/ International system is still slow. Furthermore, we observed that both RAMS and LCC are considered powerful tools these are not fully understood hence their development is slower than anticipated.

In section 4 we presented the physical design for a Web-GIS application based on open source tools and libraries according to Open Geospatial Consortium (OGC) specifications. This architecture includes the following layers: presentation, proxy, application and database & model.

The presentation, proxy and application layers shall be elaborated in WP 6 (the detailed architecture will be presented in task 6.2) however, the database layers are already made available within this deliverable.

The Database Layer is the most important level of presented architecture, because the databases store and manage attribute data, spatial data and map tiles via a spatial database, an object-relational database and a file system. Additionally, the entity relationship diagram (ERD) is designed to support the geospatial analysis of costs, drivers of failure and life of track infrastructure, which is presented in the ANNEX 4: Design of data repository.

The Entity Relationship Diagrams is a data modelling visual tool that helps organize the data in the project into entities and define the relationships between the entities.

The structure of the database consists in following entity categories:

- Localizations – manage information related to counties and regions
- Railway Infrastructure – manage information related to Railway Infrastructure

    - Railways
    - Switch & Crossing
    - Rail Stations
    - Railway gauge
    - Railway track
    - Power supply systems
    - Interlocking systems
    - Track Circuits
    - Components
- LCC - manage information related to LCC at Railway Infrastructure level
- Failure - manage information related to failure at Railway Infrastructure level
- Traffic volume - manage information related to traffic volume (passenger and freight) at Railways or Regional levels
- Rolling Stock - manage information related to Rolling Stock at Rail Operators level
- Actors - manage information related to actors involved in Rail Industry
    - Infrastructure Managers
    - Rail Operators

One of the aims of task 2.1 is identifying the type of geographic railway information available at country level for partners involved in this task, as well data collection, at the level of railway and regions, regarding cost, maintenance and failure. The data collected will be used to understand the variability of information relating to railway infrastructure maintenance costs and to make comparisons at the geographical level. In this regard, in section 6 we present the details regarding the availability of spatial data and data relative to infrastructure costs, maintenance and failure at the level of each analysed country.

From the point of view of geographic information available, the data collected was transposed via QGIS tools in OGR shape format and also in WKT format. For the UK, the collected geographic information consists of the following layers: UK boundary, England railway network, Scotland railway network, Wales railway network, North Ireland railway network and over the 2540 rail stations.

For Nederland the collected geographic information consists of: Nederland boundary, Nederland railway network.

For Slovenia the collected geographic information consists of: Slovenian boundary, Slovenian railway network.

For Turkey the collected geographic information consists of: Turkey boundary, Turkey railway network.

For Romania the collected geographic information consists of: Romanian boundary, Romanian railway network and over the 2100 rail stations.

From the point of view of general information, the data collected has been transposed via SQL scripting from an Excel spreadsheet into the MySql relational database.

Below we present the most important data categories collected for the study areas:

For the UK:

- Overview of Network infrastructure
- Activity volumes
    - Track renewals
    - Rail renewed
    - Sleepers renewed
    - Ballast renewed
    - Switches and crossings renewed
    - Track drainage renewals
    - Signalling renewed
    - Level crossing renewals
    - Telecom renewals
- LCC, Failure and Traffic Volume at UK level

For Slovenia:

- Overview of Network infrastructure
- LCC, Failure and Traffic Volume at 4 railway level (lines: Ljubljana Šiška-Kamnik Graben; Pivka-Ilirska Bistrica-d.m.; Divača-cepišče Prešnica and cepišče Prešnica-Koper)

For Turkey:

- Overview of Network infrastructure

For Romania:

- Overview of Network infrastructure
- LCC, Failure and Traffic Volume at RCCF railway level (line Bartolomeu-Zărnești)

Based on the data collected and available so far in the database we are able to provide several basic descriptions of the data by presenting the main statistics in terms of costs, failures and traffic volume. Various cost categories, failure type and incidence and, traffic volume information was presented in a comparative manner across case study lines. These first level analyses are accompanied by a correlation analysis performed on an aggregated country level and individual line level. Although not fully representative due to the low number of data points, these still show some interesting possible data behaviours such as negative, albeit weak correlation which goes against the intuitive scenario in which more traffic leads to more failure which require more cost to remedy.

As a final remark, it is interesting that any RAMS-LCC analysis indicates the consequences of under budgeting maintenance and renewal. This is why we conceptualised our own database starting from cost components to define the database structure and RAMS-LCC integration to define some database relations.

9 Next steps

The data collection under Task 2.1 will further be provided and analysed under Task 1.2.

The presentation, proxy and application layers of Web-GIS application shall be elaborated in WP 6 (the detailed architecture will be presented in task 6.2).

In this respect, at the project meeting on 29th October 2015, the partners involved in WP6 have agreed on the following future actions:

- The database to be converted from MySQL with spatial extension to PostgreSQL with PostGIS extension.
- Finding a solution for translating information integrated/used in RailTopoModel and RailML.

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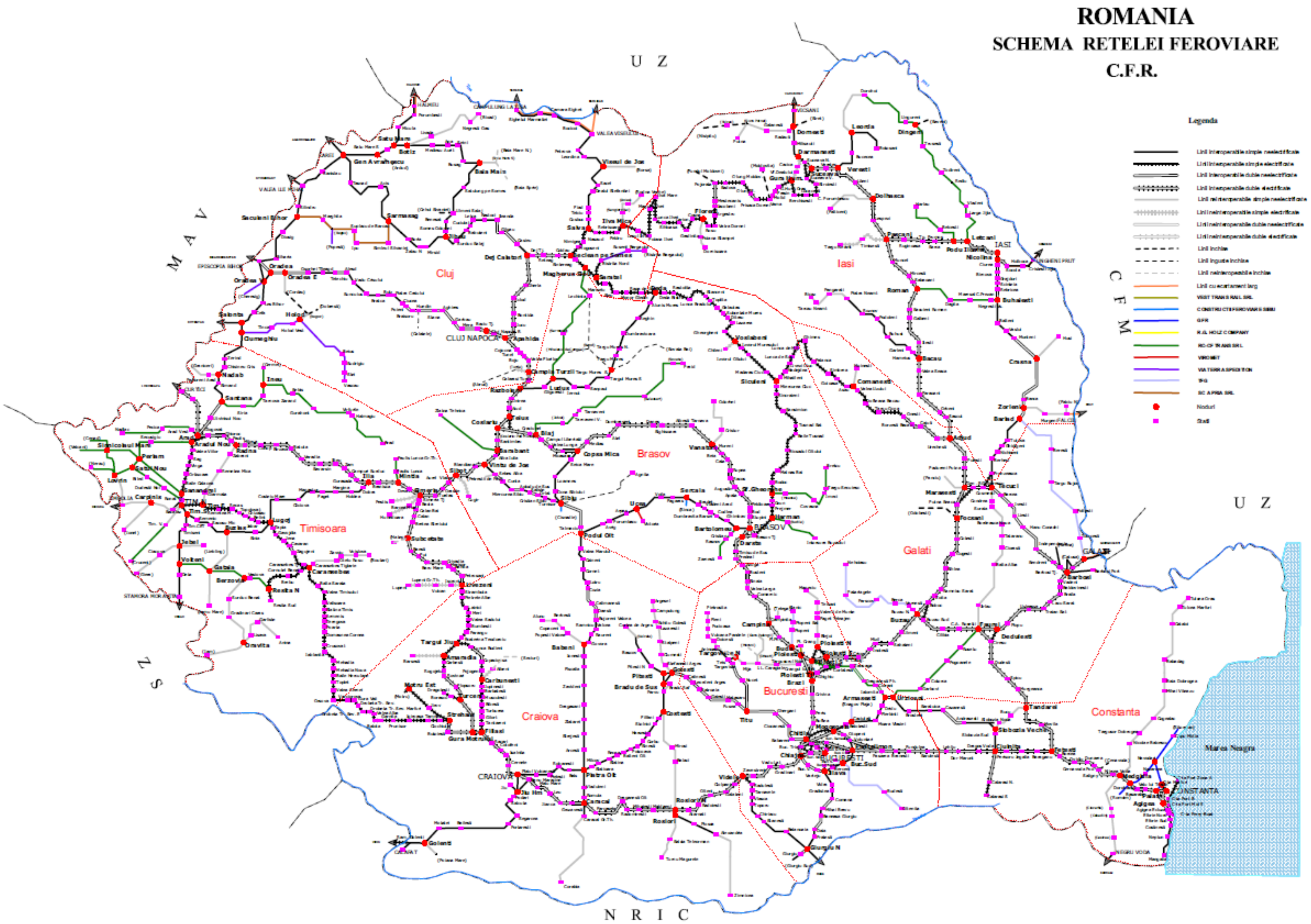
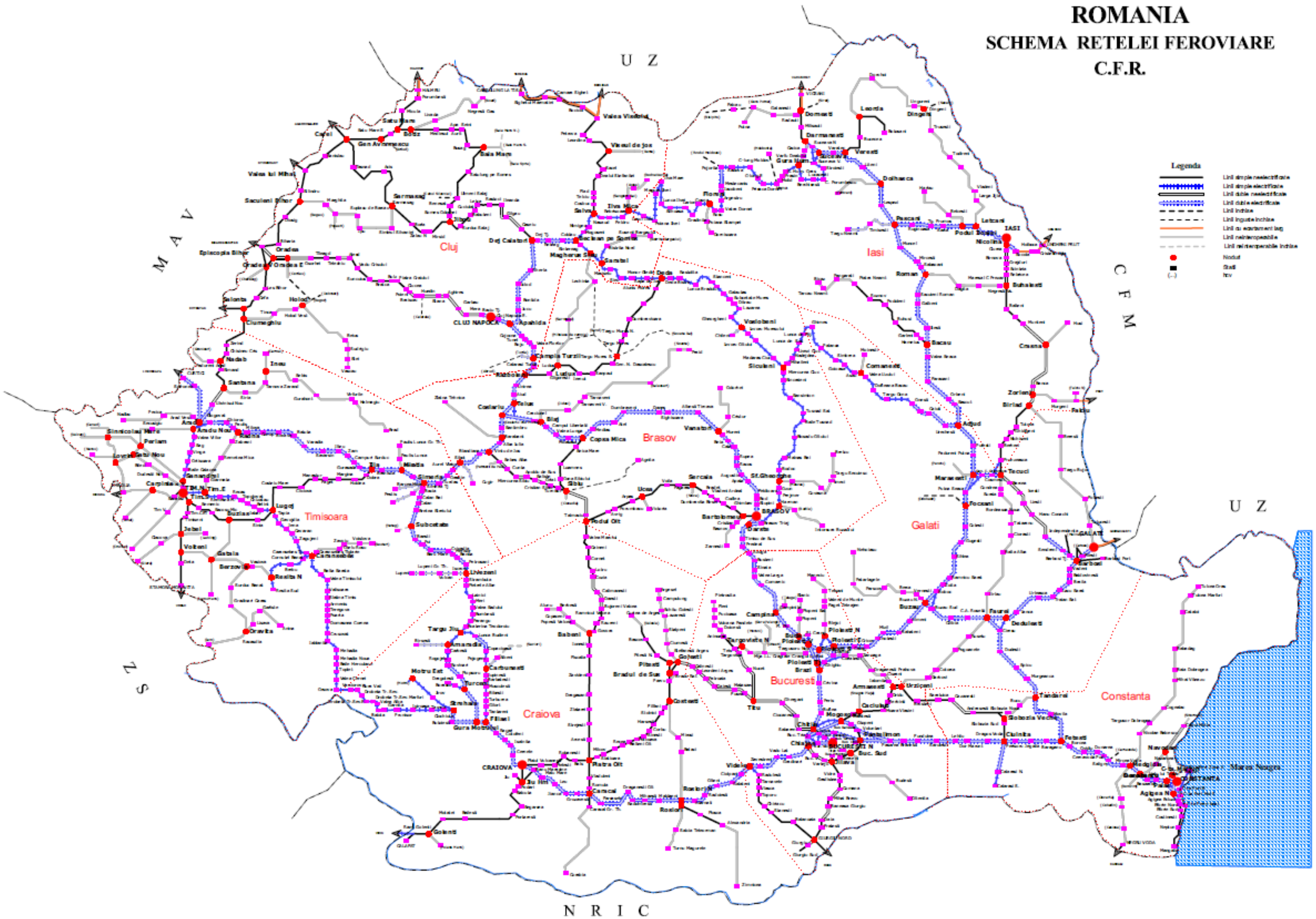
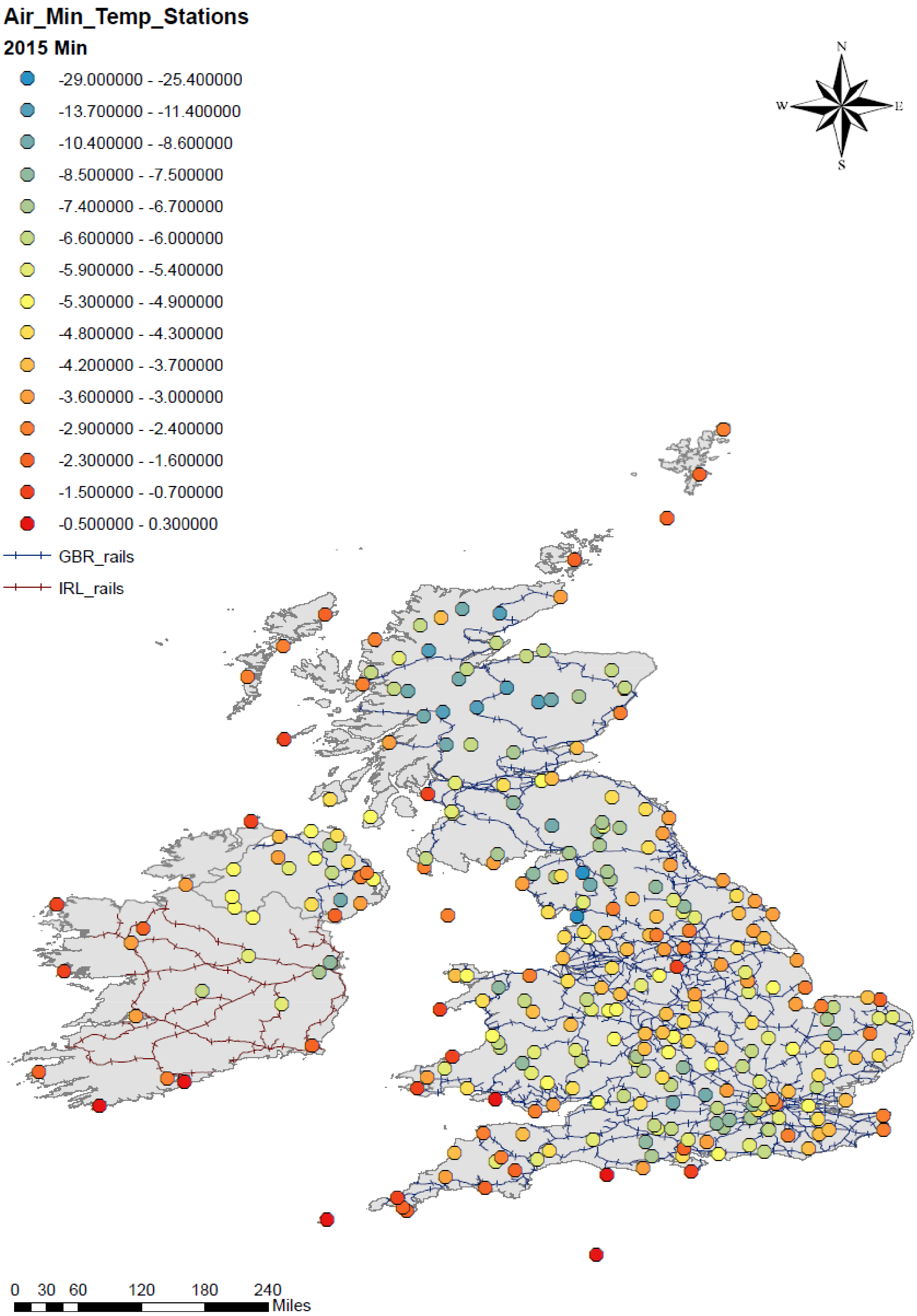
ANNEX 1: Map of Interoperable and Non-Interoperable Romanian Lines



ANNEX 2: Overview Map of the CFR Network



ANNEX 3: Map of the UK Network



ANNEX 4: Design of data repository

Design of conceptual model of data repository

The entity relationship diagram (ERD) designed to database support for geospatial analysis of costs, drivers of failure and life of track infrastructure is presented below.

Entity Relationship Diagrams is a data modelling visual tool that helps to organize the data in the project into entities and define the relationships between the entities.

An ERD typically consists of four different graphical components:

- Entity - A data entity is anything real or abstract about which we want to store data. Entity types fall into five classes: roles, events, locations, tangible things or concepts. E.g. country, railway, infrastructure manager etc.
- Relationship - A data relationship is a natural association that exists between one or more entities. E.g. Infrastructure manager manages a railway.
- Cardinality - Defines the number of occurrences of one entity for a single occurrence of the related entity. E.g. a railway can be part of many routes, but cannot be used by electric trains if it was not designed this way supply.
- Attribute - A data attribute is a characteristic common to all or most instances of a particular entity. Synonyms include property, data element, and field. E.g. Name, address, country are all attributes of the entity infrastructure manager. An attribute or combination of attributes that uniquely identifies one and only one instance of an entity is called a primary key or identifier. E.g. managerID is a primary key for infrastructure manager.

The structure of the database consists of principal entities (entities on which will make analysis) and secondary entities that support the characterization of principal entities (lists of attributes for the principal entities).

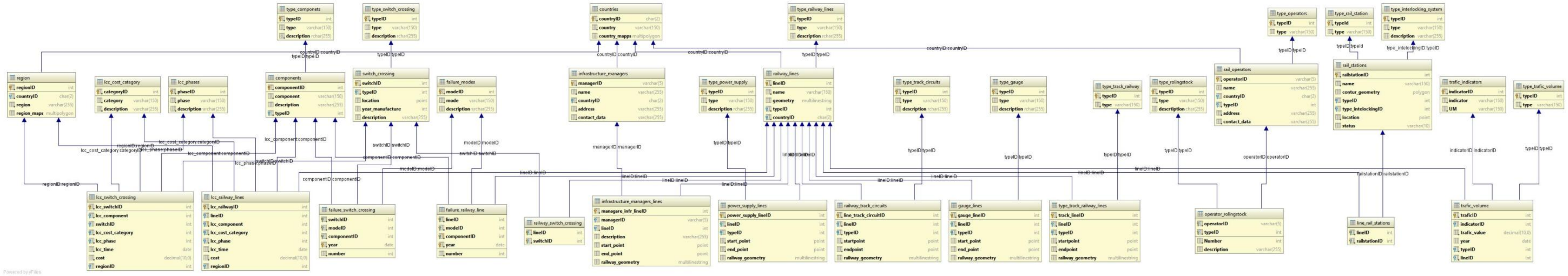


Figure 0-1 Structure of database support for geospatial analysis of costs, drivers of failure and life of track infrastructure

Summary of database

In this section, we present the list of the entities constituting the database support for geospatial analysis of costs, drivers of failure and life of track infrastructure.

Category of Entity	Entity Name	Description
Localizations	**countries**	In this table information is managed on the countries for which you wish to perform analysis
Localizations	**region**	In this table information is managed on the region for which you wish to perform analysis
Railway	**type_railway_lines**	In this table is managed information regarding the classification of types railway
Railway	**railway_lines**	In this table is managed information on the railway for which you wish to perform analysis
Rail Stations	**type_rail_station**	In this table is managed information regarding the classification of types rail stations
Rail Stations	**rail_stations**	In this table is managed information regarding the nomenclatures of rail stations
Rail Stations	**line_rail_stations**	In this table is managed information regarding the rail stations at railway level
Infrastructure Managers	**infrastructure_managers**	In this table is managed information regarding the nomenclatures of infrastructure managers
Infrastructure Managers	**infrastructure_managers_lines**	In this table is managed information regarding the infrastructure manager at railway level
Rail Operators	**type_operators**	In this table is managed information regarding the classification of type of rolling stock operators
Rail Operators	**rail_operators**	In this table is managed information regarding the nomenclatures of railing stock operators
Rolling stock	**type_rolingstock**	In this table is managed information regarding the classification of type of rolling stock
Rolling stock	**operator_rolingstock**	In this table is managed information regarding the rolling stock at rail operator level
Railway gauge	**type_gauge**	In this table is managed information regarding the classification of railway gauge
Railway gauge	**gauge_lines**	In this table is managed information regarding the gauge at railway level
Railway track	**type_track_railway**	In this table is managed information regarding the classification of types of railway track Eg. one-track rails (trains use the same track for both directions) , two-track rails (each track is used for train traffic in a certain direction)
Railway track	**type_track_railway_lines**	In this table is managed information regarding the type of railway track at railway level
Power supply systems	**type_power_supply**	In this table is managed information regarding the classification of types of power supply
Power supply systems	**power_supply_lines**	In this table is managed information regarding the power supply at railway level
Switch & Crossing	**type_switch_crossing**	In this table is managed information regarding the classification of types of switch & crossing Eg. Slip switches Double slip Single slip Outside slip

Category of Entity	Entity Name	Description
		Dual gauge switches Rack railway switches
Switch & Crossing	**switch_crossing**	In this table is managed information regarding the switch & crossing at descriptive level
Switch & Crossing	**railway_switch_crossing**	In this table is managed information regarding the switch & crossing at railway level
Interlocking systems	**type_interlocking_system**	In this table is managed information regarding the classification of types of interlocking systems Eg. Mechanical interlocking, Electro-mechanical interlocking, Relay interlocking, Electronic interlocking
Track Circuits	**type_track_circuits**	In this table is managed information regarding the classification of types of track circuits Eg. Automatic line block, Common automatic line block, Dedicated automatic line block, Simplified automatic line block
Track Circuits	**railway_track_circuits**	In this table is managed information regarding the track circuits at railway level
Components	**type_componets**	In this table are managed information regarding the types of constituent components of the railway, Switch & Crossing etc.
Components	**components**	In this table are managed information regarding the constituent components of the railway, Switch & Crossing etc. E.g. Switch rail, Slide chair, Ballast, Schiwag Roller, Stretcher bar, Stock rail , Crossing , Fishplate, Back Drive, Sleeper, Spacer Block
LCC	**lcc_phases**	In this table is managed information regarding the classification of LCC phases according to standard IEC 60300-3-3
LCC	**lcc_cost_category**	In this table is managed information regarding the classification of LCC cost categories according to standard IEC 60300-3-3
LCC	**lcc_railway_lines**	In this table is managed information regarding the LCC at railway level
LCC	**lcc_switch_crossing**	In this table is managed information regarding the LCC at switch & crossing level
Failure	**failure_modes**	In this table is managed information regarding the classification of different types of failure modes. E.g. Obstructed (Iced,..), Dry Chairs, Cracked/Broken , Voiding (Ballast) , Out of adjustment, Contaminated (Leaves,..), Plastic deformation/Lipping, Wear, Loosed/missing(Nuts) , Squat, RCF, Creep (Switch,..), Track gauge variation , Wet bed
Failure	**failure_railway_line**	In this table is managed information regarding the failure at railway level
Failure	**failure_switch_crossing**	In this table is managed information regarding the failure at switch & crossing level
Trafic volume	**type_trafic_volume**	In this table is managed information regarding the classification of different types of traffic volume Eg. Passenger traffic volume, Freight traffic volume
Trafic volume	**trafic_indicators**	In this table is managed information regarding the classification of different types of traffic volume indicators.

Category of Entity	Entity Name	Description
		Eg. passenger-km/year, passenger journeys/year, passenger train-km/year , freight train-km/year, gross tonne-km/year etc.
Trafic volume	**trafic_volume**	In this table is managed information regarding the traffic volume at railway level

Table 0-1 Entities considered in database

Details of database entities

This section presents the details of each entity and relationship of them in the database

Entity “countries”

Columns Summary

Name	DataType	Constraints	Nullable	Description
countryID	char(2)	PK	No	Primary key or identifier of country
country	varchar(150)		No	Name of country
country_mapps	polygon		Yes	Spatial geometry of country

Relationships

region_ibfk_1 : Relationship	
To	region
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table region because the specific region belong to a country

railway_lines_ibfk_2 : Relationship	
To	railway_lines
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table railway_lines because the railway belong to a country

infrastructure_managers_ibfk_1 : Relationship	
To	infrastructure_managers
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table infrastructure_managers because the infrastructure manager belong to a country

rail_operators_ibfk_1 : Relationship	
To	rail_operators
On Delete	No action

rail_operators_ibfk_1 : Relationship	
On Update	No action
To Multiplicity	0..*
From Multiplicity	0..1
Description	Ensure the relationship with table rail_operators because the railway operators belong to a country

Entity “region”

Columns Summary

Name	DataType	Constraints	Nullable	Description
regionID	int(11)	PK	No	Primary key or identifier of specific region
countryID	char(2)	FK (countries.countryID)	No	Foreign key which defines the contry of region
region	varchar(255)		No	Name of region
region_maps	int		Yes	Spatial geometry of region

Relationships

lcc_railway_lines_ibfk_5 : Relationship	
To	lcc_railway_lines
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	0..1
Description	Ensure the relationship with table lcc_railway_lines because LCC for railways can be calculated at the level of region

lcc_switch_crossing_ibfk_5 : Relationship	
To	lcc_switch_crossing
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	0..1
Description	Ensure the relationship with table lcc_switch_crossing because LCC for S&C can be calculated at the level of region

region_ibfk_1 : Relationship	
From	countries
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table region because the specific region belong to a country

Entity “type_railway_lines”

Columns Summary

Name	DataType	Constraints	Nullable	Description
typeID	int(11)	PK	No	Primary key or identifier of types of railway
type	varchar(150)		Yes	Name of type of railway
description	varchar(255)		Yes	Description of types of classification railway

Relationships

railway_lines_ibfk_1 : Relationship	
To	railway_lines
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	A specific railway is part of a certain type of railway

Entity “railway_lines”

Columns Summary

Name	DataType	Constraints	Nullable	Description
lineID	int(11)	PK	No	Primary key or identifier of railway
typeID	int(11)	FK (type_railway_lines.typeID)	No	Foreign key which defines the type of railway to which it belongs railway
countryID	char(2)	FK (countries.countryID)	No	Foreign key which defines the county to which it belongs railway
name	varchar(150)		No	Name of railway
geometry	multilinestring		Yes	Spatial geometry of railway

Relationships

infrastructure_managers_lines_ibfk_1 : Relationship	
To	infrastructure_managers_lines
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table infrastructure_managers_lines because any railway has an infrastructure manager

power_supply_lines_ibfk_1 : Relationship	
To	power_supply_lines
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1

power_supply_lines_ibfk_1 : Relationship	
Description	Ensure the relationship with table power_supply_lines because a railway may have a power supply system

line_rail_stations_ibfk_1 : Relationship	
To	line_rail_stations
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table line_rail_stations because any railway has more stations

railway_track_circuits_ibfk_1 : Relationship	
To	railway_track_circuits
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table railway_track_circuits because any railway has a specific track circuit

railway_swich_crossing_ibfk_1 : Relationship	
To	railway_switch_crossing
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table railway_switch_crossing because any railway has swich & crossing

trafic_volume_ibfk_3 : Relationship	
To	trafic_volume
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table trafic_volume because any railway has a specific trafic volume

failure_railway_line_ibfk_1 : Relationship	
To	failure_railway_line
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table failure_railway_line because failure occur at the level of railways

gauge_lines_ibfk_1 : Relationship	
To	gauge_lines

gauge_lines_ibfk_1 : Relationship	
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table gauge_lines because any railway has a type of gauge

lcc_railway_lines_ibfk_1 : Relationship	
To	lcc_railway_lines
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table lcc_railway_lines because LCC is calculated at the level of railways

type_track_railway_lines_ibfk_1 : Relationship	
To	type_track_railway_lines
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table type_track_railway_lines because any railway has a type of track

railway_lines_ibfk_1 : Relationship	
To	type_railway_lines
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	A specific railway is part of a certain type of railway

railway_lines_ibfk_2 : Relationship	
To	countries
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table countries because the railway belong to a country

Entity “type_rail_station”

Columns Summary

Name	DataType	Constraints	Nullable	Description
typeId	int(11)	PK	No	Primary key or identifier of types of rail station
type	varchar(150)		No	Name of type of rail station

Relationships

rail_stations_ibfk_1 : Relationship	
To	rail_stations
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	A specific rail station is part of a certain type of rail station

Entity “rail_stations”

Columns Summary

Name	DataType	Constraints	Nullable	Description
railstationID	int(11)	PK	No	Primary key or identifier of rail station
typeID	int(11)	FK (type_rail_station.typeId)	No	Foreign key which defines the type of rail station to which it belongs rail station
type_intelockingID	int(11)	FK (type_interlocking_system.typeID)	No	Foreign key which defines the type of interlocking to which it belongs rail station
name	varchar(150)		No	Name of rail station
contur_geometry	polygon		Yes	Spatial geometry of railway station

Relationships

line_rail_stations_ibfk_2 : Relationship	
To	line_rail_stations
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table line_rail_stations because the rail station belong to a railway

rail_stations_ibfk_2 : Relationship	
To	type_interlocking_system
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table type_interlocking_system because any rail station has a type of interlocking system

rail_stations_ibfk_1 : Relationship	
To	type_rail_station
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1

rail_stations_ibfk_1 : Relationship	
Description	A specific rail station is part of a certain type of rail station

Entity “line_rail_stations”

Columns Summary

Name	DataType	Constraints	Nullable	Description
lineID	int(11)	PK/FK (railway_lines.lineID)	No	Compozit Primary key for identifier of railway and a specific rail station Foreign key which defines the railway
railstationID	int(11)	PK/FK (rail_stations.railstationID)	No	Compozit Primary key for identifier of railway and a specific rail station Foreign key which defines the rail station

Relationships

line_rail_stations_ibfk_2 : Relationship	
To	rail_stations
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table rail_stations because the rail station belong to a railway

line_rail_stations_ibfk_1 : Relationship	
To	railway_lines
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table railway_lines because the rail station belong to a railway

Entity “infrastructure_managers”

Columns Summary

Name	DataType	Constraints	Nullable	Description
managerID	varchar(5)	PK	No	Primary key or identifier of infrastructure manager
countryID	char(2)	FK (countries.countryID)	No	Foreign key which defines the country to which it belongs infrastructure manager
name	varchar(255)		No	Name of infrastructure manager
address	varchar(255)		No	Address of infrastructure manager
contact_data	varchar(255)		No	Condact data of infrastructure manager

Relationships

infrastructure_managers_lines_ibfk_2 : Relationship	
To	infrastructure_managers_lines
On Delete	No action
On Update	No action

infrastructure_managers_lines_ibfk_2 : Relationship	
To Multiplicity	0..*
From Multiplicity	0..1
Description	Ensure the relationship with table infrastructure_managers_lines because any railway has a infrastructure manager

infrastructure_managers_ibfk_1 : Relationship	
To	countries
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table countries because the infrastructure manager belong to a country

Entity "infrastructure_managers_lines"

Columns Summary

Name	DataType	Constraints	Nullable	Description
managare_infr_lineID	int(11)	PK	No	Primary key or identifier of infrastructure manager at railway level
managerID	varchar(5)	FK (infrastructure_managers.managerID)	Yes	Foreign key which defines the infrastructure manager to which it belongs railway
lineID	int(11)	FK (railway_lines.lineID)	No	Foreign key which defines the railway
start_point	point		Yes	Spatial geometry of start point for a specific railway managed by a specific infrastructure manager
end_point	point		Yes	Spatial geometry of end point for a specific railway managed by a specific infrastructure manager
railway_geometry	multilinestring		Yes	Spatial geometry of a specific railway managed by a specific infrastructure manager
description	varchar(255)		Yes	Description of a specific railway managed by a specific infrastructure manager

Relationships

infrastructure_managers_lines_ibfk_2 : Relationship	
To	infrastructure_managers
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	0..1
Description	Ensure the relationship with table infrastructure_managers because the infrastructure manager belong to a railway

infrastructure_managers_lines_ibfk_1 : Relationship	
To	railway_lines
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table railway_lines because the infrastructure manager belong to a railway

Entity "type_operators"

Columns Summary

Name	DataType	Constraints	Nullable	Description
typeID	int(11)	PK	No	Primary key or identifier of type of operator
type	varchar(150)		Yes	Name of type of operator

Relationships

rail_operators_ibfk_2 : Relationship	
To	rail_operators
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	A specific railway operator is part of a certain type of railway operator

Entity "rail_operators"

Columns Summary

Name	DataType	Constraints	Nullable	Description
opratorID	varchar(5)	PK	No	Primary key or identifier of rail operator
countryID	char(2)	FK (countries.countryID)	Yes	Foreign key which defines the country to which it belongs rail operator
typeID	int(11)	FK (type_oprators.typeID)	No	Foreign key which defines the type of rail operator to which it belongs rail operator
name	varchar(255)		Yes	Name of rail operator
address	varchar(255)		No	Address of rail operator
contact_data	varchar(255)		No	Condact data of rail operator

Relationships

operator_rolingstock_ibfk_1 : Relationship	
To	operator_rolingstock
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1

operator_rolingstock_ibfk_1 : Relationship	
Description	Ensure the relationship with table operator_rolingstock because any rolling stock has a rail operator

rail_operators_ibfk_1 : Relationship	
To	countries
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	0..1
Description	Ensure the relationship with table countries because the railway operators belong to a country

rail_operators_ibfk_2 : Relationship	
To	type_oprators
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	A specific rail operator belongs to a certain type of rail operator

Entity "type_rolingstock"

Columns Summary

Name	DataType	Constraints	Nullable	Description
typeID	int(11)	PK	No	Primary key or identifier of types of rolling stock
type	varchar(150)		No	Name of type of rolling stock
descrtiption	varchar(255)		Yes	Description of types of rolling stock

Relationships

operator_rolingstock_ibfk_2 : Relationship	
To	operator_rolingstock
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table operator_rolingstock because the railway operator has a one or more type of roling stock

Entity "operator_rolingstock"

Columns Summary

Name	DataType	Constraints	Nullable	Description
operatorID	varchar(5)	PK/FK (rail_operators.operatorID)	No	Compozit Primary key for identifier of railway operator and a specific type of rolling stock Foreign key which defines the railway operator
typeID	int(11)	PK/FK	No	Compozit Primary key for identifier of

Name	DataType	Constraints	Nullable	Description
		(type_rolingstock. typeID)		railway operator and a specific type of rolling stock Foreign key which defines the type of rolling stock
number	int(11)		No	Number of specific rolling stock owned by railway operator
description	varchar(255)		Yes	Descriptioan of specific rolling stock owned by railway operator

Relationships

operator_rolingstock_ibfk_2 : Relationship	
From	type_rolingstock
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table type_rolingstock because the railway operator has a one or more type of roling stock

operator_rolingstock_ibfk_1 : Relationship	
From	rail_operators
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table rail_operators because any rolling stock has a rail operator

Entity “type_gauge”

Columns Summary

Name	DataType	Constraints	Nullable	Description
typeID	int(11)	PK	No	Primary key or identifier of types of gauge of railway
type	varchar(150)		Yes	Name of type of gauge of railway
description	varchar(255)		Yes	Description of types of gauge of railway

Relationships

gauge_lines_ibfk_2 : Relationship	
To	gauge_lines
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table gauge_lines because the railway has a type of gauge

Entity “gauge_lines”

Columns Summary

Name	DataType	Constraints	Nullable	Description
gouge_lineID	int(11)	PK	No	Primary key or identifier of gouge of a specific railway
lineID	int(11)	FK (railway_lines.lineID)	No	Foreign key which defines the specific railway
typeID	int(11)	FK (type_gauge.typeID)	No	Foreign key which defines the type of gauge to which it belongs specific railway
start_point	point		Yes	Spatial geometry of the point at which a type of gauge
end_point	point		Yes	Spatial geometry of the point where it ends a type of gauge
railway_geometry	multilinestring		Yes	Spatial geometry of railway with specific type of gauge

Relationships

gauge_lines_ibfk_2 : Relationship	
To	type_gauge
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table type_gauge because the railway has a type of gauge

gauge_lines_ibfk_1 : Relationship	
To	railway_lines
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table railway_lines because any railway has a type of gauge

Entity “type_track_railway”

Columns Summary

Name	DataType	Constraints	Nullable	Description
typeID	int(11)	PK	No	Primary key or identifier of types of track of railway
type	varchar(150)		No	Name of type of track of railway

Relationships

type_track_railway_lines_ibfk_2 : Relationship	
To	type_track_railway_lines
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table type_track_railway_lines because any railway has a type of

type_track_railway_lines_ibfk_2 : Relationship	
	track

Entity “type_track_railway_lines”

Columns Summary

Name	DataType	Constraints	Nullable	Description
track_lineID	int(11)	PK	No	Primary key or identifier of type of track of a specific railway
lineID	int(11)	FK (railway_lines. lineID)	No	Foreign key which defines the specific railway
typeID	int(11)	FK (type_track_ra ilway.typeID)	No	Foreign key which defines the type of track to which it belongs specific railway
startpoint	point		No	Spatial geometry of the point at which a type of track
endpoint	point		No	Spatial geometry of the point where it ends a type of track
railway_geometry	multiline string		Yes	Spatial geometry of railway with specific type of track

Relationships

type_track_railway_lines_ibfk_2 : Relationship	
To	type_track_railway
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table type_track_railway because any railway has a type of track

type_track_railway_lines_ibfk_1 : Relationship	
To	railway_lines
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table railway_lines because any railway has a type of track

Entity “type_power_supply”

Columns Summary

Name	DataType	Constraints	Nullable	Description
typeID	int(11)	PK	No	Primary key or identifier of types of power supply
type	varchar(150)		No	Name of type of power supply
description	varchar(255)		Yes	Description of types of power supply

Relationships

power_supply_lines_ibfk_2 : Relationship	
To	power_supply_lines
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	0..1
Description	Ensure the relationship with table power_supply_lines because the railway has/or not a type of power supply

Entity “power_supply_lines”

Columns Summary

Name	DataType	Constraints	Nullable	Description
power_supply_lineID	int(11)	PK	No	Primary key or identifier of power supply of railway
lineID	int(11)	FK (railway_lines.lineID)	No	Foreign key which defines the specific railway
typeID	int(11)	FK (type_power_supply.typeID)	Yes	Foreign key which defines the type of power supply to which it belongs specific railway
start_point	point		No	Spatial geometry of the point at which a type of power supply
end_point	point		No	Spatial geometry of the point where it ends a type of power supply
railway_geometry	multiline string		Yes	Spatial geometry of railway with specific type of power supply

Relationships

power_supply_lines_ibfk_1 : Relationship	
To	railway_lines
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table railway_lines because a railway may have a power supply system

power_supply_lines_ibfk_2 : Relationship	
To	type_power_supply
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	0..1
Description	Ensure the relationship with table type_power_supply because the railway has/or not a type of power supply

Entity “type_switch_crossing”

Columns Summary

Name	DataType	Constraints	Nullable	Description
typeID	int(11)	PK	No	Primary key or identifier of types of switch & crossing
type	varchar(150)		Yes	Name of type of switch & crossing
description	varchar(255)		Yes	Description of type of switch & crossing

Relationships

switch_crossing_ibfk_1 : Relationship	
To	switch_crossing
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	A specific switch & crossing system is part of a certain type of switch & crossing

Entity "switch_crossing"

Columns Summary

Name	DataType	Constraints	Nullable	Description
switchID	int(11)	PK	No	Primary key or identifier of switch & crossing system
typeID	int(11)	FK (type_switch_crossing.typeID)	No	Foreign key which defines the type of switch & crossing system
location	point		Yes	Spatial geometry of the point at which a switch & crossing system
year_manufacture	int(11)		Yes	Year of manufacture of the switch & crossing system
description	varchar(255)		Yes	Description of specific switch & crossing system

Relationships

railway_swich_crossing_ibfk_2 : Relationship	
To	railway_swich_crossing
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table railway_swich_crossing since a switch & crossing system belongs to a railway

lcc_switch_crossing_ibfk_1 : Relationship	
To	lcc_switch_crossing
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table lcc_switch_crossing because each switch & crossing system has own LCC

failure_switch_crossing_ibfk_1 : Relationship	
To	failure_switch_crossing
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table failure_switch_crossing because a specific failure may occur in each switch & crossing system

switch_crossing_ibfk_1 : Relationship	
To	type_switch_crossing
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	A specific switch & crossing system is part of a certain type of switch & crossing

Entity "railway_switch_crossing"

Columns Summary

Name	DataType	Constraints	Nullable	Description
lineID	int(11)	PK/FK (railway_lines.lineID)	No	Compozit Primary key for identifier of a specific railway and a specific switch & crossing system Foreign key which defines the railway
switchID	int(11)	PK/FK (switch_crossing.switchID)	No	Compozit Primary key for identifier of a specific railway and a specific switch & crossing system Foreign key which defines switch & crossing system

Relationships

railway_swich_crossing_ibfk_2 : Relationship	
To	switch_crossing
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table switch_crossing because any railway has a swich & crossing system

railway_swich_crossing_ibfk_1 : Relationship	
To	railway_lines
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table railway_lines because any railway has a swich & crossing system

Entity "type_interlocking_system"

Columns Summary

Name	DataType	Constraints	Nullable	Description
typeID	int(11)	PK	No	Primary key or identifier of type of interlocking system
type	varchar(150)		No	Name of type of interlocking system
description	varchar(255)		Yes	Description of type of interlocking system

Relationships

rail_stations_ibfk_2 : Relationship	
To	rail_stations
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table rail_stations because any rail station has a type of interlocking system

Entity “type_track_circuits”

Columns Summary

Name	DataType	Constraints	Nullable	Description
typeID	int(11)	PK	No	Primary key or identifier of type of track cicuits
type	varchar(150)		No	Name of type of track cicuits
description	varchar(255)		Yes	Description of type of track cicuits

Relationships

railway_track_circuits_ibfk_2 : Relationship	
To	railway_track_circuits
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table railway_track_circuits because any railway has a type of track circuits

Entity “railway_track_circuits”

Columns Summary

Name	DataType	Constraints	Nullable	Description
line_track_circuitID	int(11)	PK	No	Primary key or identifier of track circuit of railway
lineID	int(11)	FK (railway_lines.lineID)	No	Foreign key which defines the specific railway
typeID	int(11)	FK (type_track_circuits.typeID)	No	Foreign key which defines the type of track circuit to which it belongs specific railway
startpoint	point		No	Spatial geometry of the point at which a type of track circuit
endpoint	point		No	Spatial geometry of the point where it ends a type of track circuit

Name	DataType	Constraints	Nullable	Description
railway_geometry	multiline string		Yes	Spatial geometry of railway with specific type of track circuit

Relationships

railway_track_circuits_ibfk_2 : Relationship	
To	type_track_circuits
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table type_track_circuits because any railway has a type of track circuits

railway_track_circuits_ibfk_1 : Relationship	
To	railway_lines
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table railway_lines because any railway has a type of track circuits

Entity “type_components”

Columns Summary

Name	DataType	Constraints	Nullable	Description
typeID	int(11)	PK	No	Primary key or identifier of type of componet
type	varchar(150)		No	Name of type of componet
description	varchar(255)		Yes	Description of type componet

Relationships

components_ibfk_1 : Relationship	
To	components
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	Physical
Description	A specific component is part of a certain type of componet

Entity “components”

Columns Summary

Name	DataType	Constraints	Nullable	Description
componentID	int(11)	PK	No	Primary key or identifier of component
typeID	int(11)	FK (type_componets.typeID)	No	Foreign key which defines the type of component

Name	DataType	Constraints	Nullable	Description
component	varchar(150)		No	Name of type of component
description	varchar(255)		No	Description of component

Relationships

lcc_railway_lines_ibfk_5 : Relationship	
To	lcc_railway_lines
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table lcc_railway_lines because the component is a dimension of LCC at railway level

failure_switch_crossing_ibfk_3 : Relationship	
To	failure_switch_crossing
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table failure_switch_crossing because the component is a dimension of failure at swich & crossing level

failure_railway_line_ibfk_3 : Relationship	
To	failure_railway_line
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table failure_railway_line because the component is a dimension of failure at railway level

lcc_switch_crossing_ibfk_2 : Relationship	
To	lcc_switch_crossing
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table lcc_switch_crossing because the component is a dimension of LCC at swich & crossing level

components_ibfk_1 : Relationship	
To	type_componets
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	A specific component is part of a certain type of componet

Entity “lcc_phases”

Columns Summary

Name	DataType	Constraints	Nullable	Description
phaseID	int(11)	PK	No	Primary key or identifier of LCC pahse
phase	varchar(150)		No	Name of type of LCC pahse
description	varchar(255)		No	Description of LCC pahse

Relationships

lcc_railway_lines_ibfk_4 : Relationship	
To	lcc_railway_lines
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table lcc_railway_lines because the LCC phase is a dimension of LCC at railway level

lcc_switch_crossing_ibfk_4 : Relationship	
To	lcc_switch_crossing
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table lcc_switch_crossingbecause the LCC phase is a dimension of LCC at switch & crossing level

Entity "lcc_cost_category"

Columns Summary

Name	DataType	Constraints	Nullable	Description
categoryID	int(11)	PK	No	Primary key or identifier of LCC cost category
category	varchar(150)		No	Name of type of LCC cost category
description	varchar(255)		No	Description of LCC cost category

Relationships

lcc_railway_lines_ibfk_3 : Relationship	
To	lcc_railway_lines
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table lcc_railway_lines because the LCC cost category is a dimension of LCC at railway level

lcc_switch_crossing_ibfk_3: Relationship	
To	lcc_switch_crossing
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1

lcc_switch_crossing_ibfk_3: Relationship	
Description	Ensure the relationship with table lcc_switch_crossing because the LCC cost category is a dimension of LCC at switch & crossing level

lcc_railway_lines_ibfk_4 : Relationship	
From	railway_lines
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	0..1
Description	Ensure the relationship with table lcc_railway_lines because LCC for railways can be calculated at the level of spefic railway line

Entity "lcc_railway_lines"

Columns Summary

Name	DataType	Constraints	Nullable	Description
lcc_railwayID	int(11)	PK	No	Primary key or identifier of LCC for railway
lineID	int(11)	FK (railway_lines.lineID)	Yes	Foreign key which defines the railway
regionID	int(11)	FK (region.regionID)	Yes	Foreign key which defines the region
lcc_componet	int(11)	FK (components.componentID	No	Foreign key which defines the type of LCC component
lcc_cost_category	int(11)	FK (lcc_cost_category.categoryID)	No	Foreign key which defines the type of LCC cost category
lcc_phase	int(11)	FK (lcc_phases.phaseID)	No	Foreign key which defines the type of LCC phase
lcc_time	date		No	The time(year) at which the calculated LCC
cost	decimal(10)		No	LCC cost

Relationships

lcc_railway_lines_ibfk_5 : Relationship	
From	region
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	0..1
Description	Ensure the relationship with table lcc_railway_lines because LCC for railways can be calculated at the level of region

lcc_railway_lines_ibfk_5 : Relationship	
From	components
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table components because the component is a dimension of LCC at railway level

lcc_railway_lines_ibfk_3 : Relationship	
From	lcc_cost_category
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table lcc_cost_category because the LCC cost category is a dimension of LCC at railway level

lcc_railway_lines_ibfk_4 : Relationship	
From	lcc_phases
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table lcc_phases because the LCC phase is a dimension of LCC at railway level

Entity “lcc_switch_crossing”

Columns Summary

Name	DataType	Constraints	Nullable	Description
lcc_switchID	int(11)	PK	No	Primary key or identifier of LCC for S&C
regionID	int(11)	FK (region.regionID)	Yes	Foreign key which defines the region
switchID	int(11)	FK (switch_crossing.switchID)	Yes	Foreign key which defines the S&C
lcc_componet	int(11)	FK (components.componentID	No	Foreign key which defines the type of LCC component
lcc_cost_category	int(11)	FK (lcc_cost_category.categoryID)	No	Foreign key which defines the type of LCC cost category
lcc_phase	int(11)	FK (lcc_phases.phaseID)	No	Foreign key which defines the type of LCC phase
lcc_time	date		No	The time(year) at which the calculated LCC
cost	decimal(10)		No	LCC cost

Relationships

lcc_switch_crossing_ibfk_5 : Relationship	
From	region
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	0..1
Description	Ensure the relationship with table lcc_switch_crossing because LCC for S&C can be calculated at the level of region

lcc_switch_crossing_ibfk_1 : Relationship	
From	switch_crossing
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table switch_crossing because LCC is calculated at the level of S&C

lcc_switch_crossing_ibfk_2 : Relationship	
From	components
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table components because the component is a dimension of LCC at S&C level

lcc_switch_crossing_ibfk_3 : Relationship	
From	lcc_cost_category
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table lcc_cost_category because the LCC cost category is a dimension of LCC at S&C level

lcc_switch_crossing_ibfk_4 : Relationship	
From	lcc_phases
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table lcc_phases because the LCC phase is a dimension of LCC at S&C level

Entity “failure_modes”

Columns Summary

Name	DataType	Constraints	Nullable	Description

Name	DataType	Constraints	Nullable	Description
modeID	int(11)	PK	No	Primary key or identifier of failure mode
mode	varchar(150)		No	Name of failure mode
description	varchar(255)		Yes	Description of failure mode

Relationships

failure_railway_line_ibfk_2 : Relationship	
To	failure_railway_line
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table failure_railway_line because the failure mode is a dimension of failure at railway level

failure_switch_crossing_ibfk_2 : Relationship	
To	failure_switch_crossing
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table failure_switch_crossing because the failure mode is a dimension of failure at S&C level

Entity "failure_railway_line"

Columns Summary

Name	DataType	Constraints	Nullable	Description
lineID	int(11)	PK/FK (railway_lines.lineID)	No	Composite Primary key for identifies of railway and a specific failure mode component and specific failure component in a specific year Foreign key which defines the railway
modeID	int(11)	PK/FK (failure_modes.modeID)	No	Composite Primary key for identifies of railway and a specific failure mode component and specific failure component in a specific year Foreign key which defines the type of Failure mode
componetID	int(11)	PK/FK (failure_components.componetID)	No	Composite Primary key for identifies of railway and a specific failure mode component and specific failure component in a specific year Foreign key which defines the type of Failure component
year	date	PK	No	Composite Primary key for identifies of railway and a specific failure mode component and specific failure component in a specific year
number	int(11)		No	Number of specific failure

Relationships

failure_railway_line_ibfk_3 : Relationship	
To	components
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table components because the component is a dimension of failure at railway level

failure_railway_line_ibfk_2 : Relationship	
To	failure_modes
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table failure_modes because the failure mode is a dimension of failure at railway level

failure_railway_line_ibfk_1 : Relationship	
To	railway_lines
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table railway_lines because failure occur at the level of railways

Entity “failure_switch_crossing”

Columns Summary

Name	DataType	Constraints	Nullable	Description
switchID	int(11)	PK/FK (switch_crossing.switchID)	No	Composite Primary key for identifies of S&C and a specific failure mode component and specific failure component in a specific year Foreign key which defines the S&C
modeID	int(11)	PK/FK (failure_modes.modeID)	No	Composite Primary key for identifies of S&C and a specific failure mode component and specific failure component in a specific year Foreign key which defines the type of Failure mode
componetID	int(11)	PK/FK (failure_components.componetID)	No	Composite Primary key for identifies of S&C and a specific failure mode component and specific failure component in a specific year Foreign key which defines the type of Failure component
year	date	PK	No	Composite Primary key for identifies of S&C and a specific failure mode component and specific failure component in a specific year
number	int(11)		No	Number of specific failure

Relationships

failure_switch_crossing_ibfk_3 : Relationship	
To	components
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table components because the component is a dimension of failure at S&C level

failure_switch_crossing_ibfk_2 : Relationship	
To	failure_modes
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table failure_modes because the failure mode is a dimension of failure at S&C level

failure_switch_crossing_ibfk_1 : Relationship	
To	switch_crossing
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table switch_crossing because failure occur at the level of S&C

Entity “type_trafic_volume”

Columns Summary

Name	DataType	Constraints	Nullable	Description
typeID	int(11)	PK	No	Primary key or identifier of type of traffic volume
type	varchar(150)		No	Name of type of traffic volume

Relationships

trafic_volume_ibfk_2 : Relationship	
To	trafic_volume
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	A specific traffic volume is part of a certain type of traffic volume

Entity “trafic_indicators”

Columns Summary

Name	DataType	Constraints	Nullable	Description
indicatorID	int(11)	PK	No	Primary key or identifier of traffic volume indicator
indicator	varchar(150)		No	Name of traffic volume indicator
UM	varchar(150)		No	Measurement unit of traffic volume indicator

Relationships

trafic_volume_ibfk_1 : Relationship	
To	trafic_volume
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	0..1
Description	A specific traffic volume is characterized by a certain indicator

Entity “trafic_volume”

Columns Summary

Name	DataType	Constraints	Nullable	Description
traficID	int(11)	PK	No	Primary key or identifier of traffic volume
lineID	int(11)	FK (railway_lines.lineID)	No	Foreign key which defines the specific railway
typeID	int(11)	FK (type_trafic_volume.typeID)	No	Foreign key which defines the specific type of traffic volume
indicatorID	int(11)	FK (trafic_indicators.indicatorID)	Yes	Foreign key which defines the specific indicator for traffic volume
trafic_value	decimal(10)		No	Value of indicator for traffic volume
year	date		No	Year to which it relates the measurement for traffic volume indicator

Relationships

trafic_volume_ibfk_2 : Relationship	
To	type_trafic_volume
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	A specific traffic volume is part of a certain type of traffic volume

trafic_volume_ibfk_3 : Relationship	
To	railway_lines
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Description	Ensure the relationship with table railway_lines because the traffic volume is measured for a specific railway

trafic_volume_ibfk_1 : Relationship	
To	trafic_indicators
On Delete	No action
On Update	No action

To Multiplicity	0..*
From Multiplicity	0..1
Description	A specific traffic volume is characterized by a certain indicator