Economic conditions and Safety

Final Report – February 2025

EUROPEAN
UNION
AGENCY
FOR RAILWAYS

Executive summary

The study explores the complex linkages between economic conditions, public finances, and railway safety within the EU. It aims to understand how macroeconomic factors influence railway operations and safety, particularly in the light of recent events such as the tragic Greek railway accident in February 2023.

The main outcome is the identification of key indicators beyond traditional specific railway safety measures which could be used to identify in advance potential railway safety deterioration in Member States.

The study employs both quantitative and qualitative analyses, including desk research, statistical analysis, and case studies. It identifies relevant indicators and data sources to explore potential linkages and predict future trends.

Key findings include:

- *Significant influence of GDP per capita on both rail safety and rail infrastructure spending per line kilometre; higher GDP per capita generally leads to better safety outcomes due to increased public spending on infrastructure and maintenance,*
- *Significant influence of public investment per capita on rail infrastructure per line kilometre,*
- *Significant influence of GDP per capita on safety outcomes,*
- *Close tracking of changes in number of infrastructure manager staff is highly relevant,*
- *Correlation analysis / regression analysis can provide useful insights on how macroeconomic conditions influence (e.g. accident rate vs. GDP per capita),*
- *Cluster analysis and related techniques allow for the synthesis of various influencing variables, highlighting commonalities and differences among Member States.*

Contents

1. Background, context and objectives

Economic conditions as well as public finances influence the overall context in which railways are operating. For instance, state subsidies for railways may diminish during periods of austerity, which in turn could cause infrastructure managers to reduce investments in infrastructure maintenance or delay renewals and upgrades.

These linkages are highly complex (especially considering the multimodal dimension of transport services), may not be transferable between countries and could be subject to substantial variation over time along with the presence of several other influencing factors. Despite these challenges it is important to understand how macro-economic conditions influence railway operations in a country, so that lessons can be drawn to improve the safety and resilience of the railway system. Levels of safety comes with an associated cost and balancing safety; performance and cost are one of the key challenges for the railway sector. At the same time, also targeted public investment in transport infrastructure should be considered being crucial for fostering economic growth and development and an efficient allocation and management of public funds towards these infrastructures might maximize their positive impact on economic growth and public welfare.

Following the tragic Greek accident in February 2023 as well as follow-up initiatives, notably the plans for a second round of Priority country programme, this study explores the possible linkages between economic conditions / public finances / national transport policy priorities and railway safety[1]. In particular, the study objectives include:

- *Examine how economic conditions and public finance are linked to: a) public investments; b) transport investments; c) railway (safety) investments; d) maintenance investments; e) staffing and resources for railway authorities; f) maturity of railway operators incl. safety culture and safety management;*
- *Assess the linkage between the context for railways (in terms of investment, resources, maturity and safety culture) and outcome measures for safety performance;*
- *Validate the linkage between economic conditions / national policy priorities and safety performance outcomes incl. accident and incident related indicators.*

In relation to the legal framework to support this work the following is relevant:

- *Article 13(2) of the Regulation (EU) 2016/796 states: "The Agency shall address recommendations to the Commission, at the request of the Commission or on its own initiative, on other measures in the field of safety, taking into account the experience gained.";*
- *Article 35(2) of the Regulation (EU) 2016/796 states: "The Agency shall monitor the overall safety performance of the Union rail system. The Agency may in particular seek the assistance of the bodies referred to in Article 38, including assistance in the form of the collection of data and access to the results of the peer review in accordance with Article 22(7) of Directive (EU) 2016/798. […].";*
- *Article 35(4) of the Regulation (EU) 2016/796 states: "The Agency shall monitor progress on the safety and interoperability of the Union rail system. Every 2 years it shall present to the Commission, and publish, a report on progress on safety and interoperability in the single European railway area."*

Based on the recalled legal framework, this study provides a preliminary outcome on the identification of key indicators which could be used to identify in advance potential critical situation concerning railway safety in Member States. This might be even more possible if one considers that within the Common Safety Targets

[1] Following the advice on railway safety in Poland (2013), the Agency received on 14 March 2014 a similar request from EC for an advice concerning railway safety in 6 EU Member States: Romania, Estonia, Croatia, Slovakia, Lithuania, and Latvia.

(CST) assessment, Greece never showed any 'possible deterioration' in any risk category largely due to the methodological issues highlighted in the recent ex-post evaluation of the legal framework[2].

2. Methodology and data

This exploratory study took a broad perspective in order to permit a wider understanding of the linkages between economic conditions and safety. As such, the study was undertaken in stages in the form of a scoping study. The scoping study may later on be used to develop a more in-depth (targeted) study.

Considering the complexity of the topic, the methodology for this exploratory assessment comprises both quantitative and qualitative analysis. Desk research was undertaken in order to review available studies on this topic. In addition, relevant indicators for the different elements to be examined were identified and data sources considered. Subsequently, quantitative exploratory analyses were undertaken to consider possible linkages from statistical perspectives. The quantitative analysis was complemented with case study analysis to explore in-depth any possible examples of linkages. Furthermore, it was assessed the extent to which the findings from the exploratory assessment can be used for prediction. It is also foreseen to outline possible areas of future analysis in this field.

The final report summarises the findings of the exploratory study. It is intended that results from the study will contribute to strengthen the monitoring and reporting of Member States' approach to railway safety (e.g. through the definition and development of indicators).

3. Preliminary considerations and literature review

From a traditional macroeconomic perspective public spending (incl. transport spending and investment) is mainly considered in terms of influencing aggregated demand and hence GDP through a demand-based multiplicator (short-medium term) or from a supply-side perspective by strengthening productive capacity and productivity. In this study, we consider a different direction re. public sector spending and investment as enabled through GDP / public sector revenue (taxation).

Overall, the available literature on this topic is relatively limited. Below, selected recent studies are briefly summarised:

- *Alotaibi et al. (2022) examines the impact of large-scale transport investment and the resulting increase of accessibility in GDP in Saudi Arabia. Results show that: i) the value of transport investment for the one-year lag shows positive and significant statistical relationships with regional GDP among; ii) railway accessibility value presents positive and significant impact on GDP in two years lag, requiring a larger period to deliver its benefits compared with (i).*
- *Wemakor et al. (2017) analyses publicly available data to suggest how rail safety considerations have impacted in a more general way upon railway performance and by extension, derive lessons for emerging and developing economies.*

[2] This is largely because in 2004-2009, based on which the references values were set, the FWSI (fatalities and weighted serious injuries) was very high and dropped since. Ex-post evaluation report: Report - Common Safety Method for Assessment of Achievement of Safety Targets.pdf (europa.eu). Although the RSD (Art. 4 (f)) requires Member States to develop and publish annual safety plans setting out the measures envisaged to achieve the CSTs, this finding seriously questions the actual CST-approach as a proper tool to pro-actively follow up safety performance and to trigger Member States to develop and implement ambitious safety (and related investment) plans.

- *Lenz et al. (2018) assesses the macroeconomic effects of transport infrastructure on economic growth with particular focus on the case of Central and Eastern E.U. member states. The aim of this paper is to estimate the effects of transport infrastructure (road and rail) on economic growth while controlling with other variables such as population growth, gross fixed capital formation and trade openness.*
- *Evans (2013) reviews the statistics and economics of railway safety. Over the last few decades, the railways in many countries have been privatised or deregulated with the aim of improving their economic performance. Such changes have the potential to affect safety. The paper reviews evidence of the effects on safety of railway restructuring in Great Britain, Japan and the United States.*
- *Lin et al. (2023) outlines an international benchmarking framework for railroad safety-related data system and safety performance. A novel and standardized methodology was developed to collect railroad safety-related data sources among different countries and compare their data completeness and resolution. Six countries with high data availability and transparency were selected to demonstrate the benchmarking framework. High-level rail safety performance measures were derived and compared among these countries. The results showed that there are inconsistencies in the resolution of different types of rail safety data among the six countries.*
- *Mizutani (2024) investigates the demand, managerial, and regulatory factors affecting rail investments of 29 OECD countries. Using a fixed effects model, factors positively affecting investment are output as train-km, capital stock as network length, GDP per capita, and the competitiveness of passenger railways; a larger government debt ratio tends to weakly decrease investment; accident rate has a weak positive relationship with investment, but as the government debt ratio increases, the accident rate's effect on investment decreases.*
- *Polyzos and Tsiotas (2020) review the main factors affecting, either directly or indirectly, the contribution and the determinants of the size and direction of the effects transport infrastructure contribute to the economic and regional development (e.g. characteristics related to infrastructure, geography, policy externalities and socioeconomics). Overall, the paper highlights the importance of transport infrastructure policy as a tool of regional and economic policy.*
- *Rodrigues et al. (2024) address the crucial question of the macroeconomic impact of investing in railroad infrastructure in Portugal. The aim of the paper is to shed light on the immediate and long-term effects of such investments on economic output, employment, and private investment, specifically focusing on interindustry variations.*
- *Sobieralski (2021) examines the impact of different transportation infrastructure investments (including railway) on employment in 11 metropolitan statistical areas (MSAs) in the US from 1990 to 2018. Using spatial econometric techniques, he finds that the employment effects of these investments vary widely across MSAs. Railway infrastructure investment has positive employment effects in MSAs with robust rail systems and high ridership.*
- *Sinha et al. (2021) examines the relationship between fatality risk (number of fatalities per 10,000 people), the level of motorization (number of vehicles per 10,000 people) and fatality rate (number of fatalities per 10,000 vehicles), and the real per capita GDP across Indian states and union territories.*
- *Watson et al. (2021) investigated the efficiency of railways in terms of accident risk at level crossings (LCs) in 24 countries of the EU. Data Envelopment Analysis (DEA) method has been applied to evaluate the efficiency of selected railways in terms of safety at LCs. The results show that GDP per capita and density of population in the selected countries have a strong influence on the efficiency of railways in terms of safety at LCs.*

In addition, the Federal Railroad Administration confirms that the industry's safety-centred approach to investments and operations has delivered overall improvements, making the last decade the safest ever for rail. Specifically, these strong, unrelenting efforts have driven the railway accident rate down by 27% since 2000 and 6% since 2022[3].

Australia is currently experiencing a major wave of public investment in the delivery of rail infrastructure. In the National Rail Action Plan prepared for the Transport and Infrastructure Council, the National Transport Commission of the Australian Government claims that this rapid increase in public investment creates both opportunities and challenges, in particular, if offers the opportunity to leverage the investment to improve operational effectiveness and safety[4].

Moreover, our preliminary work also indicates a possible lack of comparative data at an EU level. This refers less to data on economic / financial conditions but more on data linked to railway safety aspects apart from the already existing information through the EU-wide Common Safety Indicators (CSIs) on outcomes, precursors and technical safety measures. The timely adoption of the Common Safety Method for the Assessment of Safety Level and Performance (CSM ASLP) will facilitate further insights into railway safety and railway safety management. Therefore, it is also suggested that a possible follow-up from this exploratory study could consider pertinent case studies to facilitate further insights on the possible linkages along with other steps.

4. Data categories

A number of data categories have been used for exploring possible linkages between economic / financial related aspects and railway safety elements. In particular, the considered data can be grouped as follows:

- *Category 1: National accounts*
  - *GDP per capita*
  - *Labour productivity*
  - *General government gross fixed capital formation per capita*

- *Category 2: Government finance statistics*
  - *Government expenditure per capita*
  - *Public debt per capita*

- *Category 3: Transport / railway sector specific data:*
  - *Total inland transport investment per capita*
  - *Rail investment per capita*
  - *Rail infrastructure maintenance per capita*
  - *Rail investment per line kilometre*

[3] Details are available at: Freight Rail Safety - AAR; and Freight Rail Safety Record - AAR (access: 30/07/2024).
[4] Details are available at: National-Rail-Action-Plan.pdf (ntc.gov.au) (access: 30/07/2024).

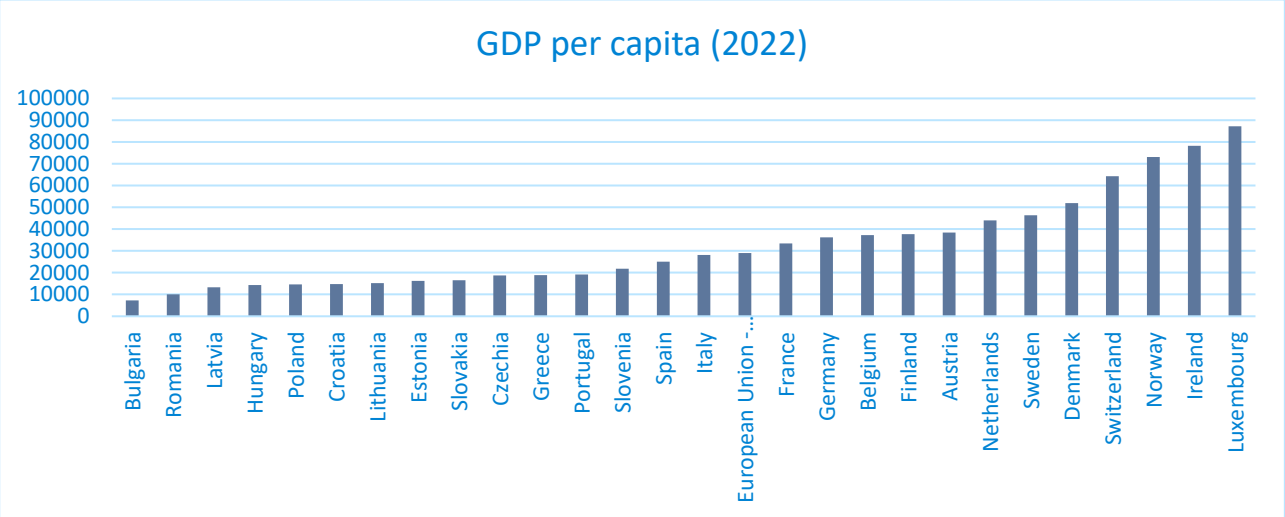
- *Category 4: Railway technical safety measures:*
  - *Passive level crossings per line kilometres*
  - *Proportion of active level crossings*
  - *Percentage of tracks with ATP in operation*
  - *Percentage of train kilometres using operational ATP systems*

While the current analysis is focused on the most up-to-date (generally 2022) value of the indicators, a more refined evaluation could consider a longer time horizons (e.g. 5 year values).

Category 1: National accounts-based information

a. GDP per capita

Figure 1. Gross Domestic Product (GDP) per capita



Source: Eurostat

Remarks on Figure 1:

- *Measure is based on GDP figures for the EU-27 Member States + Norway and Switzerland expressed in Euros in real terms (2010) relative to overall population;*
- *Chart shows GDP per capita for 2022;*
- *Overall, the chart indicates an average GDP per capita for the EU-27 countries of around 29 k EUR with the highest recorded in Luxembourg (approx. 87 k EUR) and the lowest in Bulgaria (7 k EUR);*
- *As such there remains a substantial variation in GDP per capita among the EU-27 countries, despite decades of catching-up especially among the Eastern European countries (e.g. Romania and Bulgaria);*
- *A time-series perspective could provide further insight into the ongoing catching-up trends (e.g. Romania having had for the past years the highest GDP growth within the EU).*

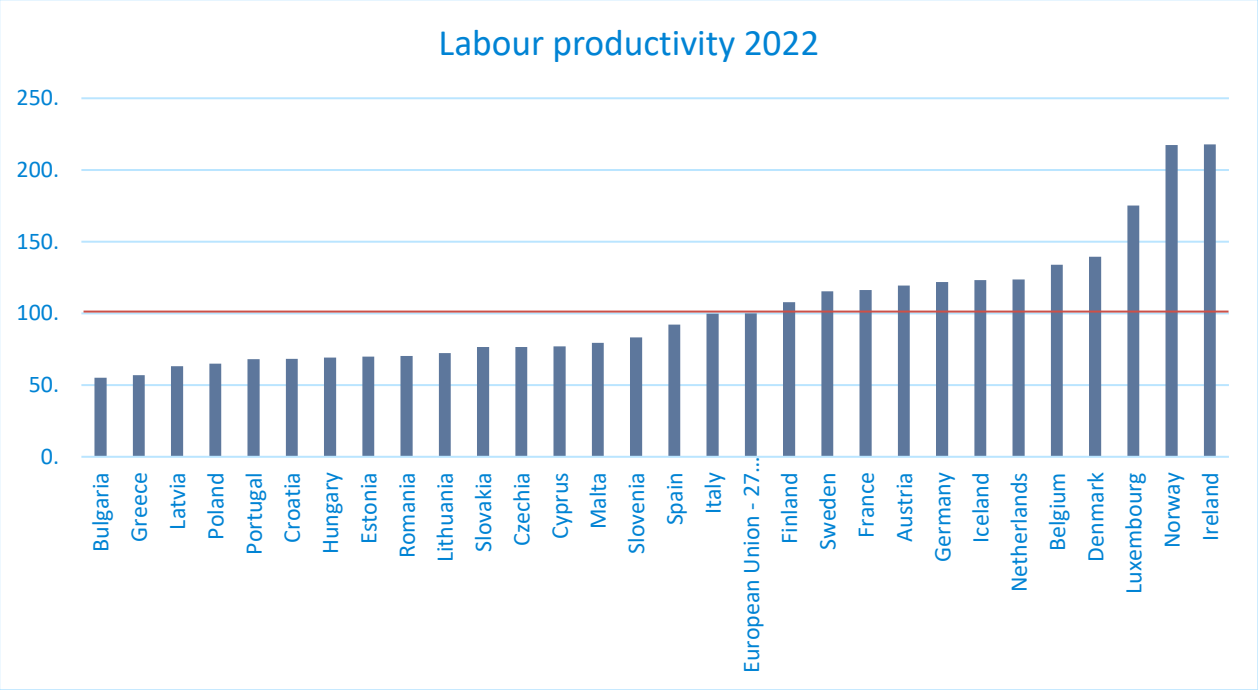
Possible linkages:

- *It is likely that a high GDP per capita would facilitate larger public budgets (all else equal) which in turn would permit higher public spending;*

- *Available indications suggest that there is relative high correlation between GDP per capita and public spending per capita;*
- *However, as public spending is influenced by overall policies in the different countries, the linkage is subject to variation (e.g. due to different views on the size of the public sector);*
- *Moreover, there is also a correlation between GDP per capita and railway accident rates;*
- *This correlation is particularly strong if the focus is not on the absolute values for these 2 indicators but rather on their relative order;*
- *As such, a low GDP per capita and / or declining GDP growth rate could be an initial warning sign that railway safety could be compromised;*
- *However, other factors would also be importance and may in fact mitigate the apparent risks associated with worsening economic conditions, e.g. past investment in safety measures or a well-developed safety culture.*

b. Labour productivity

Figure 2. Labour productivity per hour worked



Source: Eurostat

Remarks on Figure 2:

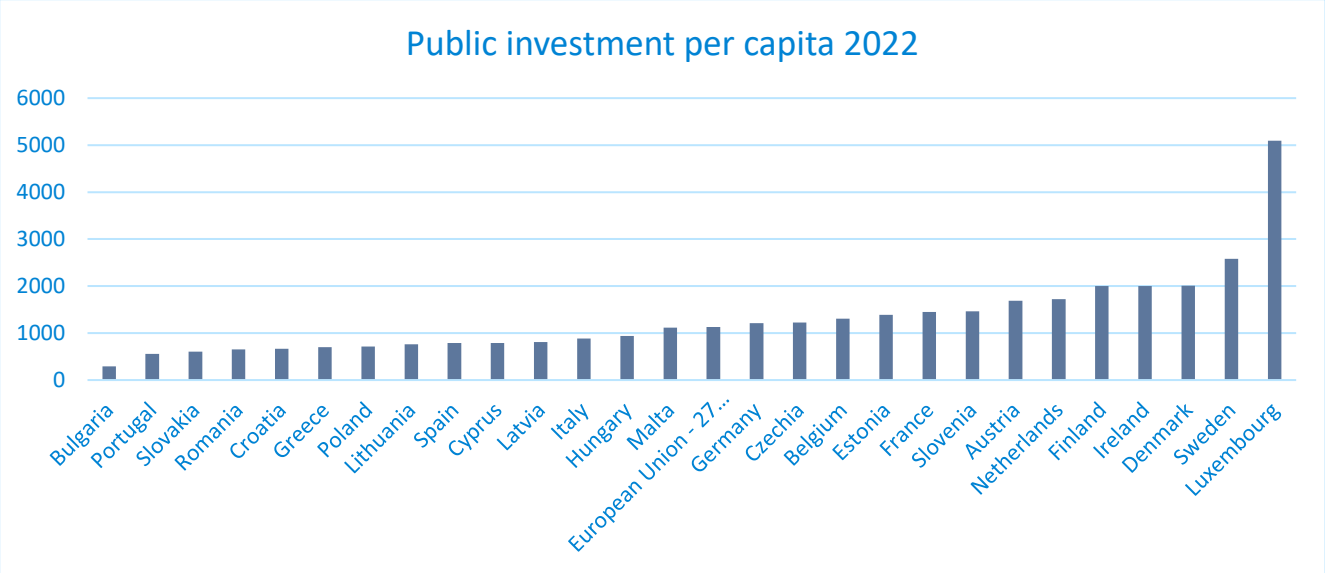
- *Figure 2 shows nominal labour productivity per hour worked (measured by the total number of hours worked) for the EU-27 countries + Norway;*
- *It is presented as an index with EU-27=100 with values for the different EU countries above or below that average. If the index of a country is higher than 100, this country's level of labour productivity is higher than the EU average and vice versa;*
- *Similar to Figure 1 there is also a strong variation across the EU-countries in terms of labour productivity with the highest value of the index being in Ireland (217) and the lowest in Bulgaria (55).*

Possible linkages:

- *Similar arguments are relevant as for Figure 1 with higher hourly productivity resulting in overall higher economic prosperity (GDP per capita) that would act as a facilitator for higher tax revenues that can support a higher public spending;*
- *Overall, it should be added that higher level of productivity is not only a facilitator of public spending but also private spending with the mix being the result of structural factors and political attitudes.*

c. Public investment per capita

Figure 3. General government gross fixed capital formation per capita



Source: Eurostat

Remarks on Figure 3:

- *The indicator measures the total additions to the stocks of fixed assets (purchases and own-account capital formation), less any sales of second-hand and scrapped fixed assets, by local, state or central government relative to the population size;*
- *General government gross fixed capital formation is also referred to as public / government investment;*
- *2022 values for this indicator are shown in Figure 3 for all EU countries as well as the EU-27 average;*
- *Overall, the Figure shows a significant variation in public investment per capita per annum, with an EU average of 1129 EUR, lowest value 289 EUR (Bulgaria) and highest value 5093 EUR (Luxembourg).*

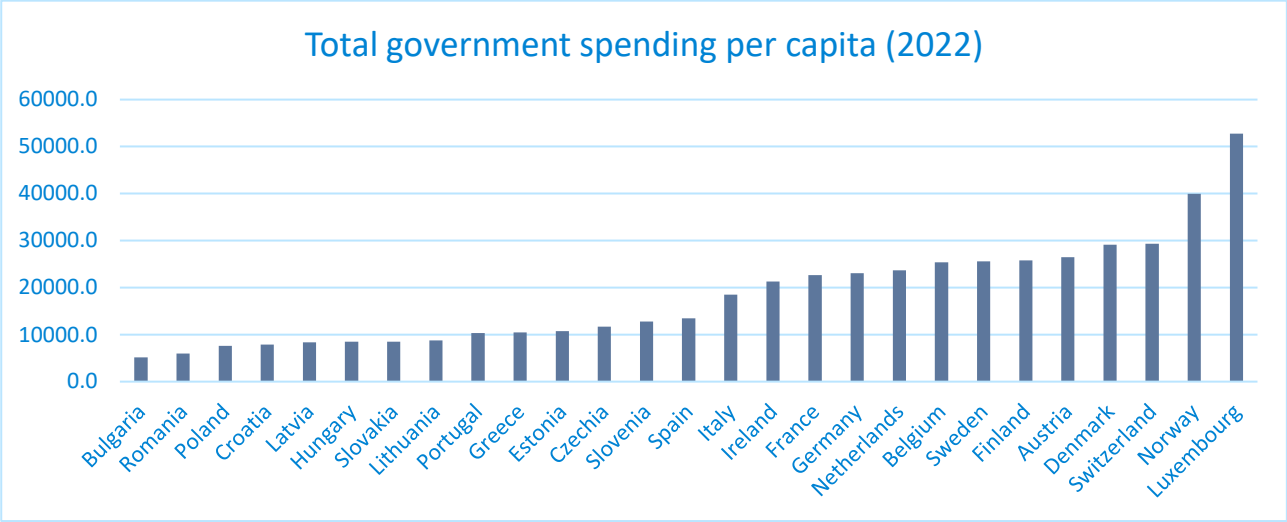
Possible linkages:

- *The total public investment budget available per country would be one of the factors influencing the available capital budget for the transport sector / railway sector;*
- *Among the countries included in the original Priority Country Programme all had below average level of public sector investment per capita with the exception of Estonia;*
- *This indicator may be utilised as an early warning signs re. railway safety. If overall public investment (per capita) is low or declining, there may be a risk of insufficient railway investment which in turn may have adverse impacts on railway safety.*

Category 2: Government finance statistics

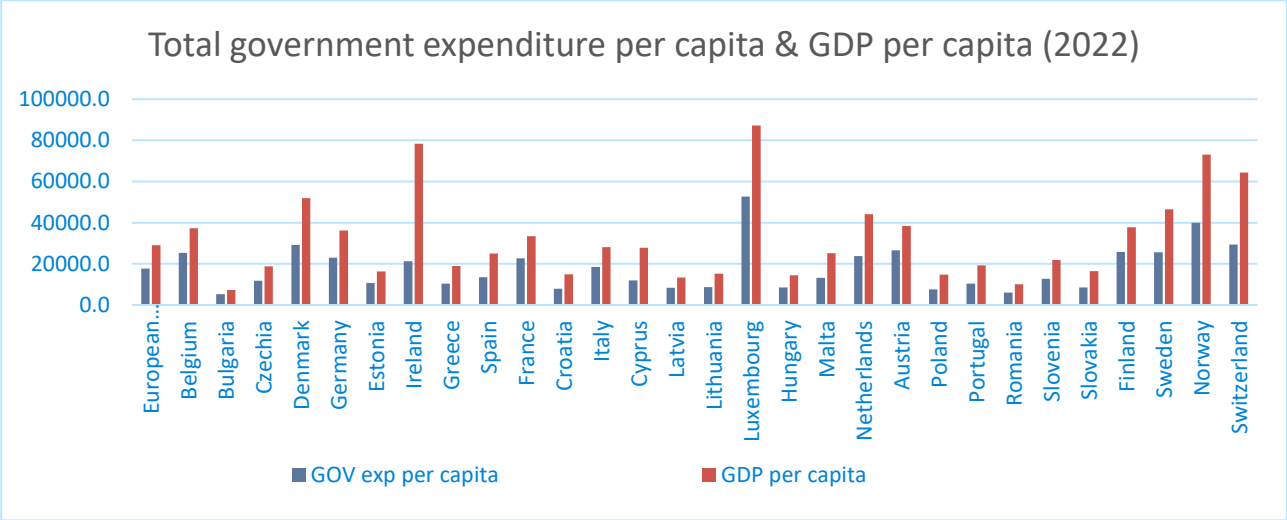
d. Public spending per capita

Figure 4. Total government spending per capita



Source: Eurostat

Figure 5. Government spending and GDP per capita



Source: Eurostat

Remarks on Figures 4 and 5:

- *Total government spending per capita in Euros is shown in Figure 4 for 2022 for all EU-27 + Norway and Switzerland;*
- *In Figure 5 this indicator is shown together with GDP per capita for each of the countries covered;*
- *A main finding from Figure 4 is the substantial variation in total government spending per capita. Figure 5 illustrates the relative strong correlation between total government spending per capita and GDP per capita.*

Possible linkages:

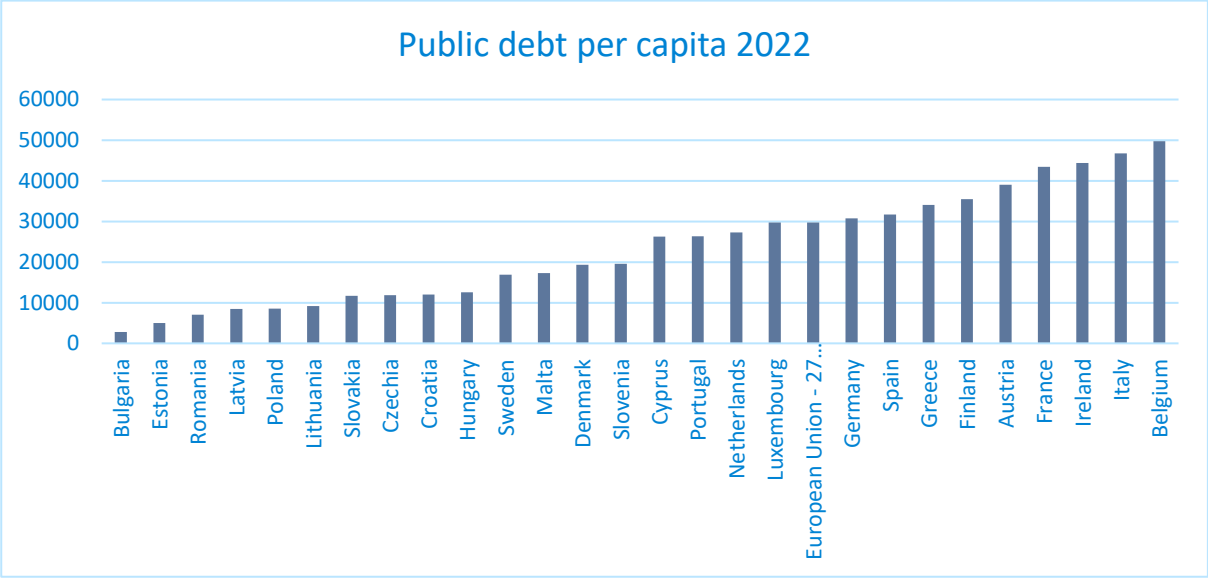
- *Total government spending could be a relevant factor determining available government spending for the transport sector / railway sector (e.g. in the form of payments for public service obligation – PSO – services along with other spending channels);*
- *As such, this could be a relevant macro indicator to monitor in order to mitigate adverse impacts on railway safety.*

One possible follow-up analysis would look further into the linkages between government spending and GDP per capita, e.g. by comparing the following four cases:

- *Countries with relative low government expenditure and relative low GDP per capita;*
- *Countries with relative low government expenditure and relative high GDP per capita;*
- *Countries with relative high government expenditure and relative low GDP per capita;*
- *Countries with relative high government expenditure and relative high GDP per capita.*

a. Public debt per capita

Figure 6. Public debt per capita



Source: Eurostat

Remarks on Figure 6:

- *The indicator shows public debt per capita for the EU-27 countries in 2022;*
- *Overall, the indicator indicates significant variation among the EU countries.*

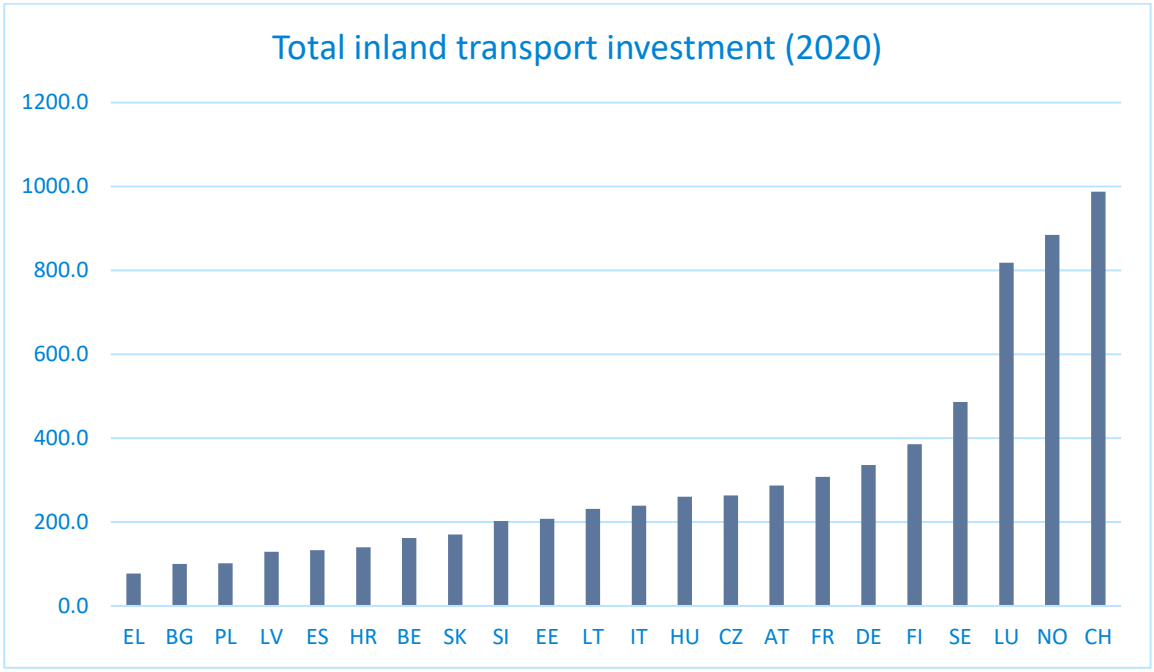
Possible linkages:

- *The main hypothesis would be that high public debt level may reduce the possibility for a national government to provide additional budget if needed. In turn, this could have a potential adverse influence on railway safety related aspects.*
- *On the basis of the available information this indicator could be complicated to use as part of an indicator system. As such, all priority country programme participants have some of the lowest levels of public debt per capita.*

Category 3: Transport / railway sector specific data

b. Transport investment per capita

Figure 7. Inland transport investment per capita



Source: ITF-OECD

Remarks on Figure 7:

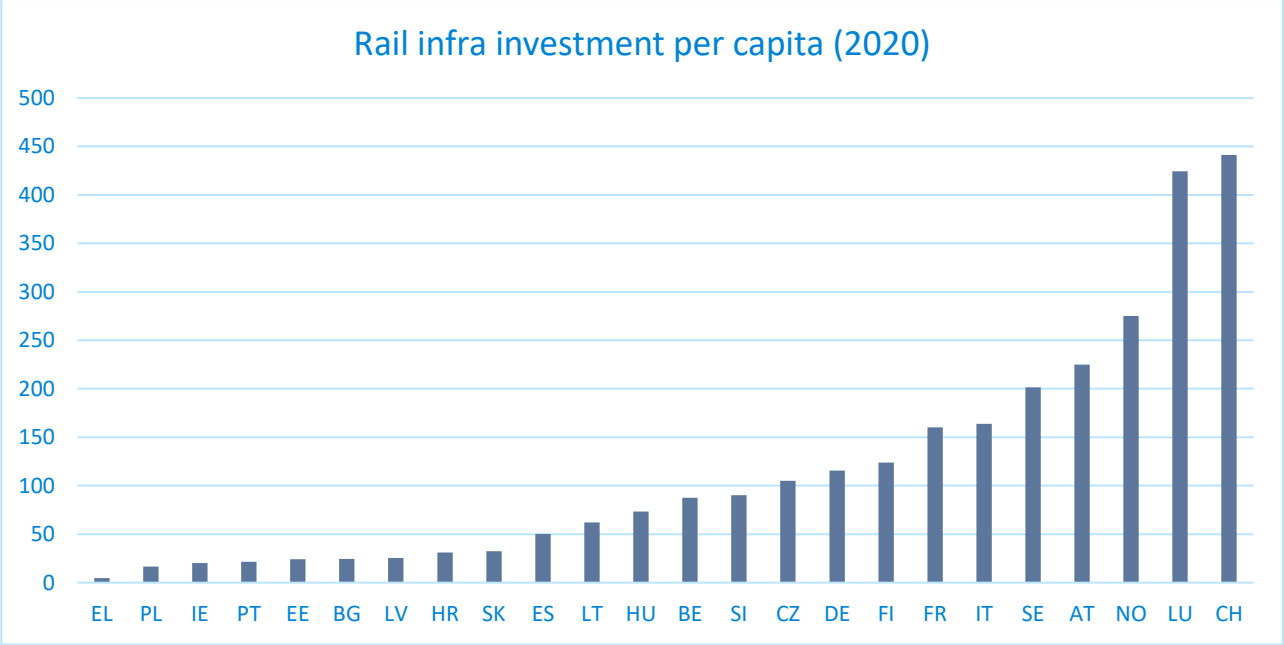
- *The indicator shows the total inland transport investment per capita for EU Countries + Norway and Switzerland for the year 2020;*
- *Inland transport investment covers road, rail and inland waterways. It should be noted that not all EU countries had provided data;*
- *As the case for other indicators in this study, there is a significant variation in the level of total inland transport investment per capita. There is a factor 13 difference between lowest and highest values;*
- *This variation is largely following patterns for indicators examined earlier (e.g. GDP per capita). In particular, it is noted that the Eastern European countries have relative low levels (incl. among the Priority Country Programme).*

Possible linkages:

- *The transport investment budget level could have an important influence on railway safety related aspects: A high level of transport investment per capita could support the modernisation of the assets in the transport sector incl. railways;*
- *It would be a very relevant indicator to monitor together with the ones in Figure 8 and 9.*

c. *Railway investment per capita*

Figure 8. Railway investment per capita



Source: ITF-OECD

Remarks on Figure 8:

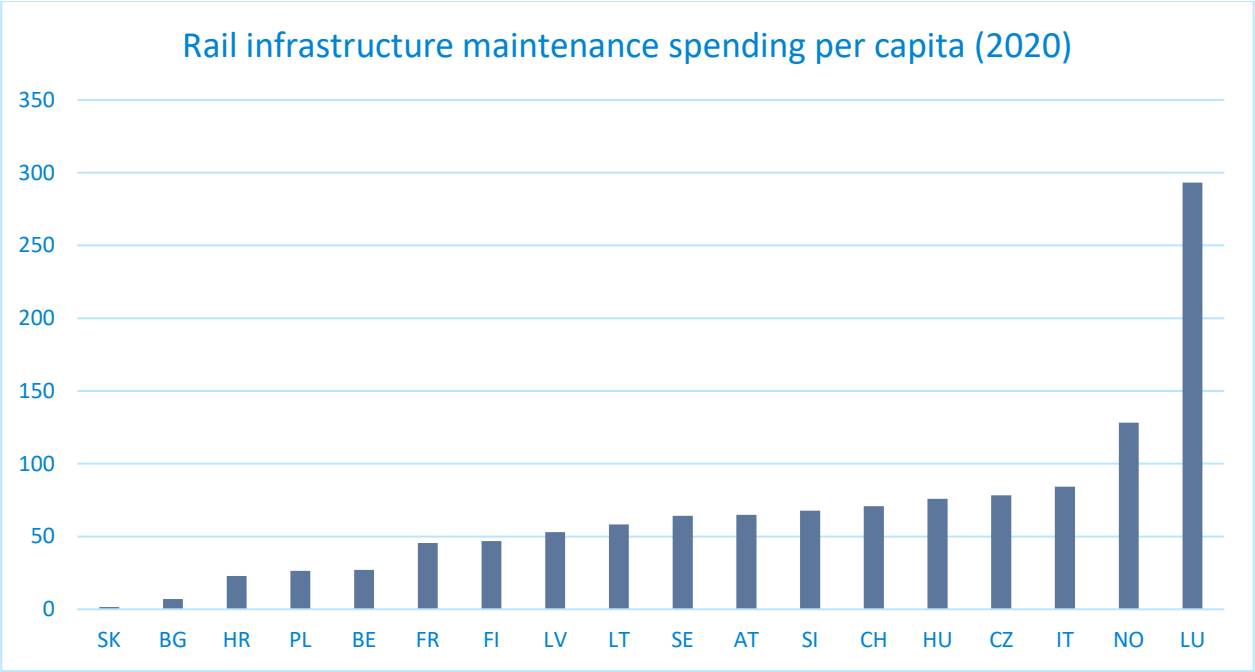
- *The indicator shows the total railway investment per capita for EU Countries + Norway and Switzerland for the year 2020;*
- *It should be noted that not all EU countries had provided data;*
- *As the case for other indicators in this study, there is a significant variation in the level of railway investment per capita. There is a factor 93 difference between lowest and highest values, which is substantial larger than for inland transport investment per capita (see Figure 7);*
- *This variation is largely following patterns for indicators examined earlier (e.g. GDP per capita). In particular, it is noted that the Eastern European countries have relative low levels (incl. among the Priority Country Programme).*

Possible linkages:

- *The railway investment budget level could have an important influence on railway safety related aspects: a high level of railway investment per capita could support the modernisation of the assets in railways;*
- *It would be a very relevant indicator to monitor together with the ones in Figure 7 and 9.*

d. Railway infrastructure spending per capita and line-km

Figure 9: Railway infrastructure maintenance per capita



Source: ITF-OECD

Remarks on Figure 9:

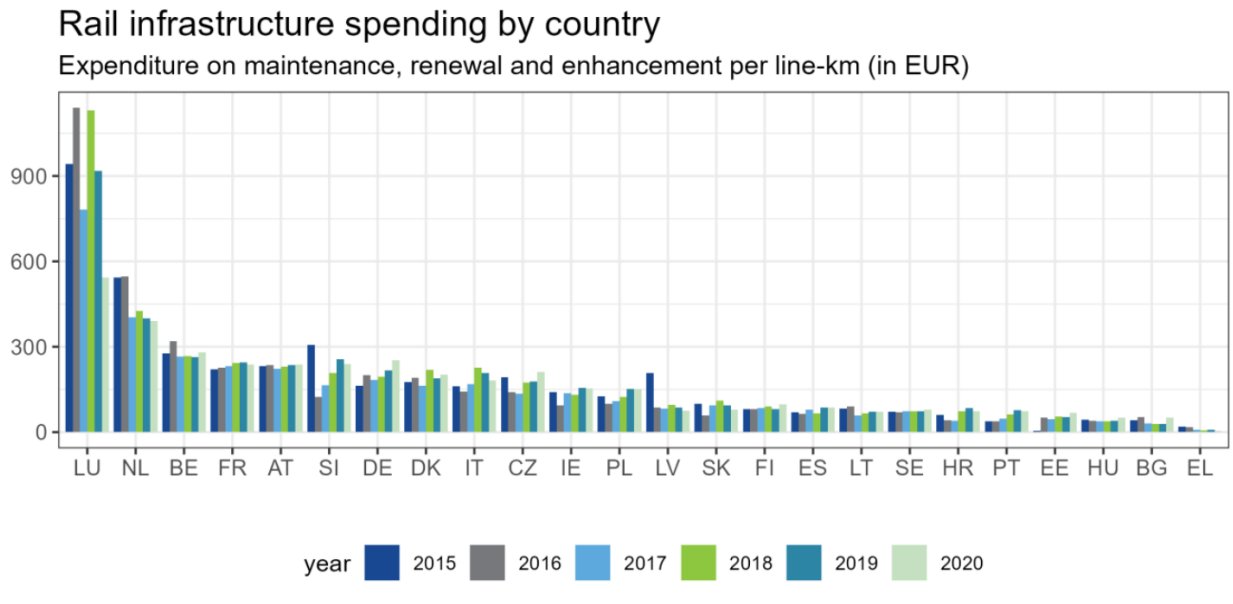
- *The indicator shows the railway infrastructure maintenance per capita for EU Countries + Norway for the year 2020;*
- *It should be noted that not all EU countries had provided data (and fewer compared to the indicators shown in Figures 7 and 8);*
- *As the case for other indicators in this study, there is a significant variation in the level of railway investment per capita. There is a factor 182 difference between lowest and highest values, which is much higher than for inland transport investment and railway investment;*
- *This variation is largely following patterns for indicators examined earlier (e.g. GDP per capita). In particular, it is noted that the Eastern European countries have relative low levels (incl. among the Priority Country Programme).*

Possible linkages:

- *The railway infrastructure maintenance budget level could have a particular important influence on railway safety related aspects: A high level for this indicator could ensure sufficient funding support towards maintenance of the network and reduce the incidence of any backlog;*
- *It would be a very relevant indicator to monitor together with the ones in Figure 7 and 8.*

Additional insights regarding how countries compare over time for rail expenditure (spending) on maintenance, renewal and enhancements per line-km, see Figure 10.

Figure 10. Rail infrastructure spending by country per line-km (2015-2020)



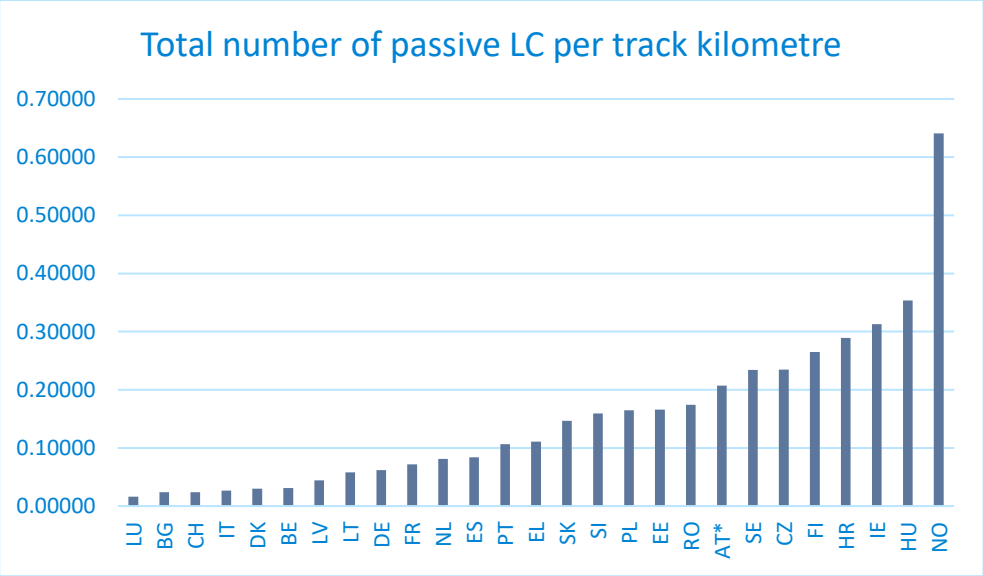
Source: RMMS (2023)

As can be derived from Figure 10, in 2020 the top 5 countries invest about seven times more per line kilometre than the bottom 5 countries. This is in part explained by the relative cost of services and materials, but also by the extent to which a high performing network is prioritised by the Member States. It should be noted that Figure 10 does not show how underinvestment accumulates over time. In some countries (e.g. Germany) this has led to large compensatory efforts that cause long-term closures with a profound disruptive effect on rail transport.

Category 4: Railway technical safety measures

e. Passive level crossings per track klm

Figure 11. Passive level-crossings per track kilometre



Source: CSI

Remarks on Figure 11:

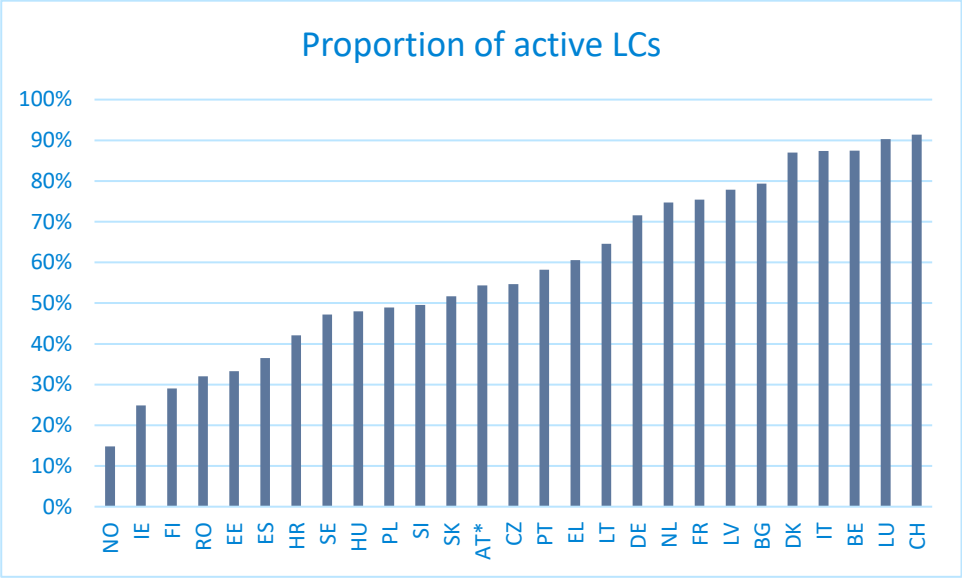
- *Total number of passive LCs per track kilometres show significant variation among the EU-countries + Norway and Switzerland;*
- *Data for this indicator is based on the Common Safety Indicators for 2022.*

Possible linkages:

- *Considering the prominence of LC accidents, it could be expected that this indicator would be of importance on the assumption that a high value could increase the risk of a LC accident;*
- *However, the Figure indicates that other aspects may be of relevance as indicated by the high value for Norway.*

a. Proportion of active level crossings

Figure 12: Proportion of active level crossings



Source: CSI

Remarks on Figure 12:

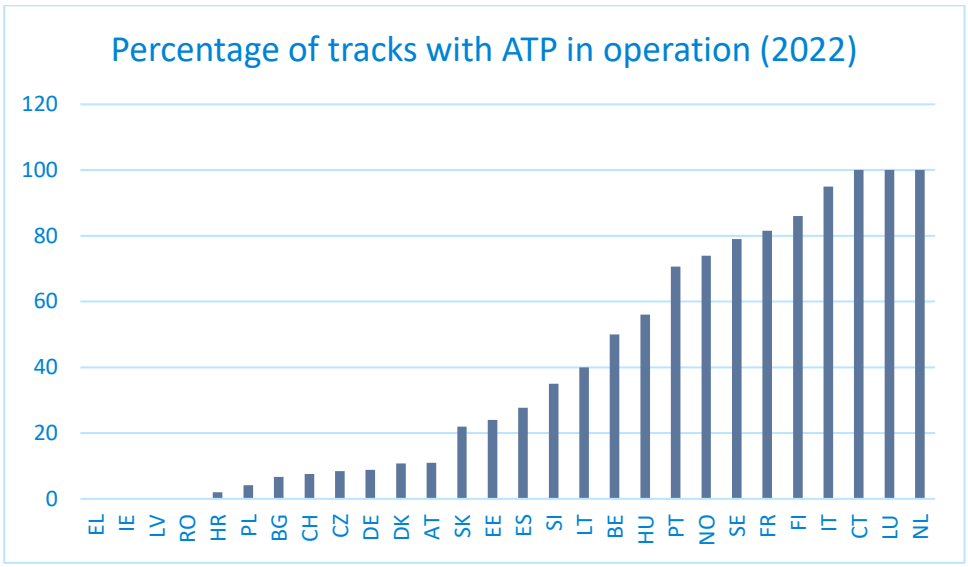
- *Proportion of active LCs out of the total number of LCs show significant variation among the EU-countries + Norway and Switzerland;*
- *Data for this indicator is based on the Common Safety Indicators for 2022.*

Possible linkages:

- *Considering the prominence of LC accidents, it could be expected that this indicator would be of importance on the assumption that a high value could lower the risk of a LC accident;*
- *However, the Figure indicates that other aspects may be of relevance as indicated by the low value for Norway and Ireland.*

b. ATP protection

Figure 13. Percentage of tracks with ATP in operation



Source: CSI

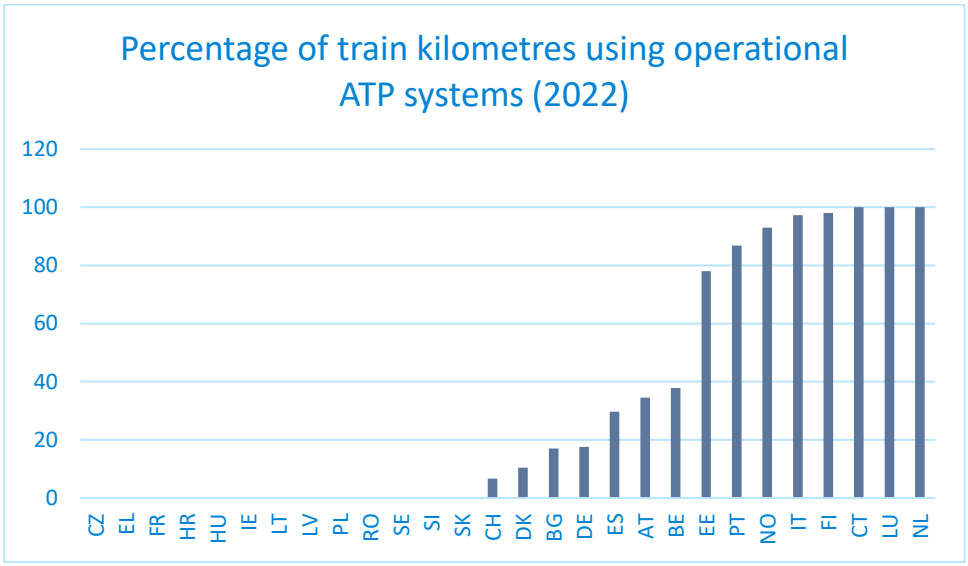
Remarks on Figure 13:

- *This indicator shows significant variation among the EU-countries + Norway and Switzerland*
- *Data for this indicator is based on the Common Safety Indicators for 2022.*

Possible linkages:

- *Considering the importance of train protection, it could be expected that this indicator would be of importance on the assumption that a high value could lower the risk of railway accident;*
- *The indicator provides a mixed impression as many countries with relatively poor railway safety performance have zero values for the indicator, although this is also the case for countries with low accident risks (e.g. IE).*

Figure 14. % of train kilometres using operational ATP systems



Source: CSI

Remarks on Figure 14:

- *This indicator shows significant variation among the EU-countries + Norway and Switzerland;*
- *Data for this indicator is based on the Common Safety Indicators for 2022.*

Possible linkages:

- *Considering the importance of train protection, it could be expected that this indicator would be of importance on the assumption that a high value could lower the risk of railway accident;*
- *The indicator provides a somewhat clearer impression compared to Figure 12 as many countries with relatively poor railway safety performance have zero values for the indicator.*

5. Extended literature review

5.1 Relationship between public finance and public investment in the transport sector

The literature shows that public investment in transport infrastructure is strongly linked to economic growth and development. Efficient allocation and management of public funds are crucial for maximizing the positive impacts of these investments.

Selected papers:

- *Aschauer (1989) investigates the productivity of different types of public expenditure, with a particular focus on infrastructure investment. The study finds that public investment in transport infrastructure significantly enhances economic productivity and growth. The findings suggest that investment in roads, bridges, and highways can have substantial economic returns.*
- *Calderón and Servén (2004) explore the impact of infrastructure development on economic growth and income distribution in developing countries. They find that investments in transport infrastructure (e.g. roads and railways), lead to significant improvements in economic growth and reductions in income inequality.*
- *Easterly and Rebelo (1993) empirically examining the relationship between fiscal policy and economic growth, find that public investment in infrastructure, particularly in the transport sector, is associated with higher economic growth. However, the effectiveness of these investments depends both on the overall fiscal policy framework and the efficiency of public spending.*
- *Canning and Bennathan (2000) estimate the social rate of return on various types of infrastructure investments, including transport. Authors find that investments in transport infrastructure (e.g. roads and railways) have high social returns and are crucial for economic development.*

5.2 Relationship between transport investment and GDP per capita

The literature review shows a positive relationship between transport infrastructure investment and GDP per capita. The effectiveness of these investments is often enhanced when combined with strong institutional frameworks and efficient public finance management.

Selected papers:

- *Canning and Pedroni (2004) examine the impact of various types of infrastructure, including transport, on long-run economic growth using a panel of countries. Authors find a strong positive relationship between transport infrastructure investment and GDP per capita, significantly boosts long-term economic growth and increases GDP per capita.*
- *Calderón and Servén (2010) focus on the role of infrastructure in economic development in Sub-Saharan Africa, finding that improvements in transport infrastructure significantly enhance GDP per capita by facilitating trade and reducing costs.*
- *Esfahani and Ramírez (2003) explore the role of institutions and infrastructure in economic growth. The paper shows that transport infrastructure investments are strongly correlated with higher GDP per capita which led to significant increases in GDP per capita, especially in countries with strong institutional frameworks.*
- *Straub (2011) analyses the impact of infrastructure investment on economic growth in Asia, with a particular focus on transport infrastructure. The study finds a strong positive correlation between transport infrastructure investment and GDP per capita growth.*

5.3 Relationship between rail transport investment and accident rate

The literature review on the relationship between rail transport investment and accident rates is aimed to verify if and how investments in rail infrastructure, safety systems, and technology can reduce the incidence of rail accidents and improve safety. The selected literature seems to show that public and private investments in rail transport infrastructure contribute to reducing accident rates. Investments in modernizing rail tracks, implementing advanced signalling and safety systems are crucial for enhancing rail safety. Moreover, they also seem to demonstrate the importance to continuous and substantial investment in rail infrastructure to achieve long-term safety improvements.

Selected papers:

- *Mizutani (2024) investigates the factors affecting rail investment with panel data analysis of 29 OECD countries. The author finds that as the government debt ratio increases, the accident rate's effect on investment decreases.*
- *Anderson and Barkan (2004) focus on the relationship between rail investment and accident rates, particularly in the context of transportation risk analysis. The paper mentions that increased investment in rail infrastructure leads to lower accident rates.*

5.4 Relationship between rail transport investment and the employment level of IMs

The literature review explores how investments in transport infrastructure influence job creation and employment stability for those managing these infrastructure projects. The literature shows that investments in rail transport infrastructure have a positive impact on employment levels. These investments create new managerial positions to handle the complexity and scale of rail projects, ensuring effective planning, execution, and maintenance.

Selected papers:

- *Wang and Zhang (2007) analyse the spatial spillover effect of transportation infrastructure on employment in the service industry with a panel data of 31 provinces in China in the past 2003-2017 year. The results on spatial spillover[5] of transportation infrastructure indicate that railway has an obvious promotion effect on the employment level of the service industry in the surrounding area(s), while the highway in contrast has hindered this effect.*
- *Rosik and Wójcik (2023) provide an overview of methods used to research the relationship between transport infrastructure investments and regional development, including employment impacts. They found that transport infrastructure investments have both demand-side and supply-side impacts on*

[5] Spillover effects refer to the impact that an action or policy in one area can have on other areas. In the context of this study, the spillover effects of transportation infrastructure on employment in the service sector indicate how improvements in transportation infrastructure in one region can influence employment levels not only within that region but also in neighbouring regions. For example, the construction of new railways may enhance connectivity and accessibility, leading to increased employment opportunities in the service sector both locally and in surrounding areas. Railways, in particular, can have significant positive spillover effects due to their ability to facilitate the efficient movement of people and goods over long distances, thereby promoting economic activities and job creation in the service industry across multiple regions. Conversely, certain types of infrastructure, like highways, may have different or even negative spillover effects on neighbouring regions.

the labour market, with the former being short-term and the latter more medium- and long-term in nature.

5.5 Relationship between rail accident rate and GDP per capita

The literature review on how economic development, as measured by GDP per capita, influences rail safety and accident rates shows that higher GDP per capita is associated with lower rail accident rates, primarily driven by the increased financial capacity of wealthier economies to invest in rail safety infrastructure, technologies, and maintenance. Economic growth thus plays a crucial role in enhancing rail safety and reducing the frequency of rail accidents.

Selected paper:

- *Evans (2013) analyses railway safety in developed countries, specifically Great Britain, the EU and the USA, and also including some results for Finland and Japan. In these countries railway safety has improved over the last two or three decades for both train accidents and to personal accidents and finds no evidence that safety deteriorated with railway restructuring. The author mentions the importance of the link between safety and economic performances.*

5.6 Relationship between railway infrastructure maintenance and economic development

The literature review examines the relationship between railway infrastructure maintenance and economic development and highlights the important role of railway infrastructure maintenance in promoting economic development. Effective maintenance enhances the reliability, efficiency, and safety of transport systems, which are essential for facilitating economic activities and growth. Neglecting maintenance can lead to increased costs and diminished economic returns, highlighting the importance of sustained investment in infrastructure upkeep.

Selected papers:

- *Savchenko (2022) analyses the existing European approach to assessing transport infrastructure expenditures and costs (especially operating and maintenance) and their impact on transport performance at the country level. The paper highlights the experience of developed countries in showing a positive relationship between investments in maintenance and construction of transport infrastructure and economic indicators.*
- *Pereira and Andraz (2013) highlight international evidence on the economic effects of public infrastructure investment, which include the importance of maintenance. This paper shows the need for ongoing maintenance to maximize economic returns from infrastructure investments, highlighting that countries with robust maintenance programs tend to have better economic outcomes.*

5.7 Relationship between railway infrastructure maintenance and safety performance

Aimed to explore the relationship between railway infrastructure maintenance and safety performance, the literature review shows that regular and adequately funded maintenance activities and the use of decision support models may be relevant for enhancing safety performance. These findings underscore

the importance of prioritizing maintenance in railway infrastructure management to achieve safer and more reliable railway systems.

Selected papers:

- *Patra (2009) integrates Reliability, Availability, Maintainability, and Safety (RAMS) analysis with Life Cycle Cost (LCC) analysis to support maintenance decisions in railway infrastructure, finding that maintenance strategies, informed by RAMS and LCC analyses, enhance safety performance and reduce the overall life cycle costs of rail transport infrastructure.*
- *Stenström (2012) studies several performance indicators for railway infrastructure maintenance and their impact on safety performance, showing that developing targeted improvement programmes based on these KPIs can significantly enhance safety outcomes.*

6. Quantitative analyses of patterns and linkages

6.1 Correlation analysis of EU Member States

Aim:
To investigate the linkages beyond the main indicators with a statistical analysis of European data.

Data and methodology:
Using main indicators of each data categories, Pearson correlation analyses of EU Member States' (MSs) data were performed. The correlation coefficient indicates the extent to which the pairs of numbers for these two variables lie on a straight line. Eurostat and CSI data were used in the analyses. Unit of measurements of data are those described in the previous section.

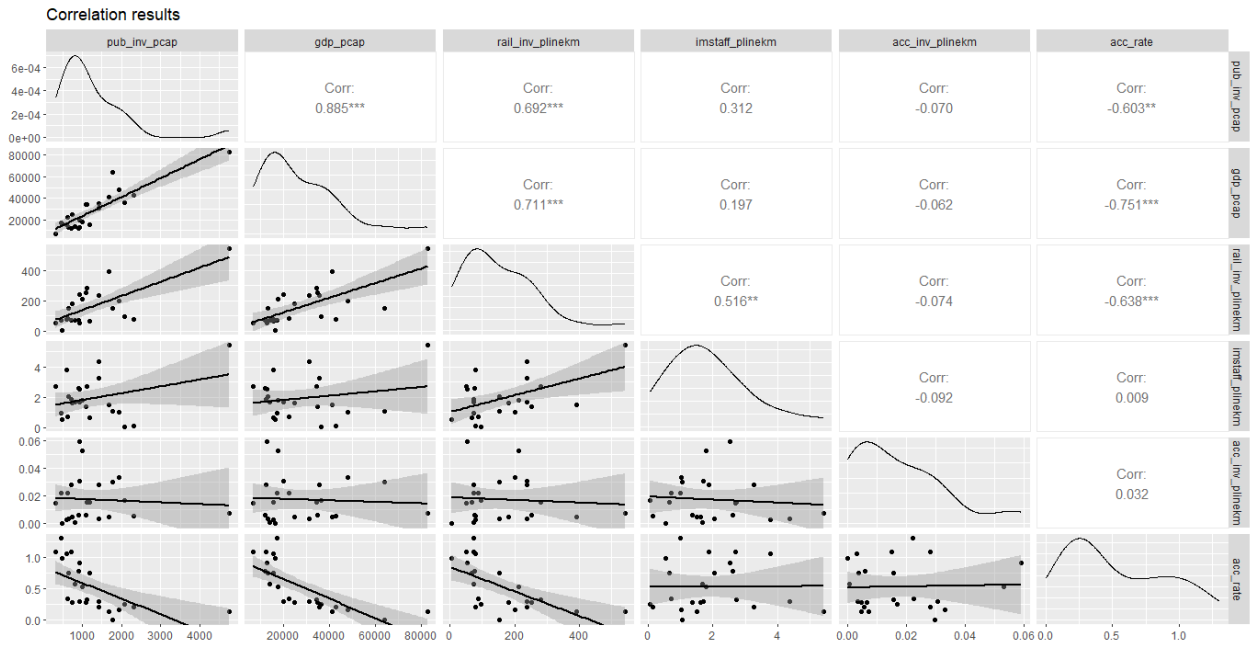
Results:
An overview of the results of the correlation analyses are provided in Figure 15, while a synthesis of the statistically significant results is reported in the following table; moreover, each linkage between two indicators is described below complemented by a dedicated graph.

Table 1. Summary of the main linkages between indicators

Indicator 1		Indicator 2	Corr sign	Corr value
Public investment	-->	Rail investment	+	0.692
		GDP per capita	+	0.885
		Accident rate	-	0.603
Rail investment	-->	Public investment	+	0.692
		Infra Manager Staff	+	0.516
		GDP per capita	+	0.751
		Accident rate	-	0.638
Accident rate	-->	Public investment	-	0.603
		Rail investment	-	0.638
		GDP per capita	-	0.751

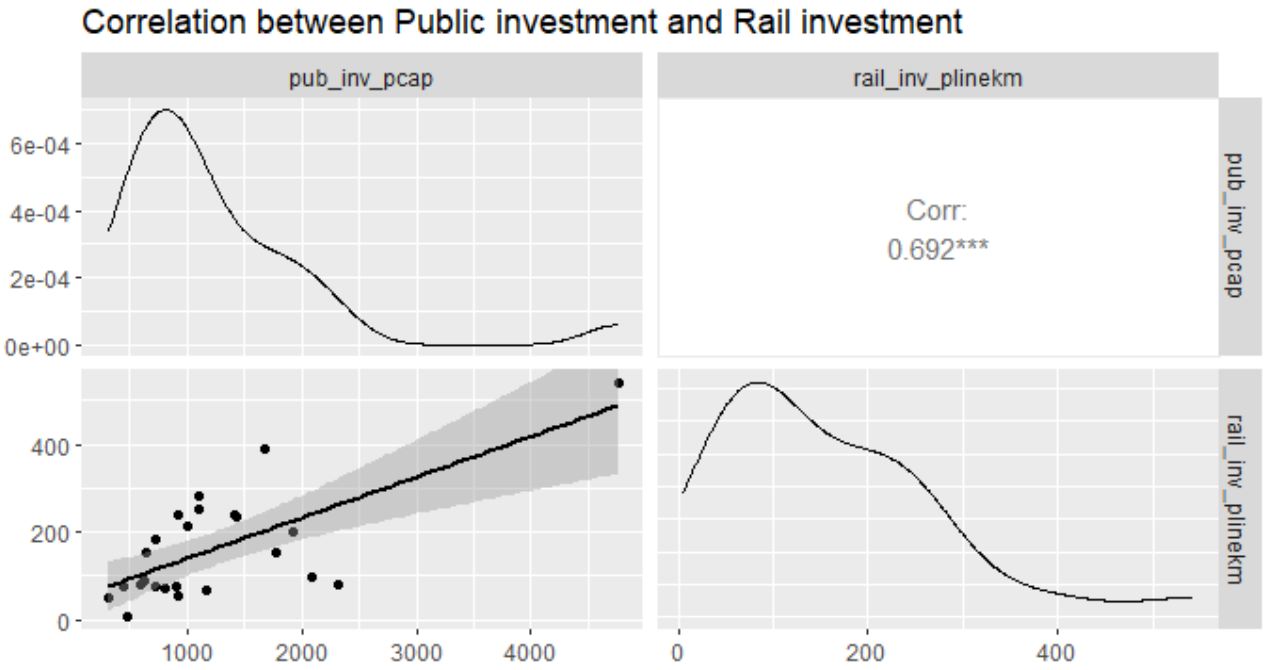
Note: corr - only statistical significant linkages are reported.

Figure 15. Overview of the correlation results of the selected indicators



The first linkage investigated is shown in the following figure.

Figure 16.

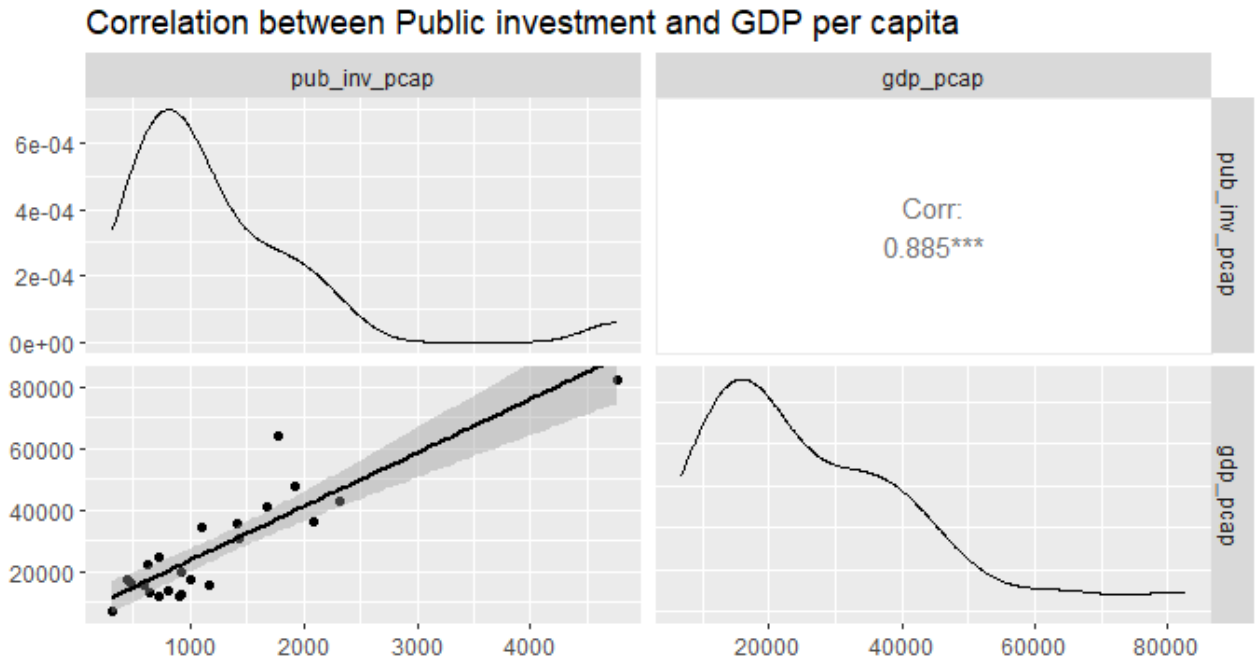


Remarks on Figure 16:

- *The correlation coefficient between public investment and rail investment of the EU MSs show a positive and high value;*

- *It confirms the expectation foreseen in (General government gross fixed capital formation per capita): total public investment budget available per country seems to be a factor influencing the available capital budget for the railway sector.*

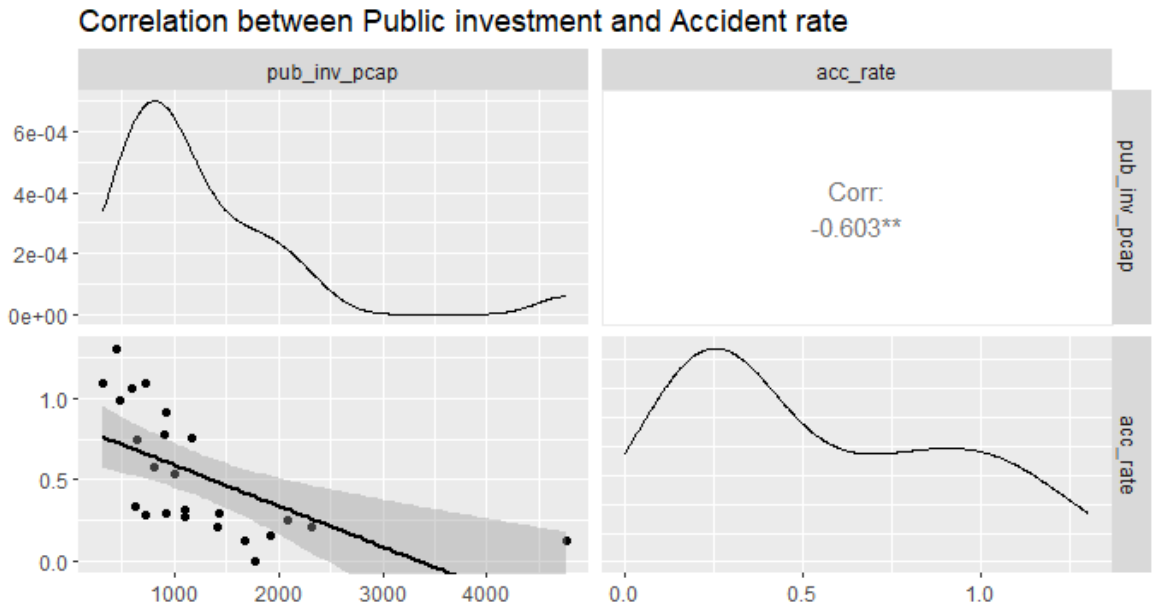
Figure 17.



Remarks on Figure 17:

- *The correlation coefficient between public investment and GDP per capita of the EU MSs show a positive and very high value;*
- *It supports the assessment provided for Figure 1 (Gross Domestic Product (GDP) per capita).*

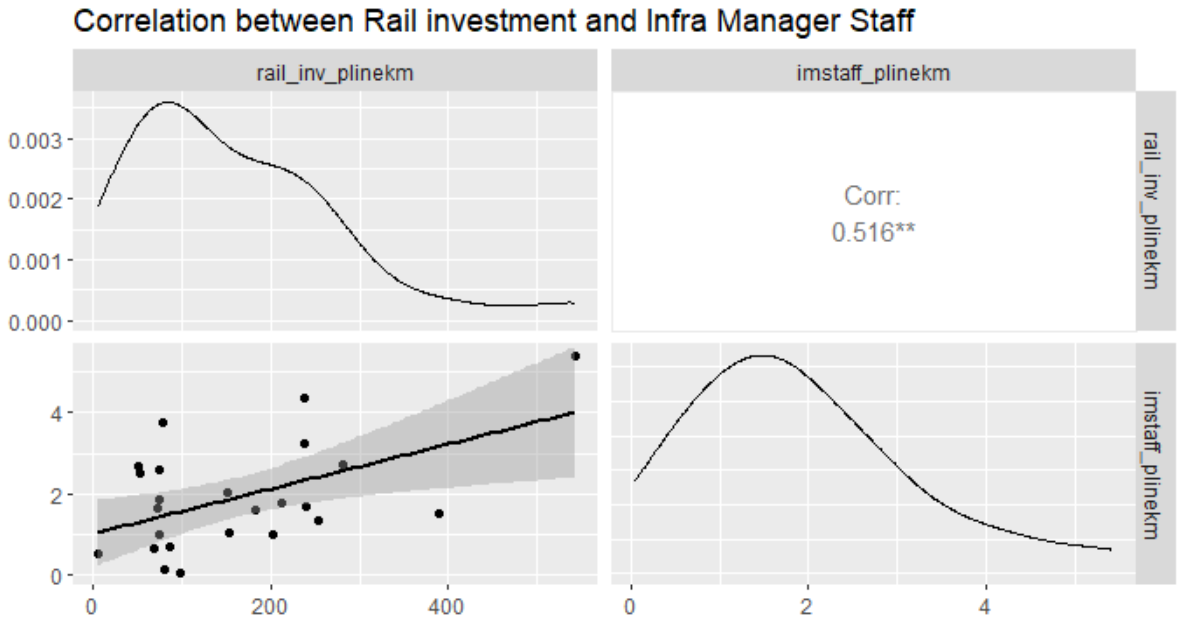
Figure 18.



Remarks on Figure 18:

- *The correlation coefficient between public investment and accident rate of the EU MSs show a negative and high value;*
- *As mentioned in Figure 3, the level of public investment could be utilised as an early warning sign re. railway safety: having a negative correlation with the accident rate, means that decreasing public investment could lead to an increase in the accident rate.*

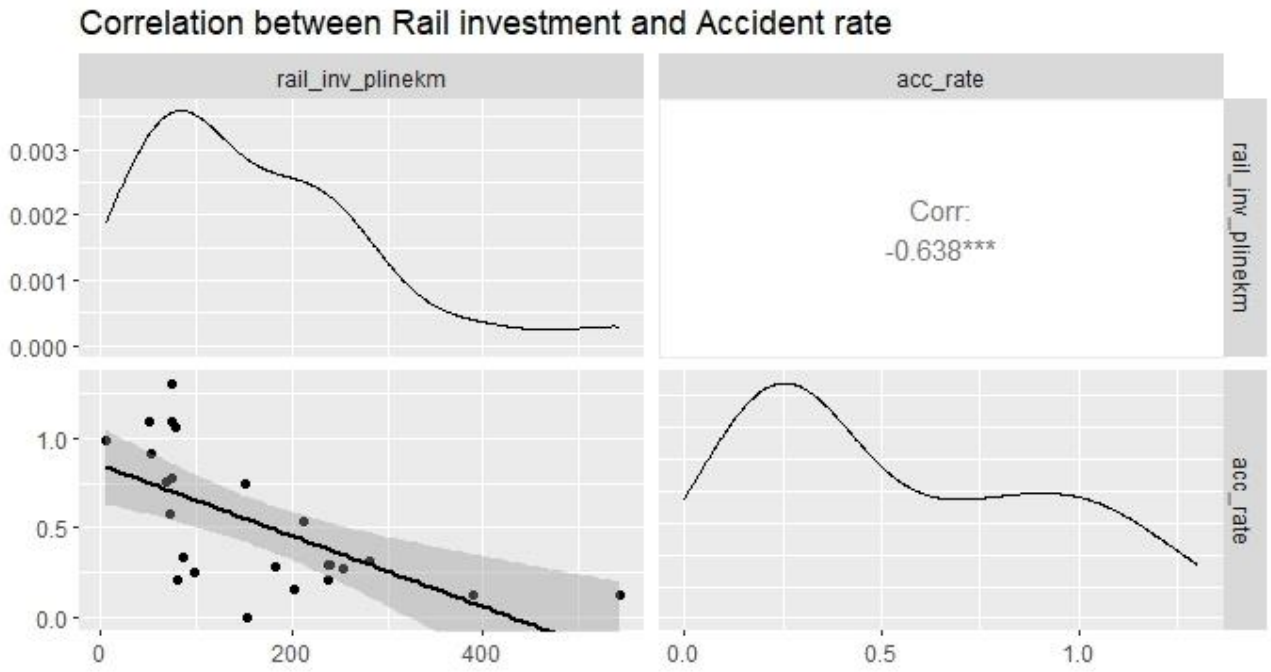
Figure 19.



Remarks on Figure 19:

- *The correlation coefficient between rail investment and IM employment of the EU MSs shows a positive though moderate value;*
- *An increase in the railway assets would lead to an increase in the employment need of the IM. Low employment levels per line kilometre may indicate understaffing, leading to insufficient oversight and maintenance.*

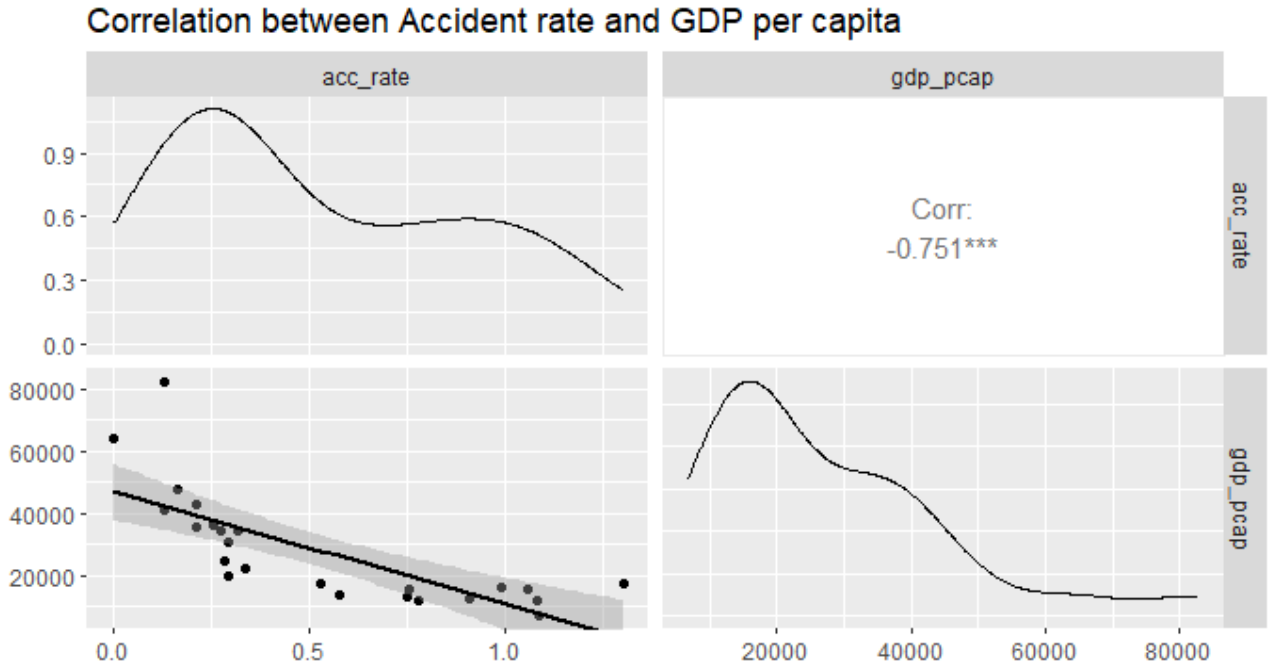
Figure 20.



Remarks on Figure 20:

- *The correlation coefficient between rail investment and accident rate of the EU MSs show a negative and strong value;*
- *Similarly to Figure 18, also rail investment may be utilised as an early warning sign re. railway safety: having a negative correlation with the accident rate, it means that decreasing rail investment could lead to an increase in the accident rate.*

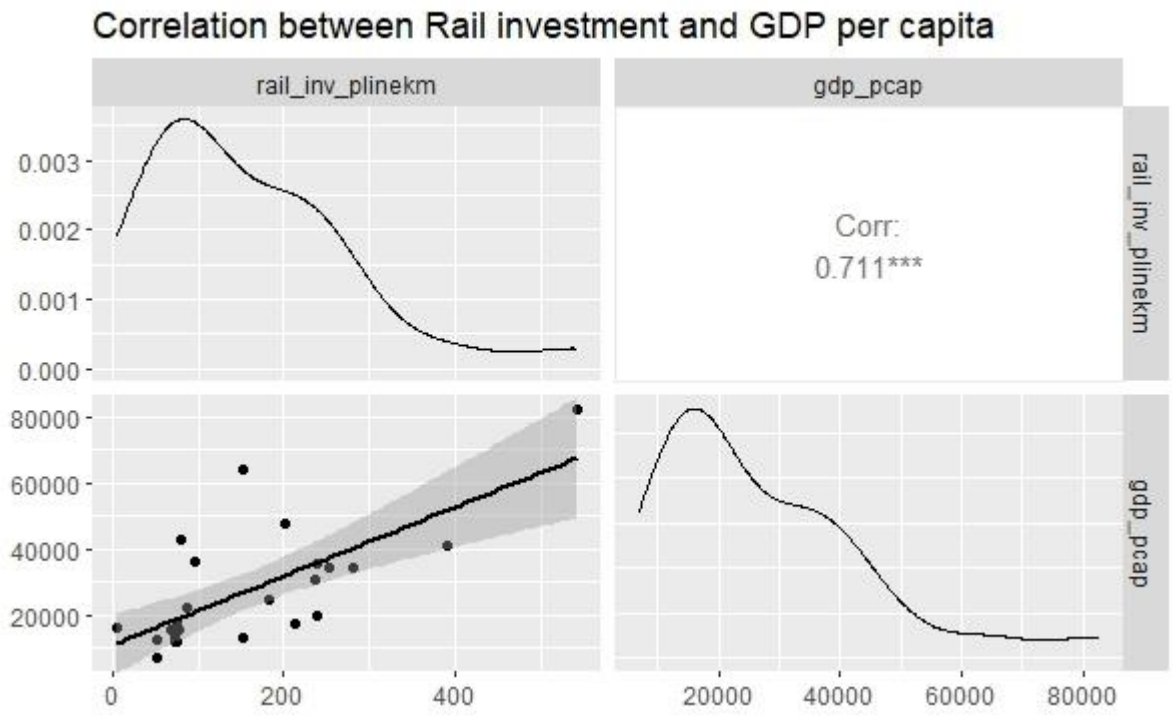
Figure 21.



Remarks on Figure 21:

- *The correlation coefficient between accident rate and GDP per capita of the EU MSs show a negative and strong value;*
- *It confirms the preliminary evaluation carried out for Figure 1.*

Figure 22.



Remarks on Figure 22:

- *The correlation coefficient between rail investment and GDP per capita of the EU MSs show a positive and very high value;*
- *It is an expected result which also confirm the findings from the literature. Similar to public investment (Figure 3), increases (decreases) in rail investment determine increases (decreases) of the GDP per capita.*

6.2 Cluster analysis of selected Member States

Aim:
To investigate the patterns beyond the main indicators by graphically superimposing the indicators and showing the changes in the selected MSs (by moving from one cluster to another).

Data and methodology:
Using main indicators of each data categories, a "graphical" cluster analysis of selected countries is performed.
Ranking the EU27+2 countries by Inland transport investment per capita (Figure 7), seven EU countries are selected representing each part of the trend: high, medium and low levels of values of this indicator. While further and more complex methods are possible (e.g. above/below/around EU average; quantile-based approach; quantitative cluster analysis etc.), a simple but straightforward visual selection (aimed to create 3 clusters of all countries) was utilised and from them 9 countries were selected to represent each cluster:

- *cluster (1) - high level: CH, NO, LU;*
- *cluster (2) - medium level: IT, HU, AT; and*
- *cluster (3) - low level: BG, PL, EL.*

A total of 8 main indicators representing each data categories were used in this analysis.
After setting the reference clusters, for each additional indicator the selected countries are placed in the related cluster based on the indicators' values.

Results:
An overview of the results is provided in Table 2. At a glance, results show that the countries positioned in the trend tails of the indicators (for both 'high' and 'low' values) display less variability than those for the cluster of intermediate values, thus remaining in the same cluster for all (or almost all) indicators.

Table 2. Results of the graphical cluster analysis

Indicators:	Cluster (1) High level									Cluster (2) Medium level					Cluster (3) Low level							
Figure 7. Inland transport investment per capita	CH	NO							LU	IT	HU	AT			BG	PL					EL	
Figure 8. Railway investment per capita	CH	NO	AT	IT					LU		HU				BG	PL					EL	
Figure 9. Railway infrastructure maintenance per capita		NO		IT	HU				LU			AT	CH		BG	PL						
Figure 1. Gross Domestic Product (GDP) per capita	CH	NO							LU	IT		AT			BG	PL	HU				EL	
Figure 4. Total government spending per capita	CH	NO							LU	IT		AT			BG	PL	HU				EL	
Fatality rate (fatalities per bn trainkm)					HU	BG	PL	EL		IT								AT	CH	NO		LU
Total significant accidents							PL			IT	HU	AT			BG				CH	NO	EL	LU
Number of reported NIB accident investigations					HU		PL			IT				BG				AT	CH	NO	EL *	LU *

In particular, Cluster 1 (Switzerland, Norway and Luxembourg) have high inland transport investment per capita, high rail investment per capita and high rail infrastructure maintenance per capita. It seems positively linked to both high levels of GDP per capita and total government spending per capita. Moreover, it is also reasonable that these countries have high safety performance measures as low values of fatality rates, total significant accidents and number of reported NIB accident investigations.

Similarly, Cluster 3 (Bulgaria, Poland and Greece) show low levels of rail / transport investment per capita (including rail infrastructure maintenance) as well as low values of GDP and government spending per capita; displaying high values of the selected (3) indicators, rail technical safety measures seem, from a graphical point of view, negatively linked to rail investments, national account, and government expenditure. It seems that this cluster behaves like Cluster 1 but in the opposite direction. Countries in Cluster 2 (Italy, Hungary, Austria) show the highest variability between indicators. In particular, while Austria has a similar pattern to the Cluster 1's countries (except for the 'total significant accident' indicator), Italy displays high values of rail / transport investment (including maintenance) per capita, with moderate values of both the macroeconomic indicators (e.g. GDP) and safety performance. Given the "same level" of investment of Cluster 1, the difference in the safety indicators could show that there is room for further improvement and / or need to further investigate factors driving the change (on this, see the additional analysis provided at the end). Always in Cluster 2, the values of Hungary's indicators are positioned in all clusters: medium levels of rail / transport investment per capita (and high value of maintenance per capita), macroeconomic indicators' low values and safety measures' low values.

Overall, the graphical cluster analysis of selected EU countries seems to show a positive link between: rail transport investment / economic health of the country / technical safety performance. Rooms for improvement appear:

- *for all countries with: i) low values (Cluster 3) of the selected indicators, and,*
- *for some countries (e.g. Hungary) with (ii) medium values (Cluster 2) of the transport and economy-related indicators.*

It is worth to mention that additional analyses are advisable and aimed to identify which factors further explain country differences. Examples include, but are not limited to, the following indicators:

- *Concerning the 'network usage intensity' (train-km per route km per day, 2022 values, Figure 25 of the last IRG-Rail Market Monitoring report), having high network usage intensity, Switzerland and Austria are reasonable in Cluster 1 (except Norway), while Italy and Hungry*

are in Cluster 2 with average values of the indicator; with low network usage intensity (being in the tail of the ranked EU values), Poland and Bulgaria are in Cluster 3. This positioning pattern matches the results reported in Table 2;

- *The rail network size, measured as the 'length of railway lines by number of tracks' (2022 values, Eurostat) and the 'density of railway network relative to surface area and population' (line-km per million people and line-km per thousand km^2, 2020 values, last RMMS data) do not seem to explain the movement patterns of countries belonging to the different clusters: in all clusters, countries have a mix of network sizes;*
- *Evolution of staff levels among infrastructure managers. Exploratory analyses suggest that significant changes in number of staff in IMs could be an early warning sign for possible safety risks. Normally, considering the role of IMs, staff levels would be relative stable, and the available data confirms that. Sudden and significant changes would therefore suggest that important adjustment of the IM / rail sector in a country is underway (e.g. restructuring or similar). As part of the data analyses undertaken it was apparent that IM staff levels in Greece was reduced significantly due to the economic crisis - by about 50% between 2013 and 2014 - linked to significant budget cuts including rail infrastructure.*

7. Selection and review of case studies

Building on the aggregated analyses a case study analysis will be undertaken in this section in order to determine the extent to which country-based quantitative indicators could provide the basis for an early warning system re. safety performance in Europe.

The following indicators will be assessed for selected countries:

- *GDP per capita,*
- *Total public sector investment per capita,*
- *Government spending per capita,*
- *Railway infrastructure spending per line kilometres,*
- *IM employment trends (change in staff levels between 2011 and 2020),*
- *Share of tracks equipped with TPS, and*
- *Proportion of passive LCs.*

The selected case study countries include:

- *Greece,*
- *Denmark,*
- *Bulgaria,*
- *Austria,*
- *Italy.*

For each of the selected indicators the countries are grouped according to whether they have relatively low, medium or high values using a colour code (countries belonging to the group with relative highest value are in 'green'; countries belonging to the group with relative lowest value are in 'red' and countries with relative medium values are 'yellow'). For all indicators a high value is positive except for proportion of passive LCs where an absolute low value is positive. This exception is integrated in the colour coding. Table 3 shows the overall results obtained for the selected case study countries.

Table 3. Country dashboard for early warning system

Selected indicators	Greece	Denmark	Bulgaria	Austria	Italy
GDP per capita					
Public sector investment per capita					
Government spending per capita					
Rail infra spending per capita					
Relative change in IM employment 2011-2020					
% tracks equipped with ATP					
% passive LCs					

Greece:

- *5 out of 7 indicators are red, while the remaining 2 are yellow;*
- *Particular concerns would be linked to the level of general investment and transport investment incl. railway infrastructure spending;*
- *Moreover, the significant reduction in IM staff levels comparing 2020 to 2011 value is the reason for Greece to be in the low category (red) for this variable .*

Denmark

- *5 out of 7 indicators are green, while the remaining 2 are yellow;*
- *Limited immediate concerns although attention to the 2 yellow indicators (rail infra spending per capita and % tracks equipped with ATP).*

Bulgaria

- *6 out of 7 indicators are red, while one indicator is green (% of passive LCs);*
- *Particular concerns would be linked to the level of general investment and transport investment incl. railway infrastructure spending as well as GDP per capita;*
- *It is noted that although Bulgaria is in the low category for IM employment trends the decrease in staff level is much smaller compared to the change in Greece.*

Austria

- *4 out of 7 indicators are green, while the remaining 3 are yellow;*
- *Attention to the 3 yellow indicators: Relative change in IM employment, % tracks equipped with TPS and % passive LCs.*

Italy

- *5 out of 7 indicators are yellow, while the remaining 2 are green;*
- *For these indicators Italy is mainly in the middle group without any values belonging to the low group;*
- *Attention to the 5 yellow indicators, although it is noted that the indicator on railway infrastructure spending Italy has a relative high value among the countries in the middle group.*

Overall, this preliminary analysis would suggest that particular attention should be given to Bulgaria and Greece.

8. *Further perspectives and next steps*

This exploratory study has involved a number of analyses in order to provide insights re. the linkages between economic / financial context and safety-related aspects. These analyses provide preliminary insights on which indicators to monitor to identify in advance potential railway safety deterioration. Key findings include:

- *Significant influence of GDP per capita on rail infrastructure spending per line kilometre;*
- *Significant influence of public investment per capita on rail infrastructure per line kilometre;*
- *Significant influence of GDP per capita on safety outcomes (e.g. fatality rates);*
- *Close tracking of changes in number of infrastructure manager staff is highly relevant;*
- *Correlation analysis / regression analysis can provide useful insights on how macroeconomic conditions influence;*
- *Cluster analysis and related techniques allows a synthesis of the different influencing variables.*

The study highlights the importance of economic conditions and public investment in ensuring railway safety. By understanding and addressing these linkages, policymakers can improve the resilience and safety of the railway system across the EU.

Further areas for in-depth analysis have been identified during the study and could be relevant to take forward, e.g. in the form of a targeted study depending on resource availability. In particular, two areas are listed below:

- *Analysis of more complex linkages, e.g. 2 or more independent variables (including rail investments / GDP, size of authorities e.g. NSA, NIB, and additional indicators of the supply side of the economy) along with the application of quantitative techniques for panel data rather than cross-section or quantitative cluster analysis (considering a broader both time horizon and countries);*
- *Moreover, the specified Dashboard could be further developed in order to increase its useability and should ideally be based at least on 5-year values.*

Other areas to explore further include:

- *Select a few Member States for an in-depth analysis of the main indicators to complement the interpretation and better understand the graphical cluster analysis carried out;*
- *Implement a monitoring system of railway safety which include also economic conditions of Member States.*

References

Alotaibi, S., Quddus, M., Morton,C., Imprialou, M. (2022) Transport investment, railway accessibility and their dynamic impacts on regional economic growth, Research in Transportation Business & Management, 43 (2022) 100702.

Anderson, R. J., & Barkan, C. P. L. (2004) Railroad Accident Rates for Use in Transportation Risk Analysis. Transportation Research Record: Journal of the Transportation Research Board, 1863(1), 88-98.

Aschauer, D. A. (1989). Is Public Expenditure Productive? Journal of Monetary Economics, 23(2), 177-200.

Calderón, C., & Servén, L. (2004) The Effects of Infrastructure Development on Growth and Income Distribution. Policy Research Working Paper No. 3400. The World Bank.

Calderón, C., & Servén, L. (2010) Infrastructure and Economic Development in Sub-Saharan Africa. Journal of African Economies, 19(suppl_1), i13-i87.

Canning, D., & Bennathan, E. (2000) The Social Rate of Return on Infrastructure Investments. Policy Research Working Paper No. 2390. The World Bank.

Canning, D., & Pedroni, P. (2004) The Effect of Infrastructure on Long-Run Economic Growth. The World Bank.

Easterly, W., & Rebelo, S. (1993) Fiscal Policy and Economic Growth: An Empirical Investigation. Journal of Monetary Economics, 32(3), 417-458).

Esfahani, H. S., & Ramírez, M. T. (2003). Institutions, Infrastructure, and Economic Growth. Journal of Development Economics, 70(2), 443-477.

Evans, A.W. (2013) The economics of railway safety, Research in Transportation Economics, 43, 137-147.

Lenz, N.V., Skenderand, H.P., Mirkovic, P.A, (2018) The macroeconomic effects of transport infrastructure on economic growth: the case of Central and Eastern E.U. member states, Economic Research-Ekonomska Istraživanja, 31(1), 1953-1964.

Lin, C-Y., Gerstein, T., Barkan, C.P.L., Jack, A., Blumenfeld, M. and Abdurrahman, U.T. (2023) International Benchmarking of Railroad Safety Data Systems and Performance – A Cross-Continental Case Study, Journal of Rail Transport Planning & Management, 26(1).

Mizutani, F. (2024) Empirical analysis of the factors behind rail infrastructure investment, Transport Policy, 150 (2024) 244–254.

Patra, A. P., & Espling, U. (2015) Maintenance Decision Support Models for Railway Infrastructure Using RAMS and LCC Analyses. PhD thesis, Luleå University of Technology, Division of Operation and Maintenance Engineering, 2009.

Pereira, A. M., & Andraz, J. M. (2013) On the Economic Effects of Public Infrastructure Investment: A Survey of the International Evidence. Journal of Economic Development, Chung-Ang University, Department of Economics, vol. 38(4), pages 1-37, December.

Polyzos S., Tsiotas D. (2020) The contribution of transport infrastructures to the economic and regional development: a review of the conceptual framework, Theoretical and Empirical Researches in Urban Management, Vol. 15, No. 1, (February 2020), pp. 5-23.

Rodrigues, P.G., Pereira, A.M. and Pereira, R.M. (2024) Railroad infrastructure investment and economic performance in Portugal: An industry-specific analysis, Journal of Infrastructure, Policy and Development 2024, 8(2), 2942.

Rosik, P., & Wójcik, J. (2009) Transport Infrastructure and Regional Development: A Survey of Literature on Wider Economic and Spatial Impacts, Sustainability, 15, 548.

Savchenko, L.V., (2022) Relationship between transport infrastructure expenditures and costs and transport indicators - an overview of European and Ukrainian situation, The electronic scientifically and practical journal - “Intellectualization of Logistics and Supply Chain Management”, Vol. 11, pages 29-45, ISSN 2708-3195.

Sinha, A., Singh, S. K. and Singh, V. (2021) Linkage Between Road Safety and Economic Development: A Case Study of India, Metamorphosis, 20(1) 7–15.

Stenström, C., Parida, A., & Kumar, U. (2016) Performance Indicators and Improvement Programs for Railway Infrastructure. International Journal of Productivity and Performance Management, 65(1), 34-50.

Straub, S. (2011) Infrastructure and Growth in Developing Asia. Asian Development Review, 28(1), 119-156.

Wang, H.; Zhang, M. (2020) Does China’s transportation infrastructure have an impact on employment in the service sector? Kybernetes, 49, 2737–2753.

Watson. I., Ali, A. and Bayyati, A. (2021) Factors affecting efficiency of railways in terms of safety at railway level crossings, International Journal of Transport Development and Integration, 5(2), 190-207.

Wemakor, W., Anson, J. and Schmid, F. (2017) Establishing the Relationship between Railway Safety & Operational Performance, International Journal of Transport Development and Integration, 2(1), 98-114.