NeTIRail

Needs Tailored Interoperable Railway Infrastructure

Deliverable D1.8

Final Business Case Synthesis Final Report

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Executive Summary

This deliverable synthesizes and brings together all the elements of the economic and social assessment of the NeTIRail-INFRA railway innovations, which have been developed in previous Deliverables D1.4, D1.6, D1.7, D5.2 and D5.3. Hence, this deliverable brings together the Cost-Benefit Analyses (D1.4), the societal analyses (D5.2 and D5.3), the wider economic impact research (D1.6) and the investigation on incentives for the implementation of innovations (D1.7).

The main outcomes of this research can be summarized as follows:

- The consortium of NeTIRail-INFRA has developed a wide range of technologies, contributing to improve multiple railway technology elements: rail track and overhead line monitoring, transition zones, fastenings systems, lubrication systems, electrification methods or S&C among others.
- The investment and maintenance costs of the technologies have been evaluated and assessed against the estimated and/or expected benefits. In general, NeTIRail-INFRA technologies aimed at providing low-cost affordable solutions.
- The main direct economic benefits, common across most technologies, are reductions in life cycle costs. Other related benefits include extended asset life and optimized capacity via higher track availability.
- Rail user benefits are also expected from most technologies, mostly in the form of reliability improvements (e.g. delay reductions). Safety benefits are also expected in some cases, with noise and pollution reductions expected from one of the innovations.
- The societal impact assessment provided a qualitative analysis (using surveys) of the impact of the innovations on the case study lines, based on passengers' current needs and perceptions. This complements the economic assessment, using a different methodology.
- Barriers for innovation can be significant in the fragmented railway industry, especially when agents may have short-term objectives (e.g. short franchises). The promotion of innovation must deal with existing barriers – e.g. by aligning objectives between IMs and operators - to make sure new technologies are implemented and to their full potential for the benefit of society. There is no panacea solution here, but the following mechanisms can bring greater co-ordination and in turn incentives for innovation: independent regulation, including a focus on whole system and life-cycle costs; funding certainty beyond the annual budgetary cycle (through an economic regulator or a multi-annual agreement with government); cost-reflective track access charges and well-calibrated performance regimes to align incentives; an active holding company, co-ordinating the activities of the infrastructure manager and train operators (as occurs in Germany) - provided such a structure does no inhibit market entry, which itself can stimulate innovation.
- In general the innovations studied as part of NeTIRail-INFRA can probably be justified largely based on cost savings to the party undertaking the investment (the infrastructure manager). As a result, whilst the incentive issues relating to fragmentation noted above are highly relevant in general, this is less true for the case study innovations (though there are benefits that accrue elsewhere, such as delay reductions). Further, the general findings regarding mechanisms that support long term investment in railways subject to tight funding constraints are relevant, as most of the innovations involve at least some (if generally small) up-front investment.

No major deviations in relation to the NeTIRail-INFRA Grant Agreement are reported for the content of this deliverable.

Table of contents

Abbreviations and acronyms

Abbreviation / Acronym	Description
ABA	Axle Box Accelerations
BCR	Benefit-Cost ratio
CBA	Cost-Benefit Analysis
D	Deliverable
DM	Do Minimum
DN	Do Nothing
DS	Do Something
IM	Infrastructure manager
LCC	Life Cycle Costs
M&R	Maintenance and renewal
NPV	Net Present Value
OLE	Overhead line
PVB	Present Value of Benefits
PVC	Present Value of Costs
S&C	Switches and crosses
T	Task
VoT	Value of Time
WP	Work Package
WTP	Willingness-to-Pay

1. Introduction

1.1 Task Description

Quoting from the NeTIRail-INFRA grant agreement Annex 1 (Part A – section 1.3.3 WT3 Work Package Descriptions, p.15):

> *The output of this final task is a cost benefit analysis for the innovations developed in the project to establish the business case. It will draw on the cost and benefit quantitative work in tasks 1.3 (cost and user benefits), 1.4 (wider economic effects) and WP5 (societal effects). This final task will also draw on the outputs of task 1.5 so that appropriate consideration is given to the incentive-related economic implementation issues.*

1.2 Introduction

This report synthesizes and brings together all the elements of the economic and social assessment of the NeTIRail-INFRA railway innovations. Thus it brings together the Cost-Benefit Analyses (D1.4), the societal analysis (D5.2 and D5.3), the wider economic impact research (D1.6) and the analysis on incentives for the implementation of innovations (D1.7).

The NeTIRail-INFRA project has developed and brought forward a series of technological innovations for the railway infrastructure. At the core of the project was a motivation to provide low-cost affordable solutions for the railway, in particular for secondary lines which could struggle to survive due to financial and economic reasons. The innovations cover and address a range of aspects of the railway infrastructure, such as inspection technologies, renewal processes, materials, maintenance activities and electrification. They also spread across a range of Technology Readiness Levels (TRLs), as defined by the European Commission guidelines. Some innovations are truly novel (TRL 1-3), e.g. trolley wire for overhead line (previously applied to tram but not to railways) or new designs for transition zones; some are somewhat more developed (TRL 4-7), such as the Axle Box Acceleration, on track monitoring, smart phone monitoring, tailoring wire tension and tailoring track to avoid corrugation; and others are really just the application of technology (TRL 8-9), i.e. technologies that are known and fairly mature, where the innovation has been to apply existing technology and techniques and advise on what is most appropriate for different locations, e.g. lean techniques for S&C assembly and installation.

In WP1 and WP5, we have assessed the innovations from a socio-economic perspective. A central part of the evaluation has been a Cost-Benefit Analysis for each innovation. This comprises a detailed understanding of all costs involved in the construction and implementation of the technology, as well as all benefits that are expected to be derived from it. The CBA identifies all impacts of the innovation, and to whom they accrue. Where possible, the CBA has quantified the impacts in monetary terms for a thorough comparison of costs and benefits.

Simultaneously, the project partners have worked on a social assessment of the case study lines which were selected for this project in the early stages of the research. Lines are a mixture of busy, secondary and freight lines, located in Turkey, Slovenia and Romania. Surveys were conducted among rail users to understand users' perceptions and the social role of these lines. The societal analysis provides a qualitative assessment of the potential social importance of each innovation, based on their expected impacts and users' perceptions on the lines where they could be implemented. We have been careful to avoid any double counting, and the CBA and the societal analysis can be seen as two different perspectives about the technologies. In practice, however, the complementarities are large due to the difficulties in obtaining data for a monetary valuation of user benefits (mainly in terms of delay reductions). In this sense, the CBAs have mainly covered the impact on railway costs – which constitute the main direct impact of the innovations -, whereas the societal analysis complements the CBAs by shedding light on the potential relevance of the impacts on user benefits (where it has not been possible to monetize these due to lack of data).

In the main, the proposals under consideration by NeTIRail-INFRA will improve the delivery of rail services through cost decreases (e.g. maintenance and renewal costs) and improvements in reliability (e.g. reduction in delay minutes) and safety; with potential for some other additional effects. Improvements for rail users such as those in reliability can potentially be converted into generalised cost savings and economic impacts measured through associated accessibility improvements. Similarly, in the long term, reductions in infrastructure costs might also be converted into lower costs for users if they are passed through via lower fares. Thus, as part of the wider economic impacts evaluation we have also outlined how these could be estimated in D1.6, both through impacts on agglomeration and employment.

Finally, but not least important, a strong programme of research has been conducted to understand the role of incentives for the implementation of technological innovations in the industry. Industry representatives and experts were interviewed as part of the NeTIRail-INFRA project to assess how potential barriers for implementation may be removed or reduced. New econometric work has also been conducted shedding light on:

a. The impact of quality on costs (Deliverable 1.7 Annex 2).
b. Methodological aspects of marginal cost modelling: Estimating the marginal cost of different vehicle types on rail infrastructure (Deliverable 1.7 Annex 3).
c. Methodological aspects of marginal cost modelling: Bayesian techniques (Deliverable 1.7 Annex 4).
d. Methodological aspects of marginal cost modelling: Dynamic techniques (Deliverable 1.7 Annex 5).

Econometric approaches can create new information on key matters of policy interest, such as the marginal wear and tear cost of running an extra train on the network – useful for track access charging purposes (items b. to d. in the list above); or how much costs change as quality improves (item a. above). As will be discussed later in the report, econometric techniques have also been used to create new evidence on matters relating to the cost-benefit analysis of the innovations, such as the cost implications of transition zones. Such analysis complements bottom-up engineering analysis.

The remainder of the report is structured as follows. In section 2 we summarise the findings of the cost-benefit analysis of the innovations, before discussing the societal implications from the analysis in WP5 in section 3. Section 3 then brings these two central aspects together to give an overall assessment of the NeTIRail-INFRA innovations. Section 4 synthesises the findings of the project in respect of how wider economic impacts of the NeTIRail-INFRA innovations could be estimated. The incentives research is summarised in Section 5. Section 6 concludes.

2. Synthesis of the Cost-Benefit Analyses

Cost-Benefit Analysis (CBA) is a widely used tool to provide an economic assessment of transport projects and policies. As part of the EC-funded NeTIRail-INFRA project, CBA has been applied for a range of railway infrastructure engineering innovations which have been proposed and developed within the project. While CBA is frequently used for investment appraisals, one of the conclusions from this project is that CBA is also well suited, while less often used, for the evaluation of technical improvements. This section synthesises the outcomes from the quantitative cost-benefit analyses conducted as part of Task 1.3 and which are reported in full detail in Deliverable D1.4 (Cost and User Benefit Report).

As discussed in the introduction, Cost-Benefit Analysis (CBA) is a central element in the evaluation of the NeTIRail-INFRA railway innovations. Other important evaluative elements are additional societal considerations (those not fully captured in the CBA), wider economic impacts (if a transport project has effects beyond the transport market, e.g. beyond a particular railway line in question) and the incentives for implementation of the innovation.

The central role of the CBA lies in its ambition to identify all possible direct effects of an innovation, monetary and non-monetary ones, for all agents involved. The perspective taken to conduct the CBA is the society's perspective. Monetization is then only a way of translating all impacts into a common unit (e.g. €). In this way, the result of a CBA can be captured by its Net Present Value (NPV; benefit net of costs over the life of the innovation) or the Benefit-Cost Ratio (BCR; which is the same benefits and costs as in the NPV measure, albeit handled in a different way) that can inform about the economic merits of the innovation. A positive NPV or a BCR above one indicates that a project adds to social welfare.

The main limitation of CBA is that some impacts of the projects cannot be monetized or even quantified. Hence, it is useful to complement CBA with further insights into those elements that have only been identified but not incorporated quantitatively.

This deliverable will summarise all the main outcomes of the CBA of the NeTIRail-INFRA railway innovations. As part of the summary, we will discuss in detail which impacts of the innovations have received additional attention beyond the CBA – which will in turn be discussed in the following sections 3, 4 and 5 of this Deliverable D1.8.

2.1 Methodological challenges and contributions

Various challenges emerged in conducting CBA for the *innovative engineering technologies* that are in focus of the NeTIRail-INFRA project. Surprisingly, the financial and economic understanding of engineering processes is vague. Such processes can be complex and surrounded by uncertainties, especially if a technology is new., One of the observations from a Rail Structure Symposium organized at the University of Leeds with international experts in the railway, in the latest stages of the NeTIRail-INFRA project (January, 2018) was indeed that it is costly to gain full economic understanding of rail engineering choices.

The major challenge for scholars in general and for the evaluation of NeTIRail-INFRA in particular is, however, to establish that the alternative is even more costly; without appropriate information, there is a clear risk that resources are spent on research on technical improvements that would be too costly to implement. Indeed, poor information about costs and benefits that leads to implementation may establish a benchmark that could make the industry perform worse than if the current technology would not be replaced.

Moreover, some information may be made confidential due to the competitive pressures exercised on the railway in certain countries. Since many railways are or have been funded with taxpayers' money, we argue that data transparency should be demanded much more by regulators and funders.

In order to contribute to a robust economic understanding of the costs and benefits (CBA) of various rail technologies, five different analytical techniques have been identified as part of the NeTIRail-INFRA research. Four of these five techniques have been implemented in the project, and it is worth noting they are complementary with each other. The five approaches are: i) on-site empirical observations, ii) econometric analysis, iii) interviews with experts and engineers, iv) the switching values approach (DfT, 2017), and v) usage of an engineering-based decision-making tool. Each of these techniques contributes to the generation of the necessary information and economic analysis outputs. It has proven useful to think of these different tools at the time of conducting the analysis, given that it was generally the case that some of these techniques/paths were not available for each particular case study.

Overall, the economic analyses undertaken within the NeTIRail-INFRA framework do not represent an innovative approach to the CBA methodology. Instead, the contribution is three-fold: a) to produce new empirical findings in respect of the economic case for specific technical innovations in specific localities (and where possible to generalise these results); b) to highlight the importance of doing economic evaluation for technologies and the difficulties and barriers that practitioners often encounter; and c) to indicate alternative ways of obtaining the necessary inputs and overcoming the challenges. While the research and the discussion is framed around the railway industry, some of the challenges also apply to other sectors, within and outside transportation.

2.2 Summary of CBA outcomes

Nine different railway innovations have been assessed. All of these innovations have been developed within the overall goal of the NeTIRail-INFRA project, i.e. to provide affordable solutions for the railway, in particular, for low density routes which typically struggle more from a financial point of view. In all cases, results emanate from cooperation between engineers, IMs and railway experts to identify the investment requirements and the impacts of each innovation. Lower costs for renewals and maintenance have been identified as the main direct impact. Additionally, 7 out of 9 innovations have the potential to also generate user benefits, mainly in the form of reliability and safety improvements.

Overall, to obtain necessary inputs for the CBAs, we have made use of: i) on-site empirical observations, ii) interviews with experts and engineers, and iii) econometric analysis. We particularly highlight the potential of the latter method to provide new information on how costs vary with different technologies – to complement engineering judgement. Where some key input was missing so that an estimate of the NPV could not be calculated, the 'switching values' approach (DfT, 2017) was used to reach conclusions. The 'switching values' approach evaluates what level of benefits (cost savings etc.) is necessary to achieve a predetermined level of NPV (for example, NPV equal to zero).

A Life Cycle Cost (LCC) perspective has guided the quantification and monetization of costs and benefits in this project. In other words, the CBAs have mainly attempted to quantify all changes that would occur to investment, replacement and maintenance costs as a result of an innovation. These impacts are directly related to Infrastructure Managers (IMs) and Train Operators. Due to the challenges described above and data limitations in the contexts of study, the additional benefits on rail users have not been quantified and monetized – although where possible, some indicative illustrative monetization has been provided. Instead, they have been assessed qualitatively for a particular context of study under the societal analysis. The societal analysis is summarised later in section 3 and is fully reported in Deliverable D5.3.

Tables 1-3 below presents a summary of the CBA of each innovation, respectively for WP2, WP3 and WP4. It includes an indication of the context of study, the investment costs of the innovation, a summary of the CBA outcomes and a description of any additional (non-monetized) benefits which are important but not part of the CBA summary metrics (i.e. the NPV or the BCR)[1]. Further details of the full economic appraisal are provided in Deliverable D1.4 and the page references in that deliverable for each innovation are listed below in Tables 1 to 3.

Table 1. Summary of the CBA for each innovation (WP2)

	Innovation	Case study	Investment Cost	CBA summary	Additional, non-monetized benefits
1a	2.3a: Lean techniques for S&C (off-site assembly)	Turkish railway network	Zero cost: managerial changes (the application of this innovation only requires a change in the current patterns of replacement of S&C such that resources are used more efficiently)	Net Present Value (NPV) = €2.4M over 30 years, if applied to 375 switches/year. (€4.8M for 750 switches*). Most benefits arise from higher productivity. The NPV is hence highly proportional to labour costs, and hence the monetised benefits in absolute terms could vary greatly by country. *A total of 750 switches are replaced every year in Turkey.	187 yearly shifts of track availability across the whole network (1/4 of all switches replacements)
	Reference for further details of the full economic appraisal: NeTIRail-INFRA Deliverable D1.4, pp.23-30				
1b	2.3b: Lean techniques for S&C (trackside assembly)	Turkish railway network	Zero cost: managerial changes (see above 1a for more details)	NPV = €2.9M over 30 years, if applied to 375 switches/year. (€5.8M for 750 switches). The NPV is highly proportional to labour costs (see above 1a for more details).	375 yearly shifts of track availability across the whole network (1/2 of all switches replacements)
	Reference for further details of the full economic appraisal: NeTIRail-INFRA Deliverable D1.4, pp.23-30				

[1] Note: in the tables, the figures from the CBA outcomes are expressed in net present value terms, discounted at 3%. All details and assumptions of the CBAs are presented in NeTIRail-INFRA Deliverable D1.4.

2	2.4: Choice between different fastening systems	Swedish railway network	The additional material cost of a Fast clip compared to an E-clip is €4.29 more expensive[2]. With an average of 6.66 clips per track meter, and assuming a clip life of 10 years: relative to E-clips, installing Fast clips costs €55 per meter over a 25 years period (final figures expressed in net present value terms, discounted at 3%).	Net Present Value of Benefits (NPB) = €10.7 million over 25 years for the average track section (70 200 meters) – these relate to the benefits of reduced maintenance. Net Present Value of Investment Costs (NPC) = €3.84 million over 25 years for the average track section Overall NPV = €6.86 million over 25 years for the average track section Benefit Cost Ratio = 2.8 (according to UK WebTAG guidelines, this indicates Good Value for Money) In general, NPV > 0 if the switch to Fast-clip costs less than an extra €153 per meter	• Increased track availability (if less grinding needed). • Reduced delays (if fewer failures) • Reduced noise for households near tracks.
	Reference for further details of the full economic appraisal: NeTIRail-INFRA Deliverable D1.4, pp.31-36 and pp.86-102				
3	2.5: On-board lubrication techniques	Divača – Koper; Slovenia (freight line)	€2,443 per locomotive/per year The approach taken here – i.e. presenting results for one locomotive - means that results are generic for any locomotive using the innovation, which facilitates decision-making.	The NPV of this innovation for 1 locomotive only (excluding external positive effects on the track) is equal to €125k over 30 years, for 1 route with 1 equipped train, relative to no lubrication. This is driven by reduced wheel grinding, longer wheel asset life and higher availability of the locomotive over the 30-year period. BCR=3.20 Additional benefits on track are positive (i.e. reduced grinding needs) but are dependent on the number of locomotives and train-km in the route. These benefits have therefore been excluded from the appraisal.	• Track grinding cost savings; for the route analysed, these amount to €83.5k over 30 years, but they might only be achieved by several locomotives being equipped (i.e. this benefit should be split among the number of locomotives in the corridor) and hence have been excluded from the economic assessment • Reduced delays • Improved safety

[2] See Arup (2011) "Network Rail Materials Costs Benchmarking Study". *Network Rail and the Office of Rail Regulation - Part A Independent Reporter Mandate AO/008*

					• Reduced pollution
	Reference for further details of the full economic appraisal: NeTIRail-INFRA Deliverable D1.4, pp.37-44				
4	2.6: Heavier sleepers for transition zones	Swedish railway network	Heavier sleepers would cost approximately twice as much the cost of normal sleepers. Per transition zone, this means an additional installation net present cost of €3,779 over a 25-year period. This estimate assumes a cost of €49.4 per sleeper, 40 sleepers per transition zone and an asset life of 10 years.	For the Swedish railway, it is estimated that improving transition zone design can bring life cycle benefits of (in Net Present Value terms) €59,553 per transition zone over 25 years (i.e. €119,106 per bridge or tunnel). For the estimated costs, these benefits would imply a NPV = €55,774 (€59,553-€3,779) and a BCR = 15.7 (very high value for money). Note however that these estimates may not be applicable to other countries, and are based on the assumption that the new technology would allow asset life and maintenance of transition zones to resemble more closely that of standard track. In general, NPV > 0 if transition zone can be upgraded for less than €59,553	• Reduced delays (fewer failures) • Improved safety (fewer failures)
	Reference for further details of the full economic appraisal: NeTIRail-INFRA Deliverable D1.4, pp.45-48 and pp.86-102				

Table 2. Summary of the CBA for each innovation (WP3)

	Innovation	Case study	Investment Cost	CBA summary	Additional, non-monetized benefits
5	3.4a: Trolley wire model for overhead lines (instead of Catenary Wire model)	Bartolomeu-Zarnesti ; Romania (secondary line)	€12.2M (instead of €26.1M of the traditional Catenary Wire model based on costs from Great Britain). These estimates are based on the length of the selected case study route in Romania, equal to 24.5km	In general, NPV > 0 provided that ongoing maintenance costs are less than €702k/year (for comparison, data from Great Britain shows that ongoing maintenance costs for the Catenary wire model costs are €117k/year). Ongoing maintenance costs might not differ too greatly between the two systems. On the one hand, Trolley Wire may have potential higher failure rates due to flexibility of the system; on the other hand, this may be offset by its simplicity – fewer physical elements - leading to lower costs. If maintenance costs are similar to the Catenary wire model, we can assume €117k/year, leading to an NPV = €13.9M, relative to traditional system, which is the difference in the investment costs of the two models. These results assume that speed limit is not an issue; see next column) As a sensitivity test, in a more negative scenario, if maintenance costs were double those of Catenary Wire, the NPV would still be positive at €11.1M.	• Longer travel times (speed limit of 80km/h instead of 120km/h). For this line, the limit is 80km/h anyway, so no time loss in the short term. In cases where higher speed is desirable, the loss from time savings could significantly damage the economic case for the trolley wire model and would have to be factored in the analysis.
	Reference for further details of the full economic appraisal: NeTIRail-INFRA Deliverable D1.4, pp.48-61				

6	3.4b: On-board overhead lines monitoring	Generic analysis at route level (applicable to any electrified line); illustrative example using the Divača – Koper; Slovenia (freight line)	The total cost of this innovation is equal to €1,500 every 5 years (i.e. €3,000 over a 10-year period; €300/year before discounting is applied). When considering the temporal dimension of the investments and applying the discount rate of 3%, the Net Present Cost over 10 years is equal to €2,793 (i.e. approximately an average of €279 per year in net present value terms)	NPV > 0 if benefits (e.g. life cycle cost savings) are at least €318 per year, before discounting is applied (€279 per year in net present value terms). The size of the necessary benefits is very small relative to the expected maintenance costs of an electrified route. For instance, for the Slovenian freight line, with a length of 48 km, the British data on maintenance costs referred to in relation to Innovation 5 above would indicate an expected yearly maintenance cost of approximately €234k. In this context, achieving 1% cost savings in overhead line maintenance would mean approximately €2,340 per year, which is significantly higher than the €318 yearly costs. This plausible saving would lead to an NPV = €17.8k and a BCR = 7.3 (BCR > 4 is regarded as Very high Value for Money; see DfT, 2017).	• Reduced delays (fewer failures) • Improved safety (fewer failures) • Increased track availability
6	Reference for further details of the full economic appraisal: NeTIRail-INFRA Deliverable D1.4, pp.63-64				

Table 3.Summary of the CBA for each innovation (WP4)

	Innovation	Case study	Investment Cost	CBA summary	Additional, non-monetized benefits
7	4.1: On-track monitoring of turnouts S&C sections	Bartolomeu-Zărneşti ; Romania (secondary line)	The investment cost of this innovation is dependent on the line characteristics and number of turnouts and S&C. For this line, the cost is approximately €15,000 every 3 years plus €4,500 in running costs every year. Over 9 years, in present value terms, this means a total cost of €74,972. [The costs above are calculated for the following line-specific requirements: 96 WSDR; 35 WCDR and 35 WLRCD to cover 10 railway switches (40 WSDR), 11 bridges (44 WSDR) and 3 curves with small radius (12 WSDR)]	In general, NPV > 0 if benefits (e.g. life cycle cost savings) are at least €9,349 per year before discounting is applied (this means, €8,330 per year in present value terms, i.e. when discounting is applied). Current costs (inspection, maintenance and renewal costs) of the Romanian railway for this line are on average €215k per year. Therefore, a yearly saving of approximately 4.5% would achieve cost savings of €9.5k per year that would compensate the investment (note that other benefits in form of delays and safety would be likely to occur and would be additional to the cost savings) – see next column. 10% cost saving: in Bartolomeu-Zărneşti, a 10% saving in maintenance costs would appear plausible given the high cost of having a sub-optimal mix of preventative and reactive maintenance. This would lead to an NPV = €114k and a BCR = 2.52. However, to estimate the exact savings possible would require a detailed analysis of current practice and precisely how that would change given the new information provided by the monitoring devices. Individual railways would need to conduct this analysis to calculate a precise saving and NPV. Judgement: NPV would be higher in lines with severe corrective maintenance problems and busier lines.	• Reduced delays (fewer failures) • Improved safety (fewer failures)
	Reference for further details of the full economic appraisal: NeTIRail-INFRA Deliverable D1.4, pp.66-79				

8	4.2: Axle box acceleration (ABA), on-train monitoring system.	Generic analysis at route level (applicable to any line); Illustrative example using Bartolomeu-Zărneşti ; Romania (secondary line)	The capital cost of this technology is expected to be approximately €100k every 10 years. Additionally, it will require approximately €5,000/year in maintenance and running costs and one cable renewal (approx. €2k) required within each 10 year period. Over the 10 year-period, these costs, in net present value terms, make a total of €145,655 (i.e. an average yearly net present cost of €14.5k)	The main benefit of this innovation lies in the high-quality information provided about the track health and condition, which can be used by the Infrastructure Manager to use more proactive (less corrective) practices and minimize costs. NPV > 0 if benefits (e.g. life cycle cost savings) are at least €16,580 per year before discounting is applied, including all costs – capital and maintenance costs (€14.5k per year in net present value terms once discounting is applied). In the Bartolemu-Zarnesti secondary line (Romania), total renewal and maintenance are on average €215k per year. This means that a 7.7% yearly cost saving would correspond to €16,580 and would pay for the cost of the innovation. Other benefits (more reliable and safer services) would be additional and would help to make a case for this technology if large cost savings are not expected. 10% cost saving in maintenance costs: in Bartolomeu-Zărneşti, a plausible 10% saving would lead to an NPV = €43.2 and a BCR = 1.3. Individual railways would need to conduct this analysis to calculate a precise saving and NPV. Judgement: NPV would be higher in lines with severe corrective maintenance problems and busier lines.	• Reduced delays (fewer failures) • Improved safety (fewer failures)
	Reference for further details of the full economic appraisal: NeTIRail-INFRA Deliverable D1.4, pp.66-79				

9	4.3: Smartphones, on-train monitoring system.	Generic analysis at route level (applicable to any line) ; Illustrative example using Bartolomeu-Zărneşti ; Romania (secondary line)	This technology does not require any upfront heavy investment. The estimated net present value of the cost of installing and running the smartphones is approximately €30k over a 10-year period, i.e. an approximate average of €3k/year.	This innovation provides cheap and frequent high-level information about the track health, condition and vibration levels, which can be used by the Infrastructure Manager to use more proactive (less corrective) practices and minimize costs. Relative to the ABA system, information is expected to be more high-level and not to pick up the same level of detail in relation to defects. NPV > 0 if benefits (e.g. life cycle cost savings) are at least €3,415 per year before discounting is applied (this means €3k per year in net present value terms). In the Bartolemu-Zarnesti secondary line (Romania), total renewal and maintenance are on average € 215k per year. This means that a 1.6% yearly cost saving would correspond to €3,440 and would pay for the cost of the innovation. Additional benefits (i.e. on top of cost savings) are more reliable and safer services. 10% cost saving in maintenance costs: in Bartolomeu-Zărneşti, if a plausible 10% saving was achieved, it would lead to a NPV = €159k and a BCR = 6.3. Individual railways would need to conduct this analysis to calculate a precise saving and NPV. Judgement: NPV would be higher in lines with severe corrective maintenance problems and busier lines, but the low cost of this technology is likely to make it a good value-for-money option for secondary lines.	• Reduced delays (fewer failures) • Improved safety (fewer failures) • Potential to allow for improved comfort by reducing vibration in identified problem areas
	Reference for further details of the full economic appraisal: NeTIRail-INFRA Deliverable D1.4, pp.66-79				

The overall insights of the distinct CBAs, summarised in the table above, will be discussed under separate headings that highlight the key outcomes.

Affordable solutions

The first important outcome of the CBA is that we provide an estimate of the costs of implementing each innovation, allowing IMs to assess their affordability from a financial perspective. Providing affordable solutions was one of the aims of the project, and it is particularly important in a context of increasing financial pressures. Secondary rail lines can struggle to make the case for their existence due to limited demand, even if sometimes they serve as critical links for the community. Fortunately, the development of cheaper technologies for the construction and maintenance of lines can substantially help to increase the viability of those lines.

In some extreme cases, we have shown that innovation can literally even be free: this is the case of designing a better way to assemble and install switches and crossings, which comes at no extra cost. The observations carried out by the NeTIRail-INFRA team led to the development of improved planning of those activities, with our CBA showing that the benefits can be substantial. For instance, even under some mild changes and assumptions, a railway IM could do all the necessary switches replacements in a year using only 75% of the time taken with current practices. The cost savings, largely proportional to labour costs, can be at least €2.4M in the Turkish context; and up to €5.8M in the most optimistic scenario per year. Countries with higher labour costs would see proportionally larger benefits from the implementation of the proposed lean techniques. More importantly, this innovation highlights the immense possibilities the railway has to improve its performance simply by looking into the details of operations that, sometimes, might have been taken as unchangeable. Lean techniques have been adopted in many other sectors outside railways of course.

The majority of innovations do have a monetary cost associated to them – as would be expected – but this is relatively minor and can generally be deemed to be affordable. Of course, this would vary by context, but we have tried to generate general costings where possible, in the spirit of making NeTIRail-INFRA economic research transferable to the wider industry and contexts across Europe and worldwide. For instance, two of the monitoring devices developed (see innovations 6 and 8) cost no more than £300 and £3,000 per year respectively. Even if these are not the most powerful devices available in the industry, they can certainly provide a useful technology for lines which otherwise might not have access to frequent monitoring of the line conditions.

On the other hand, some of the technologies do have a substantial up-front cost, but the associated cost savings – as we shall see in the next paragraphs – is what can make them affordable. This is the case of the trolley wire model, which can cost at least €12M for a 24km line. However, if there is a need or a desire to electrify a line, trolley wire investment costs can be around 40% of the cost of the more traditional catenary wire system. Therefore, even with significant increases in maintenance costs, this has the potential to be a cheaper electrification system. Of course, the development of battery technology and bimodal trains may alter the economics around choice of overhead line solution and could possibly make the trolley wire model un-economic. The cutting-edge technology of this area is advancing fast and we have not considered it as part of the NeTIRail-INFRA project.

Similarly, the Axle Box Acceleration (ABA) monitoring system will have an up-front cost of approximately €100,000 but has proven extremely powerful in detecting defects (see the NeTIRail-INFRA Deliverables from WP2, which contains all the details of the tests conducted in Romania). This sophisticated and powerful technology can help to substantially bring costs down so that the €100,000 investment could easily be seen as affordable in the medium to long term. It must also be noted that, in some contexts, this cost may be low compared to existing alternatives such as the purchase and operation of a dedicated track recording vehicle, or the hire of a vehicle (e.g. Slovenian railways currently hires a track recording vehicle from Hungary for periodic track measurements).

Finally, some innovations tackle, at low cost, long-standing issues such as the higher costs associated with certain parts or components of the track. This is the case of the heavier sleepers for transition zones or the development of different fastening systems. The econometric analysis conducted as part of WP1 provided the first available estimates – to the best of our knowledge – for the potential for cost savings in relation to those elements. Due to the complexity of these effects and lack of data analysis in the industry, so far it was unclear the extent of costs savings that could be achieved by improving transition zones and by different fastening systems. The outcomes gives scope for a wide range of investment costs that would allow an overall positive business case assessment to result; certainly, the current estimates for the costs of the innovations are low relative to the potential gains, leading to positive NPV and BCRs. This would of course be context-dependent, and it is the duty of the respective IM to further investigate the precise scope for savings in different contexts.

Unlocking life cycle cost savings

The most important impact of all innovations considered within the scope of NeTIRail-INFRA relates to the savings in maintenance costs they can generate. They all have potential to unlock substantial economic benefits, at the very least in the form of cost savings but also notably through reliability and safety improvements for rail users.

In order to understand the potential of savings, it is necessary to have a deep understanding of the life cycle of rail investments. Maintenance and renewal activities are a target at the core of all innovations. In all cases, we observe that the innovations can impact on the amount of work needed to maintain a rail line and can help to extend the life of different rail components. For example, it is well known that transition zones are a source of additional costs for rail track maintenance and renewals, and the technical work conducted by NeTIRail-INFRA can pave the way for solutions that reduce the need for those activities to take place. Using econometric methods, we have identified the magnitude of the cost savings that would be achievable, hence putting a cap on the amount of resources that should be destined to improve this problem and, hopefully, providing precise economic incentives to IMs to tackle it. This econometric work – which uses data on actual track maintenance costs for different track sections in Sweden, together with information concerning the traffic on and characteristics of the sections – is a very powerful complement to bottom-up engineering understanding of how different technologies / approaches impact on costs.

Similarly, the CBAs have shown how the choice of fastening systems can also bring cost savings. We have provided new econometric evidence on the potential magnitude of these cost savings for a particular comparison of two types of clips. Our innovative approach and evidence in this area demonstrates the value of collecting and analysing detailed cost datasets with the aim of informing policy-making, even for what may seem to be "simple" choices such as those concerning clips and pads.

Other sources of cost savings, such as the use of lubrication techniques, are not new to the industry. However, the existing evidence of the consequences – the benefits – of using different ways to lubricate tracks and/or wheels is limited and it is important to keep in mind that, although lubrication is already widely used, these systems continue to evolve and some lubrication systems may be more beneficial than others. Nevertheless, we have developed new evidence of impacts in new contexts as part of the project.

Finally, some of the innovations – namely those related to monitoring techniques – have a very large, but not so easily quantifiable, potential to unlock cost savings. These are discussed under the next heading, as they all share one particular feature: to generate cost savings, monitoring technologies are not "self-sufficient"; that is, they need actions (changes in working practices) of the IM to take place.

Technology as a complement to actions

The CBAs highlight that some technologies require action of the IM to unlock their potential. This is especially the case for monitoring technologies (innovations 6 to 9 in table 1 above). The key here is to realize the two distinct types of maintenance and renewals activities. A certain activity (say tamping) is preventive if it is planned in beforehand in order to reduce the risk for malfunction. The same activity is corrective if it is triggered by functional deficiencies with the infrastructure.

The value of monitoring technologies is in the information they provide. The information about track conditions or specific assets of the line can be used by the IM in order to increase the focus on preventive and reduce the volume of corrective action. This is the way that could unlock the potential of the monitoring technology.

For this reason, effective data processing and communication is essential. But this is not sufficient. Rather, the challenge in doing a CBA for this type of technology is the uncertainty surrounding what actions the IM will take upon having received the newly generated information. We believe that the most effective way of assessing these technologies is to use the DfT (2017)'s switching values approach, by which we estimate what the annual benefits need to be in order to compensate the investment costs over the life of the asset and with appropriate discounting for time.

The information provided by the NeTIRail-INFRA monitoring devices can help IMs to increase their preventive maintenance and activities, and consequently reduce the need for corrective work. Noting that corrective work typically arises after a failure has occurred, it is normally costlier in monetary terms but it also is associated with lower quality in the provision of rail services (analogies also exist in the health sector, where poor care can lead to patients accessing expensive emergency services (see Gutacker et. al., 2013). As part of the project, we also conducted academic research to investigate the relationship between costs and quality, showing that it is sometimes possible to improve quality (e.g. reliability) while also reducing costs. In other words, it may not be necessary to invest extra money to improve the reliability of a line: in some instances, understanding the underlying sources of poor quality (e.g. frequent failures and delays) can help you tackle the problem without incurring additional costs or, even better, saving costs (see Smith and Ojeda-Cabral, 2017, Deliverable 1.7 Annex 2).

The CBAs of the monitoring technologies show that even small yearly cost savings (e.g. £3,400 annual saving in the case of the smartphones technology) could justify the investment of fitting one train. In the case of the most expensive (and also most powerful) device, the ABA system, yearly benefits of €16,600 would make the investment worth it from an economic perspective. It is easy to imagine how this figure can be easily achievable for many lines, especially those with regular track defects and consequently high corrective costs. For instance, in the example of the secondary Romanian line of Bartolomeu-Zarnesti, the €3,400 and €16,600 figures would correspond to annual cost savings (inspection, renewal and maintenance included) of 1.6% and 7.7% respectively (and noting that cost savings would not be the only benefit, as reliability and safety benefit would occur alongside, strengthening business cases in cases where cost savings alone do not justify the investment). Also, other monitoring devices can also be added to obtain additional information of critical parts of the track such as switches and crossings (e.g. innovation 7) or on overhead lines (innovation 6). In general, each of these devices has a huge potential to unlock cost savings if the IM uses the information to switch to a more preventive maintenance strategy, reducing the typically more expensive corrective practices.

Generating user benefits

On top of generating cost savings, almost all innovations have also the potential to bring benefits to rail users. For example, using again the case of the monitoring devices, the reduction in failures can lead to less delay incidents and more safety (e.g. less derailments). For the ABA system, it is easy to see that the value of avoiding derailments and reducing delay incidents to rail users can certainly be higher than €16,000 per year, even for small delay reductions. For instance, we showed that, for a Romanian line, every 100 minutes of delay saved (in total, in a year) for 75 passengers[3] can be valued at almost €900. Hence, even in the absence of cost savings, it is likely that user benefits alone might justify some investments. More widely, obtaining improved and more timely information at lower cost can facilitate a reduction in the imposition of speed restrictions, which can create an additional benefit to users (where in the absence of this technology, a speed restriction would need to be imposed pending data from a more expensive measurement train).

Unfortunately, we could not calculate the precise impact of the technologies on user benefits such as delays because of lack of data. However, we have provided an illustration of how those benefits could be incorporated into the assessment if the appropriate data was available (e.g. see delays example for Romania above). If the IM has information on how many minutes of delay a technology could actually save, the estimates provided in D1.4 could be used to monetize this benefit. Partly to address the lack of quantification, the importance of user benefits will be discussed in more detail as part of the societal analysis. This has been possible thanks to surveys collected in the case study lines of the project, which gave us insights into the importance and satisfaction levels of users in relation to key rail attributes such as reliability or safety. Qualitative analysis has been performed to gain insights into the potential societal impacts of the innovations. The results are best interpreted as an illustration of the role that the innovations can play for users in the case study lines.

2.3 Take-away messages from the CBAs

While the overview of each independent CBA was provided at the end of each sub-section, there are several take-away messages that emanate from looking at the overall results of the different analyses. This is the aim of this final section.

[3] 75 passengers is approximately the average train load in the case study line.

First, we have seen how the status quo of any railway in terms of operation, inspection, maintenance and renewals is never fixed, and technology can help to improve the existing situation to save resources and/or improve quality (e.g. safety, reliability, etc.). Understanding the current situation is therefore essential to understand what elements in the system can or should be altered to move forward.

Secondly, our analyses show that achieving life cycle cost savings and improvements in quality can sometimes be achieved with very low or even no upfront monetary investments. This reflects one of the initial objectives of NeTIRail-INFRA, which was to develop affordable improvements for railways that would normally struggle to innovate. For instance, observing the way in which switches and crossings (S&C) are currently assembled and installed, led to a rethinking of current practices, in a way that could help Infrastructure Managers to make more efficient use of the workers and track at zero monetary cost and without impacting on worker safety.

Another example is the use of new techniques for monitoring the quality of both the quality of tracks and structures and overhead lines. Newly developed monitoring devices can be as cheap as a smartphone and can generate very valuable information to IMs and operators. If used adequately, the information can promote a more preventative maintenance and renewals strategy that would save substantial amounts of resources to the railway and would improve passengers' experience, e.g. by avoiding failure-related delays.

Thirdly, even when a technology has a substantial financial cost upfront (e.g. the powerful ABA system for track monitoring), the potential benefits can be very large. This highlights the importance of allowing a good system of incentives in the industry that facilitates investments in innovation where the effects are in the long-term and where the costs and benefits may cross institutional boundaries (e.g. infrastructure managers and operators).

Finally, the economic analysis of technological advances in specific elements of the system, such as transition zones or the electrification of lines, have highlighted that sometimes the necessary knowledge might not exist at the level of detail that would enable IMs to make optimal choices. For example, even though it seems to be widely understood that transition zones are more expensive to maintain than the straight line, there is little evidence on what the size of the additional cost is). Similarly, cheaper forms of electrification are possible, but not much is known about the potential associated maintenance costs of those (in principle cheaper) techniques.

We have also tried to fill some gaps in the existing economic understanding of a wide range of railway infrastructure elements through using econometric methods – these derive top-down estimates of how different technologies / approaches impact on actual observed costs on different track sections.

Overall, the CBA analysis, though conducted at a relatively high level, , suggests good possibilities for the technical innovations developed in NeTIRail-INFRA, when viewed from an economic cost-benefit analysis perspective. We now consider the societal perspective, and bring that together with the CBA analysis.

3. Synthesis of societal analysis

This section synthesises the research conducted on the societal implications of the NeTIRail-INFRA innovations as part of WP5. Full details on this research can be found in Deliverables D5.1 (Societal and legal effects of transport decision: Stakeholder analysis), D5.2 (Perception of different service options: User study and data analysis), and D5.3 (Balancing societal effects and cost-benefit of different infrastructure decisions).

3.1 Approach

The basic idea of the societal impact assessment (SIA) conducted in NeTIRail-INFRA is to introduce considerations of equity in the assessment of transport innovations. Cost-benefit analysis would select innovations on the basis of economic efficiency; however, how the costs and benefits of projects are distributed between different groups in society is also important.

The partners (led by University of Freiburg) started by identifying the key values at stake (See NeTIRailL-INFRA D5.1) and decided to focus in our evaluation on accessibility for passengers, understood as the possibility for them to reach destinations important for education, employment and health care. The second step in the project consisted in understanding passengers' perceptions of the current railway service on selected NeTIRail-INFRA case-study lines, as well as their use characteristics and the importance passengers assign to different travel aspects. To this aim a survey was conducted involving more than 1000 respondents in three countries (Slovenia, Romania and Turkey). The survey results have been presented in the NeTIRail-INFRA D5.2. The third step consisted in evaluating the planned NeTIRail-INFRA innovations with respect to accessibility and in the light of passengers' perspectives. For each designed innovations, a SIA was carried out in a specific context, i.e. for a NeTIRail-INFRA case-study line (See D5.3). The assessment contains a provisional quantification, however, the final evaluation is qualitative.

3.2 Summary of research results on the societal impact

The SIA of each innovation takes into account three components, namely:

1. The objective effects that each innovation is expected to have on travel aspects such as crowding, comfort, safety, punctuality, frequency of trains and scheduled journey times. Although, in principle, changes in these elements derived from new technology could be measurable (for instance, an increase in punctuality of 10%), in NeTIRail-INFRA we had to rely on estimations provided by the NeTIRail-INFRA consortium (e.g. engineers developing technology) on the basis of literature and personal expertise.
2. Passengers' perceptions[4], including the importance assigned by passengers to the relevant travel elements (e.g. punctuality, safety and so on), and their level of satisfaction with the current situation. This component of the evaluation is based on the results of the NeTIRail-INFRA survey on the case study lines and is line-specific.
3. The selected line's characteristics, which take into account passengers' use characteristics on that line and should mirror the social significance of that route as far as accessibility to

[4] The focus of the analysis was primarily on passenger travel and not on freight travel.

education, work and health care is concerned. This part of the evaluation is based on the results of the NeTIRail-INFRA survey on the case study lines regarding use characteristics. This part of the assessment is also the one particularly important for addressing issues of justice and distribution of benefits and costs. Indeed, it calibrates the assessment on the basis of information regarding train use. Specifically, this part of the assessment reflects the idea that innovations changes are differently assessed if they significantly affect groups of passengers that rely on train use for travelling to school, university, the work place or hospitals and doctors. In principle, it is also possible to include into the assessment a score "special demographic" which evaluates whether the considered change particularly affects specially protected or disadvantaged groups. This aspect has been introduced into the methodology part, but not applied in practice when carrying out the assessment, because the survey results and the innovation characteristics led us to assume that no impact on specially protected or disadvantaged groups is to be expected. For more details see D5.3, section 2.1.2 "Quantification methodology".

The table below recapitulates the results of the societal impact carried out in D5.3, by giving an overview of the evaluation of the NeTIRail-INFRA innovations on selected lines. It is important to stress that the following table does not rank innovations against each other in any generic way but instead provides line-specific assessments of the social value of each innovation for that particular line. In other words, for any given innovation, its SIA score may well be very different if the line chosen as case study was a different one.

Innovation	Line for the SIA	SIA score
2.3: Lean techniques for S&C	Sincan-Ankara-Kayaş	1,38
2.4: Choice between different fastening systems	Sincan-Ankara-Kayaş	2,97
2.5: On-board lubrication techniques	Pivka - Ilirska Bistrica	4,09
2.6: Heavier sleepers for transition zones	Ljubljana-Kamnik line	3,76
3.4: Trolley wire model for overhead lines (instead of Catenary Wire model)	Divriği- Malatya	-0,67
4.1: On-track monitoring of turnouts S&C sections	Bartolomeu-Zărneşti	4,81
4.2: Axle box acceleration (ABA), on-train monitoring system	Bartolomeu-Zărneşti	4,81
4.3: Smartphones, on-train monitoring system.	Bartolomeu-Zărneşti	5,28

Table 3.1 – Summary of SIA and CBA for each innovation

Broadly categorising, the table shows three levels of scores:[5]

- a low segment (red background colour, scores < 2) containing the innovations in T2.3 “lean techniques for S&C” evaluated on the Sincan-Ankara-Kayaş route and T 3.4 “trolley wire model for overhead lines” evaluated on the Divriği- Malatya line;
- a medium segment (yellow background colour, scores between 2 and 5) containing most of the innovations: T 2.4 “tailoring track to avoid corrugation” evaluated on the Sincan-Ankara-Kayaş line; T 2.5 “optimal lubrication techniques” on the Pivka - Ilirska Bistrica line; T 2.6 “new design for transition zones” evaluated on the Ljubljana-Kamnik line, T 4.1 “on-track monitoring of turnouts S&C sections” and T 4.2 “Axle box acceleration”, both tested on the Bartolomeu-Zărneşti line;
- a higher segment (green background colour, scores ≥ 5), consisting of T 4.3 “smartphones, on-train monitoring” tested on the Bartolomeu-Zărneşti line.

The final score of an innovation on a given line is influenced by all the three factors mentioned above (objective effects; passengers’ perceptions; line characteristics), so that the reasons why an innovation scores low, medium or high on a given line can be very different. We focus below on the bottom and top segments to illustrate which factors have influenced the final assessment and discuss them also taking into account the results of the economic analysis.

3.3 Societal impact discussion and linkage to economic analysis

This section discusses some of the main outputs of the societal impact - summarised on the table 3.1 above – linking them to the economic analysis results (see section 2). The aim of this section is to briefly showcase the implications for the community around the case-study lines of the NeTIRail-INFRA innovations. The analysis is line-specific and any attempts to generalize the results shall be made carefully. All details of the combined discussion of societal impacts and economic analysis can be found in NeTIRail-INFRA Deliverable 5.3

It must be reiterated that the societal impacts discussed above (and below) were not part of the quantified element of the Cost-Benefit Analysis. This is important as some of these societal impacts would typically be a part of the CBA (e.g. passenger time-related changes). For this project the CBAs primarily covered the investment and life cycle costs changes, and due to data limitations we did not quantify and valued the identified user benefits. This is the reason why Table 1 in this report includes standard user benefits within the ‘additional non-monetized’ benefits, and also why some of these are analysed as part of the societal impact assessment.

[5] It is important to stress that the range of possible scores is much broader than that, ranging from a minimum of -22 to a maximum of 22. However, it is very unlikely to reach these scores in practice, since they imply that a given innovation has a high impact (either positive or negative) on all travel aspects, that passengers in the current situation are dissatisfied with all travel aspects *and* that the route has a high societal significance in term of accessibility.

In the low sector of SIA scores we have the innovation “trolley wire model for overhead lines” on the Divriği- Malatya line, which scores – 0,67. This result is due to the fact that this innovation could bring about a worsening of the aspect “travel times”, since the maximal speed allowed on the line, by introducing this innovation (compared to the “do-minimum” scenario, which is the traditional catenary wire), would decrease from 120 to 80 km/h. This would worsen an aspect (travel times) which, according to our survey, is already seen as an issue by passengers on that line: indeed this is the travel aspect with which levels of dissatisfaction are highest. This negative impact would only partially be compensated by an improvement of punctuality, so that in the end we have a negative SIA score. In this context, it may well be that IMs decide that the investments associated with this innovation are not worth the expected benefits. However, this innovation can be beneficial from both a societal and economic perspective when applied to lines where a limited maximal speed of 80 km/h does not constitute a problem. This is potentially the case for the Bartolomeu-Zărneşti line used as a case-study in D 4.1 to conduct the cost-benefit analysis.

The other innovation scoring low in terms of SIA, the T 2.3 innovation “lean techniques for S&C” on the Sincan-Ankara-Kayaş route, has a different background. The low score is due to the fact that the planned innovation has a medium positive impact only on punctuality and no impact on any other travel elements. Punctuality does not seem to be an issue on this line, since our survey showed that passengers are already quite satisfied with the current situation. However, due to the fact that the economic analysis showed that this innovation has no monetary costs and substantial economic benefits in terms of efficiency for the IM, an IM can establish that it is worth implementing it, even if the expected societal impact is positive but limited.

The innovation which scores highest among our sample is the T 4.3 innovation “Smartphones, on-train monitoring” applied to the Bartolomeu-Zărneşti line. This line has a high societal significance for accessibility, being a line used by a high share of passengers travelling for employment, educational or health care purposes and who rely on train as only means of transport to reach their destinations. On the other hand, passengers on this line are already quite satisfied with the travel aspects in the scope of our survey, but, among them, the aspects “punctuality” and “safety” are the ones for which the discrepancy between importance and satisfaction, as seen by passengers, is highest (in other words, surveys may be pointing out that for critical travel aspects there might always be scope for improvement). The innovation “smartphones, on-train monitoring” is expected to have an impact exactly on these two elements, in addition to travel comfort, so that the final score for this innovation on this line is relatively high. From an economic perspective, this innovation requires negligible upfront investments (see section 2 and Deliverable D1.4), so that it can be seen by IMs and railway operators as a meaningful way to collect relevant information for improving the service.

The rest of the innovations have relatively positive SIA scores. These qualitative SIA scores can be interpreted as hinting that the technology in question is beneficial from a societal perspective for the case study lines, above and beyond the life cycle costs benefits calculated as part of the quantified element of the CBAs. The SIAs help, in this case, to shed some light on the identified but non-quantified user benefits such as punctuality or safety improvements.

3.4 Contribution beyond the state of the art

The NeTIRail-INFRA WP5 provided a methodology to assess the societal impact of railway innovations, as well as a framework to combine the results of the societal and the economic assessment. Regarding the societal impact, the methodology presented contributes to the research aiming to integrate considerations of justice and equality into the evaluation of transport policies.[6]

We understand the contribution of the work done in WP5 to be twofold. First, in a specific meaning, it provides a preliminary assessment of the innovations developed in NeTIRail-INFRA on selected case-study line, so that IMs and operators have an element more to decide on the feasibility of the innovations on those specific lines. Second, WP5 also offers a more general contribution, by presenting a methodology that can be applied to both ex-ante and ex-post evaluations of transport innovations beyond the scope of the NeTIRail-INFRA project.

Concerning the use of the results of policy guidelines, is important to stress that the SIA scores provide a quick overview of the expected societal impact of each innovation on a given line, but an explanation and a further qualitative overall evaluation, as demonstrated in the previous section, is needed in order to provide a base for decision making. Moreover, the societal impact assessment can be conducted only in context, i.e. with reference to a particular line, its use characteristics and passengers' perceptions. However, with caution, it is possible to tentatively generalise the results achieved regarding a particular context to lines with similar characteristics.

[6] See among others Di Ciommo, Floridea, Shiftan, Yoram, Transport equity analysis, in: Transport Reviews, 37/2, 2017, 139–151; Martens, Karel, Ciommo, Floridea Di, Travel time savings, accessibility gains and equity effects in cost–benefit analysis, in: Transport Reviews, 37/2, 2017, 152–169; Martens, Karel, Transport Justice: Designing fair transportation systems. : Routledge 2017https://www.routledge.com/Transport-Justice-Designing-fair-transportation-systems/Martens/p/book/9780415638326, gesehen am 28.2.2018; Mladenović, Miloš N., Transport justice: designing fair transportation systems, in: Transport Reviews, 37/2, 2017, 245–246; Pereira, Rafael H. M., Schwanen, Tim, Banister, David, Distributive justice and equity in transportation, in: Transport Reviews, 37/2, 2017, 170–191; van Wee, Bert, How suitable is CBA for the ex-ante evaluation of transport projects and policies? A discussion from the perspective of ethics, in: Transport Policy, 19/1, 2012, 1–7; Van Wee, Bert, Roeser, Sabine, Ethical Theories and the Cost–Benefit Analysis-Based Ex Ante Evaluation of Transport Policies and Plans, in: Transport Reviews, 33/6, 2013, 743–760

4. Synthesis of wider economic effects analysis

This section summarises the research from Task 1.4, reported in Deliverables D1.5 (Wider Economic Benefits intermediate report) and D1.6 (Wider Economic Benefits final report).

Economic impacts of rail investments typically stem from improvements in accessibility based on changes in generalised cost which generate benefits to rail users (user benefits). Sources of wider economic benefits (that are additional to transport user benefits) are increased productivity agglomeration, increased output in imperfectly competitive markets and changes in employment. The relevant market failures and transmission mechanisms for measuring these impacts and the associated valuation approaches have been outlined in D1.6. Here we have transferred models used elsewhere to capture the agglomeration impacts and imperfect competition effects.

In the main the proposals under consideration by NeTIRail-INFRA will improve the delivery of rail services through cost decreases (e.g. maintenance and renewal costs) and improvements in reliability (e.g. reduction in delay minutes). Such improvements in reliability can potentially be converted into generalised cost and economic impacts measured through associated accessibility improvements. We have outlined how these could be estimated in D1.6, both through impacts on agglomeration and employment.

With the exception of lubrication techniques, reliability improvements associated with the innovations have been identified and qualitatively assessed in D5.3. However, these have not been quantified in the CBA in D1.4, i.e. a user benefit has not been quantitatively identified due to the lack of data on existing delay information on the case study lines. Consequently, it is not possible to estimate the extent of the wider economic impacts associated with these innovations through the application of the approaches in D1.6.

D1.4 shows that many of the innovations are likely to mainly generate cost savings to the rail infrastructure or operator. To the extent that these are passed on in terms of fare reductions or in terms of improved train performance, these will generate wider economic benefits. Given the case study lines are state-owned, pass-through is more likely. However, this is a long-term proposition as most of these lines will currently be sustained through operating subsidies.

If the NeTIRail-INFRA innovations were to be adopted, there is scope for a more detailed CBA with a more detailed specification of the service quality improvements and cost savings to derive user benefits from a demand based model; which could utilise the findings from D1.6. Suggested model parameters pertinent to Eastern Europe have been drawn from the literature and presented to give a set of models that can be used to estimate the wider economic impacts of the NeTIRail-INFRA innovations.

4.1 Further research

We have made a significant contribution to the discussion on the employment effects of rail investments. Unpicking the results found potentially offers some fruitful avenues for further research. The interaction between employment effects and rail only and rail plus land use investments is one area. A second area is focusing on the development of employment models that can be used easily in appraisal and transferred between projects – for example one based on changes in economic density.

In our literature search on parameters for the agglomeration effects and imperfect competition effects we also found that there is limited evidence on these effects in east European countries. There therefore remains the need to develop that evidence base too.

5. Synthesis of incentives analysis

This section provides a summary of the work conducted in Task 1.5 on the incentives for implementation of railway innovations. Deliverable D1.7 contains all details on this strand of research.

A key purpose underpinning the workstream in Deliverable D1.7 is the recognition that for innovations to be developed and implemented, the right incentives need to be in place for key industry actors. This is particularly the case in vertically separated railways – but even within more integrated structures, such as the holding company model – where costs may be incurred by one part of the industry, with the benefits felt elsewhere. Further, infrastructure managers may be subject to incentives induced by economic regulators and through multi-annual agreements with governments, with a focus in some cases on a 5-year control period (as in Britain). On the other hand, some train operators may have short-term perspectives, for example based on the length of the franchise, which in many cases will be less than 10 years (and where investments take place close to the end of a franchise, operators will have a very short-term perspective).

Considerable efforts have been made across Europe through the track-access charging frameworks, regulatory models, multi-annual agreements and performance regimes, to align the incentives of different industry players and give the industry incentives to reduce cost and improve performance. It is against this backdrop – given that at least some of the NeTIRail-INFRA innovations require up-front investment, and most involve benefits that accrue at least partly elsewhere – that a programme of research on incentives has been incorporated into WP1.

Deliverable D1.7 developed the research frontier in several areas with results that are both generalizable and have specific relevance to the case study countries and to the innovations being developed in the other work packages.

In Annex 1, through literature review and interviews across several countries, two primary barriers to innovation and efficiency were found to be: (1) fragmentation, leading to a misalignment of incentives between different parts of the industry where the costs may be carried by one party and the benefits felt by another; and (2) regulatory and franchising arrangements leading to a short-term focus in place of a focus on life cycle costs. Given that EU countries are required to introduce competition for passenger services, which for public service contracts will mean increased adoption of franchising, there are important lessons here for the case study countries.

Whilst the introduction of competition can lead to cost reduction and potentially innovation, short-franchises, combined with a vertically-separated rail infrastructure manager facing regulatory targets, can cause significant challenges for co-ordination of innovation and investment and a focus on short-term cost reductions at the expense of sensible long-term planning. Funding constraints imposed by government can also have this effect, making it more cost effective in the short-term to favour maintenance over renewals. In principle, an independent economic regulator could play an important role here in terms of ensuring a longer-term focus and potentially encouraging co-ordination, but there may be limits to what can be achieved in practice. Of the three case study countries in this project, only Romania has a vertically separated structure.

In Britain, the debate continues as to how Network Rail should be regulated. At a House of Commons Transport Committee Enquiry on Rail Infrastructure Investment, consideration was given to whether the 5 year control periods are long enough for Network Rail to plan, and also to give certainty to its supply chain. Professor Andrew Smith, WP1 leader, gave evidence at the Transport Committee in March 2018, and noted (based on the work done as part of Deliverable D1.7), that 5 year cycles are adopted in other multi-annual agreements, as for example in Germany[7]. It should be noted that, as compared to the situation where an infrastructure manager is subject to annually imposed cash limits, dependent on the state of the government's finances, 5 year funding certainty is a substantial improvement. Funding certainty, overseen by an independent economic regulator with a focus on efficiency, should provide both strong incentives for infrastructure managers, whilst also ensuring sufficient investment to keep the network in good health.

Importantly, contractual mechanisms (track access charges and performance regimes, if calibrated correctly, can play an important role in aligning incentives within a separated structure. However, in general across Europe there is a lack of differentiation of track access charges for different vehicle types (Britain being an exception). Greater differentiation of track access charges should encourage the development of vehicle designs that do less track damage as the incentives of operators would be more closely aligned with the infrastructure manager. A wider issue is the fact that there are substantial differences in approaches to setting charges across Europe, resulting in widely different levels. Engineering approaches give considerably different results to those from econometric models (we return to this point below).

As an alternative to vertical separation, many countries across Europe have adopted a holding company model, including Germany, France and Slovenia (Turkey also has a structure similar to the holding model). Through the interviews conducted as part of the research reported in Annex 1, it is clear that the holding model can offer solutions to the co-ordination in principle and in practice (if the holding plays a significant co-ordination role); however, this model could also reduce the extent of new entry, which in turn could hamper innovation.

It should be noted that the results indicate that, in general, the innovations studied as part of the project can probably be justified in terms of the cost savings to the infrastructure manager (see Section 2). Therefore, for the NeTIRail-INFRA innovations, whilst there may be other benefits that accrue to train operators and others (including users), for example through improved safety, reduced speed restrictions and fewer delays, the up-front investment cost (typically small) of the innovations can mainly be justified in terms of cost savings to the infrastructure manager. Therefore, whilst the incentives research produces important generalizable findings in respect of incentives structures and mechanisms that may support rail innovation, the findings in respect of the innovations studied here are more muted. Nevertheless, it is still the case that in one of the case study countries, Romania, there is a vertically separated structure which could result in problems for investments that do depend on benefits arising beyond the company paying for the investment. The general findings regarding mechanisms that support long term investment in railways subject to tight funding constraints are also relevant, as most of the innovations involve at least some (if generally small) up-front investment.

Turning to the research contained in the other annexes of Deliverable 1.7, Annex 3 is specifically concerned with developing a new method for estimating the relative cost of damage imposed by different rail vehicles. Such research is important because it is not sufficient to recognise that track

[7] https://www.parliament.uk/business/committees/committees-a-z/commons-select/transport-committee/news-parliament-2017/rail-infrastructure-evidence3-17-19-/

access charges should be differentiated by vehicle type it is also necessary to calculate those relative costs. Annex 4 is concerned more with the general variability of rail infrastructure costs with respect to traffic (needed to calibrate track access charges) and offers a means of obtaining better estimates when an individual country has limited data available for estimation. Such an approach could be useful for the case study countries where obtaining disaggregate data has proved to be a challenge. Annex 5 likewise proposes methodological enhancements to better estimate marginal costs of rail infrastructure usage, with a view to developing more cost reflective access charges.

Strengthening the evidence base in this area is important for EU countries (given the legislation), but also to any railway seeking to set access charges based upon marginal wear and tear costs (and indeed to Turkey which seeks to align its policy with EU legislation). The importance of developing the evidence base and approach for setting charges was highlighted at the Track Access Charges Summit in Amsterdam[8], where some aspects of the NeTIRail-INFRA research were presented. A key issue, and the focus for the presentation by University of Leeds, was the issue of how engineering approaches compare to econometric methods and why the results can differ. The approach developed in Annex 3 seeks to harness both methods into a single methodology, aiming to capture the strengths of both. The fact that data might be limited for some countries was also discussed at the Summit. Annex 4 specifically addresses that point by showing how limited datasets in a given country could be used to understand cost variability with respect to traffic - and in turn track access charges - by incorporating evidence from other countries directly into the modelling approach.

Finally, Annex 2 focuses on a particular aspect of cost modelling that is relevant to many of the innovations – namely the relationship between cost and quality. It may not be possible to directly apply this analysis to the case study countries because of a lack of data available on the relevant quality metrics (e.g. delay minutes for the case study lines). However, this work points not only to the idea that improving quality is likely to require increased preventative costs, but also to the possibility of a lose-lose scenario, where quality is poor and reactive costs are so high as to lead to a situation where quality is low and overall costs are higher than they need to be. Similar relationships have been observed in the health sector.

Overall, what becomes clear is that not only should there be a strong overall business case for an innovation to be implemented (as shown by CBA), perhaps supplemented by a strong societal case, there needs to be a financial case for different players in the industry. The extent to which this financial case can be made will depend on the structure of the industry and how it is regulated, and on the particular incentives created by, inter alia, track access charges and performance regimes.

[8] https://events.railtech.com/track-access-charges-summit-2018/

6. Conclusions

The NeTIRail-INFRA project has developed a variety of railway technologies to achieve the overarching goal of providing affordable solutions for the railways. This report summarises the multiple outcomes from an extensive analysis about the impacts and potential of the developed technologies. The analysis has covered all economic aspects through a cost-benefit analysis (Deliverable D1.4); a societal impact assessment (D5.2 and D5.3) and discussion of potential for wider socio-economic impacts (D1.6); and an in-depth investigation of the incentives and barriers for innovation in the railway (D1.7). Deliverable D1.8 hence synthesizes and brings together all these elements of the economic, political and social assessment of the NeTIRail-INFRA railway innovations.

In most (if not all) industries, technological innovations may improve efficiency and productivity and can make goods and services more accessible to all. This certainly holds true for the transport sector and, in particular, the railways – the context of our research. However, the implementation of engineering technologies often comes with great uncertainties and can involve substantial investment. Therefore, an economic understanding of the implementation and impacts of technologies is necessary. This is particularly relevant to the railway industry where technical leaps may be very costly and where it accordingly is more necessary to provide both a financial rationale (for the infrastructure provider) as well as a wider economic motive for large investments. Furthermore, railways can play a crucial social role in bringing communities together and enabling good access to basic human needs such as education, employment or health. Consequently, societal implications are also at the heart of assessing innovations.

The NeTIRail-INFRA technologies are varied and have been shown to contribute to a number of aspects: rail track and overhead line monitoring, transition zones, fastenings systems, lubrication systems, electrification methods or switches and crossings. A very brief overview of the analyses conducted could start by highlighting that life cycle cost savings and improvements in quality of services can sometimes be achieved with very low or even no upfront monetary investments. Among all new technologies, the potential socio-economic benefits cover reductions in maintenance and renewals costs, better and more information about track conditions – at small cost - reliability improvements, safety benefits, optimised use of capacity via greater track availability and noise and pollution reduction. All details about the precise costs and benefits – economic and societal – can be found in D1.4 and D5.3 deliverables.

Yet, the potential of all these benefits might be locked by industry structure and it is critical to ensure innovation can occur by working together to lift the barriers. This was precisely one of the key outcomes of the NeTIRail-INFRA analysis of incentives for innovation in the railway, where – in general - industry fragmentation and regulatory-led short-term focus were found to be two significant barriers for innovations across several European countries. It should be noted that the results indicate that, in general, the innovations studied as part of the project can probably be justified in terms of the cost savings to the infrastructure manager (see Section 2). Therefore, whilst the incentives research produces important generalizable findings in respect of incentives structures and mechanisms that may support rail innovation, the findings in respect of the specific innovations covered in the case studies here are more muted. Nevertheless, it is still the case that in one of the case study countries, Romania, there is a vertically separated structure which could result in problems for investments that do depend on benefits arising beyond the company paying for the investment. The general findings regarding mechanisms that support long term investment in railways subject to tight funding constraints are also relevant, as most of the innovations involve at least some (if generally small) up-front investment.

Finally, another issue that should be highlighted is the potential for econometric methods – relating actual costs to features of the infrastructure and the nature of traffic running on the network – to provide useful and top-down evidence on the impact of different technologies on costs. This approach, utilising track section data, proved informative for building the business case for the technical research on transition zones and fastening systems. Such an approach is a useful complement to engineering methods / expert judgement.

7. References

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NeTIRail-INFRA Deliverable D1.2. Database of economic data on case study lines

NeTIRail-INFRA Deliverable D1.3: Cost model development report

NeTIRail-INFRA Deliverable D1.4. Cost and User Benefits report

NeTIRail-INFRA Deliverable D1.5: Wider economic benefits intermediate report

NeTIRail-INFRA Deliverable D1.6: Wider economic benefits final report

NeTIRail-INFRA Deliverable D1.7: Incentives final report

NeTIRail-INFRA Deliverable D5.1. Societal and legal effects of transport decision: Stakeholder analysis.

NeTIRail-INFRA Deliverable D5.2. Perception of different service options: User study and data analysis.

NeTIRail-INFRA Deliverable D5.3: Balancing societal effects and cost-benefit of different infrastructure decisions