Modelling the socio-economic impact of implementing innovative infrastructure and rolling stock concepts on railway Trans-European Corridors

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Abstract

Transport constitutes a key sector of European economy as well as a major contributor to economy itself.

European Union set challenging goals in its transport policy, collecting them in its White Papers on transport.

These objectives, especially congestion and Green-House Gases emissions reductions cannot be achieved without the solution of the main European railways current challenges: scarcity of capacity, lack of reliability and low travel competitiveness.

Manifold are the projects currently under development regarding railways world in response to these challenges, including the development of TEN-T projects.

Many research projects are also supported by European funds. Among them there is Capacity4Rail.

Due to their global character, these projects need the building of new tools to allow the assessment of the profitability of the investments, which constitutes a major concern of EC policy, especially in a period of global crisis as the one we are living.

The main aim of this work is indeed to cooperate with the Instituto Superior Técnico researchers' team in establishing a methodology to assess the socio-economic impact of innovations developed within the framework of the European Project Capacity4rail.

After a revision of the current practices on railway infrastructure project appraisal, the methodology elaborated in partnership with IST research team in charge for C4R is presented, highlighting what differentiates it from a common Cost-Benefits Analysis, in particular the solution to the scarcity and uncertainty of input data and the evaluation of capacity occupation and extreme events consequences in terms of delays.

An example of application of the elaborated methodology to the Swedish part of the TEN-T Scandinavian-Mediterranean corridor is then presented.

Eventually, inputs on further requirements and improvability of the approach developed are provided, in particular the extension of the approach to bigger sections of corridors is also considered, with regards to the necessary modifications.

Keywords: White papers, European Transport Policy, TEN-T, Capacity4Rail, Cost-Benefit Analysis, Capacity Occupation, Delays, Scan-Med corridor

1. Introduction

The main aim of the present work is to cooperate with the Instituto Superior Técnico researchers' team in establishing a methodology, to assess the socio-economic impacts of innovations to be developed within the framework of the European Project Capacity4rail.

Before the presentation of the elaborated methodology, the main outlines of European transport policy are referred and a revision of the current practices on railway infrastructure project appraisal is made.

The structure of the new methodology and its application to selected sections of Trans-European Core Network (TEN-T) corridors is then presented.

A probabilistic analysis, based on Monte Carlo techniques is also included.

Finally, inputs on further requirements and improvability of the approach developed are provided.

2. Scope of the work

2.1 Outlines of European transport policy

Since 2001, EU has elaborated two books, called White Papers, where the main issues of EU transport systems are addressed. According to the last of these papers, the major challenges nowadays are:

- congestion.
- oil dependency.
- greenhouse gas emissions.
- infrastructure quality is uneven across the EU.
- competition from fast-developing transport markets in other regions.

2.2 Current challenges for European Railways

Even though railway system might contribute greatly to the achieving of EU policy goals in the transportation field, Rail transport in Europe has been in decline in recent decades, especially in freight.

This is due to the fact that rail does have certain weaknesses that it must overcome.

The main consequences of EU rail weaknesses are:

- the scarcity of capacity;
- the lack of reliability;
- the low travel time competitiveness.

2.3 Possible answers to European Railways challenges

EU funded many projects concerning railway system during the last decades, in order to seek answers to the challenges presented in the last paragraph.

Much work has been carried out with the aim of giving priority to some very important corridors constituting a network covering almost every corner of the continent. Since July 1996, this network has the name of TEN-T (Trans-European Transport Network) and has been object of great EU funding.

Many projects focused on the development of new technologies have also been funded by EU.

Among the most important projects funded in the recent past we may find Eurobalt and Innotrack, mainly focusing on rail track, while, nowadays, a new major project is in progress, envolving 48 partners (among which IST), with the objective of developing new technologies both on the infrastructure and on the vehicles sides, and its name is Capacity4Rail (C4R). As it is clear from the name, the project's main objective is to find solutions for the scarcity of available capacity, but many of the rail weaknesses previously described are considered. The main technological innovations that will be developed regard:

- new track concepts;
- Switches and Crossings;
- novel freight wagons;
- upgrade of interchanges;
- advanced monitoring systems.

Due to the special character of these projects, a big challenge is to provide adapted methods and tools for the assessment of innovations, technologies and concepts, creating and assessing scenarios with the objective of achieving European Transport Policy goals.

The present work is indeed aimed to elaborate a proposal of an assessment tool for the innovations introduced by C4R on TEN-T corridors, developed in partnership with the investigation team of IST in charge for C4R, and evaluate some basic scenarios in order to take conclusions that could help to orientate about which is the most profitable combination of innovations. The main goal is to understand if the new technologies have any impact and, then, if it is a positive or negative impact and which combination of investments has the best impact.

3. Railway Investments Appraisal

3.1 Investment appraisal tools to assess major investments

The main aim of economic evaluation of projects is to identify and quantify their contribution to the well-being of society. Due to the lack of resources, which is always reflected by public administrations, together with the need for investment decision, the Cost-Benefit Analysis (CBA) of public investments became a fundamental instrument of projects evaluation, required by European legislation for decision making in the appraisal of the so-called major projects.

3.2 Cost-Benefits Analysis according to EC guidelines

European Commission (EC) offers practical guidance on major projects appraisal through Guides to Cost-Benefit Analysis of investment projects, the last of which was published in 2014.

According to EC guidelines, a standard CBA should be structured in seven steps:

1. Description of the context
2. Definition of objectives
3. Identification of the project
4. Technical feasibility and Environmental sustainability
5. Financial analysis
6. Economic analysis
7. Risk assessment.

The core of CBA analysis is constituted by Financial and Economic Analysis, where projects are evaluated in monetary terms. The difference between them is mainly related with the point of view from which they are carried out: while Economic analysis is usually carried out from the point of view of society, so it must include all the social costs and benefits of all the stakeholders affected by the project, Financial analysis should generally be carried out from the point of view of the infrastructure owner, then it just considers cash outflows and inflows.

The standard approach to EA is to move from Financial to Economic Analysis. Firstly, the following adjustments should be made:

- fiscal corrections;
- conversion from market to shadow prices;

- evaluation of non-market impacts and correction for externalities.

Then, costs and benefits occurring at different times should be discounted considering the Social Discount Rate (SDR). Then, it is possible to calculate the project economic performance measured by the following indicators: Economic Net Present Value (ENPV), Economic Rate of Return (ERR) and benefit/cost ratio (B/C ratio).

A risk assessment should always be included in the CBA, in order to deal with the uncertainty that is always associated to investment project. The steps recommended to carry out a risk assessment procedure are:

- sensitivity analysis, allowing the identification of the "critical variables";
- qualitative risk analysis;
- probabilistic risk analysis;
- risk prevention and mitigation.

The decision rules for projects, in case of disregarding or considering the uncertainties, are summarized in the following pictures:

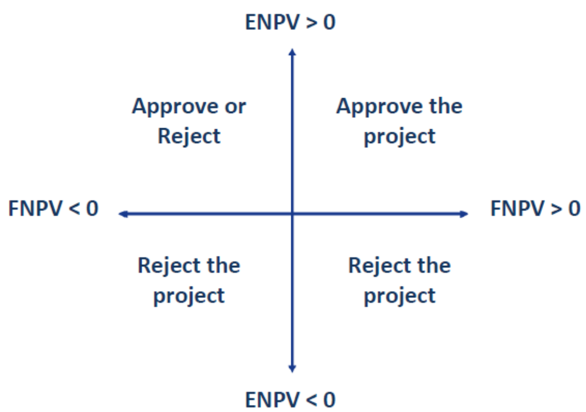


Figure 1 - Decision criteria disregarding uncertainties [Adaptation from De Rus et al. (2010), Manual de evaluación económica de proyectos de transporte]

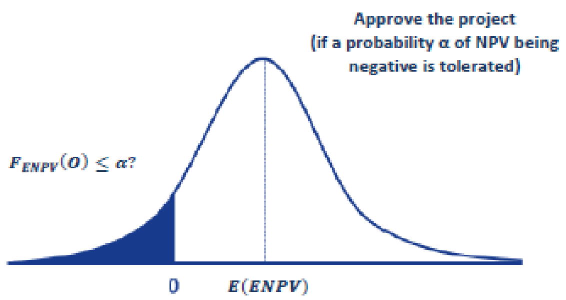


Figure 2 - ENPV distribution. [Adaptation from De Rus et al. (2010), Manual de evaluación económica de proyectos de transporte]

3.3 Main critical aspects of CBA and possible complementary methods

One of the main critical aspects of CBA is the fact that the distribution of benefits across users and the other stakeholders is not captured well, producing the risk of developing inequity.

A possible way for the consideration of distributional effects is a methodology drawing from the approach of the SE Matrix suggested in the RAILPAG Guide: a matrix can be developed linking each project effect with the sectors and the stakeholders affected by that impact.

SE MATRIX		STAKEHOLDERS						
		USERS	TRANSPORT SERVICE OPERATORS	INSURANCE COMPANIES	CONTRACTORS & SUPPLIERS	INFRASTRUCTURE MANAGERS	NON USERS	GOVERNMENT
EFFECTS	USER SERVICE							
	OPERATION							
	ASSETS							
	EXTERNAL EFFECTS							

Figure 3 - Basic SE Matrix [From RAILPAG]

Another way to deal with inequity could be a Multiple-Criteria Decision Analysis (MCDA) considering "Equity" as a criterion of MCDA.

Besides these general criticisms, more case-specific aspects may be identified in the proposed general methodology: in particular, there is not a specific indication of the way to evaluate capacity occupation and delays related to congestion and extreme events.

4. Approach to assess the impact of technological innovations

In view of the above, it is clear that we are not dealing with an ordinary investment appraisal:

- first of all, the geographic scope of every analysis is extremely wide;
- the analyzed investments are made up by dozens of individual projects;
- the considered investments are based on the implementation of technologies that are still under development;
- eventually, input data are often scattered, inconsistent and incomplete.

4.1 The structure of the approach

The following flowchart represents the structure of the approach developed in partnership with IST research team.

The structure of the approach is based on the comparison of different investment scenarios, as in common CBAs.

One of them is always given by the "Baseline" scenario. It does not foresee any investment but the ones due to the end of the useful life of parts of the infrastructure and assets.

The TEN-T scenario is also always considered and it includes the investments listed in the TEN-T corridor reports, available on the EC website.

Then, C4R investments are considered. When C4R innovations are foreseen, it is always considered that also TEN-T investments are executed, meaning the adoption of an incremental approach. However, many combinations of different C4R technologies in different locations are considered, creating thus many C4R scenarios, in order to find out which combination would be the most profitable.

The comparison is based on the elements represented with rectangles: costs and benefits deriving from Investments scenarios, Externalities, Operating costs, Infrastructure maintenance, Time valuation and Value of Delays are summed up and discounted according to

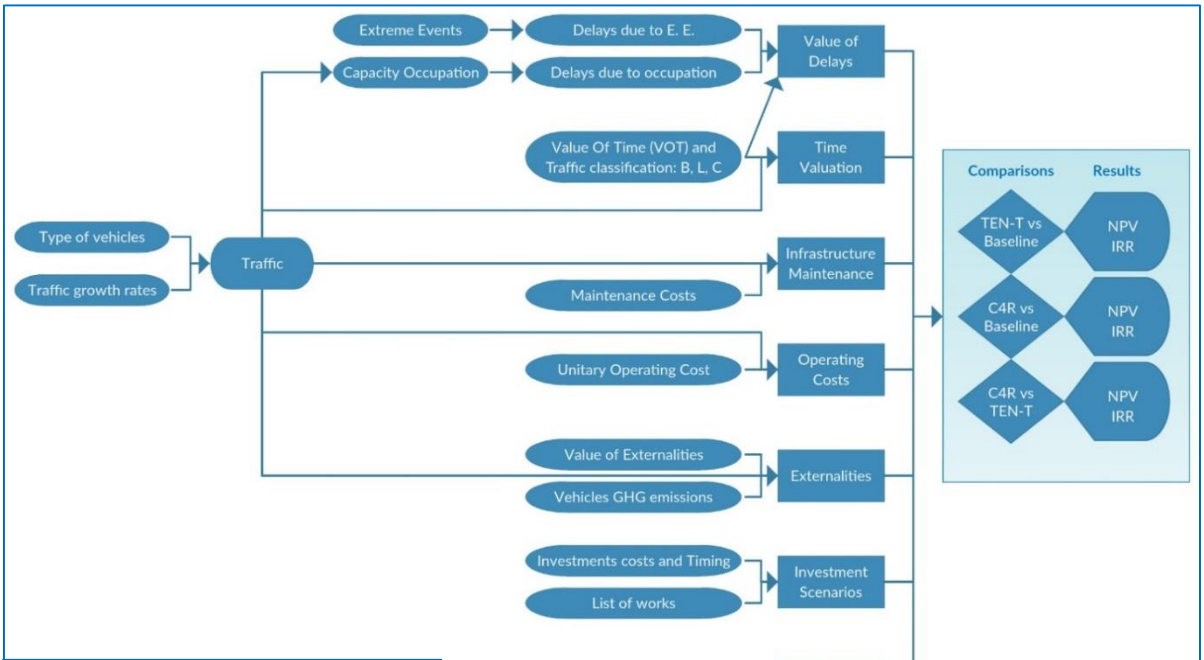


Figure 4 - The structure of the approach.

the economic parameters.

4.2 Input Data

An entire part of the C4R project is dedicated just to the elaboration of the inputs to be used for the assessment. However, nowadays, many of these studies about the inputs are not available yet and for the present work many of them were just assumed from references and validated through expert judgement of the IST research team involved in C4R project.

4.3 Features added to traditional CBA

4.3.1 Capacity occupation

It was decided to evaluate capacity consumption according to the guidelines contained in UIC 406 file. The formula, is the following:

$$k = A + B + C + D, \qquad (1)$$

where k indicates the total consumption time [min], A the infrastructure occupation [min], B the buffer time [min], C the supplement for single-track lines [min] and D the supplements for maintenance [min].

In percentage terms, we have:

$$K = k \cdot 100/U, \qquad (2)$$

where K is the capacity consumption [%] and U is the chosen time window [min].

4.3.2 Reactionary delays

Obviously, high capacity consumption means a higher probability to show delays, called in this case reactionary delays.

Among the models relating capacity occupation rate and delays, it was chosen to adopt a model presented by Stephen Gibson et al.

According to it, the form that best fitted the observed data was an exponential one and the form of the relationship chosen was:

$$D_{it} = A_i \cdot exp(\beta \cdot C_{it}), \qquad (3)$$

Where D_{it} is the reactionary delay on track section i during time period t, A_i a route section specific constant, β a route specific constant and C_{it} the capacity occupation index (as defined above in paragraph 4.3) on track section i during time period t.

For the moment, a value of 1 is assumed for A_i, while a value of 2,5 is assumed for β.

4.3.3 Extreme events

In order to the make the analysis more complete, it was chosen to include the modeling of extreme events.

A simple but clear model regarding the effects of precipitations on flooding of the railways, a possible event in Sweden was found in the master thesis of Tim Gilbert, University of Birmingham.

This model relates the annual delay minutes (D) with the monthly precipitation $(r_m, in\ mm)$ through the following formula:

$$D = 370{,}4 \cdot \sum_{m=1}^{12}(r_m - 80). \qquad (4)$$

4.3.4 Monetary evaluation of delays

It is not correct to evaluate these losses with the same VOT considered for travel time. In order to calculate the Total Costs of Travel Time Variability, it is possible to use a formula proposed by one of the most advanced guidelines set for Transport Studies, the Transport Analysis Guidance (DfT, 2011) provided by the UK Department of Transport (WebTAG).

The recommended formula is the following:

$$TC_{TTV} = \sum_n(\alpha \cdot L^+ + \alpha \cdot \beta \cdot SD^+ + \alpha \cdot SI \cdot 1{,}5) \cdot VOT_n \cdot Pass_n \qquad (5)$$

Where TC_{TTV} is the total cost of travel time variability, α is the lateness factor (3 for umpredictable delays, 1 for predictable), β is the reliability ratio (1,4 for trains and other PT, 0,8 for cars), L^+ is the mean lateness, SD^+ is the standard deviation of travel times (the early arrivals are accounted as on time arrivals), SI is the service interval between the cancelled and the next train, VOT_n is the Value Of Time (differentiated by the type of trip and user segment, if available) and $Pass_n$ is the number of passangers (differentiated by the type of trip and user segment, if available).

UK Passenger Demand Forecasting Handbook states that only 25% of passengers are aware of advertised delay, thus α should be calculated like this:

$$\alpha = 0{,}25 \cdot 1 + 0{,}75 \cdot 3 = 2{,}5, \qquad (6)$$

while SI could be determined from the mean interval between train passages.

5. Application to Swedish case study

As it was already referred, for the application of the tool, a restricted geographic area was chosen, thus the analysis was applied just to the Swedish part of the Scandinavian – Mediterranean Core Network corridor.

5.1 Overview of the scenarios

The following table proposes an overview of the built scenarios, highlighting the foreseen innovation in each of them. Where dark blue is used, innovations are foreseen in the all network, while, in case light blue is used, innovations are foreseen just in the eight most congested sections.

The names given to the scenarios are made with letters able to give information about their characteristics. Thus, the first letter can be W or L, distinguishing between scenarios foreseeing the introduction of the innovations in the whole considered network and the ones involving just local innovations; the second letter can be A or P, dividing between scenarios foreseeing a total innovation, i.e. all the possible innovations offered by C4R, and partial innovations, involving just some of them. Finally, a number distinguishes between the scenarios belonging to the same category.

Later, an additional letter, being D or P, will be added before the names described above, in order to distinguish Deterministic and Probabilistic scenarios.

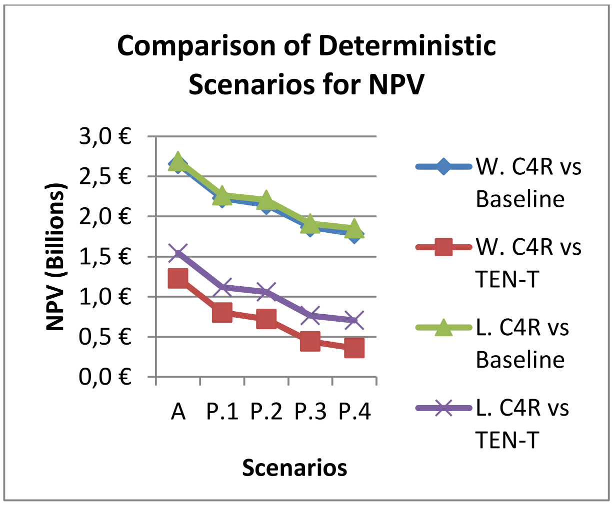
Scenarios	Slab track	S&C	Wagons	Interchanges	Monitoring
W.A					
W.P.1					
W.P.2					
W.P.3					
W.P.4					
L.A					
L.P.1					
L.P.2					
L.P.3					
L.P.4					

Table 1 - Overview of the scenarios.

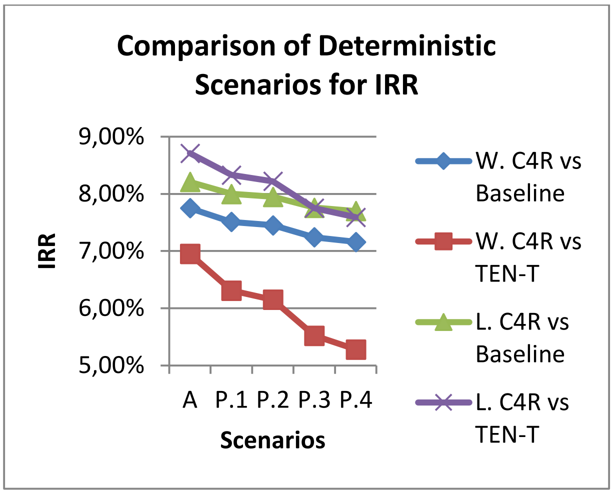
5.2 Deterministic analysis

These analysis are characterized by the fact that inputs are considered to be deterministic.

The first graph represents a comparison of the deterministic scenarios by their NPVs, while the second one represents the comparison of the same scenarios by their IRRs.



Graph 1 - Comparison of Deterministic Scenarios for NPV.



Graph 2 - Comparison of Deterministic Scenarios for IRR.

First of all, all the scenarios produce a positive NPV and an IRR higher than the adopted social discount rate, meaning that every investment scenario is profitable.

However, a decreasing tendency can be seen in both the graphs proceeding from left to right: it seems to be better to apply all the innovations instead of a partial combination of them, both from the point of view of the NPV and from the one of the IRR.

About local innovations, NPV and IRR of a local C4R scenario in comparison with a Baseline or TEN-T are always higher than the NPV and IRR of the corresponding global C4R scenario. This probably indicates that it is advisable to invest the most on local innovations than on global ones.

NPVs calculated in comparison with Baseline are always higher than the ones calculated in comparison with TEN-T, but the highest values of IRR are found in the comparison of local scenarios with TEN-T.

According to these considerations, the local scenario with the application of all the innovations seems to be the most profitable.

5.3 Sensitivity analysis

After the deterministic analysis, a sensitivity analysis was performed in order to find out which are the critical variables of the present analysis through the method suggested in the EU guidelines applied to scenario D.W.A.

These were found out to be the critical variables of the present case:

- Social discount rate;
- Shadow price conversion factor;
- Passenger trains average Load;
- Freight trains operating Cost;
- Slab track Installation cost;
- Passenger Travel Time;
- Freight Travel Time;
- C4R diverted traffic growth rate.

5.4 Probabilistic analysis

In order to run probabilistic analysis, a probabilistic distribution is assigned to the critical variables individuated in the previous paragraph.

It was chosen to exclude the consideration of probabilistic variation of economic parameters (Social Discount Rate and Shadow price conversion factor), because of the complexity associated with them.

The objective is to get a probabilistic distribution of the Economic Net Present Value through a random sampling of the values of the critical variables performed with the Monte Carlo method.

After a convergence analysis, it was chosen to run the analysis with 10,000 iterations.

The most important results of the probabilistic analysis are the following parameters, useful to study the risk of the investments:

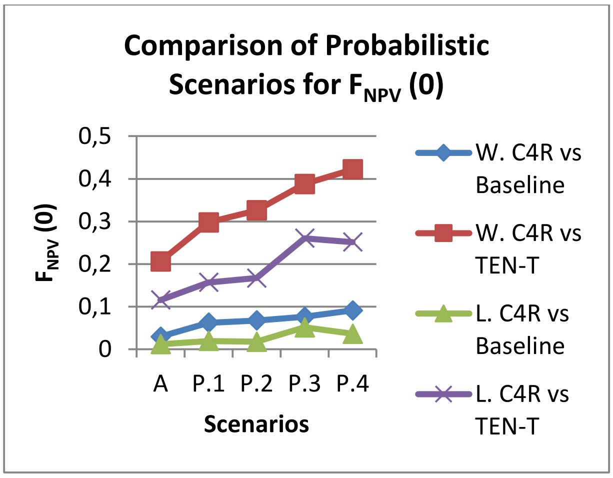
- $E(ENPV)$, the expected value of the Economic Net Present Value;
- $F_{ENPV}(0)$, the probability of $ENPV$ being negative;

- $\frac{E(ENPV)}{E(ENPV|ENPV\leq 0)}$, the ratio of the expected value of the Economic Net Present Value over the expected value of the losses.

It was chosen to run the probabilistic analysis considering a Normal distribution for each of the critical variables, having the original value of the variable as average value and variance equal to 10% of the average value.

Some graphs may allow a simple comparison between the analyzed scenarios.

The first graph represents a comparison of the scenarios based on $F_{ENPV}(0)$, which is an indicator of the probability of having losses in a certain investment scenario.



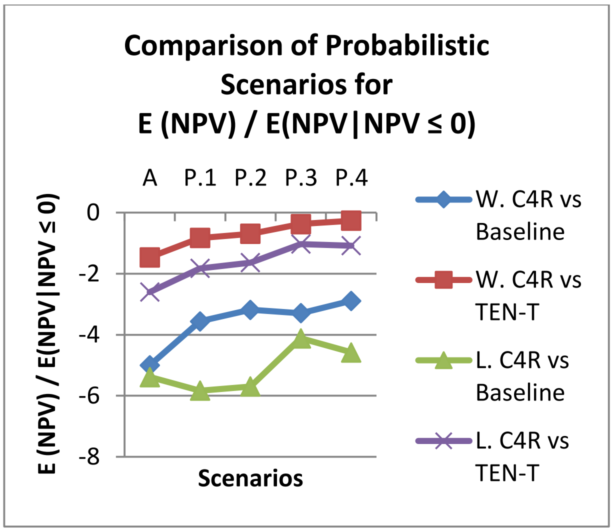
Graph 3 - Comparison of Probabilistic Scenarios for F_{NPV} (0).

A higher value of $F_{ENPV}(0)$ means a greater possibility to have losses and, thus, a higher level of risk. Looking at the graph, a general increasing tendency from left to right may be observed with the only exception of local innovations scenarios. This would suggest that partial combinations of innovations involve more risk than the application of all the innovations together.

As it is rather obvious, the possibility of having a negative ENPV is always lower when the ENPV is calculated in comparison with the Baseline Scenario than when it is calculated in comparison with TEN-T.

Regarding the comparison between scenarios involving the application of the innovations to the all network and local scenarios, the second ones present always the lower levels of risk.

The second graph presents a comparison of the scenarios based on the value of $\frac{E(ENPV)}{E(ENPV|ENPV\leq 0)}$, a parameter useful to quantify the magnitude of the possible losses in a certain scenario, comparing the mean value of the losses with the average value of the NPV. Since in every scenario $E(ENPV)$ is positive, the value of this ratio will always be negative. The bigger the modulus of this ratio is, the less important the losses are.



Graph 4 - Comparison of Probabilistic Scenarios for E (NPV) / E(NPV|NPV ≤ 0).

Observing the graph, it could be highlighted a general increasing tendency proceeding from left to right, meaning that, once again, scenarios involving the application of more innovations together are more advisable than the ones foreseeing just partial innovations, because their losses importance is smaller.

Only in the lines corresponding to the comparison with the Baseline scenario, some point do not follow the general increasing tendency.

The importance of the losses, as it natural, is lower when the comparison with Baseline is considered than when TEN-T is assumed for the comparison.

Arriving then to the comparison between scenarios of innovation all over the network with local scenarios, the second ones present always less important losses than the first ones.

Thus, also the analysis of this last parameter suggests that the best scenarios are the local ones and the one foreseeing the application of all the possible innovations in the most congested sections is, according to all the parameters analyzed, the most convenient one.

6. Conclusions

At the end of this work, it must be remarked that the main objectives referred at the beginning have been achieved: the main outlines of European transport policy were referred and a revision of the current practices on railway infrastructure project appraisal was made, highlighting its main critical aspects.

A methodology able to give significant orientations about investments choices has been developed, though there are some critical points and the tool could be improved in various aspects.

First of all, the tool would need to be more automated, meaning that, at the moment, when an input is varied, almost all its consequences have to be changed by hand, one by one, in the spreadsheet. This is especially true when it is decided to change the considered C4R scenario: when considering a different scenario, all its consequence, for example the changes in maintenance costs or travel time, have to be changed one by one, while the future aim is to make the tool as automated as possible.

This last observation is in line with one of the main objective of the tool, that is making it simple.

This is especially important in view of the extension of the tool to the analysis of the entire corridor. When applying the tool to the entire corridor, the first problem will be data search, but then, if the structure of the tool is not simple, the user will have to hand a really big amount of data and the spreadsheet can become a black box, difficult to be managed.

Another aspect to be improved regards the consideration of distributional effects. At the moment, in order not to add further complexity, the transferences of money between stakeholders (as operators tariffs, infrastructure manager taxes, etc.) are not automatically calculated by the tool, thus there are no elements to determine all the relevant effects on stakeholders and, in particular, to build the SE matrix. However, it is important to consider distributional effects, especially in railways projects, so a fundamental improvement would be the adding of these calculations to the assessment tool.

One more critical point is in the models for the calculation of delays, especially the one for extreme events. This model, in particular, gives positive values of delays just when the precipitation value is higher than 80 mm. Thus, more detailed model with eventually the consideration of other extreme events, for example big snowing, would be a great improvement.

Despite all of these aspects, it must be remarked that the tool already gives significant indications about investment decision and this is considered a satisfactory starting point, open to the improvements presented above and many others that could be added in the future.

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