Capacity for Rail

Towards an affordable, resilient, innovative and high-capacity European Railway System for 2030/2050

Integrated methodology for the analysis of scenarios and migration

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Deliverable 54.1

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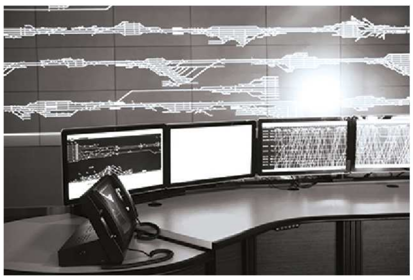

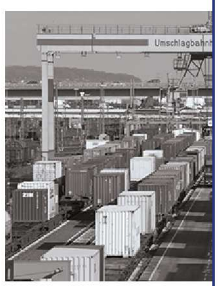

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Executive Summary

This report is the first deliverable for Work-Package 5.4 (WP5.4) under the Sub-Project 5 (SP5) of the CAPACITY4RAIL project.

This document, D5.4.1 "Integrated methodology for the analysis of scenarios and migration", aims to describe the methodology developed to assess the impacts of technologies and scenarios developed within C4R. The assessment is oriented towards the evaluation of the performances of scenarios regarding the expected socio-economic impacts and C4R milestones for the European Railway Network Vision for 2030/2050.

The document presents two complementary assessment methodologies: a Multi-Criteria Analysis (MCA) and a Cost-Benefit Analysis (CBA). These two were chosen to tackle the challenge of evaluating the impact of a set of innovation still under development on extended railway corridors.

The MCA relies on the definition of a set of targets grouped in five Key Aspects: Affordability, Adaptability, Resilience and Automation. These targets are all scored on the same scale and then weighed within each key aspect according to a method based on pairwise comparisons. This allows for the assignment of a score to each key aspect measuring the contribution of the set of innovations is expected to give to the fulfilment of the vision for the EU rail network.

The CBA is a fairly conventional methodology but which is now being used to assess the implementation technologies still under development in a wide geographical scope. This requires a careful approach to the level of detail that is possible to achieve given the available and expected information.

Given the uncertainties involved in both these analyses, a probabilistic assessment based on Monte Carlo simulations is extremely useful to bound the level of confidence in the results.

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Abbreviations and Acronyms

AHP	Analytic Hierarchy Process
C4R	Capacity4Rail
CAPEX	Capital expenditures
CBA	Cost-Benefit Analysis
DoW	Description of Work
EC	European Commission
EU	European Union
GDP	Gross Domestic Product
GHG	Greenhouse gases
KPI	Key Performance Indicator
LCC	Life-Cycle Cost
MACBETH	Measuring Attractiveness by a Categorical Based Evaluation Technique
MCA	Multi-Criteria Analysis
NMVOC	Non-methane volatile organic compounds
O&M	Operation and Maintenance
OD	Origin/Destination
OPEX	Operational Expenditures
PBS	Product Breakdown Structure
PM	Particulate Matter
R&D	Research and development
RAMS	Reliability, Availability, Maintenance, Safety
S&C	Switches and Crossings
SDR	Social Discount Rate
SP	Sub-project
TAC	Track Access Charges
TOC	Train operating companies
TRL	Technical Readiness Level
VOC	Vehicle Operating Cost
VOSL	Value of Statistical Life
WP	Work Package

1 Background

1.1 Work Package 5.1

Work Package 5.1 developed the vision of "How to obtain an affordable, adaptable, automated, resilient and high capacity railway; for 2020, 2030 and 2050?" based on the definition of five independent Key Aspects. These terms summarise the objectives of the C4R project and work as the basis to the definition of milestones to be achieved by the European Railway Network in the future.

Research and development activities undertaken on four main subjects (SP1: Infrastructure, SP2: Freight, SP3: Operations and SP4: Monitoring) should therefore align with the Key Aspects in order to contribute and ensure a step forward towards the overall vision of the European Rail Network of 2050.

The following definitions were adopted on this document:

Technology	• Output (innovation) from the project's research and development
Migration	• Technology upgrade from the baseline to its developed innovation
Scenario	• Set of migrations defined to improve the current situation
Path	• Timeline of migrations within a scenario
Target	• (Expected) Objectives to achieve within a baseline case improvement

1.1.1 Definition of Key Aspects

The focus and main purpose of the C4R project is to deliver a high capacity European passenger and freight rail network. However, according to the European strategic vision, a high capacity network will only be achievable if the network tends to be an *affordable*, *adaptable*, *automated* and *resilient* rail network, as shown in Figure 1.

The deliverable D5.1.1 proposed definitions for each of the project's Key Aspects, to guide developments and future deployments of technologies into the current system, in order to ensure that C4R adopts an overall system approach. The Key Aspects defined reflect the different points of view of the many actors involved within the project. The definitions of each Key Aspect are presented on the following sections.

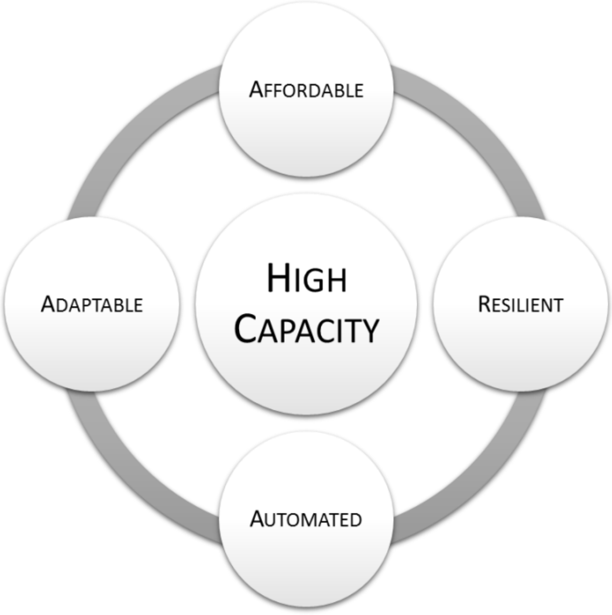

FIGURE 1. PROJECT KEY ASPECTS

Affordability

To reach an affordability railway network, it must:

- Become the *mode of choice* to investors and users (medium and long-distance travel);
- Ensure lifetime benefits that exceed lifetime costs (including the total cost of procuring, maintaining and operating the railway);
- Have optimised CAPEX and OPEX costs (which have to be transparent and predictable);
- Become energy efficient with minimum impact on the environment;
- Have an infrastructure that delivers lowest LCC while achieving increased RAMS performances;
- Meet passenger and freight capacity requirements;
- Minimise barriers to entry and provide effective access to the rail industry;
- Become competitive with other modes of transport for passengers and freight.

Adaptability

An adaptable railway network will have to:

- Be flexible and extensible to fit a range of future scenarios (service-levels; new technology developments);
- Be modular;
- Have well-defined interfaces and standards for interoperability to respond rapidly to changes in the patter of demand;
- Adapt improved and innovative construction techniques with less complexity and high standardization to reduce costs and disruption to users.

Resilience

A resilient railway network will conceptually be:

- Robust, to minimise the incidence of failures affecting services;

- Capable of recovering quickly from perturbations to normal service.

Automation

To ensure an automated railway network, it must:

- Have infrastructure and rolling stock mostly operated and maintained by machines, i.e. achieve efficient and effective operation without human intervention under normal and (most) degraded service conditions;
- Rely on automated construction and maintenance, operations, communications, ticketing and inter-modal transfers.

High Capacity

The high capacity railway network, will:

- Have virtually no constraints (bottlenecks) on operation;
- Accommodate passenger and freight demands spread unevenly through the day;
- Meet customer requirements in terms of defined service levels (such as reliability, journey time and frequency of service) in an affordable manner;
- Tolerate interventions from inspection, maintenance and enhancement with minimal impact on its availability.

2 Objectives

This document reports on the work developed in Task 5.4.1, namely, the development of integrated methodologies for the analysis of technologies and scenarios.

This task, within WP5.4, is highly intertwined with other Work Packages in SP5, namely, the definition of visions, requirements and boundaries to be made in WP5.1; the data collection and analysis templates to be developed in WP5.2 and the scenarios and migrations to be established by WP5.3.

The present deliverable thus focuses on the assessment methodologies with respect to economic, social, environmental and operational impacts. The current early version of this document aims to establish these methodologies and encourage the inevitable interplay between WP5.4 and the other WPs within SP5.

3 Assessment of Technologies and Scenarios

3.1 Motivation

The issues of assessing a technology migration or a scenario containing multiple technology migrations are of the same nature, although different in scale. They are, therefore, treated as a single problem in this document.

For this assessment, two complementary tools have been developed based on two different but established methodologies:

- A Multi-Criteria Analysis (MCA) aiming to measure the improvements on the performance of the railway system arising from a given technology or scenario against the Vision established in WP5.1;
- A Cost-Benefit Analysis (CBA) aiming to establish the overall socio-economic benefit of a given technology or scenario (set of innovative technologies).

These two approaches are complementary within the wider objectives of the Capacity4Rail project. The two approaches intend to provide an overall assessment of the impact of the innovative technologies as well as a comparable, effective evaluation of the migration scenarios for existing corridors, considering the identified visions for the European railway system. The developed technologies and scenarios for corridor migration should, simultaneously provide a positive benefit for society as a whole and contribute for the policy objectives set out by the European authorities for the railway system.

3.2 Multi-Criteria Analysis (MCA): Overview

The proposed MCA allows for a more flexible and overreaching analysis on a wider variety of aspects, namely, those Key aspects defined in WP5.1: Affordability, Adaptability, Automation, Resilience and High Capacity. By measuring the impact of a technology or scenario against the set of targets established for the European rail network, one can obtain an evaluation on how that technology or scenario helps to fulfil the vision for the European railways. This analysis includes two stages: Target Scoring and Target Weighting.

In the first stage, each target is assessed according to a measurable criterion. It is then scored based on a comparison of a baseline with the scenario under evaluation in an open scale anchored at 0, no change relative to baseline, and 100, Target fulfilment.

In the second stage, the Targets within each Key Aspect are weighted against each other based on a set of pairwise comparisons according to the method described in detail in Section 4.1.3 of this document.

This allows for the computation of a score for each Key Aspect based on the weighted average of the Targets within each one of them. This result can be elegantly represented in a Spider chart, as exemplified in Figure 2.

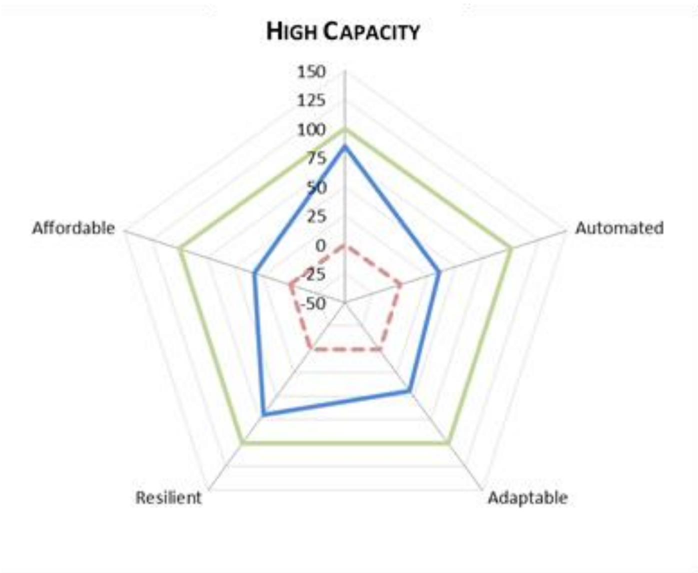

FIGURE 2. EXAMPLE OF SPIDER CHART RESULTING FROM THE MCA, MEASURING THE DEGREE OF FULFILMENT OF THE VISION FOR 2030/2050 DEPARTING FROM THE BASELINE IN EACH OF THE KEY ASPECTS. THE GREEN LINE REPRESENTS THE VISION, THE ORANGE DOTTED LINE IS THE BASELINE AND THE BLUE LINE IS THE SITUATION RESULTING FROM THE SCENARIO OR TECHNOLOGY UNDER ANALYSIS.

3.3 COST-BENEFIT ANALYSIS (CBA): OVERVIEW

The CBA is a well-established method of project assessment, based on the computation of net cash flows arising from a given project. It is thus an obvious choice to obtain an estimated of the social and economic impacts of a technology or scenario.

CBA works through the computation of all cash-flows during the analysis period and respective Net Present Values, and their assignment as expenditure or revenue to each of the involved stakeholders.

The final results of this analysis is represented in a table similar to the on shown in Figure 3. When filled, this allows for an at a glance record of economic costs and benefits to society as a whole. The effects may further be assigned to each one of the agents involved.

Cost Benefit Analysis	Baseline	TEN-T Projects	C4R Innovations	Net Cost
Infrastructure				
Investment				
Maintenance				
Residual Values				
Total Financial Cost				
Total Economic Cost				
	Baseline	**TEN-T Projects**	**C4R Innovations**	**Net Benefit** **TEN-T vs Baseline**
Consumer Surplus				
Value of Time				
Passenger				
Freight				
Producer Surplus				
Train Operating Costs				
Externalities				
Greebhouse Gas Emisiions				
Total Economic Benfits				
NPV				
Benefits to Costs Ratio				
Internal Rate of Return				

FIGURE 3. LAYOUT EXAMPLE OF CBA TABLE

3.4 Final Assessment and Probabilistic Analysis

The task that immediately follows the completion of this deliverable, Task 5.4.2, prescribes a probabilistic analysis. It is thus sensible to make a few short comments on how this should be achieved.

Most approaches to CBA include some kind of uncertainty analysis, including the one outlined in the EU Commission Guidelines. There is also some literature on this kind of analysis performed on LCC. These uncertainty analyses are almost always based on a combination of a sensitivity analysis with a Monte Carlo simulation, basically, a variation of the inputs.

The sensitivity analysis allows for the identification of the inputs to which the final results are the most sensitive, discarding the ones that have little influence. Each input is also assessed for its associated uncertainty, based on the information available. Inputs that cause a large change in the final result and, simultaneously, have large uncertainties should be the focus of the analysis. Any available data on the inputs should allow one to set hypotheses on their probability distribution.

Once this identification is made, a standard Monte Carlo simulation allows one to obtain a probability distribution for the outputs, for which confidence intervals can then be established in order to identify associated output intervals.

4 Multi-Criteria Analysis

4.1 Proposed Approach

4.1.1 Vision and Targets

The Vision for the European Railway Network developed in D5.1.1 "Railway road map – paving the way to an affordable, resilient, automated and adaptable railway" forms the basis for the assessment of the impacts of technologies or scenarios on each Key Aspect.

A set of Targets to achieve in the future were extracted from the Vision, for which adequate criteria have to be defined to assess the achievement of such milestones. Each Key Aspect will therefore be described by several criteria. This way, innovations' impacts will be scored regarding the performance of the innovations within each criterion. The involvement of stakeholders or expert judgement is required for criteria and weighting validation in order to achieve representative performance scores of the innovation's impact. In the final phase of the assessment, robustness and sensitivity analyses may be required to simulate score variations, to verify the influence of the assigned weights and due to uncertainty on performances (innovation impact) within certain criteria. Figure 4 summarises the necessary steps to accomplish successfully the assessment of scenarios.

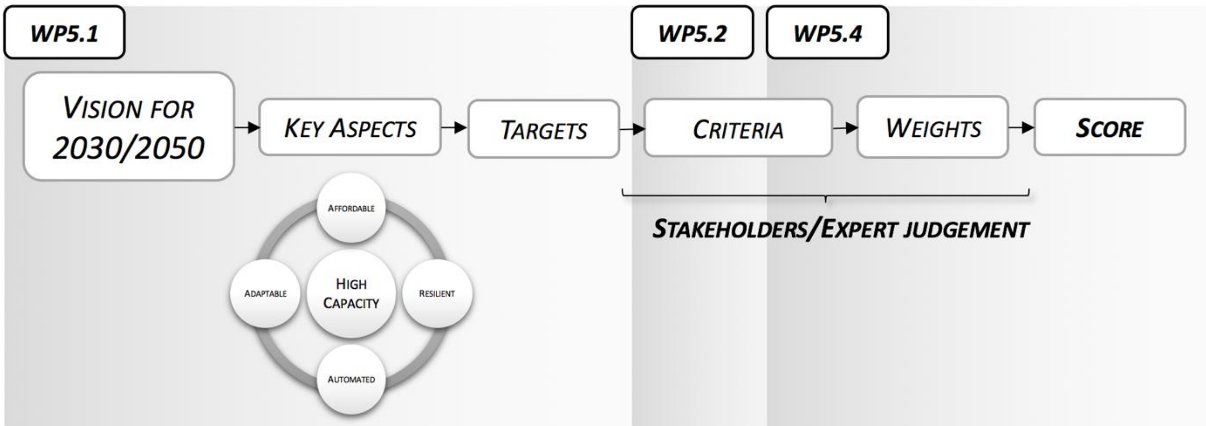

Figure 4. Scheme of the proposed methodology for assessing developed technologies (innovations)

Roadmaps for each Key Aspect were proposed by WP5.1 on Task 5.1.1. Targets provided by the roadmaps are the basis for the definition of criteria to evaluate the impacts on each Key Aspect. These describe strategic goals of each Key Aspect expected to be impacted by innovations developed within C4R. However, targets are not always directly related to the definition of Key Aspects or, on the other way, the definition of a Key Aspect may be not represented by any target. Additional targets may have to be defined in order to adequately characterise the Vision under a certain Key Aspect. For instance, the definition of an Affordable railway network includes the following sentence: *"Have an infrastructure that delivers lowest LCC while achieving increased RAMS performances"*. However, no target provided by the *Roadmap for Affordability* considers directly this goal from the definition. Similarly, other relevant outputs from other Key Aspects may also not be considered by the existing targets.

The full list the targets defined on the roadmaps resulting from Task 5.1.1. is discussed in Section 4.2. These Targets have been the subject of an ongoing discussion between the partners of SP5. The main objectives are to eliminate a number of redundancies and instances of double counting, to adapt the targets to ones that can be quantified and to crosscheck them with the Key Performance Indicators (KPI) laid out in the DoW for SP1 through SP4.

This process of target triage, adaptation and selection, while not yet finished, has already come a long way towards a shorter, more focused list of targets. A few examples of possible targets are presented in Table 1.

TABLE 1. EXAMPLES OF ROADMAP TARGETS TO ASSESS IN MCA FOR EACH KEY ASPECT.

1. Affordability	**T1.1.** *e.g.* Decrease in infrastructure Life-Cycle Cost (LCC) **T1.2.** *e.g.* Decrease in Train Operating Costs (TOC) **(…)**
2. Adaptability	**T2.1.** *e.g.* Full interoperability of freight rolling stock **(…)**
3. Resilience	**T3.1.** *e.g.* Reduction of infrastructure down time due to extreme weather events **(…)**
4. Automation	**T4.1.** *e.g.* Equipment of all new rolling stock with intelligent monitoring and diagnostic systems **(…)**
5. High Capacity	**T5.1.** *e.g.* Increase in overall freight capacity **(…)**

4.1.2 TARGET SCORING

In order to assign a score to each target, two additional steps are needed. The first is the choice of a measurable criterion against which a baseline and the technology or scenario must be evaluated. The second step is the development of a template for the computation of each criterion. Thus, this task is deeply connected with WP5.2.

Each target will be scored on an open scale where 0 (zero) represents the pre-set baseline and 100 represents the fulfilment of the target. Any value between 0 and 100 measures the relative distance to the target milestone. A negative score means that the introduction of the technology or scenario create a worst situation than the baseline with respect to the target under evaluation. A score over 100 is achieved whenever the target milestone is exceeded. Any of these situations is possible.

The templates for target scoring are currently in different stages of completeness and still pending a final list of targets. The guidelines and methods for the scoring of each target shall be added as appendixes to this document as they become complete.

In order to work with the method, the fundamental requirement on the evaluation templates is that they compute a score that can feed the Summary page on that same spreadsheet and that follows the principles already set out and summarised on Table 2.

To illustrate how these templates can work, one can take Target 2.1 from Table 1, which establishes the objective of full interoperability of freight rolling stock, as an example. One possible criterion for the scoring of this target is the number of existing barriers to that objective. The template identifies the set of possible barriers to this and asks the user to fill in which ones exist in the baseline and which ones remain after the implementation of the technology or scenario in analysis. The template then computes what percentage of initial barriers remain and scores this target based on this, where 100 points should mean the elimination of all barriers.

Other target templates base their scoring on cost performance or noise performance, for example, and ask for the appropriate inputs in order to compute a score. It should be recalled that, at this stage, the target definition is not final and, thus, these templates are not complete and stand merely as illustrative examples.

Table 2. Target scoring scale

Score < 0	Technology or scenario worse than baseline
Score = 0	Technology or scenario with no change relative to baseline
0 < Score < 100	Score measures relative distance of technology or scenario between baseline and fulfilment of target
Score = 100	Target is fulfilled
Score > 100	Target milestone is exceeded

4.1.3 Target Weighting

After each target is scored according to the principles set out in the previous section, a total score must be computed for each of the five Key Aspects. When setting out to do this, the question arose of whether each target should be given the same importance.

The main issue here is that each one of the targets, after a previous triage that eliminated those that are redundant, either because they are essentially measuring the same thing or because they are not affected by the innovations under analysis, is clearly important for the overall policy for the European rail network. Still, it is very difficult to judge that all have the same importance.

In order to overcome this hurdle, it is proposed that a Multi-Criteria Analysis method may be used to assign weights for each target.

The proposed method to achieve this is based on a set of pairwise comparisons between targets that allow for the computation of a scale measuring the importance assigned to each target. It is inspired by the MACBETH (Measuring Attractiveness by a Categorical Based Evaluation Technique) (Bana e Costa & Vansnick, 1995), although not entirely similar.

The MACBETH is a multi-criteria methodology, which assesses several decision options through a qualitative comparison. The methodology was developed in the early nineties as a new approach for decision making, in order to provide a tool for building a scale of preferences, using an interval scale, without relying on direct numerical estimations of the semantic judgement, as in the case of the AHP method (Ishizaka & Nemery, 2013). It has been used in several decision problems, such as prioritization, choice, resource allocation, performance assessment and conflict management (Bana e Costa et al., 2013).

The steps shall be illustrated with an example with three targets to weight.

The decision maker is first asked to order all the available options (creating the ordinal scale). This step is shown in Figure 5, with the cells filled by the decision maker highlighted.

Rank	Target	
3	TX.1	Target "A"
1	TX.2	Target "B"
2	TX.3	Target "C"

Rank	Target	
1	TX.2	Target "B"
2	TX.3	Target "C"
3	TX.1	Target "A"

Figure 5. Option ordering section of an example target weighting spreadsheet with three options

After that, the decision maker must assign an attractiveness level to each pairwise comparison of targets, where he will measure their relative importance. The attractiveness scale ranges from 0-*Indifferent* to 6-*Extreme*. If the 0 (zero) level is assigned to a pairwise comparison, both those options will have the same values in the computed scale. The existence of the zero level is also essential to tackle instances where it is difficult to assign a preference to one of the options being compared.

The basic scale is computed following the rule $PW(x_i, x_j) \geq PW(x_i, x_k) + PW(x_k, x_j)$, where $i < k < j$ must be verified and $PW(x_i, x_j)$ is the result of the pairwise comparison between x_i and x_j, as shown in Figure 6.

Judgement Matrix			
	TX.2	TX.3	TX.1
TX.2		1	
TX.3			3
TX.1			

Basic Scale Computation			
	TX.2	TX.3	TX.1
TX.2		1	4
TX.3			3
TX.1			

FIGURE 6. JUDGEMENT MATRIX AND BASIC SCALE COMPUTATION SECTION OF AN EXAMPLE TARGET WEIGHTING SPREADSHEET WITH THREE OPTIONS

The decision maker does not need to do all the pairwise comparisons. The minimum number of judgements needed to obtain the basic scale is *n-1*, where *n* is the number of options. However, he must include each and every single option in at least one pairwise comparison. Still, if the decision maker uses all available fields, all judgements will be used in the computation, as can be seen by comparing Figure 7 with Figure 6.

Judgement Matrix			
	TX.2	TX.3	TX.1
TX.2		1	5
TX.3			3
TX.1			

Basic Scale Computation			
	TX.2	TX.3	TX.1
TX.2		1	5
TX.3			3
TX.1			

FIGURE 7. JUDGEMENT MATRIX AND BASIC SCALE COMPUTATION SECTION OF AN EXAMPLE TARGET WEIGHTING SPREADSHEET WITH THREE OPTIONS, WITH ALL PAIRWISE COMPARISON FIELDS USED

The main difference between our method and the original MACBETH is in the way it deals with inconsistencies. While MACBETH identifies these inconsistencies and asks the decision maker to correct them, in this case an automatic inconsistency correction process was introduced, unburdening the decision maker of filtering them out.

The automatic inconsistency correction is illustrated in Figure 8. Clearly, if option TX.3 has a moderate (3) advantage over TX.1 and TX.2 has a very weak (1) advantage over TX.3, then TX.2 cannot have a weak (2) advantage over TX.1. To solve an inconsistency, the judgement comparing the options that are nearer in the ordered list always prevails, that is, if $PW(x_i, x_j) < PW(x_i, x_k)+PW(x_k, x_j)$, with $i < k < j$, then $PW(x_i, x_j)$ is replaced by $PW(x_i, x_k)+PW(x_k, x_j)$. This assumes that a decision maker is always better equipped to compare two options that are closer to each other in terms of how strong their difference is.

Judgement Matrix			
	TX.2	TX.3	TX.1
TX.2		1	2
TX.3			3
TX.1			

Basic Scale Computation			
	TX.2	TX.3	TX.1
TX.2		1	4
TX.3			3
TX.1			

FIGURE 8. JUDGMENT MATRIX AND BASIC SCALE COMPUTATION SECTION OF AN EXAMPLE TARGET WEIGHTING SPREADSHEET WITH THREE OPTIONS, WHERE AN INCONSISTENT JUDGMENT WAS MADE

Once all comparisons are made and all inconsistencies eliminated, the basic scale can be directly extracted from the last column of the filled matrix. This is, basically, the comparison of each option against the least attractive option. In effect, once a lower bound is established, this amounts to creating an absolute attractiveness scale.

This basic scale must then be normalised. The bounds used for this normalisation are arbitrary. MACBETH uses 0 as the lower bound for its normalised scale. However, in this instance, that would mean that the least attractive option would be withdrawn from the analysis. For this reason, it was chosen to use a non-zero lower bound of 0.1. The upper bound of the scale is computed, up to a maximum of 1, based on the highest attractiveness level used. The upper bound is based on the highest pairwise attractiveness level: if it is equal or higher than 6, the upper bound is set at 1, otherwise, it is set on a linear scale between 0.1 and 1, as in this example. The bounds on the normalised scale allows for the most attractive option to be up to 10 times as important as the least attractive one, which. However, we emphasize that these bounds are arbitrary in what mathematics is concerned and the criteria here used to set the bounds on the scale may be subject to discussion. The normalised scale for the three options example we have been using is shown in Figure 9.

This process allows one to obtain a single score for each Key Aspect, using the same scoring scale shown in Table 2, resulting from the weighted average of each target's scores.

The final result of this analysis is thus a set of scores, one for each Key Aspect, measuring the degree to which a given corridor has fulfilled the vision for the European Rail Network. One possible way to elegantly summarise these finding is in a spider chart similar to the one in **Erreur ! Source du renvoi introuvable.**, where one can see at a glance how close the technology or scenario under assessment brings us to the fulfilment of the targets set out for the European rail network's 2030/2050 Vision.

Attractiveness Scale		
	Basic	Normalised
T2	4	**0,77**
T3	3	**0,60**
T1	0	**0,10**

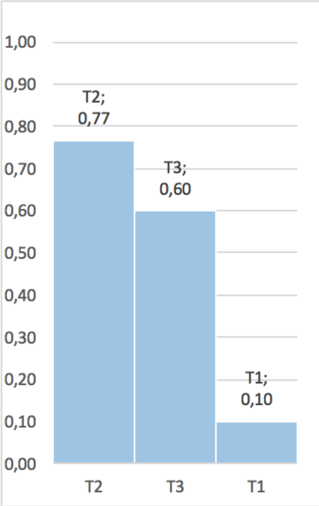

FIGURE 9. NORMALISED SCALE OF AN EXAMPLE TARGET WEIGHTING SPREADSHEET WITH THREE OPTIONS

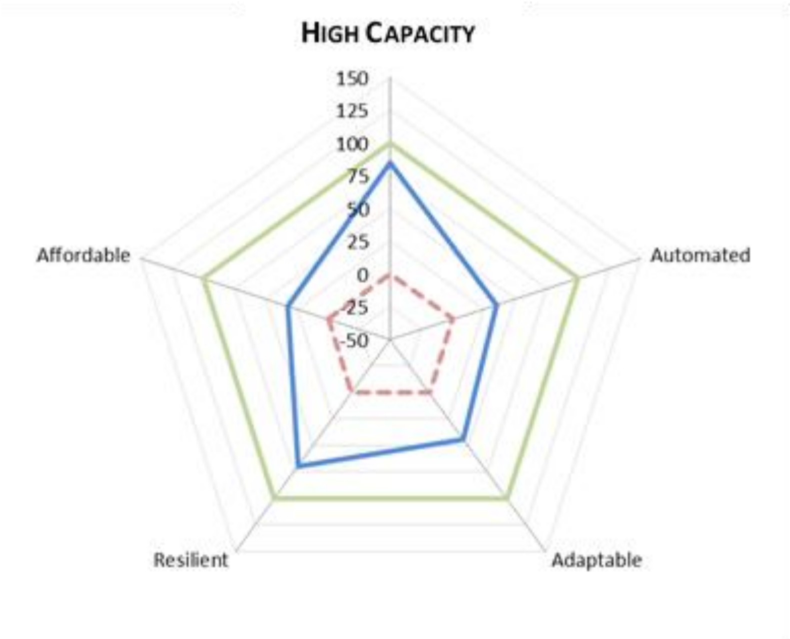

FIGURE 10. SPIDER CHART RESULTING FROM THE MCA, MEASURING THE DEGREE OF FULFILMENT OF THE VISION FOR 2030/2050 DEPARTING FROM THE BASELINE IN EACH OF THE KEY ASPECTS. THE GREEN LINE REPRESENTS THE VISION, THE ORANGE DOTTED LINE IS THE BASELINE AND THE BLUE LINE IS THE SITUATION RESULTING FROM THE SCENARIO OR TECHNOLOGY UNDER ANALYSIS

This still leaves open the issue of who is the decision maker that sets these pairwise comparisons leading to target weighting or how many decision makers there are, as in the pictorial representation in Figure 11. Whatever the the answer to these questions, the method allows for the combination of multiple sets of judgements, either by averaging the assigned attractiveness levels in each pairwise comparison or by averaging the resulting weights. The results of these two options will be equivalent, as long as there are no inconsistent judgements. The decision of who the decision makers for this process are is a policy decision.

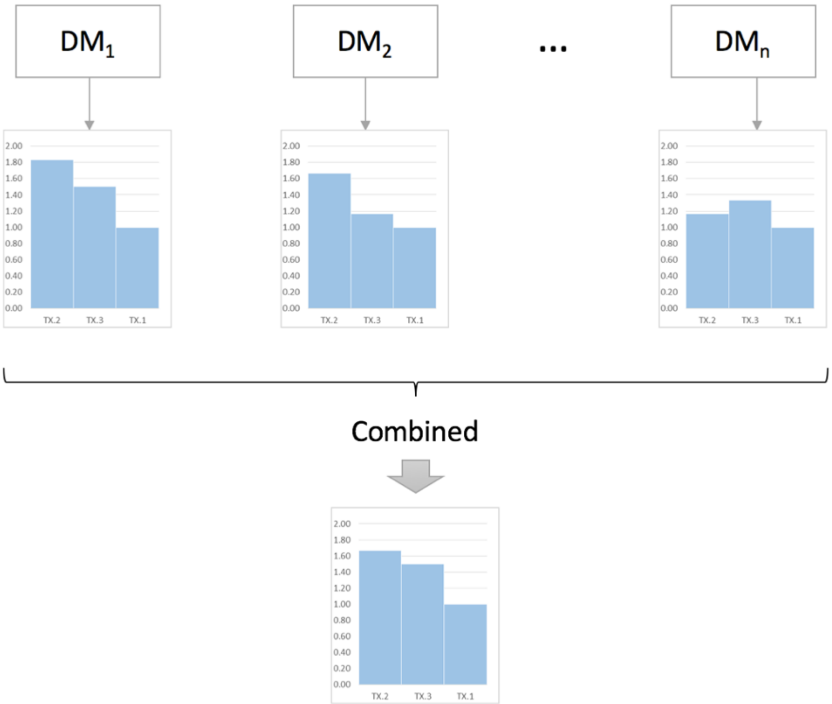

FIGURE 11. SCHEMATIC REPRESENTATION OF THE COMBINATION OF MULTIPLE DECISION MAKERS IN THE TARGET WEIGHING PROCESS.

4.2 DEFINITION OF TARGETS

The list of targets in the Roadmaps produced in WP5.1 is quite extensive. This list of targets can be found in Deliverable D5.1.1 and is reproduced here in Table 3.

This list of targets clearly contains some redundancies, some targets that lay outside the scope of the innovations being prepared by C4R and some targets that are diffuse and nor easily quantifiable. This raised the need for a thorough discussion on the list of targets to be used in the MCA. Should redundant targets remain, they would render a double counting effect towards the final score. At the same time one should avoid selecting or creating new targets based on the predictability of positive results from C4R innovations.

This discussion between the SP5 partners, while not yet complete, has already come a long way towards a consolidated and consensual set of targets to be used in the MCA. This process of target triage, adaptation and selection should follow these principles:

- All targets should be easily quantifiable;
- Double counting and redundancy should be avoided, including targets with separate milestones for different time horizons;
- Targets and milestones should be cross-checked with the Key performance indicators (KPI) established for SP1-4.

Table 3. Full list of Roadmap Targets, retrieved from D5.1.1

Affordability	**Roadmap Target:** No increase in access charges by 2050
	Roadmap Target: 50% decrease in operating costs by 2050
	Roadmap Target: 50% decrease in infrastructure maintenance costs by 2050
	Roadmap Target: 30%/50% decrease in specific CO_2 emissions by 2020/2030
	Roadmap Target: 50% decrease in total CO_2 emissions by 2030
	Roadmap Target: 50% decrease in specific energy consumption by 2030
	Roadmap Target: 50% decrease in total energy consumption by 2030
	Roadmap Target: 40% decrease in exhaust emissions (NO_x and PM_{10}) by 2030
	Roadmap Target: Elimination of operating noise problem sites by 2050
	Roadmap Target: 50% decrease of equivalent fatalities by 2050)
Adaptability	**Roadmap Target:** Unrestricted cross-border rail movements by 2050
	Roadmap Target: Fully interoperable bundling of freight rolling stock by 2050
	Roadmap Target: No access restrictions to standard freight containers by 2050
	Roadmap Target: Freight demand met for current access charges by 2050
	Roadmap Target: Minimal overcrowding on urban and inter-urban rail services, under 10% at peak times by 2050
	Roadmap Target: New rail infrastructure adapted to 50-year climate change forecasts by 2050
	Roadmap Target: New rolling stock adapted to 25-year climate change forecasts by 2050
Resilience	**Roadmap Target:** 40%/80% decrease in train delays due to Extreme Weather by 2030/2050
	Roadmap Target: 30%/60% in train cancellations due to Extreme Weather by 2030/2050
	Roadmap Target: Accessible TEN-T core network by all new rolling stock by 2030
	Roadmap Target: Accessible TEN-T comprehensive network by all new rolling stock by 2030
	Roadmap Target: 40%/80% decrease in train delays due to Infrastructure Failure by 2030/2050
	Roadmap Target: 30%/60% decrease in train cancellations due to Infrastructure Failure by 2030/2050
Automation	**Roadmap Target:** Complete ERTMS Level 2 system by 2030
	Roadmap Target: Multi-modal information, management and payment system framework by 2020
	Roadmap Target: Euro-wide ITS standard system by 2035
	Roadmap Target: All new rolling stock equipped with intelligent monitoring systems by 2035
	Roadmap Target: Intelligent monitoring systems maximised in all new infrastructure by 2045
High Capacity	**Roadmap Target:** 300% increase/completion of HS rail network by 2030/2050
	Roadmap Target: Completed TEN-T core rail network by 2030
	Roadmap Target: Completed TEN-T comprehensive rail network by 2050
	Roadmap Target: Completed HS rail links to TEN-T core airports by 2050
	Roadmap Target: Completed rail freight links to TEN-T core seaports by 2050
	Roadmap Target: Multi-modal information, management, booking and payment on-line system framework in place by 2020
	Roadmap Target: 30%/50% shift of road freight over 300 km to rail by 2030/2050
	Roadmap Target: 50% shift of medium distance passenger road traffic to rail by 2050

Given the abovementioned general criteria, a small discussion on each one of the Roadmap Targets established in WP5.1 follows. The aim is to establish a final list of targets to assess through the proposed MCA approach.

4.2.1 Affordability Targets

Merge	**Roadmap Target:** No increase in access charges by 2050 **Roadmap Target:** 50% decrease in infrastructure maintenance costs by 2050
New	**Proposed Target:** 20% decrease in infrastructure Life-Cycle Costs (LCC) by 2050

Infrastructure pricing models vary widely across European infrastructure managers resulting in a very wide spread of track access charges for a similar passenger or freight train running across Europe[1]. Pricing philosophy ranges from pure marginal cost based systems, including or not mark-ups to explore operator's WTP, up to pure full cost principles. However, in theory, cost relatedness should be preferably based on robust infrastructure Life-Cycle Costs modelling (LCC), as a methodology to assess marginal, average and full costs. Therefore, infrastructure LCC itself, per unit length, should be a more appropriate target, and easier to quantify.

Since average annual costs of inspection and maintenance are part of the infrastructure LCC, double counting would occur if targets for both LCC and infrastructure maintenance costs were to be kept. Therefore, these two targets are merged into the new LCC reduction target.

The milestone for the LCC reduction is set at 20% in line with the Key Performance Indicator (KPI) stated in the Description of Work (DoW).

Keep	**Roadmap Target:** 50% decrease in Train Operating Costs (TOC) by 2050

This target comprises all the Train Operating Companies' expenses included in the movement of trains, such as fuel and energy consumption from train traction and auxiliary systems, personnel costs, rolling stock CAPEX and OPEX. In order to avoid double counting, Track Access Charges (TAC) shall not be considered, since they are already implied in the infrastructure LCC target.

Merge	**Roadmap Target:** 30%/50% decrease in specific CO_2 emissions by 2020/2030 **Roadmap Target:** 50% decrease in total CO_2 emissions by 2030
New	**Proposed Target:** 50% decrease in specific CO_2 emissions, including embodied carbon, by 2030

Specific CO_2 emissions is an indicator used by the European Environment Agency (EEA) to assess and monitor the efficiency of the various passenger and freight transport modes operating in Europe. The indicator is specified for each transport mode and defined as emissions of CO_2 per transport unit, *i.e.* passenger-kilometre or tonne-kilometre, for passenger and freight transport respectively.

Strategic objectives for the reduction of total CO_2 emissions from train operations are based on historical and forecasts data. The latest publication reported a decrease of 24% on the total rail emissions level in Europe, since 1990 until 2011[2] meaning that if the trend continues, the target is likely to be achieved by 2030, mainly from the shifting from diesel to electric trains, as well as for technological improvements and increased load factors.

Also, the preceding target already accounts for CO_2 emissions, therefore there is no need for two targets measuring the same effect. In addition, the decrease in total CO_2 emissions of the European railway system cannot be measured by the performance evaluation of a scenario (railway corridor or

[1] See "UIC Study of European Railway Infrastructure Charges for Freight" and "INFRACHARGES: UIC study on railway infrastructure charges in Europe" for detailed information on European charging systems.
[2] *Railway Handbook 2014: Energy Consumption and CO_2 Emissions*, p. 18

section), since the evolution of total emissions are dependent on the traffic forecast and the existent rolling stock on the European railway network.

Remove **ROADMAP TARGET:** 50% decrease in specific energy consumption by 2030
ROADMAP TARGET: 50% decrease in total energy consumption by 2050

Specific energy consumption is directly related to the energy efficiency levels of the transport sector. The reduction of the specific energy consumption will necessarily lead to improvements towards environmental issues, such as greenhouse gas and air pollution emissions due to lower needs of energy production. Like CO_2 emissions, energy consumption is expressed in terms of passenger-kilometre and tonne-kilometre depending on the transport sector considered. In the reference year 1990, railway specific energy consumption was 0.133 kWh/pkm in the passenger transport sector and 0.066 kWh/tkm in the freight transport sector[3]. Therefore, the goals for specific energy consumption values for the rail transport sector would be 0.067 kWh/ pkm and 0.033 kWh/ tkm in 2030. By 2011, the European railways had reduced passenger specific energy consumption by 17% and freight specific energy consumption by 23%. Double counting is avoided by not considering this target, since specific energy consumption is already accounted in the Train Operating Costs target.

Strategic objectives for the reduction of rail transport total energy consumption from train operations were set based on historical and forecasts data. The latest publication reported a decrease of 31% on the European total diesel energy consumption with a parallel increase of 14% of total electric energy consumption, since 1990 until 2011[2], resulting in a total decrease of 17% of the total energy consumed by transport operations, so far. However, if one considers the variation on total energy consumption from 1990 to 2010, the total decrease is higher (25%) which demonstrates the potential impact of demand variations on the freight sector (the comparison between the years of 1990 and 2010 shows a decrease of 45% in terms of freight energy consumptions). Nevertheless, it is projected that the target for total energy consumption in 2050 will be reached around 2030[3]. Similarly to the target related to total CO_2 emissions, the target performance is strongly influenced by variations in railway traffic demand on the European railway network thus the focus on a single corridor would not properly reflect the target. Furthermore, it could be considered that energy consumption would be better described by the specific energy consumption target since it takes into consideration the actual capacity utilisation of the corridor.

Remove **ROADMAP TARGET:** 40% decrease in exhaust emissions (NO_x and PM_{10}) by 2050

Diesel locomotives are the main cause of exhaust emissions in railways. Despite being the transport mode with the lowest share of emissions, the European railways have committed to reduce their total exhaust emissions, regardless of the projected traffic growth in order to reduce the health risk produced by these air pollutants. UIC reported a 35% decrease of NO_x and PM emission levels in 2006 regarding 1990 levels. Therefore, it is more than reasonable to consider that the roadmap target will be achieved long before 2050 rendering the evaluation of the innovations' impact useless. The removal of this target also avoids a possible double counting with the specific CO_2 emissions target, since emissions of NO_x and PM_{10} from electric trains are mostly related to the countries' electricity generation, as CO_2 emissions are.

[3] *Energy consumption and CO_2 emissions: 1990-2010 European data overview*, p. 6

Keep **ROADMAP TARGET:** Elimination of operating noise problem sites by 2050

Noise emissions from railway operations are part of the European environmental agenda and innovations deployed in C4R are expected to address noise problems, therefore the target should be kept.

According to the CER/UIC report "Moving towards sustainable mobility. A strategy for 2030 and beyond for the European railway sector", the European railways will strive towards noise and vibrations no longer being considered a problem for the railways– meaning that noise levels are socially and economically acceptable and allow for 24-hour passenger and goods operations in 2050.

Remove **ROADMAP TARGET:** 50% decrease in equivalent fatalities by 2050

Equivalent fatality is a safety metric used to assess the frequency and severity of hazardous events. It considers that a fatality is statistically equivalent to a given number of lesser injuries, whose weighting varies according to the type and severity of the injury. The greatest risk contributions for railway equivalent fatalities are related with adult trespassers struck or crushed while standing on the mainline (excluding suicides) and train collisions with road vehicles on level-crossings. Nevertheless, the railway is considered one of the safest transport modes and train accidents resulting in fatalities has been falling significantly over time. The implementation of TEN-T corridors includes the deactivation of level crossings along the corridors, and the installation of ERTMS level 2 which will lead to continuously higher safety levels by ensuring appropriate safe speeds and distance between trains. Therefore, the safety target for 2050 is most likely to be achieved with or without C4R technology innovations since the corridors' planned investments are very likely to significantly reduce the number of equivalent fatalities, increasing the downward trend registered in the last decades.

4.2.2 ADAPTABILITY TARGETS

Replace **ROADMAP TARGET:** Unrestricted and seamless cross-border movements by 2050
ROADMAP TARGET: No access restrictions to standard freight containers by 2050

New **PROPOSED TARGET:** Freight rolling stock adaptable to cope with different freight containers by 2050

The two original targets were meant to obtain a rail network where freight transport would ave no barriers. While they were centred on infrastructure and operational limitations. Still, the technical requirements for infrastructure modernization in TEN-T corridors are already defined. Furthermore, rolling stock designed for a given corridor already incorporates any restriction that may limit freight transportation, for instance loading gauges and axe loads.

Given the fact that freight traffic is expected to become increasingly containerised, it is important to assess the ability of future rolling stock to cope with current and adapt to possible future container requirements. Thus, the new target proposed to replace the original two is mainly focused on the rolling stock and its compatibility with different types of containers. It is desirable that there are no restrictions to container transport coming from rolling stock.

Keep **ROADMAP TARGET:** Fully interoperable bundling of freight rolling stock by 2050

The lack of interoperability of the rail freight network is one of the major issues to improve freight train performances and the rail freight attractiveness to shippers and logistic operators. The shunting and bundling of freight wagons should have no technical restrictions. Ensuring conditions for a fully interoperable bundling of freight rolling stock will enable the decrease of door-to-door costs by increasing the train sizes and loads, service frequency (better infrastructure utilisation) and optimal transhipment and terminal operation time. The elimination of restrictions to interoperability will improve the performance of the freight corridors.

Remove **ROADMAP TARGET:** Freight demand met for current access charges by 2050

Access charges practiced along the railway network impact on the modal choice of logistic operators and freight customers. The competitiveness of road and rail freight transport relies on the transport modes' operating costs and the charges to use the infrastructure. Variations in rail access charges and road tolls will necessarily vary the attractiveness of the rail transport to users. The consideration of this target will lead to double counting with the Affordability target of "No increase in access charges", merged into the target of "Decrease of infrastructure LCC" and the High Capacity targets of shift to rail from road traffic.

Remove **ROADMAP TARGET:** Minimal overcrowding on urban and inter-urban rail services, under 10% at peak times by 2050

The rail network's ability to ensure minimal overcrowding on its urban and inter-urban rail services depends on the network's capacity and traffic demand. The target is heavily dependent on demand scenarios therefore not easily quantifiable. Therefore, the target is directly related with the capacity of the corridors, therefore with the Key Aspect "High Capacity".

However, even given the argument above, this target is still under debate, since some countries have specific regulations regarding overcrowding of rail passenger services and the impacts from C4R scenarios might be significant.

Remove **ROADMAP TARGET:** Infrastructure adapted to 50-year climate change forecast by 2050

Impacts of climate change on railway infrastructure may jeopardize the future well-functioning of the European railway network. Rising temperatures and sea levels will cause increased frequency and intensity of extreme weather events, which may lead to increased infrastructure failure rates and service disruptions. This target is very difficult to translate into a quantifiable measurement, since the requirements to adapt the infrastructure to climate change will be specific to each particular case. It also double counts the effect of extreme weather events on the railway infrastructure, which is also considered in the Key Aspect "Resilience".

Remove **ROADMAP TARGET:** New rolling stock adapted to 25-year climate change forecast by 2050

Increased global temperatures may lead to increased failure rates on rolling stock's electric and electronic equipment, lead to passenger discomfort or even damage perishable commodities if trains are not adapted for climate change issues. Still, this target is not easily quantifiable since it is not clear how rolling stock has to be adapted for climate change.

New **PROPOSED TARGET:** Infrastructure adaptable to new operational requirements from traffic demand by 2050

A new target is proposed to reflect the definition of the Key Aspect "Adaptable" since none of the roadmap targets is directed towards the vision of a modular railway. Thus, the new target matches the vision of an adaptable and modular railway, which is expected to be adaptable to changing operational requirements without the need for a full reconstruction or major works, in an effort to reduce the costs and disruption to users. This target thus requires that the main operational variables, such as running speeds, cant levels, axle loads, signalling systems or electrification are susceptible to change over the infrastructure's lifetime.

4.2.3 Resilience Targets

Merge	**Roadmap Target:** 40%/80% decrease in train delays due to Extreme Weather by 2030/2050 **Roadmap Target:** 30%/60% in train cancellations due to Extreme Weather by 2030/2050
New	**Proposed Target:** 80% reduction of train delays due to Extreme Weather events by 2050

Train operations may be seriously affected by climate conditions, and in particular, extreme weather events. Main causes for train delays or cancellations due to extreme weather conditions are related to track unavailability during heavy snowfall and frost, heavy rain and flooding, etc. Increased resilience of infrastructure elements to extreme weather situations will lead necessarily to increased availability of the track. Since rail users perceive train delays as train cancellations, there is the possibility of double counting the same effect. Thus, these targets are merged into one. This assessment should be performed through SP3 approach.

Remove	**Roadmap Target:** TEN-T core network accessible by all new rolling stock by 2030 **Roadmap Target:** TEN-T comprehensive network accessible by all new rolling stock by 2050

The accessibility of the TEN-T network relies on the non-existence of technical restrictions to the movement of the future rolling stock, *e.g.* axle loads, train length, commercial speeds or profile clearance. Such technical restrictions are already accounted for in the Adaptability target "Unrestricted and seamless train movements", therefore there would be a double counting. Furthermore, High Capacity roadmap targets include the completion of both TEN-T core and comprehensive networks by the same year, which already implies the accessibility of all new rolling stock.

Merge	**Roadmap Target:** 40%/80% decrease in train delays due to Infrastructure Failure by 2030/2050 **Roadmap Target:** 30%/60% decrease of train delays due to Infrastructure Failure by 2030/2050
New	**Proposed Target:** 80% reduction of train delays due to Infrastructure Failure by 2050

Infrastructure failures may lead to the imposition of speed restrictions on certain track segments, or even impose path detours until the problem is fixed. In the worst-case scenario, infrastructure failures may result in train cancellations when rail operators become unable to move trains safely in affected areas. Like the targets related to train delays and cancellations due to extreme weather events, it is suggested to merge both targets into one, avoiding double counting of effects.

4.2.4 Automation Targets

Remove	**Roadmap Target:** Completion of ERTMS Level 2 by 2030

The European Railway Traffic Management System (ERTMS) is a continuous communication-based signalling system, which aims to establish a single standard and contribute to enhance the cross-border interoperability in the European rail network. The implementation of ECTS/ERTMS system is already on going and the achievement of the target is not likely to be influenced by any of the new developments from the project. Instead, the level of completion of the ERTMS level 2 should be considered as a boundary condition on the definition of assessment scenarios in WP5.3.

Remove	**ROADMAP TARGET:** Multi-modal information, ticketing, management and payment system framework in place by 2020

The existence of a MIMP system in the European multimodal transport network will allow users to optimise their modal choice by ensuring punctual, cost efficient, and minimal environmental impact. Multimodal information systems rely mostly on data availability and share of existing data. Multimodal management systems are related to the optimal use of the available transport resources, ensuring the avoidance of congestion and traffic disruption issues. Multimodal ticketing and payment systems will simplify the use of the transport network in the users point of view, and ensure secure and easy access to the transport network. The establishment of the system's framework by 2020 does not imply the implementation of actual technical systems by then. Instead, it supposes the existence of a harmonised, legal and technical environment among the European countries. The target is set to 2020, which is a rather short period after the end of the C4R project. Since none of the developed technologies are expected to be fully developed (at TRL 9) by 2020, and the target does not imply any actual technical system to be implemented, we suggest the target to be kept out of the MCA.

Merge	**ROADMAP TARGET:** Euro-wide standard ITS system completed by 2035 **ROADMAP TARGET:** All new rolling stock equipped with intelligent monitoring systems by 2035
New	**PROPOSED TARGET:** Automated rail freight system by 2050

Euro-wide Intelligent Transport Systems (ITS) refers to the incorporation and integration of information and communication technologies in the rail network with the aim of achieving optimal economic performance, safety, mobility and environmental sustainability of the European network. This comprises technologies such as traffic control and management systems, V2I communication systems, advanced monitoring or traceability of commodities. The target is not easily quantifiable as its concept is somewhat diffuse. However, it should be considered within the assessment as ITS include technologies to traffic control and management systems (SP3 innovations).

The integration of advanced monitoring systems in rolling stock will enable to increase current RAMS performances of rolling stock by reducing needs of inspection and maintenance, consequently increasing the rolling stock availability.

Both these targets point towards the wider concept of an automated rail freight system. Thus, these two targets are merged into a new target that shall evaluate the attainment of a fully automated rail freight system by 2050.

Replace	**ROADMAP TARGET:** Intelligent monitoring systems maximised in all new infrastructure by 2045
New	**PROPOSED TARGET:** 50% reduction of track unavailability due to monitoring & inspections by 2050

The introduction of advanced monitoring systems in the rail infrastructure will enable intelligent monitoring and diagnostic, thus improved reliability, safety and efficiency. However, the concept is somewhat diffuse thus a new target is proposed to replace it. The new proposed target is based on the KPI that reflects the impacts expected to result from introducing advanced monitoring systems in a lower need for infrastructure inspection operations. This target can be extended to include maintenance and renewal operations as well.

4.2.5 High Capacity Targets

Remove **Roadmap Target:** 300% increase/completion of the high-speed rail network by 2030/2050

The completion of the HS rail network is strongly related with the European investment and strategies in coming years. Innovative outputs from the project may enhance the pace of construction of the network or decrease the required investments. Nevertheless, the fulfilment of the targets is independent from migration to SP1-4 innovations.

Remove **Roadmap Target:** Completion of the TEN-T core network by 2030
Roadmap Target: Completion of the TEN-T comprehensive network by 2050

The TEN-T policy considers a dual layer approach to the development of the European TEN-T rail network. The priority layer is the core network, which strategically focuses on the most important links and nodes of the Trans-European transport network; the comprehensive network will ensure accessibility to other regions of the EU not envisaged in the core network. Although C4R innovations may indirectly contribute to the fulfilment of these targets through enhancing construction timings or investment affordability, the achievement of the completion of the TEN-T corridors is mostly dependent on the European strategies and investments. Any such enhancements are already accounted in Affordability targets. For these reasons, the targets are not independently considered in the adopted approach.

Remove **Roadmap Target:** Completion of the high-speed rail links to TEN-T core airports by 2050
Roadmap Target: Completion of the rail freight links to TEN-T core seaports by 2050

These targets are closely linked to the previous targets on high-speed rail network and TEN-T network completion (The TEN-T core network actually already comprises 37 key airports with rail connections into major cities, and 20 of the major airports are already connected to the rail network. The TEN-T core network also comprises 83 core seaports with rail connections into major cities, and only 35 of the major ports are already connected to the rail network). Therefore, the same reasoning applies so the targets should not be independently considered in the analysis.

Remove **Roadmap Target:** Multi-modal information, management, booking and payment on-line system framework in place by 2020

This target is a repetition of another target in the Key Aspect "Automation", where it was already discussed and slated for removal.

Replace **Roadmap Target:** 30%/50% shift of road freight over 300 km to rail by 2030/2050
Roadmap Target: 50% shift of medium distance passenger road traffic to rail by 2050

New **Proposed Target:** 100% increase in overall freight capacity by 2050
Proposed Target: 100% increase in overall passenger capacity by 2050

Among other transport strategies for Europe outlined on the White Paper of Transport from the European Commission, the EC set specific goals for the modal shift from road transport to railway (and waterborne transport). Modal shift from road to rail depends on many key drivers and constraints existent on both infrastructures and perceived by the networks users. Due to the targets' dependence on external factors, the evaluation of the scenarios' performance within these targets should focus on the ability of the studied corridor to meet a 100% growth in demand. This depends on factors like the infrastructure capacity, the vehicle's capacity and load factors (both in terms of passengers and goods). These targets are adapted to new targets T5.1 and T5.2.

4.2.6 Proposed List of Targets

Table 4. Set of Roadmap targets to be assessed in the MCA.

1. Affordability	**T1.1.**	20% decrease in infrastructure Life-Cycle Cost (LCC) by 2050
	T1.2.	50% decrease in Train Operating Costs (TOC) by 2050
	T1.3.	50% decrease in specific CO_2 emissions, including embodied carbon, by 2030
	T1.4.	Elimination of operating noise problem sites by 2050
2. Adaptability	**T2.1.**	Freight rolling stock adaptable to cope with different freight containers by 2050
	T2.2.	Fully interoperable bundling of freight rolling stock by 2050
	T2.3.	Infrastructure adaptable to new operational requirements from traffic demand by 2050
3. Resilience	**T3.1.**	80% reduction of train delays due to Extreme Weather events by 2050
	T3.2.	80% reduction of train delays due to Infrastructure Failures by 2050
4. Automation	**T4.1.**	Automated rail freight system by 2050
	T4.2.	50% reduction of track unavailability due to monitoring & inspections by 2050
5. High Capacity	**T5.1.**	100% increase in overall freight capacity by 2050
	T5.2.	100% increase in overall passenger capacity by 2050

The discussion in the preceding subsection allows us to present a shorter and more focused list of Targets, as shown in Table 4. At this point, the targets are presented without their quantitative milestones and timeframes since a more detailed discussion on them is presented in the next section about Target Assessment Criteria.

4.3 Target Assessment

Each Target needs a quantifiable criterion in order to be scored. While some of them are relatively self-evident, others shall require further consideration in order to develop an effective assessment method. With this in mind, the partners decided to establish workgroups and assign a leader to each target. These workgroups, listed in Table 5, will be responsible for the scoring of each target.

Although the bulk of the work involved in target scoring will be carried out by the workgroups, it is useful to outline a preliminary set of scoring criteria. For each one of them, the criterion, scoring scale and inputs are envisaged below in

Table 6 to Table 10.

Much of the required data will have to be provided by the SPs. Although, at this stage, the full list of required data is not yet closed, it is already possible to list what should cover, for the most part, the information the needs to be provided, as listed in

Table 11.

TABLE 5. WORKGROUPS FOR MCA TARGET SCORING.

Target		Leader	Available to Contribute
T1.1	20% decrease in infrastructure Life-Cycle Cost (LCC) by 2050	DB	IST; USFD; COMSA; SYSTRA; DB; ADIF
T1.2	50% decrease in Train Operating Costs (TOC) by 2050	USFD	IST; USFD; TRV
T1.3	50% decrease in specific CO_2 emissions, including embodied carbon, by 2030	COMSA	IST; USFD; COMSA
T1.4	Elimination of operating noise problem sites by 2050	COMSA	IST; COMSA; SYSTRA; DB
T2.1	Freight rolling stock adaptable to cope with different containers by 2050	TRV	IST; TRV; UIC
T2.2	Fully interoperable bundling of freight rolling stock by 2050	UIC	IST; TRV; UIC
T2.3	Infrastructure adaptable to new operational requirements from traffic demand by 2050	IST	IST; USFD; COMSA; SYSTRA; DB; ADIF
T3.1	80% reduction of train delays due to Extreme Weather events by 2050	USFD	IST; USFD; TRL; NR; (SYSTRA); DB; TCDD
T3.2	80% reduction of train delays due to Infrastructure Failures by 2050	USFD	IST; USFD; TRL; NR; (SYSTRA); DB; TCDD
T4.1	Automated freight system by 2050	DB	IST; TRV; DB;
T4.2	50% reduction of track unavailability due to monitoring & inspection by 2050	DB	IST; COMSA; STSTRA; DB; ADIF
T5.1	100% increase in overall freight capacity by 2050	IST	IST; COMSA; TRL; NR; DB
T5.2	100% increase in overall passenger capacity by 2050	IST	IST; COMSA; TRL; NR; DB

Table 6. Envisaged assessment criteria for Affordability targets.

T1.1	20% decrease in infrastructure Life-Cycle Costs (LCC) by 2050
Criterion	Comparison of infrastructure life-cycle costs, between baseline and innovation scenarios, in €/km
Scoring Scale	Linear scale, with Score = 100 for 20% decrease regarding baseline scenario
Inputs	Unit costs for procurement, operation, inspection, maintenance and unavailability; RAMS parameters
T1.2	**50% decrease in Train Operating Costs (TOC) by 2050**
Criterion	Comparison of current and future (2050) train operating costs, in €/pkm and €/tkm
Scoring Scale	Linear scale, with Score = 100 for 50% decrease regarding baseline scenario
Inputs	Rolling stock CAPEX and OPEX; energy consumption; train crew; traffic demands
T1.3	**50% decrease in specific CO_2 emissions, including embodied carbon, by 2030**
Criterion	Comparison of current and future (2030) specific CO_2 emissions, including embodied carbon, averaged for freight and passenger traffic, in kg-CO_2/pkm and kg-CO_2/tkm
Scoring Scale	Linear scale, with Score = 100 for 50% decrease regarding 1990 levels*
Inputs	Energy consumption of reference trains, emission factors from electricity generation or diesel consumption, embodied carbon of infrastructure components.
T1.4	**Elimination of operating noise problem sites by 2050**
Criterion	Comparison of current and future (2030) noise emissions (or exposure) from rail operations.
Scoring Scale	Two linear segments with different slopes: Score = 0 for noise levels above 75 dB(A); Score = 100 for noise emission levels lower than 51 dB(A). Different slopes from the 70 dB(A)
Inputs	Estimate of train operating noise levels: current situation and innovation impacts on train operating noise levels.

Table 7. Envisaged assessment criteria for Adaptability targets

T2.1	Freight rolling stock adaptable to cope with different containers by 2050
Criterion	Comparison of the number of barriers to unrestricted and seamless movement of trains in current and future (2050) circumstances.
Scoring Scale	Linear scale with Score=0, for elimination of none of the current barriers; Score=100 for elimination of all the identified barriers
Inputs	List of factors currently preventing the movement of trains along the corridor, and which ones are expected to be eliminated with the introduction of the innovations in the scenario, based on expert judgement.
T2.2	**Fully interoperable bundling of freight rolling stock by 2050**
Criterion	Comparison of the number of barriers to fully interoperable bundling of rolling stock in current and future (2050) circumstances.
Scoring Scale	Linear scale, with Score=0 for elimination of none of the current barriers; Score 100 for elimination of all the identified barriers
Inputs	List of factors currently preventing the bundling of rolling stock and which ones are expected to be eliminated with the introduction of the innovations in the scenario, based on expert judgement.
T2.3	**Infrastructure adaptable to new operational requirements from traffic demand by 2050**
Criterion	Comparison of the requirements to which the infrastructure is susceptible to adapt to respond to changes in demand in current and future (2050) circumstances.
Scoring Scale	Score=0 for no capability to respond to changes; Score=100 for easy adaptation of all identified requirements. The scale may be linear or, as an alternative, specific capabilities can be weighted differently within the scale in a process similar to the MCA itself.
Inputs	Identification of possible and foreseeable design parameters that could be required or useful to change based on expert judgement; identification of response capabilities of baseline and innovation.

TABLE 8. ENVISAGED ASSESSMENT CRITERIA FOR RESILIENCE TARGETS

T3.1	80% reduction of train delays due to Extreme Weather events by 2050
Criterion	Comparison of current and future (2050) train delays due to EW events, in h-km
Scoring Scale	Two linear segments with Score = 0 for no change; Score=80 for 50% reduction and Score = 100 for 80% reduction.
Inputs	Estimated current and future frequency of extreme weather events causing infrastructure unavailability.
T3.2	**80% reduction of train delays due to Infrastructure Failures by 2050**
Criterion	Comparison of current and future (2050) train delays due to infrastructure failures, in h-km.
Scoring Scale	Two linear segments with Score = 0 for no change; Score=80 for 50% reduction and Score = 100 for 80% reduction.
Inputs	RAMS parameters

TABLE 9. ENVISAGED ASSESSMENT CRITERIA FOR AUTOMATION TARGETS

T4.1	Automated rail freight system by 2050
Criterion	Fulfilment of a set of technical requirements to be implemented for the rail freight system to be fully automated by 2050 *or* Comparison of current and future (2050) percentage of rolling stock and infrastructure fully automated in the corridor.
Scoring Scale	Score=100 all requirements fulfilled; Score=0 for no requirements fulfilled. The scale may be linear or, as an alternative, specific requirements can be weighted differently within the scale in a process similar to the MCA itself. *or* Linear scale with Score=100 for 100% automation of all rolling stock and infrastructure
Inputs	Identification of technical requirements for the ITS system, based on expert judgement; time-frame for the availability of the different capabilities.
T4.2	**50% reduction of track unavailability due to monitoring & inspection by 2050**
Criterion	Comparison of current and future (2050) Mean Down Time due to monitoring & inspection*, in h·km.
Scoring Scale	Linear scale with Score = 100 for 50% reduction.
Inputs	SP1, SP4, RAMS parameters

TABLE 10. ENVISAGED ASSESSMENT CRITERIA FOR HIGH CAPACITY TARGETS

T5.1	100% increase in overall freight capacity by 2050
Criterion	Comparison of current and future (2050) corridor freight capacity, in t·km
Scoring Scale	Linear scale with Score=100 for a capacity increase of 100% for rail freight transport.
Inputs	Capacity simulations to be performed by SP3.
T5.2	**100% increase in overall passenger capacity by 2050**
Criterion	Comparison of current and future (2050) corridor passenger capacity, in seat-km
Scoring Scale	Linear scale with Score=100 for a capacity increase of 100% for rail passenger transport.
Inputs	Capacity simulations to be performed by SP3.

Table 11. Summary of minimum required information from C4R SP1-4 for the MCA. The column on the right lists possible alternatives to obtain the data in the second column, should it be impossible to be provided directly.

Innovation	Minimum Required Data	Targets	Alternative, to estimate minimum required data
SP1, Slab Track and New Switches and Crossings	Average construction/installation cost (€/km or €/switch)	T1.1	Component costs and engineering details.
	Embodied carbon (kg CO_2/km or kg CO_2 /switch)	T1.3	Component list and unit embodied carbon.
	Average maintenance cost (€/MGT)	T1.1	Maintenance requirements (RAMS) and operations unit costs.
	Time and cost of changing track operational parameters that are susceptible to be changed.	T2.3	Required operation and unit cost for parameter change.
	Expected reduction in unavailability due to weather events (%).	T3.1	Weather conditions that determine closure and time to recover.
	Expected reduction in unavailability due to infrastructure failure (%).	T3.2	Failure rates (RAMS) and time to recover.
	Average required unavailability due to inspections (h/day).	T4.3	Inspection cycles (RAMS), and time required for each operation.
SP2, New Freight Wagons	Freight capacity (T/wagon)	T1.2	
	Axle load (T/axle)	T.1.1	
	Maximum speed (km/h)	T1.2	
	Time-frame for availability (year)	T1.2, T2.1, T2.2, T4.2	
	Purchase cost (€/wagon) and/or cost reduction (%)	T1.2, T2.1, T2.2, T4.2	
	Maintenance cost or change relative to current wagons (€/year or %)	T1.2	Maintenance requirements and operations unit costs.
SP2, New Freight Terminals	Operational cost reduction in new terminals (2.3.5)	T1.2	
SP3, Traffic Management Systems	Technical features of ITS	T4.1	
	Change on delays resulting from unavailability (%)	T3.1, T3.2	
	Change in capacity (% or number of trains)	T5.1, T5.2	
	Impact on train average speeds or travel times (km/h or h)	T1.2	
SP4, Monitoring Systems	Change in average track down time for inspection (h/day or %)	T4.3	New inspection cycles (RAMS) and time required for each operation.
	Change in track maintenance costs (€ or %)	T1.1	Track inspection and maintenance requirements (RAMS) and operations unit costs.

4.4 NEXT STEPS

It was decided[4] that the multi-criteria assessment here developed will not be pursued further in the framework of WP5.4.2. but merged instead into the WP.3.1. capability trade-offs tool. Therefore, the assessment of the impact of C4R innovations towards the different key aspects (Affordability, Adaptability, Resilience, Automation and Capacity) will be provided exclusively within WP.3.1. outputs.

[4] Agreed in the SP5 meeting of April 19-20, 2016 and in SP5/SP3 phone conference meeting of May 12th 2016.

5 Cost-Benefit Analysis (CBA)

5.1 Approach

The aim of this analysis is to assess the impact of the implementation of a set of investments related with Capacity4Rail innovations in a given corridor. This means the technologies underlying the investments under analysis are often not yet fully developed and lacking technical detail, including in what regards its Life-Cycle Costs and operational benefits. Adding to that the scale of the analysis, a traditional detailed CBA would quickly become totally unusable.

This specific problem requires an approach that is flexible enough to accommodate different scenarios and to make them easily comparable. It should be highlighted that this CBA must be ready for a probabilistic analysis using Monte Carlo simulations.

These restrictions make it extremely hard to obtain a reliable numerical figure for the total costs and benefits. To do so would require the superposition of detailed CBAs performed for each investment. This is not only totally unfeasible in the context of an entire corridor that may run across the entire rail networks of one or more countries, it would require all innovations to be assessed to have readiness levels they have not currently attained. Thus, one should reframe the mind-set of a traditional CBA and adapt it to a larger scope and to an often ill-defined set of investment.

The consequence is that the results should be interpreted as approximate. One will be able to tell in which categories, if any, a given investment has an impact, how significant it is and if costs and benefits are approximately balanced. One will also be able to compare different investment scenarios and identify the variables that have the greater impact on the final results. Finally, the probabilistic analysis will be able to provide the likely range of the results.

The approach to CBA chosen for this task departs from the main CBA categories and progressively builds detail depending on the available information or on the hypotheses resulting from the construction of the Scenario. All items for which there is no information available or no reasonable assumptions can be made should not be included in the analysis.

The analysis is built upon an Investment Scenario, which lists the projects already planed in the TEN-T programme and shall include the investments in C4R innovations that are to be part of the Investment Scenario. These investments in C4R innovations may complement or replace some of the TEN-T projects. Thus, the CBA is made incrementally, from a baseline with only the minimal required investment to maintain current conditions, a second level with TEN-T projects and a third level with C4R innovations.

5.2 Description

5.2.1 Available and Expected Information

Since the corridors to be analysed in the context of this task are contained or coincide with the TEN-T corridors, the documentation produced in the context of the TEN-T programme is a crucial source of information for this analysis.

The construction of the CBA follows an incremental approach, as prescribed by the EU Commission Guidelines for investment appraisal. Following this principle, the investment on the implementation of C4R Innovations is built upon the already established TEN-T projects, as listed on the respective corridor reports. The listed TEN-T projects include a brief description, time-frame and cost estimate, reflecting the level of detail that we aim for in this CBA analysis.

Another extremely important piece of information available in the TEN-T reports are the traffic demand projections. Although their format level of detail is not uniform, it should always be the main source to establish the baseline for the traffic scenario.

Aside from that, C4R SP1 to 4 should be able to provide estimates on the cost of the implementations of their innovations and the effects on the operation (or enough data to be able to perform this assessment). For example, the minimal data needed from SP 2 would be the initial and maintenance cost of a new wagon, its freight capacity, tare weight, length, maximum speed and axle load. Should figures for these parameters be unavailable, they will have to be estimated by SP5, but always with the support of SP1 to 4.

As said in the previous section, any non-essential item for which there is no reliable information available or reasonable way to estimate it should be left out of this CBA. We recall that we don't aim for a definite value for the net benefits, but rather approximate values and, more importantly, the sensitivity of the result to certain inputs.

5.2.2 Investment Scenario

In the Investment scenario one identifies a set of investments to be made on the rail corridor under analysis. The assessment includes three incremental steps to build the scenario. The baseline assumes no investments are made besides maintenance and replacement of end of life items. The second level includes investments already planned in the context of the TEN-T corridors. The final level is to introduce investments related to C4R innovations. The table should be built in such a way that the user is able to easily choose which investments to use in each analysis, all of this in articulation with the scenario defined in WP.5.3.

5.2.3 Traffic Scenario

The baseline for the traffic scenario is built upon an extrapolation of the traffic forecasts provided in the TEN-T reports. The minimum information for the construction of this baseline are two traffic values for two different years or a values for one year plus an average annual growth rate (AAGR). In order to build the CBA, data for rail and road traffic will be needed.

The data use for the construction of the baseline is, in many cases, given in vehicles per year instead of passengers or tons per year for a given section. In any case, some of the variables are dependent on the number of vehicles while other on the number of passengers or amount of freight. In order to convert between both, we establish reference vehicles and trains. In order to keep the calculation manageable, we may assume, at most, one kind of passenger and freight train or road vehicle for each of the investment levels mentioned in the previous section. The correct vehicle should be assigned to each section of the corridor under analysis once the necessary investments to allow for its running are complete. For example, we might assume a 500 m freight train with 22,5 T/axle for the baseline, a 750 m train with 22,5 T/axle for section after the TEN-T projects are complete and a 750m train with 25 T/axle after the implementation of C4R innovations.

The traffic scenario also includes estimates on the amount of diverted and generated traffic as a result of investments. The data is input in the same format as the baseline traffic, although, in most case it will have to be estimated or assumed as part of the Traffic Scenario.

5.2.4 Infrastructure Parameters

If we follow the TEN-T corridor segmentation, each corridor is divided into sections which are further subdivided into subsections, which may differ between road and rail.

For each subsection, we need to know which one of the reference vehicles is allowed to run after each investment level and have a measure of its performance. Thus, the minimal information needed for each subsection and each investment level includes subsection length, average speed and/or travel time for passenger and freight trains, maximum train length and axle load. We also need to assign the year when each investment level becomes available for each section (i.e. when the needed investments are complete).

In many case, the listed parameters may not be available directly and may have to be computed or estimated. For example, if baseline travel time is not available or provided by the infrastructure manager, it may be estimated from train timetables. The impact of the investments in these parameters will, in many cases, have to be estimated as well.

5.2.5 Capacity

The approach taken regarding capacity computation is based on UIC Code 406. It takes into account the number of trains running through a given section (a block) and their average speeds to compute the amount of time the section is occupied. Buffers between trains and, in the case of a single track, crossing buffers are added as well as a daily supplement for maintenance. This allows for the computation of the total time the infrastructure is occupied each day and its ratio to a 24-hour day. We consider that the infrastructure cannot support additional trains once 100% occupation is reached. These occupation ratios may also allow us to compute delays due to congestion, assuming an appropriate model is available.

5.2.6 Infrastructure Maintenance Costs

Ideally, infrastructure maintenance costs comparison (differences among alternatives) should be computed simply by splitting into two components: a fixed cost including activities that do not vary with traffic (e.g. some inspection and routine scheduled maintenance cost, structure cost, etc.) and an additional variable cost obtained multiplying the gross traffic (MGTs) by an average (marginal) maintenance cost. This maintenance cost should be different for each investment level.

While the average maintenance cost for the baseline maybe estimated with available information, it might be difficult to obtain a reliable value for a C4R innovation like slab track, for example. In this case, and if the respective SPs are unable to provide an estimate, we may use as more detailed LCC analysis, already prescribed in the MCA, to obtain this estimate.

5.2.7 Vehicle Operating Costs

The approach to vehicle operating costs is similar to infrastructure maintenance, insofar as, ideally, they would be obtained by multiplying the traffic by an average cost. If there is no way to obtain an estimate either based on data or on some reasonable hypotheses, a more detailed analysis may have to be used to obtain these values. Once again, the analysis of this parameter is already prescribed in the MCA, so the methods developed for that analysis may become useful to feed the CBA analysis.

5.2.8 Time Valuation

The value of time savings may turn out to be on of the most relevant parameters in the CBA. It is essentially dependent on the travel times and traffic scenario and is divided into existing, diverted and generated traffic.

A time value is assigned to each type of passenger and freight. In the context of this analysis, and keeping with the simplified approach laid out in the beginning of this chapter, it is always better to have average values based on less segmented data. Ideally, one average (weighted) value for passenger and freight on each mode. As an alternative, there will be the need to additionally gather the breakdown of passengers (business, leisure, etc.) and freight in each segment. Should averages or estimates have to be made, the conservative approach should be followed, where we always prefer to underestimate the benefits as opposed to overestimating them.

The time value savings for existing and diverted traffic is simply computed by multiplying the time value by the difference in travel time. For the generated traffic, the “rule of half” is used, as prescribed in the EU Commission guidelines for CBA. With the 2rule of half, each generated passengers receives half the benefit that an existing passenger receives.

5.2.9 Externalities

For the externalities, the minimum setup the we built includes only Greenhouse Gas (GHG) emissions. The GHG emission per travelled distance has to be estimated for each of the reference vehicles and then multiplied by the traffic in order to obtain the total GHG emission. This values is then multiplied by the monetized value of of GHG emission per unit mass.

5.2.10 Total Cash Flows and CBA

The sections outlined above provide the required values to compute annual total cash flows, which are need to compute the Net Present Value (NPV) and Internal Rate of Return (IRR) of the set of investments outlined for each investment scenario level. These section are also grouped into the main CBA categories (Investment, Operation and Maintenance, Residual Value, Producer Surplus, Consumer Surplus and Externalities).

All these values are computed for each of the three levels (Baseline, TEN-T projects and C4R innovations) and net results are computed for each pairwise comparison, allowing for a relative valuation of each set of investments.

5.2.11 Summary of Required Information

Following the outline of the calculation process for each part of the CBA, it is useful to compile a table with the minimal required information for this analysis. When relevant, all data should be provided or estimated for each investment level (baseline, TEN-T and C4R).

More specifically, each one of the SP’s within C4R is expected to provide certain crucial information for each innovation so that the CBA can be performed. Although the provided data does not need to have a high level of certainty, at least an estimate based on reasonable assumption should be possible. The minimum required data from SP1-4 is outlined in Table 13. Should any required data be missing or be impossible to obtain, in can, in some cases, be estimated through the information indicated in the rightmost column. Even if that proves impossible, it can always be assumed as part of the scenario and subsequently subject to probabilistic analysis.

TABLE 12. SUMMARY OF MINIMUM REQUIRED INFORMATION FOR CORRIDOR CBA.

CBA Section	Required Data
Investment Scenario	List of investments, time frames and cost estimates.
Infrastructure Data	Distances, travel times r average speeds for freight and passenger trains, maximum train length, axle load.
Traffic Scenario	Demand forecasts for rail and road, estimates or assumptions regarding diverted and generated traffic.
Rail Traffic	Reference trains with tare weight, capacity and load factor.
Road traffic	Same as above for road vehicles.
Capacity	Block length, daily supplement for maintenance, buffer times.
Infrastructure Maintenance	Average infrastructure maintenance costs (per km).
Train Operating Costs	Average train operating costs (per train or per carried unit).
Time Valuation	Value of time for passengers, rail freight, road freight. Estimate on the value of time for freight diverted from road to rail.
Externalities	Greenhouse gas emissions for reference vehicles, GHG emission values.
CBA	Discount rates, shadow price conversion factor.

Some of this information intersects with the data required for the MCA. The exact amount of the intersection is dependent on the exact methodology followed for the analysis of each target, which are, at this stage, not yet defined.

Data on the impact on unavailability (important outputs required for SP1 and SP4) should also be incorporated. However, the way unavailability will be accessed in the CBA will strongly depend on the way capacity and traffic scenarios will be defined in the scenarios (after completion of WP.5.3).

Table 13. Summary of minimum required ingformation from C4R SP1-4 for the CBA. The column on the right lists possible alternatives to obtain the data in the central column, should it be impossble to be provided directly.

Innovation	Minimum Required Data	Alternative, to estimate minimum required data
SP1, Slab Track	Average construction cost (€/km)	Component costs and engineering details.
	Average maintenance cost (€/MGT)	Maintenance requirements (RAMS) and operations unit costs.
	Maximum axle load (T/axle)	
	Train maximum speed, if changed (km/h)	
	Impact on track unavailability due to inspection/maintenance (h/(day·track))	
SP1, Switches and Crossings	Average installation cost (€/switch)	Component costs and engineering details.
	Average maintenance costs or change relative to current S&C (€/switch or %)	Maintenance requirements (RAMS) and operations unit costs.
SP2, New Freight Wagons	Freight capacity (T/wagon)	
	Axle load (T/axle)	
	Maximum speed (km/h)	
	Time-frame for availability (year)	
	Purchase cost (€/wagon)	
	Maintenance cost or change relative to current wagons (€/year or %)	Maintenance requirements and operations unit costs.
SP3, Traffic Management Systems	Investment costs (€)	
	Operation costs (€/year)	
	Impact in capacity (% or number of trains)	
	Impact on train average speeds or travel times (km/h or h)	
	Impact on total/average delays (min)	
SP4, Monitoring Systems	Installation costs (€/km)	Component costs and engineering details.
	Impact on track maintenance/inspection costs (€ or %)	Track inspection and maintenance requirements (RAMS) and operations unit costs.
	Impact on track unavailability due to inspection/maintenance (h/(day·track))	

5.3 Implementation

5.3.1 Corridor Overview and Reference Values

To illustrate how this analysis should work, we built an example of the analysis of a simple fictional corridor and walk through the steps of the analysis. This example has a corridor with just 2 nodes and 1 section, with the rail corridor divided into 2 subsections and the road corridor into a single one, as shown in Table 14.

Table 14. Example corridor nodes and sections.

Nodes	
N1	City A
N2	City B
Sections	
S1	City A - City B

Rail Corridor Segmentaion	
S1	City A - City C
	City C - City B
Road Corridor Segmentation	
S1	City A - City B

Once the corridor is defined, the user should attend to is the References Values spreadsheet. This sheet contains a list of reference values to be used in calculation throughout the analysis. These include economic boundary conditions, maintenance unit costs, reference vehicles, reference values for time and greenhouse gas emissions and all additional values for all factors that may be included. In Figure 12 a section of this spreadsheet is shown.

CBA Boundaries		
Time horizon	40	years
Year 1	2016	
Economic Boundary Conditions		
Price base year	2015	
Financial discount rate	4,00%	
Social discount rate	4,00%	
Shadow price conversion factor	0,95	
Rail Infrastructure		
Maintenance Costs		
Ballasted track maintenance cost	1500	€/(MGT·km)
Slab track maintenance cost	750	€/(MGT·km)
Rail Vehicles		
Passenger Train 1 (Baseline)		
Length	130	m
Tare Weight	350	T
Axle load	17,5	T/axle
Maximum Speed	200	km/h
Capacity	250	passengers
Load Factor	45%	
Average Gross Weight	358	T

Figure 12. Section of example Reference Values spreadsheet. Here the user should input all required values for the analysis.

5.3.2 Investment Scenario

The investment scenario contains a list of possible investments to be included in the TEN-T projects and the C4R scenario. These two levels maybe chosen by selection columns on a spreadsheet, where the filling of the words "Yes" or "No" automatically triggers its inclusion or not. The investment distribution over the analysis period should be filled manually and the spreadsheet should coumpute the correct annual investment cash flows for each investment level. An example of how this spreadsheet could look is depicted in Figure 13.

Investment Projects		Included in			NPV	0	1	2	3
		Baseline	TEN-T Projects	C4R Scenario		2015	2016	2017	2018
TEN-T 1	Implementation of ERTMS	No	Yes	Yes	108 896 857 €	0 €	30 000 000 €	30 000 000 €	30 000 000 €
TEN-T 2	Track upgrades and sidings to allow 750 m long trains	No	Yes	Yes	262 106 843 €	0 €	50 000 000 €	50 000 000 €	50 000 000 €
C4R 1	Upgrade to Slab Track	No	No	Yes	524 213 686 €	0 €	100 000 000 €	100 000 000 €	100 000 000 €
Total Investment Cash Flows					NPV	0	1	2	3
						2015	2016	2017	2018
		Baseline			0 €	0	0	0	0
		TEN-T Projects			371 003 700 €	0	80000000	80000000	80000000
		C4R Scenario			895 217 385 €	0	180000000	180000000	180000000

Figure 13. Example of investment scenario spreadsheet. The list of projects and their annual cash flow distribution should be input by the user.

5.3.3 Infrastructure Data

The minimal set of data regarding rail and road infrastructure should be inserted in its own spreadsheet. This sheet is built on the three levels established in the approach: baseline, TEN-T and C4R, assigning to each one a year when it becomes available in a given subsection. The minimal required information to be filled here includes the subsection length and travel times for passenger and freight vehicles. In this approach, the operational data are used only in assigning the vehicle parameters for each level, that is done in the Reference Data section. These values are input by the user based on information obtained about the infrastructure.

Rail																
		Year	Length	Number of Tracks	Switches and Crossings Density	Capacity				Maintenance Costs			Passenger		Freight	
						Block Length	Buffer Time	Crossing Buffer	Supplement for Maintenace	Track Fixed	Track Variable	S & C	Av. Speed	Time	Av. Speed	Time
			km		1/km	km			h/track	€/(year·km)	€/(MGT·km)	€/year	(km/h)	(h)	(km/h)	(h)
Baseline																
S1	City A - City C	2015	239	2	0,14	15	5%	0%	5	160000	2000	0	124	1,93	50	4,78
S1	City C - City B	2015	227	2	0,14	15	5%	0%	5	160000	2000	0	153	1,48	49	4,60

Figure 14. Example of Infrastructure data spreadsheet to be filled by the user.

5.3.4 Traffic Scenario

The construction of the traffic scenario depends on the source data used to establish the demand forecasts. In the example, we assume that forecasts were available in terms of number of vehicles per day in a given section for two different years. This allows for the computation of an Average Annual Growth Rate, which is then used to extrapolate the time evolution of traffic demand, as shown in Figure 15.

A second section of the spreadsheet is also included to account for diverted and generated traffic as a result of the investments to be performed. The data is filled with the same structure as the existing traffic data, though it will, most likely, have to be estimated or assumed as part of the scenario. An example for diverted traffic as result of TEN-T projects is shown in Figure 16. Similar tables are included for the C4R scenario and for generated traffic.

This is the last sheet to be filled by the user. If all information was inserted correctly up to this point, the sheets that follow should compute automatically.

Rail Traffic													
		Distance	Passenger						Freight				
		(km)	Year	(trains/day)	Year	(trains/day)	AAGR	Year	(trains/day)	Year	(trains/day)	AAGR
S1	City A - City C	70	2010	135	2030	188	1,7%	2010	28	2030	34	1,0%
	City C - City B	220	2010	71	2030	112	2,3%	2010	24	2030	30	1,1%
Road Traffic													
		Distance	Passenger						Freight				
		(km)	Year	(cars/day)	Year	(cars/day)	AAGR	Year	(trucks/day)	Year	(trucks/day)	AAGR
S1	City A - City B	305	2010	12500	2030	15125	1,0%	2010	3600	2030	4860	1,5%

FIGURE 15. EXAMPLE OF TRAFFIC DEMAND SPREADSHEET TO BE FILLED BY THE USER.

Diverted Rail Traffic, from Road												
		Distance	TEN-T Projects									
			Passenger					Freight				
		(km)	Year	Fraction of Total	Year	Fraction of Total	AAGR	Year	Fraction of Total	Year	Fraction of Total	AAGR
S1	City A - City C	239	2020	0%	2022	10%	5,0%	2020	0%	2022	10%	5,0%
	City C - City B	227	2015	0%	2030	0%	0,0%	2015	0%	2030	0%	0,0%

FIGURE 16. EXAMPLE TABLE FOR DIVERTED TRAFFIC AS RESULT OF TEN-T INVESTMENTS TO BE FILLED BY THE USER.

5.3.5 RAIL AND ROAD TRAFFIC

Based on the data inserted in the tables established in the previous section, annual traffic figures must be produced in terms of traffic units (passengers or tons per year), number of vehicles or trains per year and number of Gross Tons per year in each subsection of the rail corridor. The same has to be made for the road corridor, except for gross traffic.

For each investment level, existing, diverted and generated traffic are computed separately. The only significant challenge arises when the rail corridor segmentation does not match the road corridor segmentation. In these situations, it is assumed that the transfer is uniform in the most aggregated segment, keeping the number of transferred p·km or T·km constant. This means, for example, that 1 passenger diverted to a 50 km rail segment form a 100 km rail segment, means less 0,5 passengers travelling on that road. The way this works out in the spreadsheet is exemplified in Figure 17.

Rail Passengers												
Baseline												
		0	1	2	3	4	5	6	7	8	9	10
		2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
S1	City A - City C	6021923	6122466	6224688	6328617	6434281	6541709	6650931	6761976	6874876	6989660	7106361
	City C - City B	3267335	3342656	3419713	3498547	3579197	3661707	3746119	3832477	3920826	4011211	4103681
TEN-T Projects												
Diverted Traffic From Road												
		0	1	2	3	4	5	6	7	8	9	10
		2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
S1	City A - City C	0	0	0	0	0	0	332547	676198	687488	698966	710637
	City C - City B	0	0	0	0	0	0	0	0	0	0	0

Road Passngers											
Baseline											
	0	1	2	3	4	5	6	7	8	9	10
	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
S5 City A - City B	7177786	7246525	7315922	7385983	7456716	7528125	7600219	7673003	7746484	7820669	7895565
TEN-T Projects											
Diverted Traffic To Rail											
	0	1	2	3	4	5	6	7	8	9	10
	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
S5 City A - City B	0	0	0	0	0	0	-80270	-163220	-165945	-168716	-171533

FIGURE 17. EXAMPLE OF TRAFFIC DIVERSION FROM ROAD TO RAIL WITH DIFFERENT SEGMENTATIONS.

5.3.6 CAPACITY

The data inserted in the 'Infrastructure Data' sheet allows for the computation of an infrastructure occupation ratio based on the number of passenger and freight trains computed in the 'Rail Traffic' sheet. The 'Capacity' sheet not only presents the user with the figures for infrastructure occupation, but it feeds back into the traffic computations by setting an upper bound for rail traffic growth

Infrastructure Occupation												
Baseline												
		0	1	2	3	4	5	6	7	8	9	10
		2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
S1	City A -City C	79,50%	80,39%	81,30%	82,19%	83,09%	83,99%	84,89%	85,79%	86,69%	87,59%	88,49%
S1	City C - City B	55,18%	55,82%	56,46%	57,09%	57,73%	58,37%	59,01%	59,65%	60,28%	60,92%	61,56%

Figure 18. Example table for the computation of capacity usage as an infrastructure occupation ratio.

5.3.7 Infrastructure Maintenance

In this approach, the computation of rail infrastructure maintenance costs is simply the multiplication of the gross traffic in each section by an average maintenance cost per km. This average cost is filled in a Reference Data sheet and should have different values for sections that have received investments. The maintenance costs spreadsheets should be built to detect the year when investments related to each level are completed in each section, as filled in the Infrastructure Data sheet. The resulting table should give annual maintenance costs cash flows, as exemplified in Figure 19.

Maintenace Costs													
Baseline													
		NPV	Cash Flow (€)										
			0	1	2	3	4	5	6	7	8	9	10
			2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
S1	City A - City C	99 036 143,10 €	3 830 188,98 €	3 883 388,70 €	3 937 561,10 €	3 992 520,55 €	4 048 267,06 €	4 104 700,93 €	4 162 107,47 €	4 220 344,04 €	4 279 453,58 €	4 339 393,13 €	4 400 348,33 €
	City C - City B	220 531 827,62 €	8 074 424,58 €	8 211 514,96 €	8 351 078,95 €	8 493 251,57 €	8 638 481,17 €	8 785 871,03 €	8 936 452,90 €	9 089 913,42 €	9 246 565,95 €	9 405 783,79 €	9 568 328,65 €
	Total	**319 567 970,72 €**	**11 904 613,56 €**	**12 094 903,66 €**	**12 288 640,05 €**	**12 485 772,12 €**	**12 686 748,23 €**	**12 890 571,96 €**	**13 098 560,37 €**	**13 310 257,46 €**	**13 526 019,53 €**	**13 745 176,93 €**	**13 968 676,98 €**
TEN-T Projects													
		NPV	Cash Flow (€)										
			0	1	2	3	4	5	6	7	8	9	10
			2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
S1	City A - City C	104 705 687,05 €	5 029 749,36 €	3 868 821,22 €	3 922 885,16 €	3 977 593,49 €	4 033 200,69 €	4 089 495,25 €	4 273 721,04 €	4 463 141,68 €	4 526 346,18 €	4 590 578,44 €	4 655 626,92 €
	City C - City B	227 298 613,48 €	11 329 335,98 €	8 185 396,78 €	8 338 310,25 €	8 494 723,81 €	8 654 772,47 €	8 817 656,48 €	8 984 445,62 €	9 155 139,89 €	9 328 939,55 €	9 506 644,33 €	9 688 659,30 €
	Total	**332 004 300,53 €**	**16 359 085,34 €**	**12 054 217,99 €**	**12 261 195,41 €**	**12 472 317,30 €**	**12 687 973,16 €**	**12 907 151,73 €**	**13 258 166,65 €**	**13 618 281,56 €**	**13 855 285,73 €**	**14 097 222,77 €**	**14 344 286,23 €**
C4R Scenario													
		NPV	Cash Flow (€)										
			0	1	2	3	4	5	6	7	8	9	10
			2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
S1	City A - City C	42 341 642,41 €	2 203 210,64 €	1 540 861,34 €	1 563 094,24 €	1 585 497,95 €	1 608 295,39 €	1 631 505,39 €	1 710 642,39 €	1 791 943,46 €	1 818 068,79 €	1 844 644,32 €	1 871 577,39 €
	City C - City B	97 760 003,64 €	4 962 655,56 €	3 179 279,04 €	3 253 948,94 €	3 330 393,10 €	3 408 961,84 €	3 489 773,46 €	3 671 008,50 €	3 858 749,19 €	3 950 556,71 €	4 044 843,67 €	4 141 437,18 €
	Total	**140 101 646,04 €**	**7 165 866,20 €**	**4 720 140,38 €**	**4 817 043,18 €**	**4 915 891,05 €**	**5 017 257,24 €**	**5 121 278,85 €**	**5 381 650,89 €**	**5 650 692,65 €**	**5 768 625,51 €**	**5 889 487,99 €**	**6 013 014,56 €**

Figure 19. Example of maintenance costs spreadsheet.

5.3.8 Train Operating Costs

The computation of Train Operating costs follows a similar approach to Maintenance Costs, in that it is based on traffic and an average costs for each train type established in the reference data. Once again, the final result should be a list of annual cash flows for the analysis period, as shown in Figure 20 for freight trains.

Freight Train Operating Costs													
Baseline													
			0	1	2	3	4	5	6	7	8	9	10
			2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
S1	City A - City C	100 260 354,13 €	4 154 678,42 €	4 194 951,19 €	4 235 998,43 €	4 277 432,92 €	4 319 254,64 €	4 361 076,37 €	4 403 672,57 €	4 446 656,00 €	4 490 026,68 €	4 533 784,59 €	4 578 316,98 €
	City C - City B	278 459 976,38 €	11 273 388,49 €	11 399 960,06 €	11 527 748,66 €	11 656 754,29 €	11 788 193,99 €	11 919 633,69 €	12 053 507,46 €	12 188 598,27 €	12 326 123,14 €	12 463 648,01 €	12 603 606,96 €
	Total	**378 720 330,51 €**	**15 428 066,91 €**	**15 594 911,25 €**	**15 763 747,09 €**	**15 934 187,21 €**	**16 107 448,63 €**	**16 280 710,06 €**	**16 457 180,03 €**	**16 635 254,27 €**	**16 816 149,82 €**	**16 997 432,61 €**	**17 181 923,94 €**
TEN-T Projects													
			0	1	2	3	4	5	6	7	8	9	10
			2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
S1	City A - City C	73 992 176,23 €	5 344 085,61 €	2 996 553,17 €	3 025 940,91 €	3 055 328,65 €	3 085 214,49 €	3 115 100,33 €	3 145 484,26 €	3 176 366,29 €	3 207 248,32 €	3 238 628,45 €	3 270 008,58 €
	City C - City B	205 354 036,28 €	14 500 750,03 €	8 143 463,42 €	8 234 259,44 €	8 326 620,90 €	8 420 547,82 €	8 514 474,73 €	8 609 967,09 €	8 707 024,90 €	8 804 082,71 €	8 902 705,97 €	9 002 894,68 €
	Total	**279 346 212,51 €**	**19 844 835,64 €**	**11 140 016,60 €**	**11 260 200,35 €**	**11 381 949,55 €**	**11 505 762,30 €**	**11 629 575,05 €**	**11 755 451,35 €**	**11 883 391,19 €**	**12 011 331,03 €**	**12 141 334,42 €**	**12 272 903,26 €**
C4R Scenario													
			0	1	2	3	4	5	6	7	8	9	10
			2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
S1	City A - City C	68 025 958,16 €	6 241 166,11 €	2 696 807,35 €	2 723 566,01 €	2 749 742,96 €	2 776 501,62 €	2 803 841,98 €	2 831 182,35 €	2 858 522,72 €	2 886 444,80 €	2 914 948,59 €	2 943 452,37 €
	City C - City B	188 705 471,56 €	16 934 906,42 €	7 329 379,23 €	7 411 649,64 €	7 493 920,05 €	7 578 018,69 €	7 663 945,56 €	7 749 872,43 €	7 835 799,30 €	7 923 554,40 €	8 013 137,74 €	8 102 721,07 €
	Total	**256 731 429,72 €**	**23 176 072,54 €**	**10 026 186,59 €**	**10 135 215,65 €**	**10 243 663,01 €**	**10 354 520,31 €**	**10 467 787,55 €**	**10 581 054,78 €**	**10 694 322,02 €**	**10 809 999,20 €**	**10 928 086,32 €**	**11 046 173,44 €**

Figure 20. Example of train operating costs spreadsheet.

5.3.9 TIME VALUATION

Passengers Value of Time (€)													
Baseline													
			0	1	2	3	4	5	6	7	8	9	10
			2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
S1	City A - City C	1 300 974 180,58 €	48 175 384,00 €	48 979 728,00 €	49 797 504,00 €	50 628 936,00 €	51 474 248,00 €	52 333 672,00 €	53 207 448,00 €	54 095 808,00 €	54 999 008,00 €	55 917 280,00 €	56 850 888,00 €
	City C - City B	1 965 512 728,06 €	65 346 700,00 €	66 853 120,00 €	68 394 260,00 €	69 970 940,00 €	71 583 940,00 €	73 234 140,00 €	74 922 380,00 €	76 649 540,00 €	78 416 520,00 €	80 224 220,00 €	82 073 620,00 €
	Total Passenger Travel Time NPV	**3 266 486 908,64 €**	**113 522 084,00 €**	**115 832 848,00 €**	**118 191 764,00 €**	**120 599 876,00 €**	**123 058 188,00 €**	**125 567 812,00 €**	**128 129 828,00 €**	**130 745 348,00 €**	**133 415 528,00 €**	**136 141 500,00 €**	**138 924 508,00 €**
TEN-T Projects													
Existing Traffic													
		NPV	0	1	2	3	4	5	6	7	8	9	10
			2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
S1	City A - City C	1 170 876 762,52 €	43 357 845,60 €	44 081 755,20 €	44 817 753,60 €	45 566 042,40 €	46 326 823,20 €	47 100 304,80 €	47 886 703,20 €	48 686 227,20 €	49 499 107,20 €	50 325 552,00 €	51 165 799,20 €
	City C - City B	1 768 961 455,26 €	58 812 030,00 €	60 167 808,00 €	61 554 834,00 €	62 973 846,00 €	64 425 546,00 €	65 910 726,00 €	67 430 142,00 €	68 984 586,00 €	70 574 868,00 €	72 201 798,00 €	73 866 258,00 €
Diverted Traffic (Net Value)													
		NPV	0	1	2	3	4	5	6	7	8	9	10
			2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
S1	City A - City C	20 652 936,28 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €	545 835,77 €	1 109 897,41 €	1 128 428,58 €	1 147 268,33 €	1 166 424,87 €
	City C - City B	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €
Generated Traffic (Net Value)													
		NPV	0	1	2	3	4	5	6	7	8	9	10
			2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
S1	City A - City C	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €
	City C - City B	3 701 180,64 €	0,00 €	11 143,00 €	22 799,00 €	34 986,00 €	47 723,00 €	61 029,00 €	74 923,00 €	89 425,00 €	104 556,00 €	120 337,00 €	136 790,00 €
Total Traffic													
		NPV	0	1	2	3	4	5	6	7	8	9	10
			2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
S1	City A - City C	1 191 529 698,80 €	43 357 845,60 €	44 081 755,20 €	44 817 753,60 €	45 566 042,40 €	46 326 823,20 €	47 100 304,80 €	48 432 538,97 €	49 796 124,61 €	50 527 535,78 €	51 472 820,33 €	52 332 224,07 €
	City C - City B	1 772 662 635,90 €	58 812 030,00 €	60 178 951,00 €	61 577 633,00 €	63 008 832,00 €	64 473 269,00 €	65 971 755,00 €	67 505 065,00 €	69 074 011,00 €	70 679 424,00 €	72 322 135,00 €	74 003 048,00 €
	Total Passenger Travel Time NPV	**2 964 192 334,70 €**	**102 169 875,60 €**	**104 260 706,20 €**	**106 395 386,60 €**	**108 574 874,40 €**	**110 800 092,20 €**	**113 072 059,80 €**	**115 937 603,97 €**	**118 870 135,61 €**	**121 306 959,78 €**	**123 794 955,33 €**	**126 335 272,07 €**

FIGURE 21. EXAMPLE OF TIME VALUATION SPREADSHEET.

The computation of time valuation is separated into Existing, Diverted and Generated traffic, as prescribed by the EC guidelines. The value for existing traffic is always used as the base for the absolute value of time, since both diverted and generated traffic are computed directly as a net change. This is exemplified in Figure 21 for passenger traffic.

5.3.10 EXTERNALITIES

Greenhouse Gas Emissions													
Baseline													
		NPV	0	1	2	3	4	5	6	7	8	9	10
			2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
S1	City A - City C	4 296 872,32 €	178 057,65 €	179 783,62 €	181 542,79 €	183 318,55 €	185 110,91 €	186 903,27 €	188 728,82 €	190 570,97 €	192 429,71 €	194 305,05 €	196 213,59 €
	City C - City B	11 933 998,99 €	483 145,22 €	488 569,72 €	494 046,37 €	499 575,18 €	505 208,31 €	510 841,44 €	516 578,89 €	522 368,50 €	528 262,42 €	534 156,34 €	540 154,58 €
	Total NPV	**16 230 871,31 €**	**661 202,87 €**	**668 353,34 €**	**675 589,16 €**	**682 893,74 €**	**690 319,23 €**	**697 744,72 €**	**705 307,72 €**	**712 939,47 €**	**720 692,14 €**	**728 461,40 €**	**736 368,17 €**
TEN-T Projects													
		NPV	0	1	2	3	4	5	6	7	8	9	10
			2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
S1	City A - City C	4 217 554,05 €	304 612,88 €	170 803,53 €	172 478,63 €	174 153,73 €	175 857,23 €	177 560,72 €	179 292,60 €	181 052,88 €	182 813,15 €	184 601,82 €	186 390,49 €
	City C - City B	11 705 180,07 €	826 542,75 €	464 177,41 €	469 352,79 €	474 617,39 €	479 971,23 €	485 325,06 €	490 768,12 €	496 300,42 €	501 832,71 €	507 454,24 €	513 165,00 €
	Total NPV	**15 922 734,11 €**	**1 131 155,63 €**	**634 980,95 €**	**641 831,42 €**	**648 771,12 €**	**655 828,45 €**	**662 885,78 €**	**670 060,73 €**	**677 353,30 €**	**684 645,87 €**	**692 056,06 €**	**699 555,49 €**
C4R Scenario													
		NPV	0	1	2	3	4	5	6	7	8	9	10
			2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
S1	City A - City C	4 081 557,49 €	374 469,97 €	161 808,44 €	163 413,96 €	164 984,58 €	166 590,10 €	168 230,52 €	169 870,94 €	171 511,36 €	173 186,69 €	174 896,92 €	176 607,14 €
	City C - City B	11 322 328,29 €	1 016 094,39 €	439 762,75 €	444 698,98 €	449 635,20 €	454 681,12 €	459 836,73 €	464 992,35 €	470 147,96 €	475 413,26 €	480 788,26 €	486 163,26 €
	Total NPV	**15 403 885,78 €**	**1 390 564,35 €**	**601 571,20 €**	**608 112,94 €**	**614 619,78 €**	**621 271,22 €**	**628 067,25 €**	**634 863,29 €**	**641 659,32 €**	**648 599,95 €**	**655 685,18 €**	**662 770,41 €**

FIGURE 22. EXAMPLE OF GREENHOUSE GAS EMISSION VALUES SPREADSHEET.

At this stage and according to the established approach, only greenhouse gas emissions are included in externalities. It is a fairly simple computation, from the traffic values and emission values for the reference trains and road vehicles. The gas mass is then monetized according to the established values. The result is a table with annual cash flows corresponding to the greenhouse gas emissions, as shown in Figure 22. The computation of other externalities, such as accidents, may be easily included within this approach.

5.3.11 COST-BENEFIT ANALYSIS

The cost benefit analysis is finally computed from all the previously derived annual cash flows, allowing for the computation of Net Present Values for each investment level. A three-way comparison is made, presenting the net change in value for each category between baseline, TEN-T investments and C4R scenario. A separate computation of total annual cash flows also allows for obtaining the Internal Rate of Return. The final results may be summarized in a table similar to the one shown in Figure 23. The net costs and benefits may then be assigned to each one of the involved agents (e.g. infrastructure manager, passenger, train operating companies), although this may require additional data.

	Baseline	TEN-T Projects	C4R Scenario	Net Cost		
				TEN-T vs Baseline	C4R vs Baseline	C4R vs TEN-T
Infrastructure						
Investment	0,00 €	371 003 699,57 €	895 217 385,24 €	371 003 699,57 €	895 217 385,24 €	524 213 685,67 €
Maintenance	319 567 970,72 €	332 004 300,53 €	140 101 646,04 €	12 436 329,81 €	-179 466 324,68 €	-191 902 654,49 €
Residual Values	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €
Total Financial Cost				**383 440 029,37 €**	**715 751 060,56 €**	**332 311 031,19 €**
	Baseline	**TEN-T Projects**	**C4R Scenario**	**Net Benefit**		
				TEN-T vs Baseline	**C4R vs Baseline**	**C4R vs TEN-T**
Consumer Surplus						
Value of Time						
Passenger	3 266 486 908,64 €	2 964 192 334,70 €	2 715 048 383,11 €	302 294 573,94 €	551 438 525,54 €	249 143 951,60 €
Freight	1 367 076 789,68 €	1 293 271 056,08 €	1 223 134 523,16 €	73 805 733,59 €	143 942 266,52 €	70 136 532,93 €
Producer Surplus						
Train Operating Costs	378 720 330,51 €	279 346 212,51 €	256 731 429,72 €	99 374 118,00 €	121 988 900,79 €	22 614 782,79 €
Externalities						
Greebhouse Gas Emisiions	16 230 871,31 €	15 922 734,11 €	15 403 885,78 €	308 137,19 €	826 985,52 €	518 848,33 €
Total Economic Benfits				**475 782 562,72 €**	**818 196 678,37 €**	**342 414 115,64 €**
NPV				**92 342 533,35 €**	**102 445 617,81 €**	**10 103 084,46 €**
Benefits to Costs Ratio				1,24	1,14	1,03
Internal Rate of Return				5,80%	4,86%	4,15%

FIGURE 23. EXAMPLE OF CBA TABLE.

5.4 PROBABILISTIC ANALYSIS

There is an unavoidable degree of uncertainty in any CBA. In this specific instance, this uncertainty is increased by the large scale of the analysis, the already described simplifications required to make the analysis manageable and the fact that we are dealing with technologies still under development, some of them, in the early stages. In these circumstances, a probabilistic analysis is a very useful tool.

The approach we put forward to perform this probabilistic assessment methods is based on simulations through the Monte Carlo method. In this method, any input variable can be turned into a random value following a probability distribution that is assigned to it based on whatever available information there is. A large number of random values is then generated and a distribution for the outputs is obtained. Standard statistical analysis can then be performed on these results in order to compute probabilities for certain results.

The current implementation uses Macros over the CBA spreadsheet to generate the random values and a separate spreadsheet to perform the post processing of these results. This implementation has the advantage of not requiring any additional software besides the spreadsheet application (Microsoft Excel, in this case). It is also fairly flexible, since it allows any variable to be turned into a distribution and may use any of the wide range of distribution functions available. The procedure is exemplified in the screenshot in Figure 24. The only required procedure, once this is done for all the desired variables, is to run a macro and wait a few seconds for the results to be generated. In tests conducted so far, it is also reasonably fast, taking only a few seconds to perform 10000 iterations with several probabilistic variables.

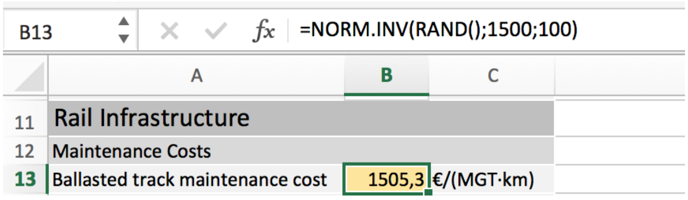

FIGURE 24. EXAMPLE OF HOW A VARIABLE CAN BE MADE PROBABILISTIC. IN THIS CASE, THE INFRASTRUCTURE MAINTENECE COSTS ARE ASSIGNED A NORMAL DISTRIBUTION WITH A MEAN VALUE OF 1500€ AND A STANDARD DEVIATION OF 100€.

The kind of information that can be obtained in post processing, besides standard statistical functions like means and standard deviations, can be exemplified in Figure 25, where a distribution of the results of one of the tests performed is shown represented in a histogram.

If required or useful, this approach to probabilistic analysis is easily extendable to the Multi-Criteria Analysis described in the previous chapter.

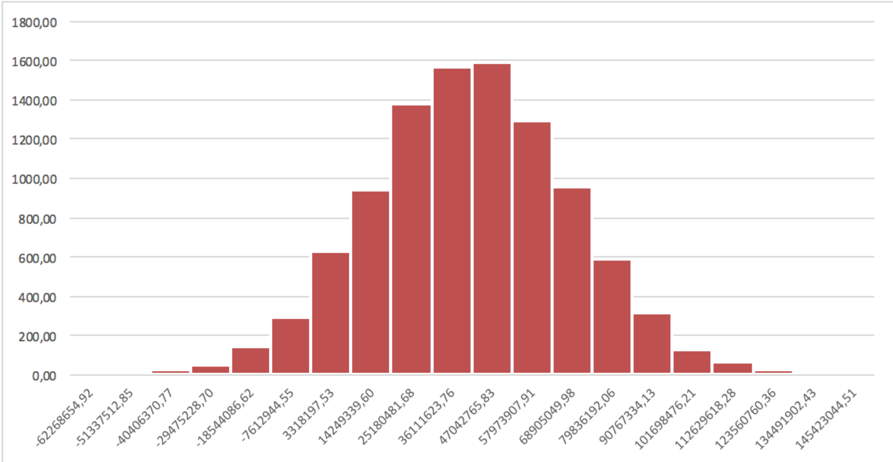

FIGURE 25. EXAMPLE OF A HISTOGRAM OBTAIN FOR THE NPV OF THE PROJECTS C4R OVER THE BASELIN IN ONE OF THE TESTS PERFORMED ON THE PROBABILISTC CBA.