Technical University of Denmark

Decision Support & Strategic Assessment (42789)

Project Report

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1 Introduction

This study aims at appraising 10 infrastructure upgrade scenarios on the EU's TEN-T (Trans European Network) project portfolio and come up with the most attractive project seen from both an economic and strategic perspective for the EU-commission.

First, a screening analysis is conducted to narrow down the number of alternatives from 10 to 4, by looking at some initial strategic aspects and different factors. To build a systematic ranking based analysis on these, the ELECTRE method is used.

It is equally important to analyze the socio-economic perspective as it is used to evaluate for the betterment of the public, where performing Cost-benefit analysis gives us the cost and benefits comparison. The important feature of the CBA process is the investment criteria, as it determines the Net present value (NPV), Internal Rate of Return(IRR), and Benefit/cost rate (BCR) for the broad transport projects[1]. Hence, then a Cost-Benefit Analysis (CBA) is performed, based on the data provided about the projects. This takes the main economic and financial factors of society into account.

The next stage in the assessment is a Multi-Criteria Decision Analysis (MCDA), in this evaluation other non-marketed benefits of the projects can also be included. This is conducted through two different methods: SMARTER and REMBRANDT that gives us broader view to take decision. A risk analysis is also performed in order to measure the risk. To evaluate the risk several techniques has been used that included - mainly a Risk matrix where we identify the frequency of risk occurrence and the type of risk that should be taken into account. Then Feasibility Risk Assessment (FRA), that is then incorporated into the MCDA results using both the COSIMA and the SIMDEC approach. Finally, these results are summarized in a composite assessment to determine the feasible project that can be taken into consideration among the other alternatives. At last, to show case the whole analysis and results we discussed final conclusion and based on the perfomance of the alternative we also discussed recommendations.

2 Description of projects

All 10 projects that are part of this assessment contain improvements on a specific section of a European TEN-T corridor. So these scenarios are not just single pieces of new infrastructure, but broader proposals to upgrade an entire corridor - including mostly railway lines and in some cases motorways, too. The initial 10 alternatives are the following which can also be seen in the maps below:

- **SC1 - Brenner Pass: München - Kufstein - Innsbruck - Verona**
  Includes the upgrade of 293 km existing railway lines and a new, 55 km long tunnel between Austria and Italy under the Brenner Pass.
- **SC3 - Iberian Link: Madrid - Salamanca - Coimbra**
  Includes the construction of 55 km new high speed line in Spain and the improvement of further 555 km, also several road links in the area.
- **SC9 - Adria East-West: Milan - Venice - Trieste - Ljubljana - Budapest**
  Includes 222 km of new high speed rail on the Italian section, and the upgrade of 1252 km existing lines, mostly in Slovenia and Hungary. Also contains 340 km of road projects.
- **SC10 - East Balkans: Kulata - Sofia - Calafat - Arad**
  Contains 456 km upgrading of existing roads, 52 km new railways, 850 km upgrading of existing

railways for passenger transport, and 931 km upgrading of existing railroads for freight transport.

- **SC11 - Romania East-West: Curtici - Brasov / Sibiu - Pitesti**
  109 km new roads and motorways, 11 km upgrading of existing roads, 288 km upgrading of existing railways.
- **SC12 - South Finland East-West: Helsinki - Vainikkala** (Russian border)
  Contains in total 139 km upgrading of existing roads, 95 km new railways, 201 km upgrading of existing railways for passenger transport, and 295 km upgrading of existing railroads for freight transport.
- **SC13 - Central Sweden: Nyköbing - Södertälje**
  Includes 147 km upgrading of existing railways.
- **SC16 - West Greece - Igoumenitsa - Kozani - Ioannina - Kalamata**
  Includes 413 km new railways, 221 km upgrading of existing railways.
- **SC18 - Fehmarn Link: Copenhagen - Rødby - Puttgarden - Hamburg**
  Includes 490 km upgrading of existing railways on the corridor and new rail&road tunnel under the sea between Denmark and Germany.
- **SC20 - West Germany: Cologne - Frankfurt - Mannheim**
  Contains 625 km upgrading of existing roads, 130 km upgrading of existing railways for passenger transport, 246 km upgrading of existing railroads for freight transport and a new high-speed line between Frankfurt and Mannheim.

Figure 1: The 10 projects on the map of Europe

3 Screening analysis

The aim of the screening analysis is to narrow down the number of alternatives from 10 to 4, by looking at the main strategic targets of these scenarios, without considering the detailed data on them. To find the 4 most attractive projects for further assessment, a simple and old outranking method, the ELECTRE is used. This method can indicate the degree of dominance between alternatives and provide a partial preference ranking.

Five different criteria were chosen to be used in the ELECTRE. These were selected in a way to cover a wide range of strategic considerations that EU might take into account when deciding on financing Transeuropean transportation projects. Weights were also assigned to these criteria in line with the preferences we assumed the international community could have when ranking such alternatives. The 5 criteria are the followings, with the weights in brackets (on a normalized scale, adding up to 1):

- **Population along the corridor (0.15)**
  This criterion considers the number of local residents possibly benefiting from the given scenario. We simply added the population numbers of the NUTS-2 regions where the corridors go through. The highest points were given to the projects affecting the most people (e.g. SC9 with 20.1 million, or SC1 with 14.8 million).

- **Serving existing passenger demand (0.15)**
  In this case the current passenger demand was examined: we took into account the current number of trains and flights serving the corridors, and also looked at some traffic flow data where it was possible. The priority here is given to alternatives with the highest current traffic, where relieving some bottlenecks would be crucial and the benefits for the current passengers are the highest. Such scenarios are, for example, the SC20, as the Cologne-Mannheim corridor is among the most congested parts of the European railway network or SC1 and SC18, as they relieve bottlenecks (the Brenner Pass and the Rødby-Puttgarden ferry respectively) and by significantly reducing travel times they can open up the possibility to divert the intense air traffic to trains on these routes.

- **Potential for economic growth and cohesion (0.35)**
  Another important purpose of these projects from the EU's perspective is economic cohesion - i.e. the potential for accelerating economic growth in the less developed regions of the Union. Thus we looked the *GDP and the HDI* values of the directly affected regions, along with the changes of the last few years - and gave high points to projects where there is both need and potential for growth and gave lower point to already developed regions. For example, higher values were assigned to projects in the Balkans (SC10, SC11, SC16), and lower ones to SC12 (in Finland) or SC 13 (in Sweden).

- **Improvement of international connections (0.1)**
  Here we considered the fact that EU funds are more likely to support cross-border projects, as these are less expected to be prioritized by national governments. High points were given to scenarios covering crucial Transeuropean links affecting more countries than the ones where it physically takes place (e.g. SC18, where the Fehmarn link is not only important for Denmark and Germany, but for whole Scandinavia) and the ones covering at least 3 countries (such as SC9 in Italy-Slovenia-Hungary or SC10 in Romania-Bulgaria-Greece). Entirely domestic projects with also low effects on neighboring countries received the lowest points, such as SC13 in Sweden or SC16 in Greece.

- **Importance for international freight traffic (0.25)**
  Finally, the importance for freight traffic and industries was also considered. We looked into statistics on freight flows within Europe and also the correlation between the scenarios and the official Rail Freight Corridors of the EU. (There are 11 RFCs, and these are not the same as TEN-T.) High points were given both to scenarios on routes that already handle high volume of traffic (Brenner Pass, Fehmarn Link, etc.) and ones that have a good potential for increase (e.g. SC10, being on a vital transit route between Asia and Europe, linking the ports of Greece and Bulgaria to the rest of the continental network better).

The ranking was performed on a scale of 5: very low (VL) - low (L) - medium (M) - high (H) - very high (VH). The results are presented in the following table. Some input data and more detailed reasoning on each grade can be found in the attached ELECTRE excel sheet.

	Population along the line	Serving existing passenger demand	Potential for economic growth and cohesion	Improvement of international connections	Importance for international freight traffic
WEIGHT	0.15	0.15	0.35	0.1	0.25
1 - Brenner pass (D-A-IT)	H	H	L	VH	VH
3 - Spain-Portugal	H	M	M	H	M
9 - Italy-Slovenia-Hungary	VH	M	H	VH	H
10 - East Balkans (GR-BG-RO)	M	VL	VH	VH	H
11 - Romania East-West	L	M	VH	M	M
12 - South Finland East-West	L	L	VL	L	L
13 - Central Sweden	L	L	VL	VL	L
16 - West Greece	L	L	H	VL	L
18 - Fehrmarn Belt (DK-D)	H	H	VL	VH	VH
20 - West Germany	H	VH	VL	L	VH

Figure 2: ELECTRE ranking

After assigning these ranks, the concordance and discordance indexes were calculated for each criteria on each project. The concordance index is given with the following equation:

$$C(a,b) = \frac{\sum_{i \in Q(a,b)} w_i}{\sum_{i=1}^{m} w_i} \in [0,1]$$

where $\sum_{i=1}^{m} w_i = 1$, because our scale is already normalized. So C(a,b) is only the sum of the weights of those criteria in which alternative 'a' is better than or equal to 'b'. For example, $C(SC1, SC3) = 0.15 + 0.15 + 0.1 + 0.25 = 0.65$, because scenario 1 is better or equal in these 4 criteria compared to scenario 3. Or $C(SC3, SC9) = 0.15$, because it is only better in term is existing traffic, having a weight of 15%. The complete table of calculation results is not presented here - it can be found in the ELECTRE excel sheet attached.

The discordance index is given with the following equation:

$$D(a,b) = \begin{cases} 1 \; if \; z_i(b) - z_i(a) > t_i \; for \; any \; i \\ 0 \; otherwise \end{cases}$$

where $t_i = 3 \quad \forall i$, meaning that project 'a' cannot outrank 'b' if there is at least one criterion where the value for 'b' is higher by at least 3 levels. (So the veto threshold is 3 for all criteria.) For example, between SC1 and SC3 there is no clear discordance (both get a value of zero), while SC1 can clearly dominate SC10 in terms of servicing existing passenger demand (H against VL). The complete set of results is again not presented, it is located in the attachment.

Finally, an outranking relation must be built which takes both the concordance and discordance indices into account with respective dominance thresholds C^* and D^*. While for the binary D values it does not make a real difference. For the C we needed to use an iterative process, where we tried several values from 0.45 to 0.8 to find an outranking which is neither too severe nor too weak. The best fitting value was found to be 0.65, as in that case there is exactly 4 alternatives, which are never clearly dominated by other projects. The results are in the following table, where 'true' means a clear outranking of 'b' (in the column) by 'a' (in the row), as C(a,b) and D(a,b) are both over their thresholds.

FINAL DOMINANCE	1 - Brenner pass (D-A-IT)	3 - Spain-Portugal	9 - Italy-Slovenia-Hungary	10 - East Balkans (GR-BG-RO)	11 - Romania East-West	12 - South Finland East-West	13 - Central Sweden	16 - West Greece	18 - Fehrmarn Belt (DK-D)	20 - West Germany
1 - Brenner pass (D-A-IT)	false	false	false	true	false	true	true	true	false	true
3 - Spain-Portugal	false	false	false	false	false	false	true	true	false	false
9 - Italy-Slovenia-Hungary	false	false	false	false	true	true	true	true	false	false
10 - East Balkans (GR-BG-RO	false	false	false	false	false	true	true	true	false	false
11 - Romania East-West	false	false	false	false	false	true	true	false	false	false
12 - South Finland East-West	false	false	false	false	false	false	false	false	false	false
13 - Central Sweden	false	false	false	false	false	false	false	false	false	false
16 - West Greece	false	false	false	false	false	true	true	false	false	false
18 - Fehmarn Belt (DK-D)	false	false	false	true	false	true	true	true	false	true
20 - West Germany	false	false	false	false	false	true	true	true	false	false

Figure 3: ELECTRE results

Applying the ELECTRE method as a screening analysis resulted in narrowing down our set of alternatives to 4 - only these projects will be examined in the next chapters:

- **SC1 - Brenner Pass**: München - Kufstein - Innsbruck - Verona
- **SC3 - Iberian Link**: Madrid - Salamanca - Coimbra
- **SC9 - Adria East-West**: Milan - Venice - Trieste - Ljubljana - Budapest
- **SC18 - Fehmarn Link**: Copenhagen - Rødby - Puttgarden - Hamburg

4 Cost-benefit analysis

From our screening analysis, **scenario 1, 3, 9 and 18** were selected for further analysis. A cost benefit analysis will be developed in this part of the paper. The goal of this analysis is to check the quantifiable impacts of the projects, compare it to the investment cost and get a grasp of the monetary feasibility of the projects. To do so, three investment criteria are commonly used:

- **Net Present Value (NPV)**: the sum of all positive and negative benefits over the investment period. In the calculations of the NPV every single cost determinant is involved, along with the scrap value, that is the monetary value of the project after its evaluation period, when it still brings benefits and requires maintenance. The NPV furthermore includes the consumer surplus, which is all the benefits of users, when they pay less for the service than their willingness to pay threshold. All the externalities - positive and negative - are included in the NPV.[1]
- **Benefit Cost Ratio (BCR)**: A ratio between all the positive or negative benefits and the investment cost of the project over the investment period. The higher this value is, the more beneficial the project must be. Benefits include all externalities, consumer surplus and scrap value, the cost is the construction, and the operation and maintenance prices. [1]
- **Internal Rate of Return (IRR)**: the discount rate that would balance the benefits and costs. The IRR is the annual rate of growth an investment is expected to generate, a number that estimates the profitability. Calculated from the NPV [1].

Below the equations of the used concepts [2]:

$$NPV = \sum_{t=0}^{T} \frac{B_t - C_t}{(1+r)^t} \qquad BCR = \frac{\sum_{t=0}^{T} \frac{B_t}{(1+r)^t}}{\sum_{t=0}^{T} \frac{C_t}{(1+r)^t}} \qquad \sum_{t=0}^{T} \frac{B_t - C_t}{(1+i)^t} = 0$$

To model the market evolution, growth rates and discount rate are applied on costs and benefits for each year of the investment period. The growth rates are 1.5 %, both the traffic and price growth, while the discount rate in the European Union is 3 %, in all countries.

4.1 Problem definition

The CBA assessment includes: *construction and maintenance costs, consumer surplus (passengers and freight time and cost savings), accidents, noise, air pollution and global warming savings.* These impacts are first calculated for the opening year. For the following years of the investment period, we estimate their benefits by applying a price and traffic growth on consumer surplus and a discount rate on all costs/benefits. The tables of externalities, consumer surplus and different rates are showcased below.

The CBA also takes into account investment costs over the construction period by applying the discount rate on the years prior to the opening year. When calculating the investment criteria, the scrap value is also considered (investment cost value after being discounted for each year of the investment period).

Assumptions
Investment period: 30 years Prices in 2020 euro Price growth: 1.4% Traffic growth: 1.4% Discount rate: 3%

Air Pollution
Car petrol Car diesel HGV diesel (heavy goods vehicle) Train person Train freight IWW (inland water ways) Air

Global warming
Car petrol Car diesel HGV diesel (heavy goods vehicle) Train person Train freight IWW (inland water ways) Air

Consumers surplus
Passengers Freight

Accidents
Car HGV (heavy goods vehicle) Train passengers Train freight

Noise
Car HGV (heavy goods vehicle) Train passengers Train freight

4.2 Results

The Cost-Benefit Analysis results are described below, showing the final monetary values and the ranking of the projects:

Scenario	Air pollution	Global warming	Accidents	Noise	Consumer Surplus	Construction cost
1	6 293 261 €	4 510 653 €	- 3 201 367 €	- 5 248 049 €	51 399 552 €	- 16 028 435 723 €
3	9 328 278 €	13 622 831 €	1 526 699 €	2 046 028 €	76 544 354 €	- 4 569 616 932 €
9	10 395 052 €	27 877 990 €	4 923 049 €	7 003 331 €	843 360 231 €	- 27 606 626 325 €
18	35 053 241 €	42 615 198 €	2 280 487 €	9 913 682 €	126 998 179 €	- 7 734 106 177 €

Figure 4: CBA first year values

On figure 4 the overall monetary values of externalities, consumer surplus and the construction cost are presented. (Negative values with red, positive with green coloring.) It stands out that project 9 has a very high consumer surplus, even though the costs are the highest for this scenario, too.

Scenario	NPV	BCR	IRR	Rank
1	- 10 461 450 303,68	0,347319	0,0067584	4
3	495 127 743,51	1,108352	0,0331332	3
9	20 046 010 261,40	1,72613	0,0483761	1
18	2 256 334 327,29	1,291738	0,0383391	2

Figure 5: CBA final values

After ranking out the three investment criteria **Scenario 9** has the best results to be considered in CBA, that can be seen above in the table. It is expressed that it is the most expensive project with an extensive construction plan (340 km upgrading of existing roads, 222 km new railways, 2300 km upgrading of existing railways). **Scenario 2** and **18** are still feasible with a **BCR > 1**. On the other hand, **Scenario 1** is not feasible from a monetary perspective, as it has the second biggest construction cost but has negative accidents impacts, negative noise impacts and also has a weak consumer surplus.

All impacts are treated equally in this assessment of CBA analysis depending on the decision makers, some criteria might be more important than others. For instance, the *consumer surplus* is the most important impact of **Scenario 9** making it the *most profitable project*. However **scenario 18** has a bigger impact on some externalities, while having a *lower construction cost*. At this stage, scenario 3, 9, 18 all have a BCR>1 which makes them all feasible choices for further analysis.

5 Multi-criteria decision analysis

Multi-criteria decision analysis is a methodology for evaluating and opting the projects based on the complex socio-economic effects. In MCDA, the individual assessment elements are taken independently and evaluated within significant dimensions. The criteria that are considered, are not equally relevant, and needs to be weighted among each other. Determining weights requires a high level of accountability, and the decision makers' experience has a major impact on the outcome of the decision and evaluation[1].

There are two main evaluation techniques: **SMART, Simple Multi-attribute Rating Technique**, which gives an overview of alternatives in terms of their ratings related to weighted attributes, and **AHP, Analytic Hierarchy Process**, where the alternatives are compared in a pair-wise way upon a decision hierarchy, where the criteria and alternatives are both weighted[1].

Here, we were interested in evaluating and comparing the outcomes by using different techniques to assess MCDA. We had initially assessed **Smart** followed by **Smarter** and **AHP**, where we used **REMBRANDT** technique as a part of AHP for evaluation. To assess SMART, SMARTER, and REMBRANDT for our four scenarios, the assessment is done on the following criteria's:

- **Renewable Energy – Fossil fuels dependency**
- **Transport Network – Accessibility**
- **Effect on labor market**
- **Improvement of international connections and coherence**
- **Effect on tourism**

5.1 SMART: Simple Multi-attribute Rating Technique

The *SMART* technique is consisting of a linear additive model. It states the total value of a defined alternative that is determined as the overall sum of the performance score of each criterion multiplied by the weight of that criterion. The following layout showcases the different stages of SMART technique to attain the assessment [1].

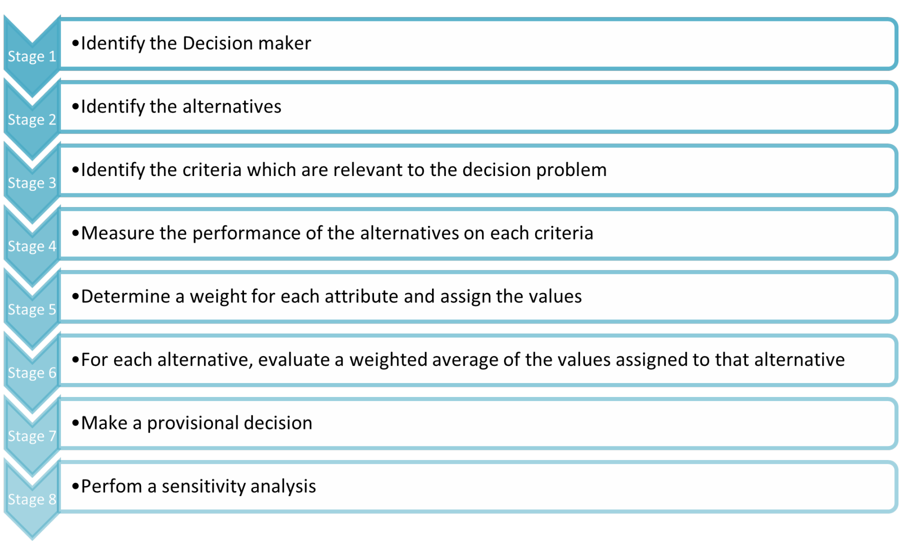

Figure 6: Simple Multi Attribute Rating Technique (Smart)

In this assessment, we have performed the first two stages above, where we have identified alternatives based on our screening analysis. Further in Stage 3, we wanted to have a solid foundation for our decision, and henceforth we were interested in looking into the criteria concern with sustainability, as we focused on the economic, social, and environmental aspects. Here the above-mentioned criteria are taken into consideration.

In Stage 4, to determine the performance of all scenarios for every criterion, we have used the following scale where V.high is very high considered to be 100 as a numeric weight and V.low as very low.

Scale	Numeric Weights
V. High	100
High	80
Medium	60
Low	40
V.Low	20
N/A	0

Figure 7: Swing weights

For our first criteria, *Renewable energy - fossil fuels dependency*, we wanted to identify the countries that require extra needs from a renewable source and the traffic demands. The second criteria is *Transport network - accessibility - travel freedom.* The four alternative projects have a huge impact on the major countries, cities and small towns, and it is crucial to take into consideration different travel options which are affecting/improving communities and also how accessible the new infrastructure is for the population.

When there is a new or upgraded infrastructure it also associates the impact on the job market and how does it change socio-demographic job distribution, the companies that are involved in the project and logistics centers along the line and hence *Effect on the labor market* is also a relevant criterion in our decision. We also considered the *Improvement of international connections and coherence* and *Effect on tourism*, as it is interesting to see the improvement of EU's core network, connecting several regions in different countries and to what extent it could be effective. Due to several upgrades of roads and rails between major countries, it will also increase the number of tourists and increase the guest nights spent in different cities. In this approach, all the criteria are measured on approximation.

At stage 5, we determined and assigned the weights based on the scale we defined and mentioned above. The following table illustrates the swing weights.

Notations	Criteria	Alternate Senario (Original Weights)			
		1	3	9	18
C1	Renewable energy - fossil fuels dependancy	100	20	60	40
C2	Transport network - accessibility	80	60	60	80
C3	Effect on labour market	100	60	80	80
C4	Improvement of international connections and coherence	80	60	100	80
C5	Effect on tourism	80	60	60	80
SUM		440	260	360	360

Normalized weights			
1	3	9	18
23	8	16	12
18	23	16	22
23	23	24	22
18	23	28	22
18	23	16	22
100	100	100	100

Figure 8: Original and Normalized weights

Further at Stage 6, the aim is to calculate the aggregated benefits and that is simply determined by multiplication of original weights and normalized weights.

Additive Model		Aggregating the benefits(Value x Weight)			
Notations	Criteria	1	3	9	18
C1	Renewable energy - fossil fuels dependancy	2300	160	960	480
C2	Transport network - accessibility	1440	1380	960	1760
C3	Effect on labour market	2300	1380	1920	1760
C4	Improvement of international connections and coherence	1440	1380	2800	1760
C5	Effect on tourism	1440	1380	960	1760
Sum		8920	5680	7600	7520
Aggregated benefits = sum/100		89.2	56.8	76	75.2
Rank		1	4	2	3

Figure 9: SMART: Additive Model

The above table illustrates the ranking of each projects after aggregating the benefits of each criteria. Overall, the **Scenario 1 and Scenario 9** are the most feasible projects according to the SMART methodology.

5.2 SMARTER

Edwards and Barron have suggested a simplified form of SMART named SMARTER (SMART Exploiting Ranks) [3]. The main reason to make the SMART technique more simplified is the assessment of value functions and swing weights. In SMART, it could be a difficult task as it solely relies on the decision-makers and they may not always be confident about making that decision.

The objective of the SMARTER technique is that the decision-makers include the criteria according to the priority and importance, for instance, Criterion 1 is more important than Criterion 2 and both were more important than Criterion 3. One of the methods to calculate the weights is Rank order distribution, where SMARTER assigns the surrogate weights according to the Rank order Distribution (ROD).

Rank order Distribution is a weight approximation technique, which means that a direct evaluation can be used for valid weights. In ROD, a weight of 100 is given to the most relevant parameter and the value for that benchmark is then evaluated.

The Raw weight = (w_i^*) is normalized to 1. If all the criteria have some relevance, it means that the potential ranges of "raw" weights are [3]:

$$w_1^* = \mathbf{100},$$
$$\mathbf{0} < w_2^* \leq 100,$$
$$0 < w_3^* \leq \mathrm{w}_2^*$$

Where in general,

$$\mathbf{0} < w_i^* \leq w_{i-1}^* \ (\textbf{where } i \neq 1)$$

Roberts and Goodwin [3] illustrated the calculation behind the ROD, where mathematically the means for each Rank Order Distribution (ROD) n = 2 to 10 are found and shown in the table below.

	Criteria								
Rank	2	3	4	5	6	7	8	9	10
1	0.6932	0.5232	0.4180	0.3471	0.2966	0.2590	0.2292	0.2058	0.1867
2	0.3068	0.3240	0.2986	0.2686	0.2410	0.2174	0.1977	0.1808	0.1667
3		0.1528	0.1912	0.1955	0.1884	0.1781	0.1672	0.1565	0.1466
4			0.0922	0.1269	0.1387	0.1406	0.1375	0.1332	0.1271
5				0.0619	0.0908	0.1038	0.1084	0.1095	0.1081
6					0.0445	0.0679	0.0805	0.0867	0.0893
7						0.0334	0.0531	0.0644	0.0709
8							0.0263	0.0425	0.0527
9								0.0211	0.0349
10									0.0173

Figure 10: Rank Order distribution [3]

Since we have five criteria mapped for the analysis, as we surrogate the weight from the marked column from the ROD table for the original weights that are expressed in the below table. While considering the sensitive analysis we can see that the assessment of both SMART and SMARTER validate the outcome is the same for each of the alternatives.

Additive Model		Alternatives Senario (Original Weights)					Weights			
Notations	Criteria	1	3	9	18		1	3	9	18
C1	Renewable energy - fossil fuels dependancy	100	20	60	40		0.3471	0.0619	0.1955	0.1269
C2	Transport network - accessibility	80	60	60	80		0.2686	0.1955	0.1955	0.2686
C3	Effect on labour market	100	60	80	80		0.3471	0.1955	0.2686	0.2686
C4	Improvement of international connections and coherence	80	60	100	80		0.2686	0.1955	0.3471	0.2686
C5	Effect on tourism	80	60	60	80		0.2686	0.1955	0.1955	0.2686
Aggregated Sum		440	260	360	360		1.5	0.8439	1.2022	1.2013
						Rank	1	4	2	3

Figure 11: SMART Exploiting Ranks: SMARTER

5.3 REMBRANDT

The AHP technique consists of an additive and a multiplicative evaluating method. In this assignment, the REMBRANDT technique is used to evaluate the projects. This method has overcome some issues raised by other comparison methods, such as using arithmetic-mean aggregation and eigenvectors. The mosaic word stands for Ratio Estimation in Magnitudes or deci-Bells to Rate Alternatives which are Non-DominaTed. In short, it evaluates alternatives based on their performance against each other over some pre-weighted criteria.

The method is simple: a three-level decision hierarchy is defined, as seen on figure 12.

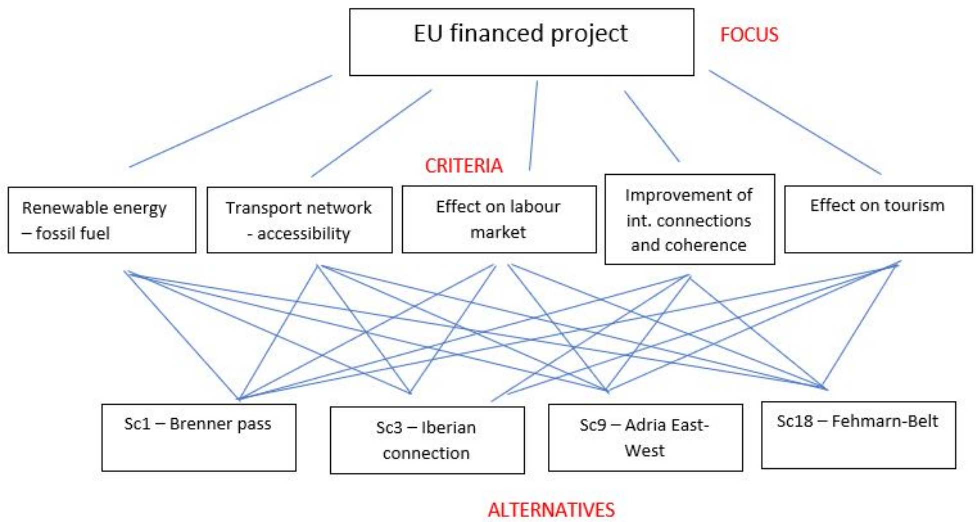

Figure 12: Decision hierarchy of the REMBRANDT

The steps of the REMBRANDT method is the following:

1. Define the criteria to be used in the analysis.
2. Conduct a pair-wise comparison among all the criteria, to see the weights each one of them has in the evaluation.
3. The pair-wise comparison works the same for criteria and alternatives; each cell within the comparison matrix corresponds to two attributes. The horizontal ones are the primary attributes, meaning that the numbers in the cells relate to the rows.
4. The domination factor (gradient index) is a number between -8 and +8, depending on the comparative judgements. The higher the value is, the more criterion 'i' dominates criterion 'j'.
5. The matrix is symmetric in a way that cell (i,j) is the negative value of (j,i).
6. All cells within the comparison matrix are converted to a geometric scale value. For the criteria, it means that all pair-wise gradient indices are put on the power of $\sqrt{2}$.
7. Then, the geometric mean is calculated for every criteria.
8. To get a standardized value, every geometric-mean is divided by the sum of all geometric-means.
9. The procedure is the same for the alternatives' value calculation, except that the conversion of the gradient indices are put on the power of 2 and alternative geometric means are not standardized.
10. For each alternative (project), the geometric mean corresponding for one criterion is put on the power of this criterion's standardized geometric mean, and the product of this is the final, not standardized value of a project, weighted by the criteria.
11. Standardizing all alternatives' final value gives the overall performance of each project.

Next, the criteria chosen for the analysis are explained. We tried to raise questions and concerns about the projects that focus on different parts of the projects' features than the criteria we used in the ELECTRA selection technique. The main idea was to have some criteria within each the three legs of sustainability: economic, social and environmental.

- **Renewable energy - fossil fuel dependency**
  The incentive is to try and label the projects upon sustainability from an environmental perspective. Electricity usage in railway transportation is the most crucial energy form, thus it was examined whether the countries that are involved in each project, have a significant amount of electricity produced from renewable sources, rather than fossil fuel. Not only the operation and maintenance, but the realization of the projects require a vast amount of electricity, too. Eurostat was used to determine gross electricity generation for each country. The share of renewables and nuclear energy were considered. For every project, the role of involvement per countries was estimated, and these figures were then multiplied by the country's renewable energy portion, to finally calculate the sumproduct for involved countries.
  - Project 1: 47,75 %
  - Project 3: 51,82 %
  - Project 9: 39,73 %
  - Project 18: 58,44 %

  There is no very big difference among any of the scenarios, so the comparison matrix along with the gradient indices are between -4 and 4. For more detail, refer to the REMBRANDT Excel sheet.

- **Transport network - accessibility**
  This was one of the most difficult criteria to quantify. What it means is basically the transport network coverage over the proposed and planned railway lines. How well the main corners are connected with other parts of the city/country/region, how easily they are accessible. A three-value scale was used to evaluate main cities along lines in terms of transport coverage. "Very good" means that the city is perfectly accessible from multiple directions, even from abroad, and that within the city every area is covered by public transportation. "Slightly good" means that the settlement is not very well covered, not accessible form abroad or farther distances directly, but has local transportation system. "Bad" means that the area is not accessible at all by other transportation means than railway, and only a very few places are covered by public transport. Upon these values, the aggregation per projects and the comparison was made. The numbers vary between -5 and 5 in the comparison matrix.

- **Effect on labour market**
  A very economical criterion, considering opportunities of larger scale labour force movement and migration, from outer parts of Europe to the featured countries or between the destinations. The willingness of moving abroad and work in other parts of the country/continent was also taken into account, furthermore the lack of existing routes that can be fulfilled with the project in order to ease commuting. Scenario 18, the Fehrmann-Belt project obtained the highest value, as we determined that the connection between Denmark capital area and Germany's most developed parts along with the whole country has the highest potential of new labour market opening. Lolland and Falster are the less developed parts of Denmark, and a direct connection to the Lübeck area would definitely raise the drift of labour force, and could develop this rarely inhabited and used area of Denmark. Moreover, the direct shortened connection between Sweden and Germany could also enhance workforce flow. Project 9 finished second in this aspect, as connecting Hungary, and indirectly Romania to Italy and the West, which is a dense connection

line of workforce.

- **Improvement of international connections and coherence**
  This social and also economical criterion tries to evaluate the projects over the accessibility of each other's countries, overtaking existing connection problems and narrow bottlenecks, additionally considering the present commuting figures along the destinations of the lines. Again, no scaling was used assessing the criterion, but more description on each scenario's relevant situation. Project 1 got the highest geometric mean, for the following reasons: connecting Bavaria with Lombardy is providing a corridor between one of the most developed parts of Europe, that already attract millions of travellers of business, leisure and much more. However, the current rail line has very narrow bottlenecks under the Alpes, since the rails run on the surface, and not underground and also only two connections exist between the North of the mountain range and the South. It would quicken travels by hours, and freight transportation would be improved by much, too. Whereas in other projects, the connection is either present or would not improve considerably.

- **Effect on tourism**
  Tourism (even though its numbers largely declined due to the Covid-19 pandemic) is a major income source for every country. This aspect is examined from a point whether recent years' top destinations and nights spent abroad show a tendency of increase, and that the project in particular would ameliorate the tourism in the countries. Again, Eurostat was used, now with the figures of nights spent in each country from abroad, and also the top destinations of tourists within Europe, originated from the countries lying along the railway lines. Project 1 countries, Germany, Austria and Italy attract the most tourists, but it does not mean that tourism flow occurs only between these countries. The top destinations for each country is observed in different Eurostat figures, and in the assessment of each project the combination of these and number of nights spent were considered. However, this project scored the highest points of all, since it dominated all other scenarios, due to the attractiveness of tourism between Germany and Austria, Austria-Italy and Italy-Germany. In the attached REMBRANDT Excel sheet, the exact numbers per country are observable.

Prior to any alternative comparison, the criteria have to be compared against each other. The matrix of this is presented below:

	C1	C2	C3	C4	C5
C1	0	3	-2	0	5
C2	-3	0	-2	-4	0
C3	2	2	0	1	6
C4	0	4	-1	0	4
C5	-5	0	-6	-4	0

Figure 13: Criteria comparison matrix of REMBRANDT

After computing the standardized values for the converted gradient indexes' geometric mean, the final order of the five criteria is the following:

1. Effect on labour market
2. Improvement of international connections and coherence

3. Renewable energy - fossil fuel dependency
4. Transport network - accessibility
5. Effect on tourism

5.4 Discussion

After an overall assessment of all techniques for each alternative based on considered criteria, we draw a conclusion based on the comparison matrix. All the alternatives are compared based on the five criteria. In the following table, the final scores of the REMBRANDT analysis compared to the SMARTER are displayed.

	REMBRANDT		SMARTER
	score	stan'dized	stan'dized
Sc18	1,948	*0,405*	0,316
Sc1	1,454	*0,302*	0,178
Sc9	1,082	*0,225*	0,253
Sc3	0,326	*0,068*	0,253

Figure 14: Final scores for REMBRANDT and SMARTER

After the assessment, it can be seen that the ranking of the four scenarios is clearly not giving the exact same results from REMBRANDT and SMARTER. One main reason is that the criteria used to conduct both analyses are not interpreted exactly in the same way. In our opinion, this should not mean any wrong, but on the contrary, it brings more points of view to the analysis, and also, it explains that these quantitative scanning are somewhat subjective and have a dependence on the evaluating person(s) opinion. *In the following parts of the assignment, the REMBRANDT results will be used*, because overall it gives a more logical outcome based on mathematical calculations and gives a clearer picture of the alternatives based on criteria, and the whole comparison process is more straightforward and can be supported and interpreted reasonably, than the SMARTER.

Scenario 18, the Fehrmann-Belt seems to be the most feasible amongst all, based on our scaling according to the criteria stated. 40.5 % is quite high, followed by the Brenner-line with 30 %, then 22.5 % for the Adria East-West project, and lastly the Iberian railway line, which performed extremely bad, obtaining only 7 % of all scores. In the SIMDEC analysis, the used comparison matrices will be utilized again, when the results of the risk analysis will be put in as a sixth criterion. More detail about it in section 7.

6 Risk analysis

The main objective of any risk analysis is to establish a rational foundation for objective decision making. The risk analysis aims at quantifying the undesirable effects that a given activity may impose on humans, the environment, or economical values. The objective of the decision process is then to identify the solution that in some sense minimizes the risk of the considered activity.

Traditional risk analysis gives the decision-maker a means by which they can look ahead to the totality of any future outcome. Traditional Technique of Risk Management included -
Risk identification, Risk assessment & Risk evaluation as in fig 26

6.1 Coarse Risk Analysis

The coarse risk analysis deals with identifying possible risks, including the consequence, and accordingly maps the probability of occurrence for the identified risks. These risks are therefore identified and classified in separate consequence classes and are mapped with severity on the scale of None, Negligible to Catastrophic. Once the approximate mapping is done with the help of nominal considerations, it is recommended for a decision-maker to understand the technique behind the consequence mapping. However, it becomes easier to accordingly quantify the risks and prepare the strategies for preventing and/or mitigating these evaluated risks.

It is, however, prominent to notice that the coarse risk analysis will bound to all of the alternatives that are considered as scenario projects. This standardized evaluation seems to be appropriate since all the scenario projects encompass the involvement of updates in railways and roadways.

6.1.1 Consequence Matrix

Initially, a list of potential consequences is determined, and accordingly, they are classified with certain criteria for each class. These individual classes are then described and the corresponding abbreviations for these classes are showcased. Furthermore, the scale of impact is decided from None/Negligible to Catastrophic and the respective impacts for each criterion are then mapped as shown in fig 15. Once, each of the impacts is mapped with certain consequences, the most appropriate consequence for the particular criteria can be later highlighted as the main area of consequence for a decision-maker to determine the ferocity of each individual alternative.

Label Consequence class	Criteria	Abbreviations	None	Minor	Significant	Serious	Critical	Catastrophic
Economic	Maintenance	MT	No Maintenace	Damages that take few days	Damages that takes more than 3 weeks	**Damages that takes more than one month**	Damages that takes more than 6 months	Damages that takes more than a year.
	Budget overrun	BO	None/Negligible	None/Negligible	**Reach reserves**	Exceeds reserves	Critically exceeds	Catastrophical exceed
People	Affected crew members	AC	Negligible delays due to injury	**Minor delays due to injury**	Injuries that require hospitalization	Serious injuries that needs more than a month of hospitalization	Critical injuries, need replacement of resource.	Fatilities
Environment	Environment	EN	Negligible environmental damage	Minor enviromental damage	**Significant environmental damage**	Serious environmental damage(Air polution)	Critical enviromental damage (High use of fuel and energy)	Catastrpphic enviromental damage(deforestation and high emission of Co2)
Social	International Coherence	IC	None/Negligible	None/Negligible	**Disconncetivity for more than 3 weeks**	Disconncetivity for more than a month	Disconncetivity for more than 6 months	Disconncetivity for more than a year
			Negligible	Tolerable	Unwanted	Unwanted	Unacceptable	Unacceptable

Figure 15: Consequence Matrix

6.1.2 Risk Matrix

A risk matrix (fig 16) is prepared based on the consequences as displayed from the subsection above in figure 15. This mapping helps decision-maker identify a particular quadrant including particular consequence they should be focusing on. This matrix showcases the valuable insights in the form of highlighted colors of green, yellow, orange & red as the severity and impact of each of the criteria.

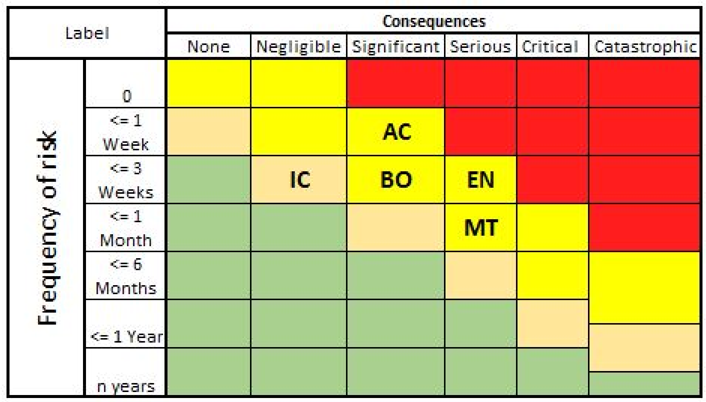

Figure 16: Risk Matrix

6.2 Quantitative Risk Analysis (QRA)

Quantitative risk analysis (QRA) approach is the possibility of differentiating the feature of risk information in terms of outcome criteria by probability distributions. QRA in transportation problems is done by defining a set of uncertain transport related impacts and hereafter determine the most descriptive discrete or continuous probability distribution function. *A quantitative analysis of the risk and the associated risk management options are available to determine or find an optimal strategy for controlling and solving the risk problem.*

The resulting single point estimate from the CBA is transformed into an interval estimate illustrated in terms of a probability distribution in the QRA. The technique used in the following work is a **Monte Carlo simulation** which involves a random sampling method concerning each different probability distribution selected for the actual model set-up. In the following, these types of scenarios are referred to as **iterations**. Each probability distribution is sampled in a manner such that it reproduces the original shape of the distribution, meaning that the actual model outcome reflects the probability of occurrence.

6.2.1 Monte Carlo simulation

It is a common technique for analyzing complex problems and is considered as stochastic model. Stochastic simulation is a statistical sampling method where the procedure collects random numbers from a particular probability distribution. Originally, the *Monte Carlo* method was considered to be a technique using random numbers chosen from a uniform interval [0;1]

As far as the corresponding assignment is concerned, we are responsible for **2000 iterations**, where, from each input distribution the sampled values become distributed in a manner which approximates the known input distribution. Thus, the sampling process collects random values from the input distributions. A schematically overview of the process is shown in Figure 27. The next procedure is now to assess and define suitable input distributions to describe the uncertain parameters in the modelling framework.

6.2.2 Deriving Suitable Probability Distributions

A common bias is a distinction between actual data fit and expert opinion in the derivation of distribution functions. Interpreting the level of knowledge (LoK) on the uncertain parameters or variables allows the analysts to define the best and most suitable input distribution. The idea behind the **Flyvbjerg** technique is to gather all possible and available information regarding implemented transport investment projects.

6.2.3 Beta-PERT distribution

The **Beta-PERT distribution** or **PERT** (Program Evaluation and Review Technique) distribution along with Monte Carlo Simulation, is used to identify risks in project and cost models. The PERT distribution is derived from the beta distribution which mathematically covers a huge variety of skewness types. It is found suitable to fit demand forecasts. The application of the distribution is based on 3 main parameters,

- **a = minimum value**
- **b = mode**
- **c = maximum value**

The cumulative distribution function (CDF) requires input in form of α & β represented below in form of mathematical expressions [4].

$$\alpha = \frac{4(b-a)}{c-a} + 1 \ \ \& \ \ \beta = \frac{4(c-b)}{c-a} + 1$$

The comparative study relied upon the **reference class forecasting** concluded that generally, traffic forecasts within rail projects of **demand forecast** bias are within an approximated range (*traffic forecasts in random rail projects calculated in percentage*) as displayed below;

RiskPERT(-92.3%; -37%; 144.2%)

The respective record depicted are found by interpolation of data points from the **Flyvbjerg** database as mentioned in [5].

In this scenario, the total count of routes including railways & roadways (updated and new) for 4 different priority projects were selected and therefore, helped conclude that the RiskPERT data required for further calculations must be assumed as relevant for the Rail projects due to its significant impact on the total count.

6.2.4 Erlang Distribution (Gamma)

The **Erlang distribution** is a probability distribution with wide applicability primarily due to its relationship with the exponential and gamma distributions. The distribution is used in the field of stochastic processes. The Erlang distribution has a positive value for all the numbers greater than zero and is parameterized by two parameters:

which is an integer - **shape k** & which is real - **the rate** λ

The distribution is sometimes defined using the *inverse of the rate parameter*, i.e. the **scale** θ

The successive calculation is derived in interpreting the uncertainties involved and determining construction cost estimates. However, suiting to the corresponding scenario, the predefined values of **k** & θ are then considered to move ahead with the total evaluation, resulting in assuming the highest impact on the projects to be the **railways**, the parameters (*Cost estimates of random rail infrastructure projects*) used were;

Shape parameter k = 23, scale parameter of θ = 0.075

The corresponding fit by using the Erlang distribution on the data are records from the **Flyvbjerg** database for the rail type projects as mentioned in [5].

6.3 Feasibility Risk Assessment (FRA)

Complementing cost-benefit with quantitative risk analysis enables a more comprehensive type of assessment. This wider type of analysis has been determined as **feasibility risk assessment (FRA)**. The two modules CBA and QRA are comprised within the modeling framework and are generally referred to as deterministic and a stochastic module. This adoption outlines the feasibility risk assessment (FRA) procedure in which decision-maker and stakeholder involvement are vital.

FRA is connected by the CBA and QRA approaches as shown in the Figure 28.

The conventional CBA represents the aggregation of benefits and costs into one single point evaluation criterion. The QRA helps to make use of various relevant probability distributions on the most uncertain elements within the CBA. The main purpose is to make the risk analysis transparent.

The main calculations for all of the 4 priority projects involved evaluating the *updated values* for *Consumers surplus, Construction costs, Scrap Value* & most importantly *BCR*.

Calculations for the respective variables goes as below;

- **Updated Consumer Surplus = BETA.INV(RAND(a,c,α,β)) * Consumer surplus**
- **Updated Construction Cost = GAMMA.INV(RAND (k,θ)) * Construction cost**
- **Updated Scrap Value = Updated Construction cost * final discount factor**
- **Updated BCR = (Operation & maintenance + Air pollution + Global warming + Accidents + Noise + Updated Consumers surplus + Updated Scrap Value)/ (Updated Construction cost)**

Once done with evaluating the distribution for almost **2000 iterations**, the values for minimum, maximum, mean and standard deviation are formulated for *Consumers surplus, Construction costs* & *BCR* for each of the projects.

In order to summarize the calculations for each of the project, a separate table is created for probability distribution of BCR values.

The corresponding values from the probability distribution are therefore plotted on the **certainty graph** or **ADG**. Communication means in FRA is the accumulated descending graph (ADG) as seen below Figure 17.

A minimalist table is then drawn in the final stage of calculations showcasing the threshold, as we considered threshold **BCR = 1** and **BCR = 0.75** for the better understanding of the certainty values. The ranking order for each of the project is then confirmed based on these certainty values. It

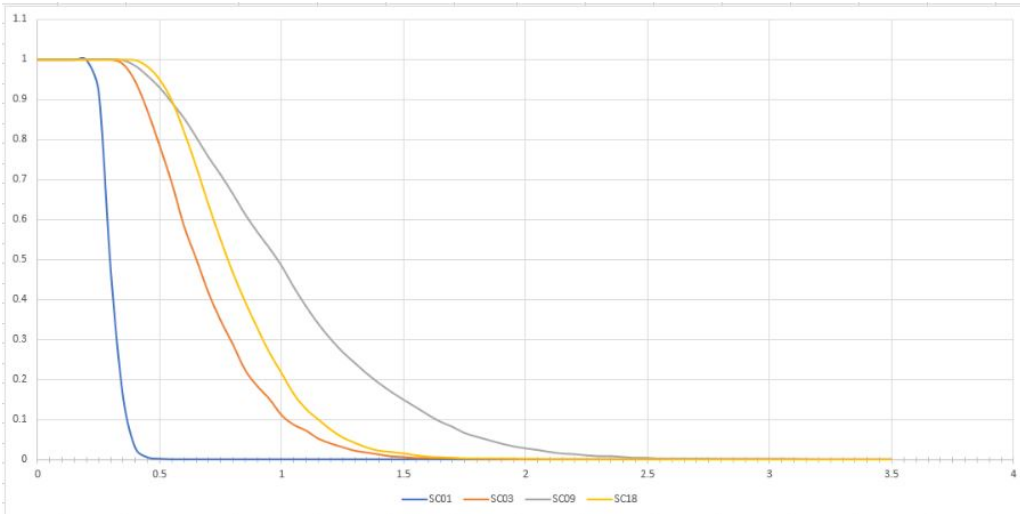

Figure 17: Accumulated descending graph (ADG) illustrating the variation in probability of the BCR

is necessary to showcase the information for all of the 4 projects scenarios and prominent to determine the threshold by setting the projects in an order with respect to its ranks as shown in fig 18.

CV for each scenario projects	SC01	SC03	SC09	SC18
(Considering threshold - 1)	0.00%	11.05%	48.35%	21.55%
(Considering threshold - 0.75)	0.00%	34.75%	71.15%	54.90%
Rank	4	3	1	2

Figure 18: Certainty Values (CV) with threshold for different projects and ranking order

Hereby, the Feasibility Risk Assessment in the actual case makes the decision-makers debate the specific risk conditions they want to adopt to frame the decision.

6.4 Discussion

The respective model has demonstrated that a combination of CBA and QRA examination can increase the decision-makers opportunities to make informed decisions. The two proposed ways of handling uncertainties provides the estimates of **BCR** with **0.75** and **0.1** as threshold per mentioned in figure 18, and the QRA has been applied with a **PERT** and **Erlang** distribution to create a mean in which the underlying uncertainty has been addressed. Herein lies the advantage of applying this model where, feasibility risk assessment are produced in terms of certainty graph as depicted in Figure 17.

A special emphasis is to be placed on the steepness of the curves indicating the decision-makers risk aversion towards a given project alternative. Additionally, the ***SC09*** and ***SC18*** crosses each other, which illustrates points where a different scenario could result in higher rate of returns given more risk in the decision making process. However, it can be concluded based on the figure 18, that the ranking to the alternatives are done on the basis of higher certainty value.

7 Composite assessment

7.1 COSIMA

The COSIMA approach tranform the non-quantifiable impacts from the MCDA into monetary impacts so they can be compared equally with the impacts from the CBA. The investment criteria from the CBA [5] and the scores from the REMBRANDT method [13] will be used to generate the **Total Rate of Return** of each project. The impacts used are the same as described previously:

- CBA: Air Pollution, Global warming, Consumers surplus, Accidents, Noise
- MCDA: Renewable energy/fossil fuel dependancy, Transport network/accessibility, Effect on labour market, Improvement of international connections and coherence, Effect on tourism

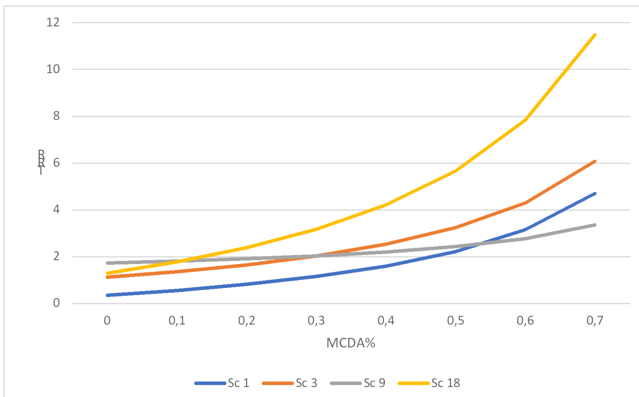

Figure 19: TRR values for the four scenarios as a function of the MCDA%

On figure 19, the TRR values increases with the MCDA%. Scenario 3 and 18 grows faster as their investment cost is lower than the other two. The ranking of criteria from the MCDA[13] also have an important impact on the TRR values. The scenarios who fair better on the higher rated criteria will also have a better improvement in their TRR value. Indeed scenario 18 has a steep growth thanks to have a high score on the *Effect on labour market*, the highest ranked criteria.

The calibration of the model was made using Scenario 3, 9 and 18 as they were all found feasible by the CBA. The **MCDA%** was set to **30** as the the monetary criteria from the CBA are more objective than the criteria from the MCDA. In other circumstances, a higher MCDA% could have been chosen as all scenarios are large strategic infrastructure projects, but the MCDA would also require insights from more decision makers.

7.1.1 Results

According to the COSIMA analysis with an MCDA% of 30 [20] , **scenario 18** is the most favorable project. It has the second highest BCR from the CBA and has the highest MCDA score which makes it a robust choice to continue with. Based on CBA only, Scenario 9 had the highest added value, however, scenario 18 scored higher on key non-monetary criteria such as the *effect on labour market, the accessibility and the usage of renewable* energy.

Scenario	Sc 1	Sc 3	Sc 9	Sc 18
CBA				
Investment costs	- 16 028 435 723	- 4 569 616 932	- 27 606 626 325	- 7 734 106 177
Total CBA benefits	5 566 985 420	5 064 744 676	47 652 636 587	9 990 440 505
BCR	0,35	1,11	1,73	1,29
MCDA				
Renewable energy - fossil fuel dependancy	1 612 359 432	3 224 718 863	201 544 929	1 612 359 432
Transport network - accessibility	570 055 144	50 386 232	677 913 633	2 711 654 532
Effect on labour market	677 913 633	239 678 664	4 560 441 151	9 120 882 302
Improvement of international connections and coherence	7 669 717 232	169 478 408	2 711 654 532	958 714 654
Effect on tourism	2 280 220 576	479 357 327	84 739 204	71 256 893
Total MCDA	12 810 266 016	4 163 619 494	8 236 293 450	14 474 867 813
Total				
Total value	18 377 251 436	9 228 364 170	55 888 930 036	24 465 308 318
Total Return Rate	1,15	2,01950	2,02	3,2
Rank	4	3	2	1

Figure 20: COSIMA results with MCDA%=30

7.1.2 Discussion

The different benefits per impact is shown on figure 21. Scenario 9 pure CBA benefits is way bigger than any other scenario. When calibrating the model, the high difference between this scenario and the others makes it's TRR growth slower than for the other projects. The MCDA% for each scenarios is also significantly different than the global MCDA% = 30 for the same reason. On that observation, the COSIMA approach might disadvantage the bigger monetary projects. For instance on the scenario 9, MCDA has very little impact on its overall benefits in comparison to other projects.

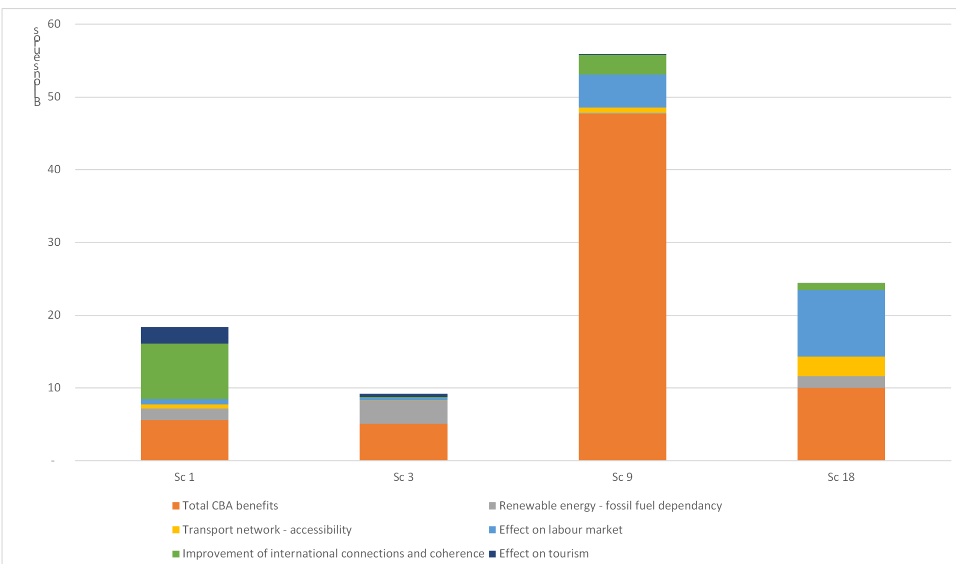

Figure 21: Benefits per impact

7.2 SIMDEC

The SIMDEC approach comprise of two major factors, economic and strategic impact in the evaluation of broad transportation facilities. This approach incorporates many parameters that demonstrate various aspects of decision-making which should be taken into consideration, rather than relying on just one factor. The core principle is that **MCDA** takes particular account of the risk analysis of the viability of each alternative project. In a category of decision criteria which display the overall efficiency, the results of **FRA** can be also used as a criterion. SIMDEC determines the impact of the different projects using the selected relevant criteria in regards to the sustainable development

In SIMDEC analysis, the feasibility risk assessment results are converted into certainty values (CV) that can be put and used in an MCDA analysis, specifically in a REMBRANDT. Initally, the risk analysis has to be conducted, which has been done above[5]. Using the results from assessment, which are the percentage values of the ratio of 2000 Monte-Carlo simulations, that the BCR is over 1, that states the benefit is overall more than the costs, hence the project is beneficial and feasible. These can be seen in the table where the are defined in the first row. 18

Conducting a REMBRANDT analysis again and adding the risk factor as a criterion along with the other considered criteria, here we have followed the exact same procedure in the first REMBRANDT method. The pair-wise comparison matrix is based on the above mentioned percentages, therefore in terms of the exploration, *scenario 9* is more feasible in regards to risk. Furthermore, the risk criterion was inserted in the criteria pair-wise comparison matrix too, where the only two criteria outperformed and seems to be more important than the risk: renewable energy - fossil fuel dependency and improvement of international connections and coherence. Combining the related matrices the final values are the followings.

	REMBRANDT stan'dized	REMB. w/ risk stan'dized	SMARTER stan'dized
Sc18	*0,405*	*0,353*	0,316
Sc9	*0,225*	*0,330*	0,253
Sc1	*0,302*	*0,236*	0,178
Sc3	*0,068*	*0,080*	0,253

Figure 22: Final scores for the REMBRANDT including risk

The results of the simple REMBRANDT and the one including the risk criterion are shown, along with the SMARTER results too. The changes are quite significant, however, the highest score still corresponds to **scenario 18**. As mentioned before, the risk assessment had the most beneficial impact on the Adria E-W project (number 9), therefore this scenario jumped to second place, scoring 33 %, increasing its performance by 50% after the first REMBRANDT. Along with this change, scenario 1 dropped to 23.6 %, while the worst project gained 1 % more.

It is clear then that including a risk factor in the MCDA analysis, the results would differ a lot compared to the one without a risk assessment. This also highlights why the feasibility risk analysis plays a key role in an evaluation process of certain projects.

8 Discussion of results

The results of all the previous decision support analysis are summarized in the following composite assessment table:

	CBA	FRA	MCDA	COSIMA
Sc1	4	4	3	4
Sc3	3	3	4	3
Sc9	1	1	2	2
Sc18	2	2	1	1

Figure 23: Composite assessment table of rankings

Scenario 9 and **Scenario 18** can both be considered as reasonable project choice.

- **Scenario 9** strength lies in its **monetary impact**. It came up first on the CBA with a BCR equal to **1.7**, with a 0.4 lead on project 18. The FRA results still give Scenario 9 an advantage with a certainty value of **48%** for a BCR threshold of 1 against 22% for project 18.
- **Scenario 18** strength lies in its **non-quantifiable impacts** highlighted by the MCDA. It ranked first on both the SMARTER and REMBRANDT methodology. Scenario 9 in comparison was respectively ranked second and third by the same methodology. When taking into account the risk assessment with the SIMDEC methodology, the difference between the two scenario gets thinner: **0.353** for Scenario 18 and **0.330** for scenario 9 - making it difficult to take a real dominant scenario through this technique.
- It is also important to note that Scenario 9 is a larger scale project than Scenario 18 - it covers a much longer corridor and the investment costs are more than 3 times higher. This can also be a factor to consider when choosing between them, not to mention that it is not easy to objectively compare projects on such different scales. This scale difference is the most easily observable on the COSIMA results 21. While other projects MCDA% counts for more than 50% of their cumulated benefits, the MCDA% of project 9 only equals to 15%.
- More diverse decision-makers should participate in the MCDA and the ELECTRE. The non-quantifiable aspect of the impacts taken into account in the MCDA and ELECTRE make them sensitive to the panel of decision makers taking part in the discussion. With other participants, the impacts considered could have been highly different as well as the pair-wise comparison results.
- We would like to also note that some projects within these scenarios are already under construction or final preparation (e.g. the Brenner Base Tunnel and the Wörgl bypass in SC1, the Brescia-Padova HSR in SC9, or the Danish railway upgrades in SC18). This means that probably more accurate data is available now on costs, and therefore the CBA could be recalculated with more accuracy (with less variation in the FRA) as a monitoring assessment.

9 Conclusions and recommendations

From the original 10 infrastructure upgrades scenarios on the EU's TEN-T project portfolio, this paper narrowed down the options to 2 projects worth considering for further analysis:

- **Scenario 9**: Adria East-West: Milan - Venice - Trieste - Ljubljana - Budapest
- **Scenario 18**: Fehmarn Link: Copenhagen - Rødby - Puttgarden - Hamburg

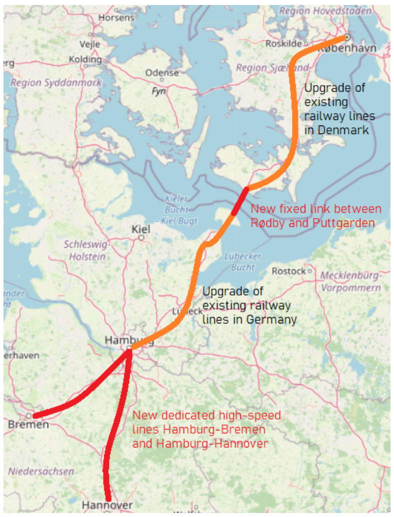

Figure 24: Scenario 18 map

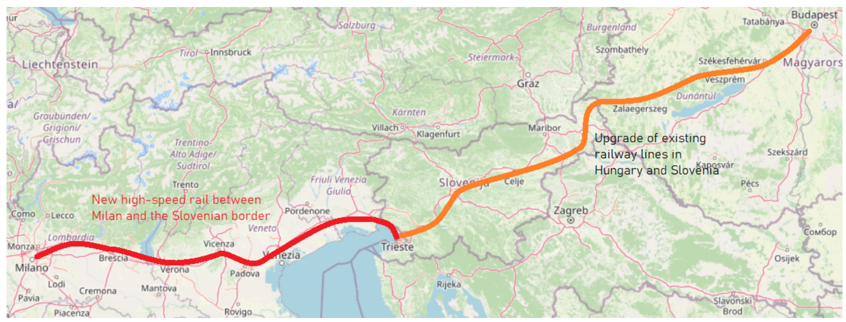

Figure 25: Scenario 9 map

To come up with this recommendation, a screening analysis using the ELECTRE method was first conducted to cut down the options to 4 projects. Then using the COSIMA approach, the monetary (CBA), non-monetary impacts (MCDA) were appraised and combined to come up with a Total Rate of Return. Finally, the SIMDEC methodology, used the Feasibility Risk Assessment to generate a risk-adjusted MCDA ranking.

Scenario 9 was found to be the best performing on terms of direct **monetary impacts (CBA results)**, which is a more objective assessment method. **Scenario 18** outranked it in the **MCDA**, which included **non-monetary impacts** that were assumed to be important in general for such projects. However, if decision makers have different priorities and they provide inputs on these during the assessment process, it could result in a different outcome.

A Appendix

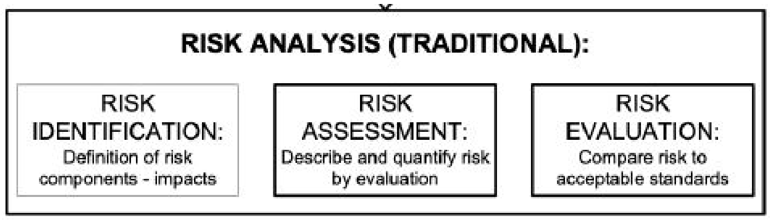

Figure 26: Traditional Risk Management [4]

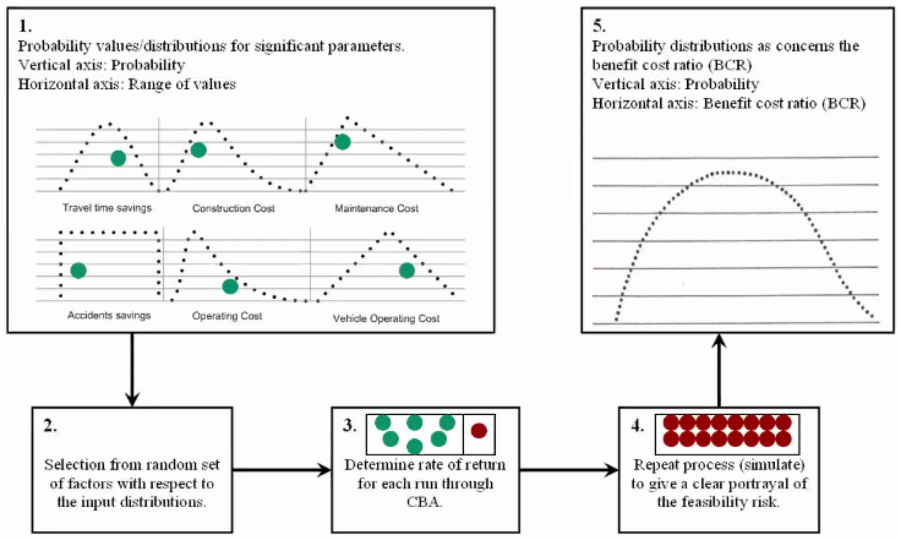

Figure 27: The sampling process applied for Monte Carlo simulation [5]

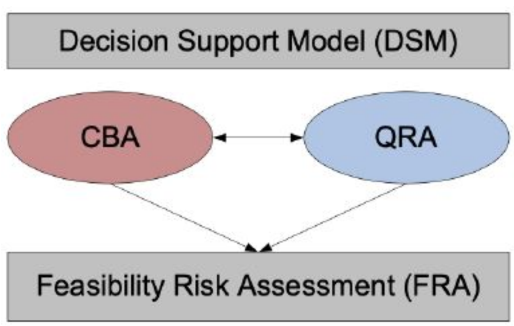

Figure 28: The feasibility risk assessment procedure [5]

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