APPLYING ELECTRE III TO THE ANALYSIS OF RAIL FREIGHT POLICY STRATEGIES: ADVANCES IN ASSESSING THE SENSITIVITY OF RANKINGS TO CRITERIA WEIGHTS*

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I. INTRODUCTION

This paper describes an automated tool that allows the analyst to systematically vary key parameters of the ELECTRE III multicriteria decision-making tool, thereby facilitating sensitivity analyses of the results. We also demonstrate how the sensitivity analyses can be presented by means of an intuitive graphical depiction of shifts in the rankings of alternatives that can be readily interpreted by decision-makers. As an illustration, we apply the method to evaluate alternative strategies for promoting seamless freight transport along a rail corridor connecting the Nordic region with Central and Southeastern Europe.

ELECTRE III is based on successive pairwise comparisons of two alternatives to establish outranking relationships with respect to a pre-determined set of criteria. Among the advantages of the method are its flexibility in: (1) simultaneously incorporating both quantitative (e.g. monetized) and qualitative outcome indicators; (2) handling uncertainty in the data; and (3) allowing for indifference, preference, and veto thresholds with respect to each of the indicators. These advantages, and the resulting sensitivity analyses, are exploited through an analysis that focuses on the economic, social, and environmental effects that would emerge from a rebalancing of freight traffic between road and rail. Since the research for this paper is being conducted under the auspices of a European Commission-financed international consortium, REORIENT, which has only recently begun its work, hypothetical data will be employed to demonstrate the performance of the sensitivity analyses.

The remainder of the paper is structured as follows. In section II, we provide a brief background of the REORIENT project, highlighting why ELECTRE III is a particularly useful tool for achieving the project's aim of evaluating interoperability policy. Section III works out a hypothetical example, systematically elaborating each step involved in producing a ranking of policy options. Section IV presents an automated tool for testing the sensitivity of the results and graphs alternative ranking outcomes that emerge from varying key parameters. Section V concludes the paper.

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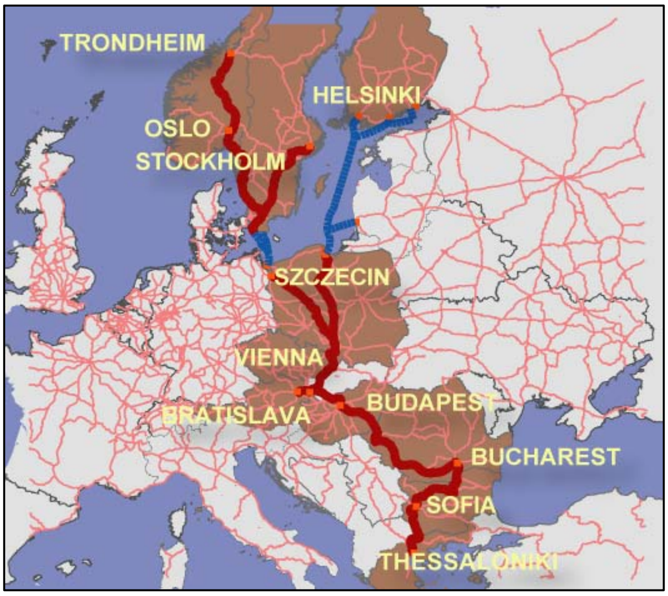
II. THE REORIENT PROJECT

The REORIENT project comprises an international consortium of research and industrial organizations charged with studying policies and business models for promoting interoperability of freight transport along the European rail system. The European Commission has identified interoperability to be of fundamental importance in making the rail network a competitive alternative to road transport [1]. Currently, there exist multiple barriers to achieving harmonization of freight operations, including incompatibilities in electrification and signaling systems and in the specifications of rolling stock. Against the backdrop of increased liberalization in the rail sector, REORIENT's work involves identifying the barriers that exist along the intermodal freight corridor connecting the Nordic region with Central and Southeastern Europe (see map) and proposing solutions for their removal. The project is grounded in a systems analytic approach [2]; it will use information obtained from stakeholder surveys and GIS-based databases to develop an integrated suite of modeling activities capturing the synergies between rail network flows and business decision-making.

Figure 1: The REORIENT Corridor (Source: REORIENT brochure)



To achieve these aims, the project has been structured into eight workpackages. The first three of these assess the present status of interoperability as well as the potential success of actions to remove barriers to seamless rail freight transport. This will involve the construction of a GIS-supported database as well as surveys of rail sector actors and the general public to gauge the strategic latitude for implementing rail freight policies. Workpackages four through six will identify business opportunities and develop new business solutions for international European rail freight transport that make it more competitive with road transport. Underpinning this work will be a detailed corridor analysis that identifies barriers to interoperability as well as an analysis of the quality factors underlying the modal choice decisions of shippers. Workpackage seven's task, which is the focus of the present paper, is to produce an integrated assessment of freight transport strategies based on the consolidation of inputs from the preceding workpackages. Specifically, the workpackage addresses the following two questions: (1) what strategies will confer net benefits relative to a do-nothing scenario and (2) what is the ranking (prioritization) of the devised strategies with reference to their potential to attract private investment, promote social cohesion, and benefit the environment? Finally, workpackage eight will collate the data and outputs from all workpackages to create a repository of data that can be accessed from project members and other interested parties (*e.g.* investors in the rail network).

The REORIENT project thus involves a diverse range of activities that will generate a correspondingly diverse range of criteria indicators for measuring progress toward improving interoperability. Given that these indicators will be measured in different units – some quantitative and some qualitative – a key challenge of workpackage seven will be to integrate them into a coherent and transparent framework that makes sensible comparisons of policy alternatives possible. Moreover, it is likely that many of the criteria used to rank the alternatives will be imprecise and subject to measurement uncertainty. Finally, information concerning the importance attached to the different criteria by stakeholders is likely to be spotty [3]. These considerations led to the selection of ELECTRE III for use as a decision-making tool in identifying the optimal strategy for achieving interoperability. Among the advantages of the method are that it:

- can facilitate consensus among multiple stakeholder groups,
- requires relatively little preference information,
- has the capacity to deal with imprecision and uncertainty in the data through the specification of indifference, preference and veto thresholds.

III. THE ELECTRE III METHOD: A BRIEF OVERVIEW AND EXAMPLE

As with most multicriteria methods [4, 5, 6], the point of departure in ELECTRE III is the definition of a set of alternatives (i.e. policy strategies) and a set of criteria with which to compare them. The method is implemented based on successive pairwise comparisons of two alternatives to determine outranking relations with respect to the criteria. An outranking relation is established when an alternative a can be said to be at least as high in the priority order as an alternative b. The set of criteria used to establish such a relation must fulfill the following properties:

- exhaustiveness, meaning that all relevant aspects for reaching a decision are represented
- non-redundancy, meaning that all relevant aspects should be represented by only one criterion, and
- coherence, meaning that the increase (decrease) of a criterion g(a) that is already greater than (less than) g(b) will not affect the ordinal ranking of g(a) relative to g(b)

An important feature that distinguishes ELECTRE from other methods is that two thresholds are assigned to each criterion, resulting in three preference categories designated by indifference, weak preference and strong preference. These preference thresholds serve to attenuate both imprecision and uncertainty in the measurement of the data. A veto threshold for any criterion can also be specified which, if exceeded, leads to the rejection of the alternative irrespective of the values of the other criteria. The final input needed to implement the method are criteria weights, which measure the importance attached by the decision-maker to each of the criteria. These weights are normalized to sum to one.

The steps in implementing ELECTRE III, elaborated in the example below, are as follows [7]:

1. Construction of partial concordance matrices based on thresholds for indifference and significance. Concordance is established from testing the hypothesis that option *a* is at least as good as option *b*.
2. Construction of an aggregated (total) concordance matrix, which takes into account the weights of the criteria.
3. Construction of partial disconcordance matrices, which take vetos into account.
4. Construction of a credibility index, which aggregates the concordance and disconcordance matrices.
5. Destillation, or the assignment of a top-down and bottom-up ranking. The ranking of the alternatives from best to worst and worst to best serves as a check for logical consistency and helps to establish whether the options are, in fact, comparable.

We now proceed to work through an example, after which we present our method for testing the sensitivity of the results to different values for the criteria weights. Readers already familiar with ELECTRE III can skip the following discussion and proceed directly to Section IV.

We begin by defining the set of criteria indicators according to the properties of exhaustiveness, non-redundancy, and coherence noted above. Conceptually, the selected indicators cover the business, social, and environmental spheres:

- Net present value [Mio €]: discounted profit that results from carrying out the alternative; for the case of the do nothing scenario, assume that the funds for financing the project are instead deposited in an interest bearing account
- Number of new jobs created – directly generated by the alternative itself or indirectly by modal-shift (e.g. decreasing/increasing number of lorry drivers)
- Hours of border waiting time savings in the corridor [h]
- Number of people exposed to noise above critical threshold
- Emissions [kg CO_2-equivalent per passage of corridor per ton of freight]
- Reduction of the value of damaged or lost goods per ton/tkm

We then define the set of strategies (or alternatives) to be ranked. Assume that the following eight alternatives have been identified:

- Construction of two strategically located freight villages
- Implementation of a unified tracking & tracing system
- Implementation of an integrated workflow management system
- Upgrade rail tracks, e.g. to a minimum of two tracks, to increase network capacity and decrease transport time
- Build a centralized costumer service center
- Modernisation of locomotives, by equipping with ERTMS (European Rail Traffic Management System)

- Modernisation of freight cars for combined freight traffic to enable transport of standard semi-trailers
- Do nothing – baseline scenario

Input data

Table 1 presents the attribute values assigned to each of the alternatives while Table 2 presents the parameters for designating the criteria weights and the indifference, significance and veto thresholds.

Table 1: Attribute values for alternatives:

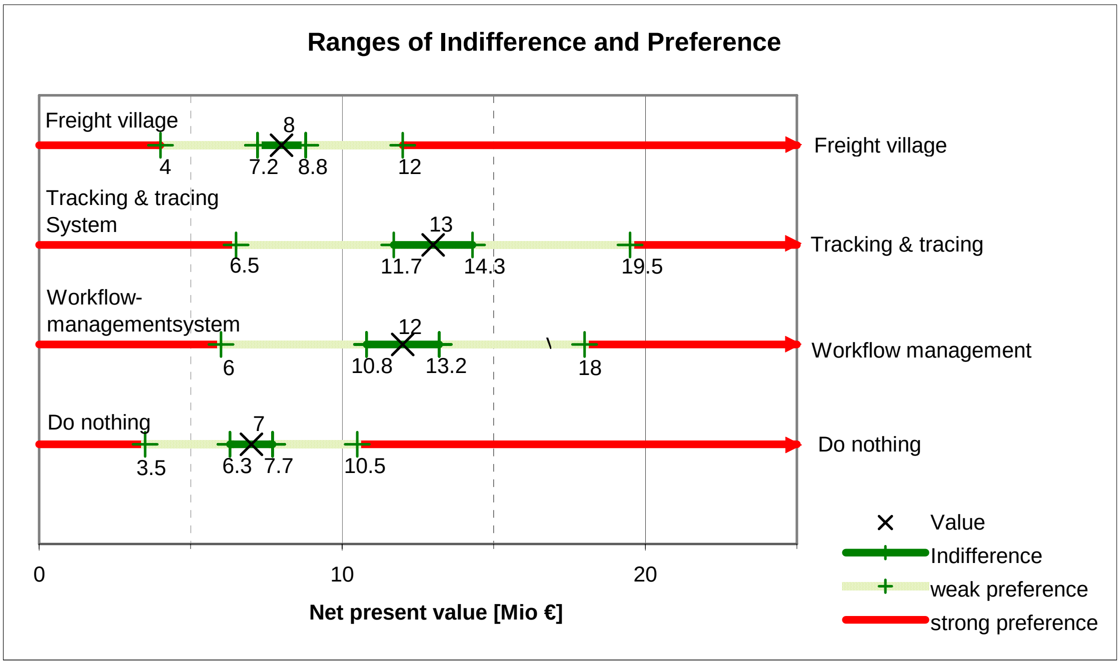
	Net present value [Mio €]	**New jobs**	**Hours of waitung time on borders saved [h]**	**Population exposed to noise reduction**	**Emissions reduction [kg CO_2-equivalent]**	**Value of damaged goods reduction [ct.€/ton-km]**
Freight village	8	1500	1.5	500	25	3
Tracking & tracing system	13	800	0	200	5	5
Workflow managementsystem	12	1400	1	1100	20	4
Upgrade of railtracks	5	350	3	0	15	0
Improve costumer service	10	400	1.5	300	23	1
Modernisation of locomotives	5	200	0.1	100	10	0
Modernisation of freight cars	6	650	1	600	5	10
Do nothing	7	1000	-2	-2000	-20	-4

Table 2: Parameters for Multi-Criteria-Assessment

	Net present value	**New jobs**	**Hours border waiting time saved**	**Population exposed to noise reduction**	**Emissions reduction**	**Value of damaged goods reduction**
Preference Direction	growing	growing	growing	growing	growing	growing
Criteria Weight	35 %	25 %	15 %	10 %	10%	5 %
Indifference Threshold	10 %	10 %	25 %	25 %	25 %	10 %
Significance Threshold	15 %	15 %	50 %	50 %	50 %	20 %
Veto Threshold	Not assigned	Not assigned	200 %	150 %	150 %	150 %

To further elaborate the interpretation of the parameters, the following chart displays the ranges of indifference and preference corresponding to the indicator of net present value for four of the alternatives (Figure 2). As catalogued in Table 2, the threshold values for this indicator are 10% and 15% for indifference and preference, respectively. For the freight village alternative, these values generate an indifference zone ranging between 7.2 and 8.8 (= 8 ± 8*0.1). Values between 8.8 and 12 indicate a weak preference for the freight village alternative over the comparison alternative, while values greater than 12 indicate a strong preference. Conversely, values between 4 and 7.2 indicate a weak preference for the comparison alternative over the freight village alternative, while values less than 4 indicate a strong preference.

Figure 2: Ranges of indifference and preference with respect to net present value for selected alternatives



Having established the input data, we now proceed to the calculation of the rankings. For this, the following notation will be useful:

- A is the set of options under consideration (a,b,c,…h)
- $g_j(a)$ is the value of option a with respect to criterion j
- $q_j(g_j(a))$ is the indifference threshold for criterion j
- $p_j(g_j(a))$ is the significance threshold for criterion j
- $v_j(g_j(a))$ is the veto threshold for criterion j
- k_j is the weight assigned to criterion j, with the weights normalized to sum to 1

1. Construction of partial concordance matrices

The first step is to identify concordance by testing the hypothesis that case *a* outranks (is at least as good as) case *b* through a series of pairwise comparisons that consider only one specific criteria at a time. These comparisons draw on the following equations to fill the cells of the matrix:

$$c_j(aSb) = \begin{cases} 1 & g_j(a) \geq g_j(b) - (q_j(g_j(a)) \\ 0 & g_j(a) < g_j(b) - (p_j(g_j(a)) \\ \dfrac{g_j(a) - g_j(b) + p_j(g_j(a))}{p_j(g_j(a)) - q_j(g_j(a))} & else \end{cases}$$

If the value is one, then case *a* is at least as good as case *b* minus the value of the indifference threshold for *a*. Alternatively stated, 1 is assigned for cases of weak and strong preference. The concordance index equals zero if the value of case *a* is less then the value of case *b* minus the value of the preference threshold for *a*.

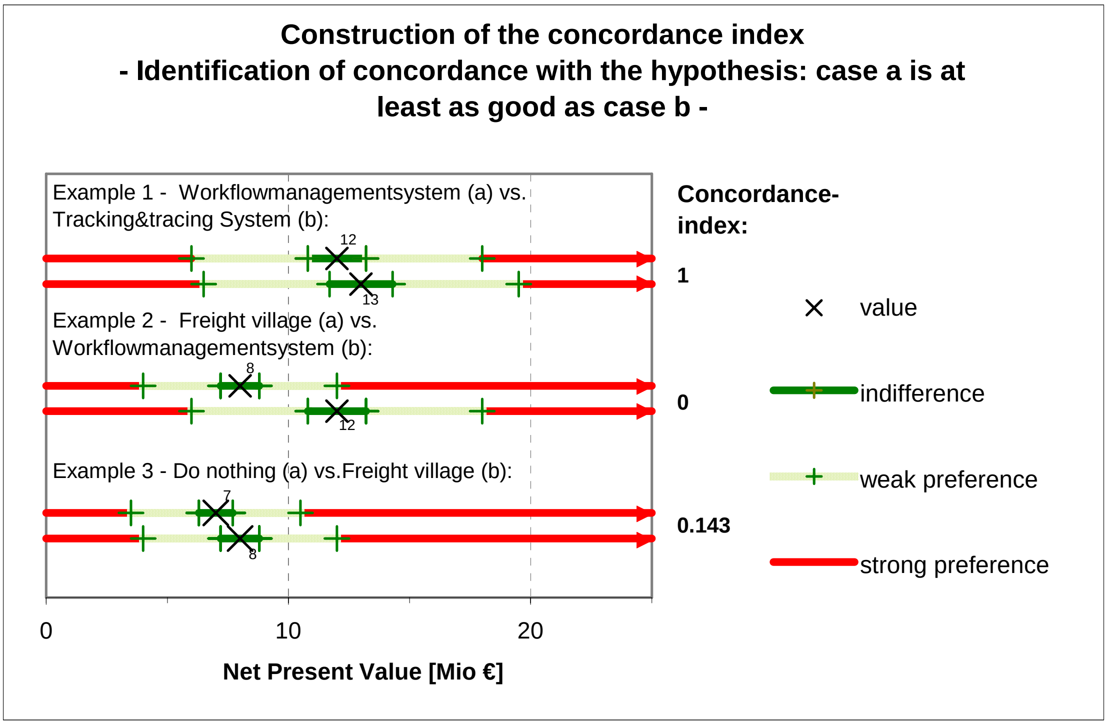
Values between these extreme constellations represent midpoints on the threshold continuum. Table 3 presents the calculation of the partial concordance index with respect to the criteria *net present value,* while Figure 3 presents a graphical representation for selected comparisons . As an example, the calculation of this index for the comparison of the alternatives **Do nothing** vs. **Freight village** is as follows:

$$c_j(aSb) = \frac{7 - 8 + (7 * 0.15)}{(7 * 0.15) - (7 * 0.1)} = 0.143$$

Table 3: Partial concordance index for the criteria *net present value*

	Freight village	**Tracking & tracing system**	**Workflow mgmt.-system**	**Upgrade of railtracks**	**Improve costumer service**	**Mod. of locomotives**	**Mod. of freight cars**	**Do nothing**
Freight village	1	0	0	1	0	1	1	1
Tracking & tracing system	1	1	1	1	1	1	1	1
Workflow-mgmt.-system	1	1	1	1	1	1	1	1
Upgrade of railtracks	0	0	0	1	0	1	0	0
Improve costumer service	1	0	0	1	1	1	1	1
Modernisation of locomotives	0	0	0	1	0	1	0	0
Modernisation of freight cars	0	0	0	1	0	1	1	0
Do nothing	0.143*	0	0	1	0	1	1	1

Figure 3: Construction of the concordance index for selected comparisons



2. Aggregated (total) concordance matrix

The total concordance index takes the weights of the criteria into account and aggregates the arguments for each case (Table 4). It is calculated as the weighted sum of the partial concordance indices according to the following formula:

$$c(a,b) = \sum_{j=1}^{m} w_j c_j(a,b)$$

Table 4: Total concordance index

	Freight village	Tracking & tracing system	Workflow mgmt.-system	Upgrade of railtracks	Improve costumer service	Mod. of locomotives	Mod. of freight cars	Do nothing
Freight village	1	0.6	0.5	0.85	0.65	1	0.95	1
Tracking & tracing system	0.4	1	0.4	0.75	0.65	0.75	0.7	0.75
Workflow-mgmt.-system	0.85	0.95	1	0.85	0.85	1	0.95	1
Upgrade of railtracks	0.15	0.25	0.217	1	0.186	0.9	0.25	0.4
Improve costumer service	0.6	0.35	0.25	0.85	1	1	0.6	0.75
Modernisation	0	0.25	0	0.5	0	1	0.1	0.4

of locomotives								
Modernisation of freight cars	0.15	0.4	0.2	0.75	0.4	0.9	1	0.4
Do nothing	0.45*	0.65	0.4	1	0.65	1	1	1

As an example, the calculation of the total concordance index for comparison of the **Do nothing** vs. **Freight village** alternatives is:

$$c(a,b) = 0{,}143 * 0{,}35 + 1 * 0{,}15 + 1 * 0{,}1 + 1 * 0{,}1 + 1 * 0{,}05 = 0{,}45$$

3. Construction of Partial disconcordance matrices

This step takes the veto condition into account, should veto thresholds be specified. It is a fuzzy measure for the hypothesis that case *a* is unacceptably worse then case *b*.

For all criteria, if the veto condition is fulfilled the value of the partial disconcordance index is 1, if it is not fulfilled its value is 0 (Table 5). The equations to determine these outcomes, as well as for outcomes between these extremes, are as follows:

$$d_j(aSb) = \begin{cases} 1 & g_j(b) > g_j(a) + (v_j(g_j(a)) \\ 0 & g_j(b) \le g_j(a) + (p_j(g_j(a)) \\ \dfrac{g_j(b) - g_j(a) - p_j(g_j(a))}{v_j(g_j(a)) - p_j(g_j(a))} & else \end{cases}$$

Table 5: Partial disconcordance index for the criteria *population exposed to noise reduction*

	Freight village	**Tracking & tracing system**	**Workflow mgmt.-system**	**Upgrade of railtracks**	**Improve costumer service**	**Mod. of locomotives**	**Mod. of freight cars**	**Do nothing**
Freight village	0	0	0.7	0	0	0	0	0
Tracking & tracing system	1	0	1	0	0	0	1	0
Workflow-mgmt.-system	0	0	0	0	0	0	0	0
Upgrade of railtracks	1	1	1	0	1	1	1	0
Improve costumer service	0.167	0	1	0	0	0	0.5	0
Modernisation of locomotives	1	0.5	1	0	1	0	1	0
Modernisation of freight cars	0	0	0.333	0	0	0	0	0
Do nothing	0	0	0	0	0	0	0	0

The calculation of the partial disconcordance index for the **Freight village** vs. **Workflow management system** with respect to the criterion *reduction of population exposed to noise* is as follows:

$$d_j(aSb) = \frac{1100 - 500 - 250}{750 - 250} = 0.7$$

4. Construction of the Credibility index

The credibility index, presented in Table 6, aggregates the total concordance and disconcordance indices (i.e. the hypothesis that case *a* is at least as good as case *b* and the hypothesis that case *a* is unacceptably worse than *b*).

This index is similar to the aggregated concordance index, with the distinction that for each criterion a test of whether the veto condition holds is conducted. If this is the case, it means that that the value of the disconcordance index is greater than zero. An additional test is then required to establish whether the value of the disconcordance index is greater than the aggregated concordance index. If so, then the credibility index is adjusted according to the following formula:

$$p(aSb) = c(aSb) \prod_{\{d_j \in J : d_j(aSb) > c(aSb)\}} \frac{1 - d_j(aSb)}{1 - c(aSb)}$$

Table 6: Credibility matrix

	Freight village	**Tracking & tracing system**	**Workflow mgmt.-system**	**Upgrade of railtracks**	**Improve costumer service**	**Mod. of locomotives**	**Mod. of freight cars**	**Do nothing**
Freight village	1	0.6	0.3	0.85	0.65	1	0	1
Tracking & tracing system	0	1	0	0	0	0	0	0.75
Workflow-mgmt.-system	0.85	0.95	1	0	0.85	1	0	1
Upgrade of railtracks	0	0	0	1	0	0	0	0.4
Improve costumer service	0	0	0	0.85	1	1	0	0.75
Modernisation of locomotives	0	0	0	0	0	1	0	0.4
Modernisation of freight cars	0	0.4	0	0	0	0.9	1	0.4
Do nothing	0.45	0.65	0.4	1	0.65	1	1	1

The calculation of the credibility index for the comparison of **Freight village** vs. **Workflow management system** is as follows:

$$p(aSb) = 0.5 * \left(\frac{1-0.7}{1-0.5} \right) = 0.3$$

5. Distillation

The final step of ELECTRE III produces two rankings of the alternatives from best to worst and worst to best. For each alternative, this involves testing whether the credibility of the statement that *a* is at least as good as *b* is substantially higher than the credibility of the statement that *b* is at least as good as *a*. To establish a 'substantially higher' degree of credibility, the following distillation index from Roy and Bouyssou (1993) is typically employed:

$$\varepsilon = 0.3 - 0.15 * \max(p) \ \textit{for} \ a \neq b$$

In the present example, we see that the maximum value of the credibility index is one, implying that ε equals 0.15. This value can then be used to fill in the cells of the distillation matrix, whereby the number one is entered in cells in which p(aSb) + ε > p(bSa), and a zero is entered otherwise (Table 7). Thereafter, the column and row sums are calculated. The alternative yielding the largest difference between the row and column sums is the best alternative. In other words, in comparison to the other alternatives, this alternative is most often superior and least often inferior. Conversely, the alternative yielding the smallest difference is the worst alternative; that is, it is most often inferior and least often superior.

Two variants of the distillation process are now undertaken. In the first, referred as the top-down distillation, the best alternative is eliminated from the credibility matrix, after which the above step is successively repeated for the remaining alternatives. At each iteration, the best alternative identified from the previous iteration is excluded. Table 8a presents the first top-down distillation matrix. The distillation is completed when each alternative is assigned a rank. Note that it is possible for more than one alternative to be assigned the same rank in the ordering. In implementing the bottom-up distillation, the first matrix of which is present in Table 8b, the above steps are repeated but with successive elimination of the worst alternative.

The final step compares whether the top-down and bottom up orderings of the alternatives are consistent. If this is the case, a clear ordering is established and the process is completed. If inconsistencies are identified, which is not uncommon, two possibilities emerge. If an alternative *a* is at least as good as an alternative *b* in both the top-down and bottom-up orderings, and better than alternative *b* in one of the orderings, then *a* is designated the superior alternative. When two alternatives occupy symmetrically opposite positions in the two orderings, they are concluded to be non-comparable.

Table 7: Matrix for the first distillation

	Freight village	Tracking & tracing system	Workfl.-mgmt.-system	Upgrade of railtracks	Improve costumer service	Mod. of loco-motives	Mod. of freight cars	Do nothing	*Rowsum*
Freight village	0	1	0	1	1	1	0	1	5
Tracking & tracing system	0	0	0	0	0	0	0	0	0
Workflow-mgmt.-system	1	1	0	0	1	1	0	1	5
Upgrade of railtracks	0	0	0	0	0	0	0	0	0
Improve costumer service	0	0	0	1	0	1	0	0	2
Modernisation of locomotives	0	0	0	0	0	0	0	0	0
Modernisation of freight cars	0	1	0	0	0	1	0	0	2
Do nothing	0	0	0	1	0	1	1	0	3
Columnsum	1	3	0	3	2	5	1	2	
Rowsum - columnsum	4	-3	5	-3	0	-5	1	1	4

Result: The best case is case **Workflow management system** with a difference of 5. Consequently, it is the first alternative that is eliminated in the top-down ranking. The worst case is **Modernisation of locomotives** with a difference of -5, which is thereby the first alternative eliminated in the bottom-up ranking

Table 8a: Second distillation matrix for establishing a "top-down" ranking

	Freight village	Tracking & tracing system	Workfl.-mgmt.-system	Upgrade of railtracks	Improve costumer service	Mod. of loco-motives	Mod. of freight cars	Do nothing	*Rowsum*
Freight village	0	1		1	1	1	0	1	5
Tracking & tracing system	0	0		0	0	0	0	0	0
Workflow-mgmt.-system									
Upgrade of railtracks	0	0		0	0	0	0	0	0
Improve costumer service	0	0		1	0	1	0	0	2
Modernisation of locomotives	0	0		0	0	0	0	0	0
Modernisation	0	1		0	0	1	0	0	2

of freight cars									
Do nothing	0	0		1	0	1	1	0	3
Columnsum	0	2		3	1	4	1	1	
Rowsum - columnsum	5	-2		-3	1	-4	1	2	

Result: The best case of the second distillation is case **Freight village** (difference = 5), which would be eliminated in the subsequent iteration.

Table 8b: Second distillation matrix for establishing a “bottom-up” ranking

	Freight village	**Tracking & tracing system**	**Workfl.-mgmt.-system**	**Upgrade of railtracks**	**Improve costumer service**	**Mod. of loco-motives**	**Mod. of freight cars**	**Do nothing**	*Rowsum*
Freight village	0	1	0	1	1		0	1	4
Tracking & tracing system	0	0	0	0	0		0	0	0
Workflow-mgmt.-system	1	1	0	0	1		0	1	4
Upgrade of railtracks	0	0	0	0	0		0	0	0
Improve costumer service	0	0	0	1	0		0	0	1
Modernisation of locomotives									
Modernisation of freight cars	0	1	0	0	0		0	0	1
Do nothing	0	0	0	1	0		1	0	2
Columnsum	1	3	0	3	2		1	2	
Rowsum - columnsum	3	-3	4	-3	-1		0	0	

Result: The worst case of the second distillation are shared by the alternatives **Tracking & tracing system** and **Upgrade of railtracks**, which would both be eliminated in the subsequent iteration.

Repeating this process until a ranking is established for all alternatives results in the top-down and bottom-up orderings presented in Table 9a.

Table 9a: Result of the distillation process

	Freight village	**Tracking & tracing system**	**Workflow mgmt.-system**	**Upgrade of railtracks**	**Improve costumer service**	**Mod. of locomotives**	**Mod. of freight cars**	**Do nothing**
Top Down	2	5	1	5	4	5	4	3
Bottom Up	2	5	1	5	4	6	3	3

Following Pictet, Maystre and Simos [8][8], the above ranking can be redisplayed in the format of Table 9b. An unambiguous ordering is established when only the cells along the diagonal are occupied.

Table 9b: Matrix representation of the distillation process

Ranking position top-down							
6	**5**	**4**	**3**	**2**	**1**		**Ranking position bottom-up**
					Workflow mgmt.-system	**1**	
				Freight village		**2**	
		Mod. of freight cars	Do nothing			**3**	
		Improve costumer service				**4**	
	Tracking & tracing system / Upgrade of railtracks					**5**	
Mod. of locomotives						**6**	

As the final ranking of Table 10 indicates, the application of the ELECTRE III method can result in an ordering in which alternatives share ranks. This occurs when insufficient evidence is found to establish a difference, as is the case here for the alternatives **Tracking & tracing system** and **Upgrade of railtracks**. While the alternatives **Modernisation of freight cars** and **Do nothing** share the same positions in the bottom up ranking, the latter’s superior position in the top-down ranking establishes its higher ranking in Table 10. The same logic applies to the comparison of the alternatives **Improve Customer Service** and **Modernisation of freight cars**.

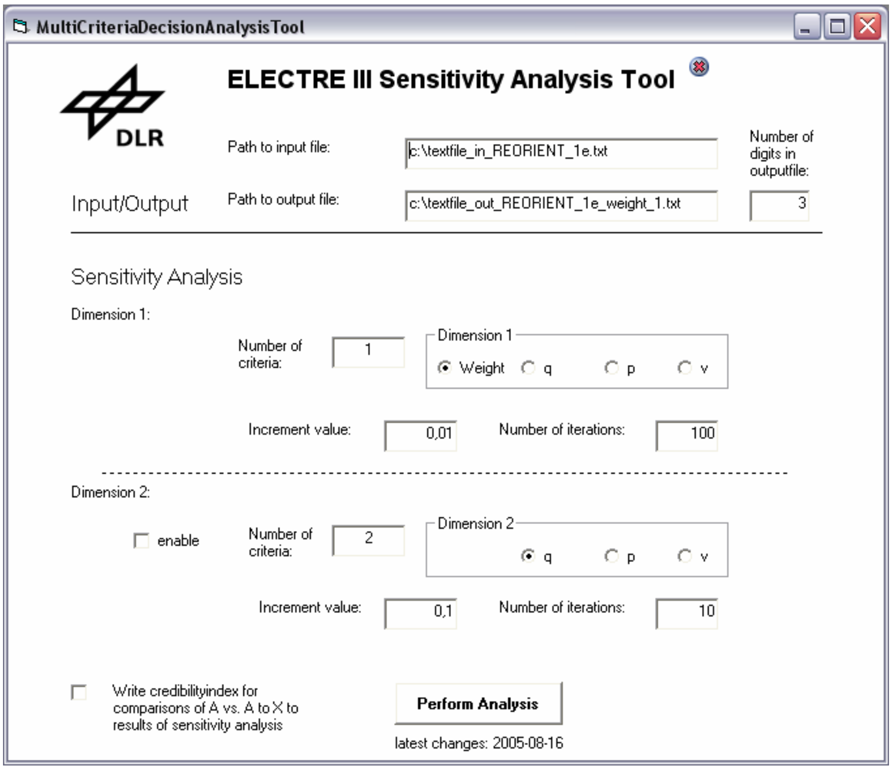
Table 10: Final complete ranking

	Freight village	**Tracking & tracing system**	**Workflow mgmt.-system**	**Upgrade of railtracks**	**Improve costumer service**	**Mod. of locomotives**	**Mod. of freight cars**	**Do nothing**
Rank	2	6	1	6	5	7	4	3

IV. TOOL AND SENSITIVITY ANALYSIS

As the above example illustrates, the implementation of ELECTRE III involves a large number of steps. Performing detailed sensitivity analyses of the results is therefore, practically speaking, not feasible in the absence of an automated algorithm. To address this difficulty, we have written a program in VisualBasic capable of repeating the analysis iteratively with gradually varying parameters. The program uses ASCII-files as inputs and outputs. Limited only by the performance of the computer, it can in principle evaluate an unlimited number of criteria and alternatives and is therefore more flexible then spreadsheet-based solutions. The program is executable within the Microsoft Windows operation system.

Figure 4: Menu of the program



The input file contains the names of the alternatives and the criteria, their initial weights, their indifference, significance and veto thresholds, and finally a table with the attribute values of all alternatives.

After executing the ELECTRE III procedure according to the base settings in the input file, which in this example is obtained from Tables 1 and 2, the program proceeds with the sensitivity analysis by incrementally varying one or two user-specified parameters (e.g. as in Table 2).[1] The menu accordingly features controls for selecting the parameters, increment values, and number of iterations (which in turn determines the range of values covered in the sensitivity analysis) (Figure 4).

[1] Although the program could be easily coded to enable the simultaneous variation of more than two parameters, this added complexity tends to prohibit gleaning useful insights from the output of the sensitivity analysis.

If variation over an indifference or a significance threshold is selected for the sensitivity analysis, a consistency check confirms that the following logical condition holds: indifference threshold < significance threshold < veto threshold (q < p <v).

The output file contains all intermediate results as well as the final ranking. Moreover, the rankings from every run of the sensitivity analysis are recorded in a table.

If the integrated features are not sufficient for a further specific task, the source code as well as the menu can be easily customized within the VisualBasic-programming environment. For example, in addition to varying the parameters, it is also possible to vary the attribute values of the alternatives or the value epsilon in the distillation index to study the resulting ranking behaviour.

As an illustration of a possible sensitivity analysis, we vary the single parameter measuring the criteria weight. With every iteration, the weight of one of the criteria is increased by 1%, while weights for the remaining criteria are decreased so as to maintain their initial proportional weight relations. This procedure is implemented using the following three criteria over the indicated ranges: *net present value* (35% to 55%), *number of new jobs* (25% to 50%) and *border waiting time* (15% to 30%).

Figure 5 shows the distribution of the ranking positions along the Y-axis for both distillation approaches as a function of changes of the criteria weights (X –axis). As is evident, only considerable variation of the weights (in this particular example above 38 %) leads to changes in ranking positions. The smaller the criteria weights, the less likely are changes.

The result of the evaluation can be considered robust for the best and worst ranked alternatives over a broad range of criteria weights. In all runs of the sensitivity analysis, the alternative **Workflow management** occupies the best rank and the alternative **Freight village** holds the second best ranking position. The alternative **Modernisation of locomotives** occupies the worst ranking position for all variations.

Changes in positions occur, however, for some of the intermediate rankings. The alternative **Modernisation of freight cars** changes its ranking position from 3 to 1 (bottom-up distillation) or – in notable contrast – from 4 to 5 (top-down distillation) with variation of the criterion *net present values* above 39 %.

The **Do nothing** scenario occupies position 3 unless the weight for the criteria *net present values* is above 39 %, in which case the alternative occupies position 4.

Upgrade of railtracks occupies the fifth position or lower in all of the sensitivity runs.

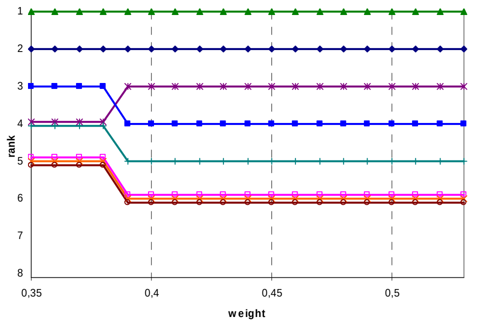
Improved customer service moves into position 3 when the criteria weight for *net present value* exceeds 38 %, but otherwise occupies position 4.

The alternative **Tracking & tracing system** occupies position 5 over a broad range of values but falls to position 6 when the criteria weight for the *number of new jobs* increases above 42%.

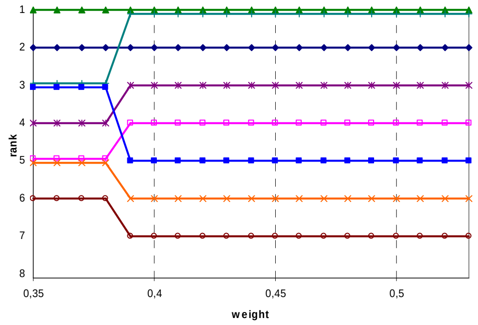
Figure 5: Results of the sensitivity analysis

1. Varying criteria weight for *net present value* (35 … 55 %)

top- down distillation

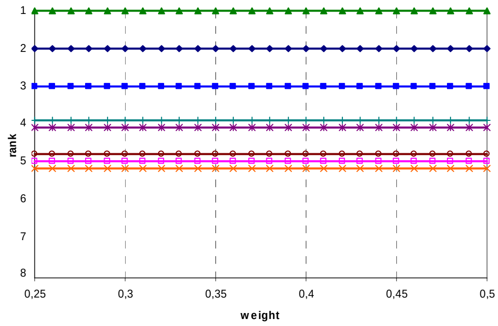


bottom- up distillation

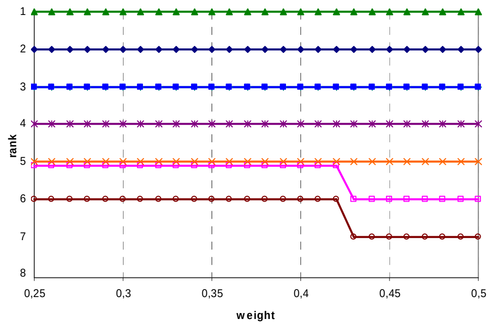


2. Varying criteria weight for *number of new jobs* (25 … 50 %)

top- down distillation

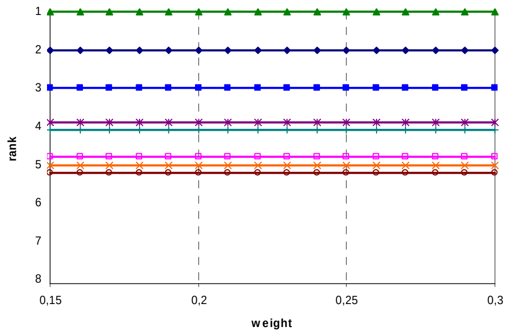


bottom- up distillation

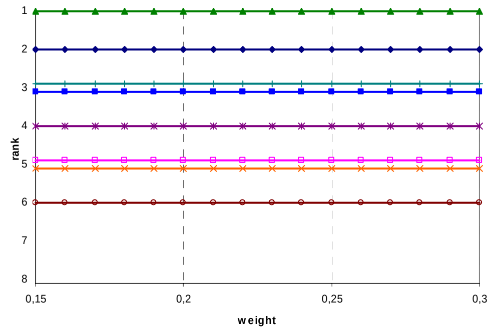


3. Varying criteria weight for *border waiting time reduction* (15 … 30 %)

top- down distillation



bottom- up distillation



Legend:

- Freight Village
- Tracking & tracing System
- Workflow management-system
- Upgrade of railtracks
- Improve costumer service
- Modernisation of locomotives
- Modernisation of freight cars
- Do nothing

V. CONCLUSIONS

The results of the application of ELECTRE III and sensitivity analysis show promise for using the method to select the best alternatives for overcoming existing barriers in rail freight transport. The stand alone software developed to implement the procedure and test sensitivity can be considered as a useful solution to deal with the otherwise tedious series of steps involved in ELECTRE III. Moreover, the sensitivity analysis has proven to be an appropriate means to arrive at a ranking of alternatives under imprecise inputs.

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