DECISION SUPPORT SYSTEM APPLIED TO COMBINED FREIGHT TRANSPORT

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ABSTRACT
The reasons for choosing a certain way of transporting goods are dependent on numerous factors. Shippers are interested in reliable logistics and low cost, while authorities are in general more concerned with minimizing the environmental impacts, while accident-free transport is in the interest of all parties involved. This paper aims at elaborating an integrated decision aiding tool regarding the selection of combined transport alternatives according to actual road freight transport situations. Based upon a wide range of criteria covering partly the European transport policies, the integrated tool is made up of two aggregation steps. Firstly, aggregation methods integrate the economic, environmental, safety and logistics related performances of transport scenarios into four global scores. Secondly, an outranking method integrates the global performances into a sustainable transport performance index, expressing the overall performance of transport chains regarding the covered European objectives. Finally, the sensitivity of these indexes is tested.

Keywords: Integrated assessment framework, decision support system, combined transport.

1. INTRODUCTION
Across Europe, specific transport chains are researched for which shippers have shown interest in moving their cargo from road to water. It is the task of the research as discussed in this paper to provide an integrated assessment model in order to evaluate the performances of these new transport chains compared to the old ones. Based upon the European transport policies by the year 2010, numerous performance indicators have been elaborated in the fields of logistics, economics, environment and safety. This assessment will result in a final sustainable performance index, aggregating the analyzed impacts and integrating them into a final score.

The performance fields are more or less important according to the actors questioned about the pursued objectives. For commercial parties, the best transport alternative will be the cheapest one that can properly accommodate his logistics related requirements, while for local authorities the safest and least polluting scenario will be the best solution.

Then, the solution will be a compromise between pursued objectives regarding the cost, the logistics, the environment and the safety.

The question that remains to be answered is how well a transport chain that meets these general objectives performs globally. This is the topic of this paper.

The next section proposes a brief overview of the literature review.

Section 3 presents the elaborated integrated decision support tool. The pyramidal structure is presented while the performance indicators and the specific aggregation methods are detailed.

In section 4, the authors review the application of the developed model in a practical case study revolving around the transport of cars, vans as well as trailers from North-Western Europe to Sofia in Bulgaria.

Finally, section 5 presents major conclusions regarding the developed model and its application as well as perspectives of further developments.

2. LITERATURE REVIEW
In the creation of the methodology described in the paper, as well as for the case study that is discussed, a number of publications proved of invaluable use.

For the creation of the integrated assessment framework, the major literature sources are (Roy and Bouyssou 1993) in which the authors detail a wide range of multicriteria decision aiding methods; and (Roy 1985) where the author details the concept of decision process and proposes an overview of multicriteria decision aiding methods as well as some application cases. Moreover, the Directorate-General for Transport presented an inventory of the state of the art for the cost-benefit and multicriteria methods for projects in inland waterways.

After studying these documents, the authors selected the outranking PROMETHEE (“Preference Organisation Method for Enrichment and Evaluation”) method because of both efficiency and understanding easiness advantages by the non-mathematical experts.

The analysis of multicriteria decision aiding method applications, highlighted in (Azibi and Vanderpooten 1997, Cescotto, Roubens, Rigo, Gao, Wang, Zhang, Lourenco, Zhou, Xiang and Ferreira 2006, Colson and Mbangala 1998, Rigo, Ndiaye, Dreyer, Zomer, Pinon and Tremeac 2007, Schweigert 1995), helped for elaborating the integrated assessment tool.

In (Brans and Mareshal 2005), the PROMETHEE method is described in detail.

In (Colson 2004, De Bruyn 2002, Ndiaye, Glansdorp, Prunieras and Willems 1993 and Roubens 1991), the authors of this paper found useful information to fine tune the integrated tool.

Moreover, in (Tyworth and Zeng 1998), interesting quantifications of logistics related aspects were found. However, due to a weak availability of data regarding the presented case study these developments were not incorporated in the integrated decision aiding tool.

Since the authors try to reach the objectives pursued by the European Commission; it is interesting to glance through numerous directives from the European Parliament and the Council or other European reports highlighting the need for internalizing external transport effects.

All in all, this review led to the elaboration of the integrated assessment tool presented in the next section.

3. METHODOLOGY

3.1. Introduction

The integrated support system developed within this paper aims at evaluating and aggregating a wide range of internal and external transport impacts in the fields of logistics, economy, environment and safety. The pursued objective is to elaborate a decision helping tool able to compare numerous transport alternatives on the basis of a pyramidal assessment structure.

3.2. The pyramidal scheme

The proposed framework is based on three major steps. Firstly, regarding the four performance domains, lists of pertinent criteria are elaborated. So, the impacts of the transport scenarios can be evaluated on the basis of these evaluation axes. Secondly, the information contained in each field is aggregated into an intermediate global score by using three different aggregation methods. Regarding the economic performances, since various independent costs are used, a sum is relevant to calculate the global cost; the logistics related impacts are aggregated on the basis of an average of normalized values while the safety and environmental impacts are integrated by using the PROMETHEE method.

The second aggregation step aims at evaluating the overall performance of transport alternatives. The PROMETHEE method is used to integrate the four intermediate scores related to the logistics, the environment, the economics and the safety into a final index.

Finally, since the second aggregation is based on specific weights allotted to the macro criteria by the decision makers, a sensitivity analysis is realized to test the robustness of the ranking.

The next section is dedicated to the presentation of the PROMETHEE methodology.

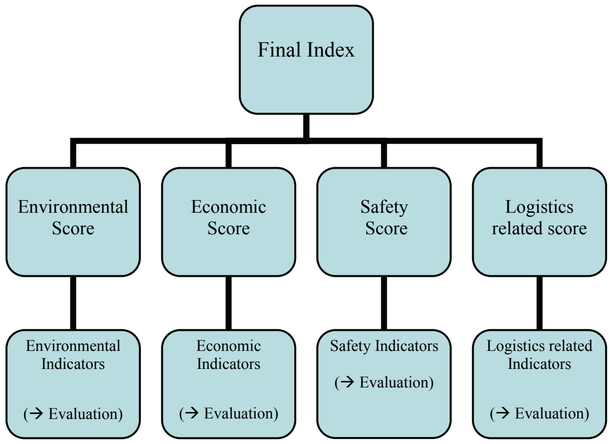

Figure 1: The pyramidal aggregation structure

3.3. The PROMETHEE II complete ranking

Since the PROMETHEE method is used for the aggregation of the environmental and safety impacts as well as for the aggregation of the intermediate scores, the following modeling is recalled.

First, let us consider a set of criteria, $\{g_1(.), g_2(.), g_3(.), ..., g_m(.)\}$ and a set of scenarios to compare $A = \{a_1, a_2, a_3, ..., a_n\}$. Let us define $g_j(a_i)$ the evaluation of scenario a_i on the axis j.

Let us consider the deviation of impacts of two actions on a criterion:

$$d_j(a,b) = g_j(a) - g_j(b); \quad \forall\, a,b \in A \tag{1}$$

In order to delete the possible scale effects related to the units of criteria, let us define the following function in the case of a criterion j to maximize,

$$0 < F_j[d_j(a,b)] \leq 1; \quad \forall\, a,b \in A \tag{2}$$

Where:

$$F_j[d_j(a,b)] > 0 \Rightarrow \; F_j[d_j(b,a)] = 0; \quad \forall\, a,b \in A \tag{3}$$

If the criterion j has to be minimized, the following relation is considered,

$$0 < F_j[-d_j(a,b)] \leq 1; \quad \forall\, a,b \in A \tag{4}$$

The pair $\{g_j(.); F_j[d_j(a,b)]\}$ is named the generalized criterion associated to the criterion g_j or the preference function related to the criterion g_j.

Various preference functions are available and can be varied to an infinite number of solutions corresponding to the needs of the users. Two examples are described here after:

The usual generalized criterion is defined as follows:

$$F_j[d_j(a,b)] = \begin{cases} 0 & if \quad d_j(a,b) \le 0 \\ 1 & if \quad d_j(a,b) > 0 \end{cases} \quad ; \ \forall a,b \in A \tag{5}$$

The U-shape generalized criterion can be defined as follows:

$$F_j[d_j(a,b)] = \begin{cases} 0 & if \quad d_j(a,b) \le q \\ 1 & if \quad d_j(a,b) > q \end{cases} \quad ; \ \forall a,b \in A \tag{6}$$

Where q is the preference threshold.
On the basis of these generalized criteria, let us calculate the aggregated preference indices as follow:

$$\begin{cases} \pi(a,b) = \sum_{j=1}^{m} F_j[d_j(a,b)] \times \omega_j \\ \pi(b,a) = \sum_{j=1}^{m} F_j[d_j(b,a)] \times \omega_j \end{cases} \quad ; \ \forall a,b \in A \tag{7}$$

Where w_j is the weight allotted to the criterion j. Then, the positive and negative outranking flows are calculated as follows:

$$\phi^+(a) = \frac{1}{n-1} \sum_{x \in A} \pi(a,x) \tag{8}$$

$$\phi^-(a) = \frac{1}{n-1} \sum_{x \in A} \pi(x,a) \tag{9}$$

The PROMETHEE II complete ranking is based on the following outranking net flow:

$$\phi(a) = \phi^+(a) - \phi^-(a) \tag{10}$$

3.4. The criteria and the aggregation methods

3.4.1. The environmental criteria

Regarding the environmental transport impacts, the authors focus on the air pollution. In order to evaluate the effect of transport scenarios on the air pollution, the authors base the approach on the major air pollutants. One of the most important greenhouse gases is CO_2. Another carbon oxide is particularly dangerous: the CO. The emissions of NOx are also considered as well as the Sulphur Oxides SOx. Finally, the particle matters are included in the environmental criteria. All these indicators are expressed in grams per cargo unit.

The environmental indicators are aggregated by using the PROMETHEE method. Therefore, weights have to be allotted to the criteria. Since the societal costs of major air pollutants are well-known, the authors use these values to weight the environmental indicators. Regarding the CO_2 indicator, the related societal cost is about €50,- per ton while the societal costs of the CO, NOx, Sox and PM are respectively about, €100,-/ton, €5000,-/ton, €3000,-/ton and €50000,-/ ton. These figures were found in (NEA, 1999). Actually, these costs are based on averages related to urban and non urban area.

Regarding the preference function, the authors propose to use the usual generalized criterion to conserve all the information.

The actual environmental evaluation of transport alternatives is not detailed in this paper since the authors want to focus on the integrated assessment tool.

As stated before, the global environmental performance is obtained on the basis of the PROMETHEE method, as follows:

$$\begin{array}{l} d_{CO2}(a,b) \ , \ \omega_{CO2} \ , \ F_{CO2}(a,b) \ ; \ \forall a,b \in A \\ d_{CO}(a,b) \ , \ \omega_{CO} \ , \ F_{CO} \ ; \ \forall a,b \in A \\ d_{NOx}(a,b) \ , \ \omega_{NOx} \ , \ F_{NOx} \ ; \ \forall a,b \in A \\ d_{SOx}(a,b) \ , \ \omega_{SOx} \ , \ F_{SOx} \ ; \ \forall a,b \in A \\ d_{PM}(a,b) \ , \ \omega_{PM} \ , \ F_{PM} \ ; \ \forall a,b \in A \end{array} \tag{11}$$

So that we can obtain $\phi_{Env}(a)$; $\forall a \in A$; the environmental performance of alternative a.

3.4.2. The economic criteria

The economic indicators are the cost of the actual transport legs. Since the authors consider combined transport chains, the possible additional cost of transhipment and intermediate storage are considered. For transhipment and non-waterborne transport, commercial cost as provided by contacted market parties are used, while for waterborne transport a detailed cost breakdown, including but not limited to depreciation interest, fuel cost, crew cost, maintenance and repair and overhead is created in order to be able to establish the interrelation between economic and environmental/safety performance of various devices added to the ship. All these details are not included in this paper and can be found in (Hekkenberg, 2006).

For the calculation of economic performances, we just have to sum the three no-redundant costs.

3.4.3. The safety criteria

Determination of proper safety indicators proved a challenge. Two principally different types of safety can be distinguished external safety and internal safety. External safety is highly dependent on the specifics of the transport route and the population centres surrounding it, which is data that was too time-consuming to process in great detail within this paper. Apart from this, external safety performance of inland waterway transport is generally accepted to be vastly superior to road transport. As a result, only internal safety was elected as a measure of safety.

The Dutch AVV (Adviesdienst Verkeer en Vervoer, Ministry of Transport) accident database reveals that on Dutch inland waterways, over 13 years, 12 fatalities occurred as a result of accidents with inland ships while 5909 accidents happened. Based on data coming from DG TREN, on average over the last 15 years, an annual transport performance of 37 billion TKM is achieved by inland waterway transport in the Netherlands. Then, the above mentioned figures lead to the following probabilities that the authors propose to use for the safety evaluation in the case study:

- Fatalities per TKM: $2.5*10^{-11}$
- Accidents per TKM: $1.23*10^{-8}$

Regarding the road safety aspects, the next table is elaborated in order to find equivalent probabilities.

Table 1: Safety figures for heavy goods vehicles per country

Country	Number of accidents	Fatalities in HGV	Freight transport (10^6 TKM)
Belgium	47619	28	20390
France	105470	132	169740
Austria	43175	12	12660
The Netherlands	33538	11	30260
Finland	6196	5	28070
Portugal	42114	18	14920
Sweden	16947	13	31840
United Kingdom	228534	63	150920
Ireland	6625	3	10730
Italy	237812	249	151970
Luxembourg	769	3	580
Denmark	7121	5	11060
Greece	16809	23	20000
Germany	362054	-	-
Spain	98433	172	129510

Based on the precedent table, since detailed safety data don't exist for some of the countries involved in the case study, the authors calculate a global EU average.

Table 2: Accident and death probabilities for heavy goods vehicles

	Road (2004)	
COUNTRY	Accidents / 10^6 TKM	Deaths / 10^6 TKM
Belgium	2,34	0,00137
France	0,62	0,00078
Austria	3,41	0,00095
The Netherlands	1,11	0,00036
Finland	0,22	0,00018
Portugal	2,82	0,00121
Sweden	0,53	0,00041
United Kingdom	1,51	0,00042
Ireland	0,62	0,00028
Italy	1,56	0,00164
Luxembourg	1,33	0,00517
Denmark	0,64	0,00045
Greece	0,84	0,00115
Spain	0,76	0,00133
Average	1,307857143	0,001121429
Per TKM	1,30786E-06	1,12143E-09

The safety performances are aggregated into a global safety score on the basis of the PROMETHEE method:

$$d_{Damage}(a,b)\ ,\ \omega_{Damage}\ ,\ F_{Damage}\ ;\ \forall a,b \in A$$
$$d_{Death}(a,b)\ ,\ \omega_{Death}\ ,\ F_{Death}\ ;\ \forall a,b \in A \qquad (12)$$

On the basis of these factors, we can calculate the following outranking net flows representing the safety performance of the studied scenarios: $\phi_{Saf}(a)\ ;\ \forall a \in A$.

3.4.4. The logistics related criteria

Perhaps the largest challenge in the provision of indicators was for those indicators related to logistics. This had two reasons: First, the market parties involved were unable to put a price tag or other numerical value on the more obvious indicators such as time and speed, nor were they able to provide sufficient background information to allow any quantitative assessment. Second, since the study case was set up in cooperation with these market parties, it was known beforehand that all transport scenarios scored a sufficient mark for logistics related performance.

As a result, the choice was made to set up an own qualitative assessment framework. The ordinal scales are given for each logistics related criterion by a group of experts, in close cooperation with the authors and the persons in charge of the logistics within the CREATING Project. Since the authors use the PROMETHEE method to calculate the final index, combinations of quantitative and qualitative approaches are allowed thanks to the preference functions. However, the authors want to recall that the proposed ordinal scales can be different according to others points of view so that the established results can be debatable and require to take precautions before actual implementation. Finally, it is useful to specify that the results are not really modified when considering that logistics related assessment.

In this, six indicators are defined. These are as follows:

- Logistics related character of the freight,
- Number of border crossings,
- Geographical conditions and traffic density,
- Volume of the transported cargo,
- Number of transshipment and cargo vulnerability,
- Flexibility.

All the following ordinal scales are defined to maximize the criteria.

The logistics related character of the freight means the double consideration of the type of cargo and the “single or long term” specificities of transport scenarios. The type of cargo deals with the possible specific transport conditions required by certain types of goods. Dangerous, cold, heavy, extremely large, fragile goods may require special care, specific rules and regulations making the transport activities more complex from a logistics point of view. A single freight means that the transport task is realized one time occasionally so that no specific interactions exist because the transport task is unique. In the other hand, long term freight means that transport activities are continuously done along a same route. In this case, some problems affecting one transport task can impact on the global continuous service leading to more complex logistics management.

The following table presents the associated qualitative value which will be normalized during the aggregation.

Table 3: The logistics related character of the freight

	Normal Cargo	Special cargo
Single freight	3	2
Long term freight	2	1

At the custom borders, the vehicles must stop and wait for custom control, which sometimes can cause considerable time wasting decreasing the time liability level of the transport service. Crossing a custom border definitely increases the logistics constraints. Table 4 has been elaborated according to the presented case study involving three border crossings at maximum.

Table 4: Border crossings

	Number of border crossings			
Absolute	0	1	2	3
Quantitative value	6	3	2	1

The geographical conditions state for the climatic and topographic characteristics of transport routes. Indeed, seasonal effects such as ice, small water depth can influence the difficulty to fulfill the transport activities and are so of key importance for the evaluation of the logistics related performances. The traffic density of the transport route has great impact on the real transportation time, in other words, on the liability of the transportation. The high traffic density on the transport networks increases the transportation time, the risk of traffic accidents and operational costs, etc. To avoid all of these effects is impossible, but being prepared to solve them is compulsory for the forwarding companies. Therefore the lower road density of the transport route performs better from a logistics point of view. If inland waterway navigation is involved into the transport chain, the nautical parameters of the shipping route have similar influence onto the transport efficiency, like the traffic density in case of road transport. Putting all these parameters together, the complex subjective evaluation of the given transport task and the proposed solution can be determined as per the following table:

Table 5: Geographical conditions and traffic density

Climatic and geographical conditions	Traffic density	
	Low	High
Easy	4	3
Difficult	3	1

In order to apply correctly this table according to the specificities of the transport route observed in the case study, further analysis has to be done.

In order to quantify the number of kilometers of a transport route with a low traffic density level, we propose to associate it with the “motorways” and “high quality IWW”. Indeed, on such sections, we can expect a quite good traffic flow due to the satisfactory circulation conditions. The same reasoning is used for the sections with a high traffic density level. High traffic density networks could be associated to “main roads” and “low quality IWW”.

Then we can evaluate the performance of transport chains regarding this indicator.

First let us define the following variables:

- Distance on motorway (km) : Mo
- Distance on Main road (km): Mr
- Distance on road (km): R = Mo + Mr
- Share of Main road from total road (%): SMr = 100*(Mr/R)
- Distance on high quality IWW (km): Hq
- Distance on low quality IWW (km): Lq
- Distance on IWW (km): I=Hq+Lq
- Share of low quality IWW from total IWW (%): SLq = 100*(Lq/I)
- Share of IWW from total (%): SI = 100*(I/[I+R])

Let us define x_l and x_h the evaluations related to table 5: low traffic density and high traffic density. The impact of a scenario on this criterion can be calculated as follows:

$$\left. \begin{array}{l} [(x_h * (100 - SMr) * (100 - SI)/10000) \\ + (x_h * (100 - SLq) * SI/10000)] \\ + \\ [(x_l * SMr * (100 - SI)/10000) \\ + (x_l * (100 - SLq) * SI/10000)] \end{array} \right/ 4 = LOG_{GC}(a) \qquad (13)$$

Where $LOG_{GC}(a)$ represents the normalized impact of a scenario *a* on this indicator.

The volume of the transported cargo volume is important for the logistics, however it can not be independent from the transportation method itself, since each transport mode "thinks" in different optimal cargo volume.

Table 6: Scale for the cargo volume

Transport mode	The volume of the transported cargo		
	< 100 tons	100 – 1000 tons	> 1000 tons
Road	3*3=9	2*2=4	1*1=1
Inland Waterway	1*3=3	2*2=4	3*1=3

In table 6 the first multiplier of the product considers the transportation mode, while the second one considers the volume of transported cargo. A factor 1 is given to amounts of cargo larger than 1000 tons because, in the absolute, we think it is more difficult to transport 1000 tons than 100 tons of cargo. However, it is interesting to associate another parameter reflecting how the transport modes "think" about these specific amounts of cargo. For example, it is very complex for the road to transport 1000 tons of cargo, so we associate a factor one.

In case of intermodal transport, the "value" of this indicator can be determined as the average of the different transport modes based on their relative lengths inside the total transport route as presented in the following calculations.

Let us define V_r and V_{IWW}, the evaluation of the volume of the transported cargo for the road and the IWW.

Then, we can calculate the impact of the transport chains on this indicator as follows:

$$\frac{(V_R * (100 - SI)) + (V_{IWW} * SI)}{100} \Big/ 9 = LOG_{VC}(a) \qquad (14)$$

Where $LOG_{VC}(a)$ is the normalized impact of a transport scenario *a* on the transported cargo volume.

The number of transshipment needed in the transport process is an important indicator characterizing the difficulty of the given transport task. Less cargo transshipments mean not only less difficulty but also a smaller risk of cargo damage as well. This ensures higher transport liability level. But the number of transshipments is still not enough to evaluate the difficulty of the entire transport process. We must consider other factors, like the type of the cargo (general, bulk – dry, liquid, dangerous goods) leading to considerations of environmental risks during transshipment, needs for transitional cargo collection or storage, cargo handling specialties, etc. Then, the authors propose the following evaluation table:

Table 7: The number of transshipment

Trans-shipments	Transitional storage and collection							
	No				Yes			
	B	G	C	S	B	G	C	S
0	13	13	13	12	12	11	11	10
1	11	11	11	10	10	9	9	7
2	10	10	10	9	7	5	5	1

B states for bulk, G for general cargo, C for container and S for special type of cargo like RORO, dangerous goods, etc.

From a logistics point of view the flexibility means, that how can a given transport solution react and adjust its output to the rapidly changing demands of the market conditions concerning the delivery time and the cargo volume. Since the economic situations and business conditions are not static in time, this indicator is very important to measure the long term market sensitivity of a given transport solution.

Table 8: The flexibility

Changes in demands		Flexibility			
Cargo volume	Delivery time	easy	fair	difficult	extremely difficult
		4	3	2	1
Growing	steady				
Growing	decreasing				
Steady	decreasing				
Decreasing	steady				
Decreasing	decreasing				

The given transport solution should be analysed and must receive a ranking number. The flexibility of the given transport solution can be considered as the average of the obtained scores.

The aggregation of the logistics related indicators is based on an average of the normalized values as follows:

Let us define:

$$\begin{aligned} &Log_{CF}(a); \forall a \in A \\ &Log_{BC}(a); \forall a \in A \\ &Log_{GC}(a); \forall a \in A \\ &Log_{VC}(a); \forall a \in A \\ &Log_{NT}(a); \forall a \in A \\ &Log_{FL}(a); \forall a \in A \end{aligned} \qquad (15)$$

Where *CF* states for the logistics related character of the freight, *BC* the number of border crossing, *GC* the geographical conditions, *VC* the volume of the transported cargo, *NT* the number of transshipment and *FL* the flexibility. So, the average of these evaluations gives the global performance regarding the logistics as follows:

$$LOG\ (a) = \frac{\begin{array}{l} Log_{CF}(a) + \\ Log_{BC}(a) + \\ Log_{GC}(a) + \\ Log_{VC}(a) + \\ Log_{NT}(a) + \\ Log_{FL}(a) \end{array}}{6}\ ;\ \forall a \in A \quad (16)$$

3.4.5. Towards the final index

According to the precedent, the PROMETHEE method is used in order to aggregate the four obtained scores into a final global index. Since the macro criteria contain independent information, the authors don't confront redundancy problems. Indeed, the definition of the indicators is done in order to avoid double counting during the calculations.

This aggregation is based on specific allotted weights. So, it is necessary to perform a sensitivity analysis by moving weights while simultaneously analyzing the possible impacts on the indexes. This is the robustness analysis performed in the case study.

4. STUDY CASE

4.1.1. Transport alternatives

The case study revolves around the transport of trailers with goods and/or new cars and vans between Frankfurt am Main in Germany and Sofia in Bulgaria. This transport is currently realized by means of trucks along the road network from North-Western to South-Eastern Europe. The goal is to study the possibility to shift that freight from road to inland ships.

When looking at the geographical and topographical characteristics, it seems that a pertinent intermodal route can be considered: a pre-haulage from Frankfurt am Main to Passau, an unaccompanied "point-to-point" inland navigation using RORO vessels from Passau to Vidin and an end-haulage from Vidin to Sofia. The distance over the pre- and end-haulage is approximately equal to 661 km, the distance over the waterborne section is equal to 1436 km.

Based upon this route, numerous alternatives are considered reviewing various types of ships and onboard technologies.

The first transport scenario is the present situation highlighting the road transport (Ref. Case: Road). The goods are transported by EURO III trucks from Frankfurt to Sofia.

When considering intermodal alternatives, concerning the pre and end-haulage, the same trucks are used while, for the waterborne section, different ships are considered.

The first intermodal alternative proposes to use a small RORO vessel, carrying 29 cargo units with a CCNR II approved engine, sailing at a speed of 16km/h (Ref. Case: SRRV_16).

The reduction of the speed should reduce the emissions by decreasing the fuel consumption. So, the Case 3 proposes to consider the same ship but slowing down to 14km/h (Ref. Case: SRRV_14).

As explained before and without entering in the details, other ships are designed by Project partners: a large RORO and a very large RORO vessel. So, Case 4 proposes to use a large RORO vessel, carrying 63 cargo units and sailing at a speed of 16km/h, equipped with a CCNR II approved engine (Ref. Case: LRRV_16_63).

As Case 3, Case 5 considers Case 4 with a speed reduced to 14km/h (Ref. Case: LRRV_14_63).

In the case of a large RORO vessel, it is proposed to consider the improvement of the hullform which results in a reduction by 5% of the resistance, saving fuel consumption. It is Case 6 considering a speed of 14km/h (Ref. Case: LRRV_14_63_5). This speed is conserved for all the following cases because of the significant fuel consumption reduction.

Case 7 consists in the use of a very large RORO vessel carrying 73 cargo units (Ref. Case: VLRRV_14).

Case 8 reviews Case 6 by increasing the loading capacity to 89 cargo units in optimal conditions (Ref. Case: LRRV_14_89).

Case 7 is reviewed in Case 9 by improving the loading conditions to obtain an optimal loading capacity of 104 cargo units (Ref. Case: VLRRV_14_104).

Case 10 reviews Case 5 by adding an SCR catalyst, a PM-filter and the use of a low sulphur fuel (Ref. Case: LRRV14SP).

4.1.2. Application of the decision support system tool

Firstly, regarding the environmental aspects, the evaluation has been performed in a parallel model (Hekkenberg, 2006), taking into account all the architectural and hydrodynamic properties of the ships. The following table comes from the decision support tool and presents the results of the calculations in gram per cargo unit. In this case, the authors consider the semi-trailer.

Evaluation

	CO2	CO	NOx	SOx	PM
Road	1480239.6	1435.65	10134.0	0.0	168.9
SRRV_16	2151860.969	7641.341379	17668.24138	1708.212759	522.8413793
SRRV_14	1643441.809	5352.49532	13238.21675	1155.936355	375.1738916
LRRV_16_63	1446644.408	4466.535484	11523.45577	942.1628199	318.0151925
LRRV_14_63	1182246.975	3276.247883	9219.673322	654.9579409	241.2224441
LRRV_14_63_5	1154540.975	3151.518579	8978.261765	624.8619667	233.1753922
VLRRV_14	1125448.786	3020.548806	8724.771883	593.260228	224.7257294
LRRV_14_89	1010128.56	2501.390075	7719.948532	467.9922503	191.2316177
VLRRV_14_104	966759.6712	2306.1482	7342.061033	420.8822754	178.6353678
LRRV14SP	1138165.451	3276.247883	5668.910613	32.46485328	129.2795284

Figure 2: Environmental evaluation table

When running the model, we obtain the following ranking classifying the transport scenarios according to their environmental performances and the allotted weights.

Ranking

N°	Scenario	Final score
1	[LRRV14SP]	0.9858603229196523
2	[Road]	0.6929397152956912
3	[VLRRV_14_104]	0.5754275341549633
4	[LRRV_14_89]	0.35320531193274096
5	[VLRRV_14]	0.1309830897105188
6	[LRRV_14_63_5]	-0.09143020922900552
7	[LRRV_14_63]	-0.3138435081685297
8	[LRRV_16_63]	-0.5553644788382535
9	[SRRV_14]	-0.7777777777777777
10	[SRRV_16]	-1.0

Figure 3: The environmental ranking

Secondly, regarding the logistics, the following properties are used to perform the calculations according to the criteria explained before.

Logistic indicators properties

Scenario1 (Road) — copy to ->

Distance on motorway:	1401.0
Distance on main road:	288.0
Total distance on road:	1689.0
Share of main road:	17.05
Distance on high quality IWW:	0.0
Distance on low quality IWW:	0.0
Distance on IWW:	0.0
Share of low quality IWW from total IWW:	0.0
share of IWW from total:	0.0

OK Cancel

Figure 4: Properties of the road scenario

Logistic indicators properties

Scenario2 (SRRV_16) — copy to ->

Distance on motorway:	429.0
Distance on main road:	232.0
Total distance on road:	661.0
Share of main road:	35.1
Distance on high quality IWW:	715.0
Distance on low quality IWW:	721.0
Distance on IWW:	1436.0
Share of low quality IWW from total IWW:	50.21
share of IWW from total:	68.48

OK Cancel

Figure 5: Properties of the intermodal route

When using the model, the following evaluation table is obtained and summarizes the logistics related impacts. Just to recall, the figures are normalized so that the most the values is close to one the best the scenario performs.

Evaluation

	Character	Border crossing	Geography	Volume	Number	Flexibility
Road	0.33333333...	0.333333333...	0.957375	0.1111111111...	1.0	0.8
SRRV_16	0.66666666...	0.333333333...	0.88638168	0.2632888888...	0.92307692...	0.45
SRRV_14	0.66666666...	0.333333333...	0.88638168	0.2632888888...	0.92307692...	0.45
LRRV_16_63	0.66666666...	0.333333333...	0.88638168	0.2632888888...	0.92307692...	0.45
LRRV_14_63	0.66666666...	0.333333333...	0.88638168	0.2632888888...	0.92307692...	0.45
LRRV_14_63_5	0.66666666...	0.333333333...	0.88638168	0.2632888888...	0.92307692...	0.45
VLRRV_14	0.66666666...	0.333333333...	0.88638168	0.2632888888...	0.92307692...	0.45
LRRV_14_89	0.66666666...	0.333333333...	0.88638168	0.2632888888...	0.92307692...	0.45
VLRRV_14_104	0.66666666...	0.333333333...	0.88638168	0.2632888888...	0.92307692...	0.45
LRRV14SP	0.66666666...	0.333333333...	0.88638168	0.2632888888...	0.92307692...	0.45

Figure 6: The logistic evaluation table

Then, the model provides the following ranking:

Ranking

N°	Scenario	Final score
1	[Road]	0.5891921296296295
2	[SRRV_16, SRRV_14, LRRV_16_63, LRRV_1...	0.587124581994302

Figure 7: The logistics related ranking

Now, if we look at the safety performances, table 9 can be elaborated on the basis of 23T cargo units.

Table 9: The safety evaluation

	TKM road	TKM water	A(total)	D(total)
Road	38847	0	0,050806	4,36E-05
SRRV_16	15203	33028	0,02029	1,79E-05
SRRV_14	15203	33028	0,02029	1,79E-05
LRRV_16_63	15203	33028	0,02029	1,79E-05
LRRV_14_63	15203	33028	0,02029	1,79E-05
LRRV_14_63_5	15203	33028	0,02029	1,79E-05
VLRRV_14	15203	33028	0,02029	1,79E-05
LRRV_14_89	15203	33028	0,02029	1,79E-05
VLRRV_14_104	15203	33028	0,02029	1,79E-05
LRRV14SP	15203	33028	0,02029	1,79E-05

Once again, the model aggregates these impacts into one safety performance score and provides the following ranking.

Ranking

N°	Scenario	Final score
1	[SRRV_16, SRRV_14, LRRV_16_63, LRRV_1...	0.09090909090909091
2	[Road]	-1.0

Figure 8: The safety ranking

Finally, the overall performance can be estimated on the basis of the following evaluation table summarizing the intermediate scores.

Evaluation

	Environment	Logistic	Safety	Economic
Road	0.6929397152956912	0.5891921296296295	-1.0	1681.98
SRRV_16	-1.0	0.587124581994302	0.09090909090909091	1686.04
SRRV_14	-0.7777777777777777	0.587124581994302	0.09090909090909091	1599.95
LRRV_16_63	-0.5553644788382535	0.587124581994302	0.09090909090909091	1311.25
LRRV_14_63	-0.3138435081685297	0.587124581994302	0.09090909090909091	1266.47
LRRV_14_63_5	-0.09143020922900552	0.587124581994302	0.09090909090909091	1261.78
VLRRV_14	0.1309830897105188	0.587124581994302	0.09090909090909091	1184.35
LRRV_14_89	0.35320531193274096	0.587124581994302	0.09090909090909091	1010.13
VLRRV_14_104	0.5754275341549633	0.587124581994302	0.09090909090909091	949.82
LRRV14SP	0.9858603229196523	0.587124581994302	0.09090909090909091	1274.27

Figure 9: The final evaluation table

Then the model performs the underlying calculations and provides the final ranking. This ranking highlights the best scenarios regarding the used indicators and makes it possible to compare the new alternatives with the present situation.

Ranking

N°	Scenario	Final score
1	[VLRRV_14_104]	0.3888888888888889
2	[LRRV_14_89]	0.2777777777777778
3	[LRRV14SP]	0.2222222222222224
4	[VLRRV_14]	0.1666666666666666
5	[LRRV_14_63_5]	0.0555555555555558
6	[Road]	0.0
7	[LRRV_14_63]	-0.0555555555555558
8	[LRRV_16_63]	-0.2222222222222224
9	[SRRV_14]	-0.3333333333333333
10	[SRRV_16]	-0.5

Figure 10: The final ranking

In such a decision aiding approach, it is very important to fine tune the parameters correctly. Indeed, the weights allotted to the criteria and the preference functions can have an impact on the final ranking and lead to different recommendations.

A difficult problem to solve is to find common weights satisfying each decision maker.

The comparison of the rankings obtained on the basis of different weightings is a way to test the sensitivity of the recommendations. On figure 11, the sensitivity tool is illustrated. The top part highlights the ranking based on new weights shown on the bottom part.

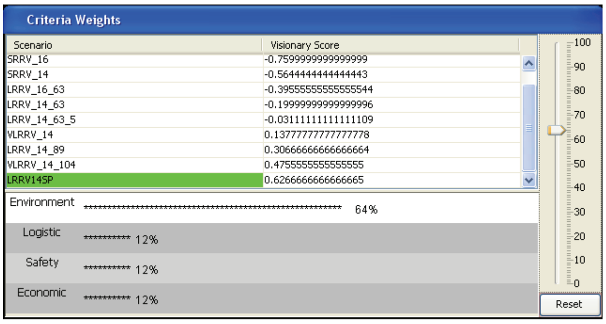

Figure 11: Sensitivity tool

5. CONCLUSION

This paper presented the development of an integrated assessment tool for the evaluation of combined transport chains.

First, the authors developed the integrated assessment framework, highlighting the pertinent indicators and their aggregation in view of the calculation of a final global score expressing the 'overall' performance of the studied transport scenarios.

This new approach has been implemented in a tool which the authors used to demonstrate the applicability of the method to a practical case study.

The authors obtained the four indexes and the final global score providing the final ranking of transport alternatives compared to the present situation.

The authors discussed this ranking by highlighting the importance of the allotted weights and presented a brief example of robustness analysis.

The methodology developed within this paper can be a powerful decision support aid for shippers and shipowners, allowing them to gain better insight into the performance they may expect from their operations.

The performed assessment methodology can be applied to new ship and transport concepts compared to non-optimized concepts in the fields of economy, environment, safety and logistics.

Possible further developments can be identified. Indeed, the internalization of a wider range of transport impacts could be considered: the noise, the congestion, the impacts on the nature and the landscape, the soil and water pollution. The internalization of these external impacts would improve the recommendations.

Finally, it could be interesting to investigate a development of the model in view of the elaboration of socio-cost-benefit ratios providing the economic impacts for the society and the involved actors. Then, we could propose an actual investment helping tool to the decision makers.

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