Performance assessment for intermodal chains

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The reasons for choosing or promoting a certain way of transporting goods are dependent on a multitude of factors. Shippers will be interested in reliable logistics and low cost, while authorities are in general more concerned with relieving congestion and minimizing the

environmental impact of transport in general, while accident-free transport is in the interest of all parties involved. Historically, many analysis methods have been developed that include one or more of the above factors, both for transport and non-transport purposes. For the European funded 6th framework project CREATING however, aims to achieve an integrated approach to the assessment of transport, focused on intermodal chains at a micro level, which required highly specific input data which was not readily available from literature.
In order to solve this, the authors have joined forces: Delft University developed a model that determines transport cost and emissions related to intermodal transport chains, based on the technical and operational aspects of the transport means utilized, while Budapest University developed a method to measure logistic performance of specific transport chains and the University of Liège developed a multi-criteria decision aiding model that can translate values obtained into a single performance indicator.
The approach developed by the authors is demonstrated by means of one of the cases under evaluation in the CREATING project.

Keywords: Economic and logistic performances, Integrated Assessment, Intermodal chain.

1. Introduction

Within the EU-funded 6th framework project CREATING, specific transport chains are researched, for which shippers have shown interest in moving their cargo from road to water and for these chains dedicated ships are designed and optimized. It is the task of the research as discussed in this paper to provide an integrated assessment methodology in order to evaluate the performance of these new transport chains compared to the old ones in the fields of logistics, economics, environmental impact and safety. This assessment will result in so-called Sustainable Transport Performance Indicators (STPIs), which give an aggregate indication for the performance in the four mentioned performance areas. The importance of each area is however dependent on a person's point of view: for commercial parties, the best way will be the cheapest one that can properly accommodate his logistic requirements, while for (for instance) local authorities the safest and/or least polluting way will be the best solution. Nearly always, the solution used in the end will be a compromise between cost, logistics, environment and safety.
The question that remains to be answered is just how well a concept that meets these general requirements performs 'overall'. This is the topic of this paper:
The section 3 discusses the development of a so-called Sustainable Transport Performance Indicator (STPI), which will provide a basis for an integral assessment of intermodal transport chains. The clear and detailed definition of evaluation parameters is essential for each considered performance area. This will be elaborated in the section 3.3 "The assessment criteria".
The authors decided to select one case study in order to illustrate the working of the elaborated methodology. It highlights the transport of new cars and vans as well as trailers loaded with goods between Frankfurt am Main in Germany and Sofia in Bulgaria along the Danube. The key element in the assessment is the determination of the effect of changing the technical specifications of the transport means. This way it is not only feasible to quickly determine the difference in performance between single-mode and intermodal transport, but it can also be made clear just what for instance the influence of new emission legislation is on

the environmental performance of a transport chain or how improved engine technology or a more efficient propulsion system can influence the cost of transport.
According to the considered scenario, the authors present the impacts of various logistic and technical choices on the assessment criteria. This comparison will at first be made in terms of the numerous available indicators (cost, tons of CO2, NOx, PM, SOx, CO…) but these will in the second step be integrated to a single indicator value, weighting the various aspects against one another in order to select the most optimal transport scenario.

2. Literature review

In the creation of the methodology described in the paper, as well as the example case that is discussed, a number of publications proved of invaluable use.
For the creation of the integrated assessment framework, the major literature sources are in which Roy and Bouyssou (1993) detail a non negligible set of multicriteria decision aiding methods; and Roy (1985) who develops the concept of decision process and gives an overview of MCDA[1] methods and the premises of their application, among others, the methodology PROMETHEE[2]. By combining these two sources, we decided to select the PROMETHEE method for both its no negligible efficiency and understanding easiness advantages by the non-mathematical experts. The analysis of applications of multicriteria decision aiding methods highlighted in the work of Azibi and Van der Pooten (1997), Cescotto et al. (2006), Colson and Mbangala (1998), Rigo et al. (2007) and Schweigert (1995) helped us for designing our structured pyramidal integrated assessment framework. Brans and Mareshal (2005) detail the PROMETHEE mathematical approach which was of key importance for the calculations of the rankings. Finally, the invaluable value of the work of Colson (2004a), (2004b), De Bruyn (2002), Ndiaye et al. (1993) and Roubens (1991) helped us to fine tune the proposed model.
In the development of the quantitative model for determination of the cost, environmental impact and safety performance of intermodal transport, the main literature source used is Bolt (2003), in which Bolt reviews a method of estimating the energy consumption of inland ships in a general way, allowing incorporation of technical aspects in a logistic model, without having to go into exact design details of specific ships, which is something that is required by many other methods. When reviewing the environmental and economic performance of transport modes, it is important to take into account any economic consequences of using measures to improve environmental performance (someone needs to pay for the soot filter…) The way of doing so that is used in the quantitative model, as well as some representative values for cost and benefits of a number of ship-related measures is presented in Blaauw et al. (2006a). The case described in this article is one of 4 cases treated within the EU project CREATING. An overview of these cases and a general description of the project is provided in Blaauw et al. (2006b). Finally a more in-depth description of the workings of the quantitative model is provided in Ndiaye et al. (2007).

[1] MCDA: Multi Criteria Decision Aiding
[2] PROMETHEE= Preference Ranking Organization METHod for Enrichment and Evaluation

3. The STPI approach

3.1 Introduction

As briefly explained in the introduction, 'STPI' stands for 'Sustainable Transport Performance Indicator'. This is the global score obtained by a transport scenario by analysing its performance according to environmental, economic, logistic and safety performance in an integrated way. The goal is to provide one score which expresses the performance of the transport scenario according to a set of indicators which need to be defined judiciously.
The analysis takes place at the micro level, meaning that the authors focus on a specific transport chain and try to calculate the global performance of the entire considered transport scenario. The authors do not highlight the score of each transport mode separately because the goal is to express the performance of transport from A to B, resulting in the need for an integral assessment of all steps in the transport chain.
The following paragraph explains the elaborated approach, proposes a graph modelling the method and gives an overview of the mathematical model.

3.2 Methodology

The defined methodology is based on a « three steps » approach highlighting two aggregation steps (see figure 1).

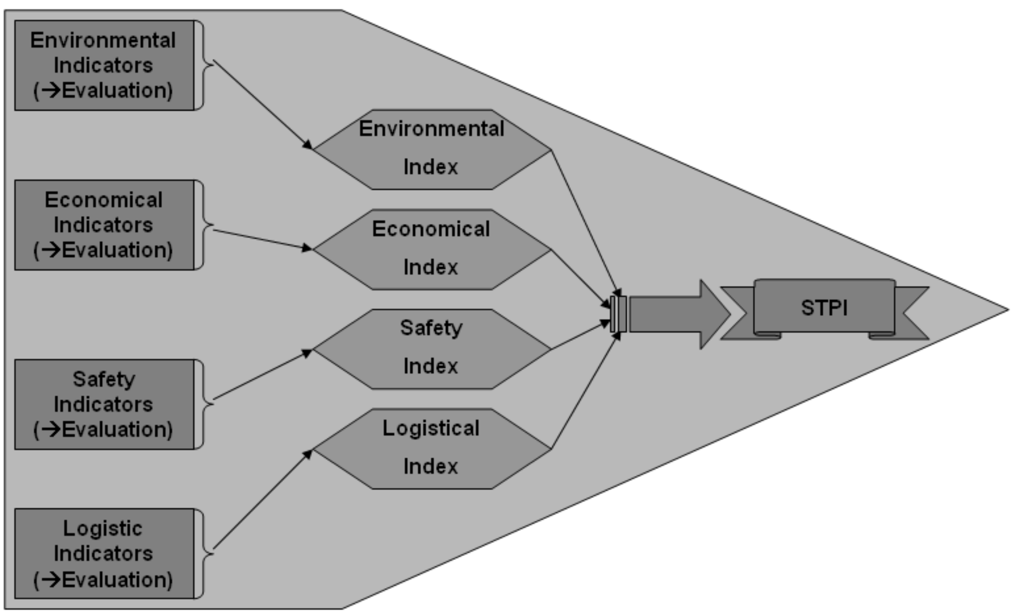


Figure 1. STPI methodology

In any decision aiding problems, the first step aims to define a list of evaluation indicators, also named criteria, on the basis of objectives and/or expected improvements set by decision makers and/or stakeholders. These evaluation axes, defined in close cooperation with the teams of the authors and fine-tuned with the CREATING consortium, make it possible to assess the transport scenarios according to four specific evaluation fields: environmental

impact, economics, safety and logistics. Each of these assessment areas is characterized by a list of indicators (see section 3.3).
So, after evaluating the impacts of transport scenarios on these criteria, we can aggregate them into four indexes representing their global environmental, economic, logistic and safety performances.
This first aggregation step can be realized by using a multicriteria decision aiding method named PROMETHEE chosen on the work of Roy and Bouyssou (1993) and Roy (1985). This methodology based on a pairwise comparison of the impacts of scenarios on the criteria involves the definition of various parameters making it possible to fine-tune the approach in order to model as correctly as possible the real nature of the problem. This method allows considering both quantitative and qualitative evaluation, a non negligible advantage in case of use of linguistic scale, as it is done in the logistic field (see section 3.3). In addition, it allows the comparison of various units. Indeed, the preference functions, used to express the preferences of the decision makers, associate all the units to an interval [0,1] on the basis of preference and indifference thresholds allowing the user to aggregate impacts related to different criteria expressed in different units. For example, it is possible to aggregate the impacts on CO_2, CO, NOx, SOx and PM emissions into one index. These preference functions are the key of the two aggregation steps presented on figure 1. In addition, the definition of weights improves the analysis by giving more or less importance to some of the criteria according to the points of view of the decision makers involved in the decision process. For example, the weights of the environmental criteria were defined on the basis of their respective societal cost as explained by Vermeulen et al. (2004), (see section 3.3).
We have to specify that the four indexes are expressed as absolute values without specific units. Indeed, based on a pairwise comparison associated with an interval [0,1], the figures coming from the "PROMETHEE II - aggregation" make it possible to compare one scenario to another.
The PROMETHEE II methodology can be modelled as follows:
Let us define the criterion *j* as a function g_j and the evaluation of the impact of scenario *a* on criterion *j*, that is $g_j(a)$.
So, let us define:

$$\forall a,b \in A, d_j(a,b) = g_j(a) - _j(b) \qquad (1)$$

where *A is the set of evaluated scenarios.*
As the units of criteria are specific and can be different, let us define:

$$F_j[d_j(a,b)]; \forall a,b \in A \qquad (2)$$

where:

$$0 < F_j[d_j(a,b)] < 1; \forall a,b \in A \qquad (3)$$

If the criterion g_j has to be maximized, (2) is giving the preference of a over b on the basis of their evaluation on g_j. (2) is equal to 0 if (1) is negative.
For a criterion to minimize, we have to consider:

$$F_j[-d_j(a,b)]; \forall a,b \in A \qquad (4)$$

These functions F are preference functions making it possible to associate all the units to an interval between 0 and 1; and including the preferences of the decision makers in the decision process. Six types of preference functions are determined in PROMETHEE and lot of other can be developed according to the need of the users.
Let us consider the basic case, the usual preference function:

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

Now, we can consider a first variation where a preference threshold q is introduced:

$$F_j[d_j(a,b)] = \begin{cases} O \xrightarrow{if} d_j(a,b) \leq q \\ 1 \xrightarrow{if} d_j(a,b) > q \end{cases} ; \forall a,b \in A \tag{6}$$

Different other variations can be made, among others, that one where an indifference threshold p is introduced:

$$F_j[d_j(a,b)] = \begin{cases} O \xrightarrow{if} d_j(a,b) \leq q \\ \dfrac{d_j(a,b) - q}{p - q} \xrightarrow{if} q < d_j(a,b) \leq p ; \forall a,b \in A \\ 1 \xrightarrow{if} d_j(a,b) > p \end{cases} \tag{7}$$

Let us consider w_j, the weight of the criterion j and k, the number of criteria, let us calculate the aggregated preference indices:

$$\begin{cases} \pi(a,b) = \sum_{j=1}^{k} F_j[d_j(a,b)] \times \omega_j \\ \pi(b,a) = \sum_{j=1}^{k} F_j[d_j(b,a)] \times \omega_j \end{cases} , \forall a,b \in A \tag{8}$$

So, as soon as (3.2.8) are calculated for all the scenarios of A, we obtain the following positive and negative outranking flows:

$$\begin{cases} \phi^+(a) = \dfrac{1}{n-1} \sum_{x \in A} \pi(a,x) \\ \phi^-(a) = \dfrac{1}{n-1} \sum_{x \in A} \pi(x,a) \end{cases} , \forall a \in A \tag{9}$$

Then, the net flow, giving the PROMETHEE II complete ranking of the scenarios, can be calculated as:

$$\phi(a) = \phi^+(a) - \phi^-(a), \forall a \in A \tag{10}$$

Scenario a will be better than scenario b if

$$\phi(a) > \phi(b) \tag{11}$$

Scenarios a and b will be indifferent if

$$\phi(a) = \phi(b) \tag{12}$$

Obviously, the following properties can be established:

$$\begin{cases} -1 \le \phi(a) < 1; \forall a \in A \\ \sum_{x \in A} \phi(x) = 0 \end{cases} \tag{13}$$

For more information, the reader can consult Brans and Mareschal (2005) and Roy and Bouyssou (1993) in which the authors present all the mathematical details; and Meyer (undated) who details the mathematical formulas.
The same multicriteria decision aiding method can be used to aggregate the four indexes in order to calculate the final STPI representing the global performance combining economic, logistic, environmental and safety aspects.
This pyramidal scheme was developed by the authors in the frame of a computer model named LODA[3].

3.3 The assessment criteria

As explained in the description of the methodology, the criteria are axes used to rank the scenarios on the basis of their performances. Although the theoretical methodology allows assessment by any indicator as long as its importance can be related to other indicators used, it is important to select the indicators to use according to the pursued objectives of the assessment and the possibility of actually acquiring the necessary input values. In the studied case, the criteria were selected as described in the following sections.

3.3.1 The environmental indicators

Many aspects relate to the environmental performance of transport chains, ranging from air emissions to noise hindrance, erosion of river banks and disturbance of animal habitats. However, keeping in mind the objective of the assessment method (assessment of the specific transport chain of the CREATING project, focused on the waterborne part), only those aspects that were actually studied within the project were involved. Since the 'hot' topic in environmental performance of inland navigation is air emissions, these were the focal area of all environmental research done in the project. As a result the following indicators were used: the emission of CO2, CO, NOx, SOx and PM, measured in grams per ton of cargo transported from A to B.
The evaluation of the impacts of the considered transport scenarios on these indicators will be made thanks to the development of a model including various calculation modules highlighting the most important technical characteristics of the ships and trucks that have an impact on these emissions. The comparison of the indicator values is done according to the shadow prices for emissions (e.g. societal cost of 1 ton of emitted CO2 equals € 56,-, while 1 ton of NOx equals € 8000,-).

[3] Logistic Optimization and Decision Aiding

3.3.2 The economic indicators

The economic indicators the authors consider are the cost of the actual transport legs as well as the added cost of transhipment and intermediate storage, if any. For transhipment and non-waterborne transport (i.e. those parts of the chain the CREATING project does not aim to optimize) commercial cost as provided by the market parties involved in the project 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. As an example, adding an SCR catalyst to a ship will drastically reduce its NOx emissions, thereby improving the environmental performance. On the other hand it is an expensive device which consumes a urea solution, as a result of which it has a negative impact on economic performance.

3.3.3 The safety indicators

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 the project. Apart from this, external safety performance of inland waterway transport is generally accepted to be vastly superior to road transport and in case of transport of non-hazardous materials (which was the case in the assessed transport chains in the project) virtually inexistent for all transport modes. As a result, only internal safety was elected as a measure of safety. Even so, arriving at the right basic values proved challenging, since for inland waterway transport hardly any reliable accident records are kept throughout Europe. On the basis of the Dutch AVV[4] database, the best non-confidential database for inland shipping accidents in Europe, it proved possible to arrive at reasonable assumptions regarding the number of accidents and number of fatalities per tonkilometer for this mode. Other accident/safety related data for inland waterway transport was not available, as a result of which these are the only indicators found to be practicable in this case. For road and rail transport corresponding values from the EU statistical pocketbook 2006 were taken and averaged out over all EU countries. From these values, the number of accidents and fatalities per vehiclekilometer were estimated, which were then multiplied with the actual number of vehiclekilometers for all assessed transport chains to arrive at the proper indicator values. The details of the evaluation can be found in section 5.3.

3.3.4 The logistic indicators

Perhaps the largest challenge in the provision of indicators for the purposes of the CREATING project 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.

[4] Adviesdienst Verkeer en Vervoer, Dutch Ministry of Transport.

Second, since the cases were all set up in cooperation with these market parties, it was known beforehand that all transport scenarios scored a sufficient mark for logistic performance.
As a result, the choice was made to set up an own qualitative assessment framework. In this, six indicators are defined. These are as follows:

- logistic character of freight and transport task,
- number of border crossings,
- geographical conditions and traffic density,
- volume of the transported cargo,
- number of transhipment and cargo vulnerability,
- flexibility.

A proper scale is chosen to each indicator (for example: 1-10 or 1-5) and the transport task that should be evaluated receives a rank on this scale. The actual scale and rank is given by a group of experts, in close communication and cooperation between the authors and the persons in charge of the logistic aspects within the CREATING project (see Haenen et al. (2006)).
Ranking a transport scenario the following considerations are taken into account:

- From different potential transport solutions, the best one is the least difficult one (not many vehicles and man power are involved in the transport process, no special type of cargo, no cargo transhipment is needed, the transportation distance is short, easy topographical, meteorological and traffic conditions on the transport route, etc.).
- From different potential transport solutions, the best one is the most reliable (more accurate in time of delivery, less risk of accident and cargo damage, less independence from the geographical and meteorological conditions, etc.)
- From different potential transport solutions, the best one is the most flexible (quick potential reaction capability in case of changes of demand concerning the cargo quantity and delivery time).

The scores on different scales are than normalized, and finally the logistic index is created by the weighted aggregation of the values. For the first calculation a weight factor of 1 was used for each sub-indicator.
All the details concerning the explanation of the qualitative logistic evaluations related to these six criteria can be found in the reference Ndiaye et al. (2007, pp. 46-52).

4. The Danube case

Five scenarios are considered: The base case is transport of 89 truckloads from Frankfurt am Main to Sofia by road only (ref. case: SinMod).
To this base case, 4 variations are made: The first of these is the intermodal base case, where cargo travels by road to the port of Passau (Germany), is then transported by ship to the port of Vidin (Bulgaria) and is transported onward again by road to Sofia. In this case, the ship is a small ship that can carry 29 truckloads and travels at a nominal speed of 16 km/h (case: Int16km). As an alternative to this case, it is reviewed what would happen to performance of the transport chain in case the speed is reduced from 16 to 14 km/h (which still fits the original service schedule), thereby reducing fuel consumption of the ship significantly and improving its resulting environmental performance as well as slightly reducing cost (ref. case: Int14km).

A 4th case assesses the effects of using a larger ship, that can carry 63 truckloads (case: Int14kmL), which provides a more cost-effective and energy-efficient alternative to the small ship.
A final case reviews the effects of applying low sulphur fuel, an SCR catalyst and PM filter to the large ship's engine, thereby vastly increasing environmental performance, but increasing investment cost (ref. case: Int14kmLCF).

5. The evaluation and the use of the models

5.1 The environmental performance

At the basis of the calculation of the performances of the various cases lies a calculation model, developed by Delft University of Technology that it is based on standardized performance of road vehicles (e.g. truck emissions are equal to EURO I, II, III, VI or V, standards, depending on user choice), but takes the ship's powering in consideration in greater detail, taking into account loading conditions, waterway characteristics, restricted water effects and so on, based on the powering calculations as discussed by, among others, Bolt (2003). This results in table 1 below. Interesting observations can be made from this table. First, the use of a different sized ship has a clear effect: the larger the ship, the smaller the fuel consumption (CO2 emissions) per truckload. Some apparently trivial issues like sailing speed also have a significant impact on the results (compare 16 km/h to 14 km/h). The poor performance of intermodal transport related to NOx and PM is due to the lower emission standards for ships. The reversal of this poor performance can be observed in case filter and catalyst techniques combined with low sulphur fuel are applied.

Table 1. Environmental Impacts

	Emissions (g/truckload)				
Case	**CO2**	**CO**	**NOx**	**SOx**	**PM**
SinMod	1480240	1436	10134	0	169
Int16km	2151861	7641	17668	1708	523
Int14km	1643442	5352	13238	1156	375
Int14kmL	1182247	3276	9220	655	241
Int14kmLCF	1138165	3276	5669	32	129

According to the proposed integrated framework, the next step is now to aggregate these results to single indices per case. The aggregation of these six criteria is only possible if we elaborate a pertinent and judicious weighting. As explained in section 3.2 and 3.3, the weights used are the societal costs of each pollutant.

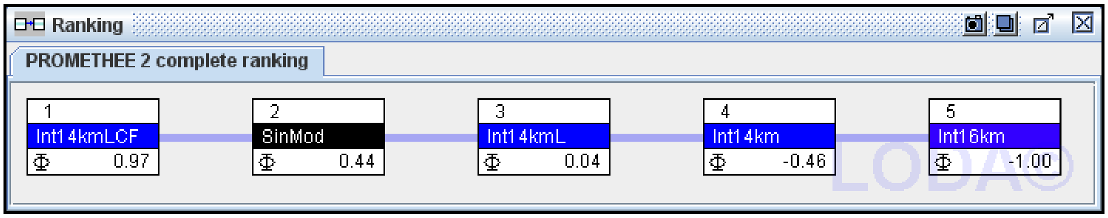


Figure 2. Environmental Ranking

The ranking is based on non-dimensional figures calculated thanks to the PROMETHEE II method on the basis of the evaluation of the environmental impacts shown in table 1, the allowed weights and the preference functions. These scores provide the above ranking (see figure 2) by highlighting the best scenario at the first place and the worst one at the fifth place.
The transport scenario obtaining the best performance considers the use of a large Ro-Ro vessel equipped with a SCR and PM filter and using low sulphur fuel. These new technologies reduce the emission of pollutants considerably.

5.2 The economic performance

The economic performance of the scenarios is simply expressed by the sum of the three considered costs (pre/end haulage, main haul and transhipment). No specific MCDA method is required. The calculation of the costs is also based on an underlying calculation model briefly described above, in which particular attention is paid to the cost of operating the ship (which can be influenced by the results of CREATING) while cost of transhipment and road transport (which the CREATING project does not have any influence on) are taken according to commercial prices rather than specific determination of all factors that make up these cost.
Then, we can present the evaluation table of the economic impacts and the related total costs.

Table 2. Economic Impacts

	Cost (€.truckload)			
Case	**Pre/End Haulage**	**Main Haul**	**Transhipment**	**Total**
SinMod	0	1689	0	1689
Int16km	449	1047	140	1636
Int14km	449	961	140	1550
Int14kmL	449	629	140	1218
Int14kmLCF	449	637	140	1226

From table 2, the effects of using a different ship again become apparent, but it is most important to note that measures that significantly improve environmental performance have only a minor effect on overall transport cost.
The cheapest scenario is characterized by the use of the large vessel. Indeed, significant reduction of the main haul cost is observed for those cases due to the obtained advantages of scale over the small ship.

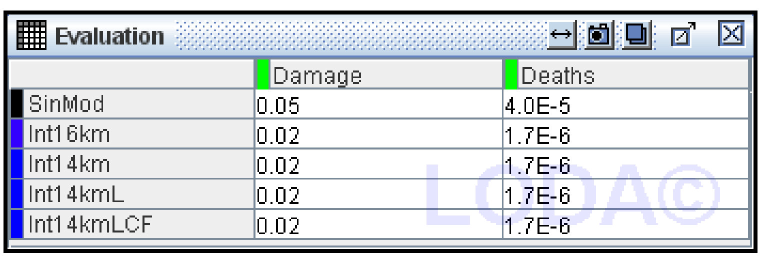
5.3 The safety performance

The section 3.3 described briefly the method used to evaluate the safety criteria. More explanations including figures are given in this section.
The first step consists of the calculation of the number of ton kilometres (TKM) and vehicle kilometres (VKM) of transport related to each scenario. These figures are shown on table 3.

Table 3. TKM and VKM of transport scenarios

	TKM per truckload		VKM per truckload	
Case	**Road**	**Water**	**Road**	**Water**
SinMod	38847	0	1689	0
Int16km	15203	33028	661	50
Int14km	15203	33028	661	50
Int14kmL	15203	33028	661	23
Int14kmLCF	15203	33028	661	23

The next step consists of collecting the national EU standards in the references European Commission, 2006) and the Dutch AVV databases in order to estimate the average number of accidents and deaths per ton kilometre - Indeed, the data available in the European Commission reference (2006) are only linked to the transported ton kilometres (TKM) and not the vehicle kilometres (VKM). - which we can valued respectively at 1.3079E-06 and 1.1214E-09 for the road transport; 1.23E-08 and 2.5E-11 for the waterborne transport. Translation of these values from TKM to VKM is done by assuming an average amount of cargo transported in a roadborne or waterborne vehicle
So, by using the TKM and VKM evaluations presented in table 3, we can express the precedent standard estimations on a basis of vehicle kilometres. These results are shown on figure 3.


Evaluation

	Damage	Deaths
SinMod	0.05	4.0E-5
Int16km	0.02	1.7E-6
Int14km	0.02	1.7E-6
Int14kmL	0.02	1.7E-6
Int14kmLCF	0.02	1.7E-6

Figure 3. Safety Impacts

On the basis of the evaluations shown in figure 3, and using the multicriteria decision aiding method selected, we are able to rank the scenarios on the basis of the safety performances. It appears clearly that the intermodal scenarios including waterborne transport are the most competitive. Using the PROMETHEE II method, the four intermodal scenarios obtained a safety index equal to 0.25 due to the same parameters related to safety aspects, compared to -1 for the road scenario. This is due to the important reduction of vehicle kilometres when we include the waterborne transport in the logistic chain.
Based on a pairwise comparison, the methodology provides so a delta of 1.25 between the intermodal scenarios and the road transport. It highlights not only a good safety performance

of the considered intermodal scenarios but also a high level of competitiveness compared to only road transport. It is important to note that due to the high level of safety of waterborne transport as well as the relatively small number of vehiclekilometers associated with this transport leg, the effects of using a larger ship do not show up in the safety ranking, virtually all risk is related to the roadborne part of transport.

5.4 The logistic performance

As it was briefly explained in section 3.3., the logistic performance is calculated on the basis of six indicators. Figure 4 shows the normalized quantitative values associated to the linguistic levels of the indicators for the different scenarios. Since the examined intermodal scenarios are different only from the technical and not the logistical point of view, for these the figure 4 highlights the same results. Due to the lack of detailed input data from the cases of CREATING, the effect of using a larger or smaller ship does not show up in the final results.

Evaluation

	CharFreight	Border crossing	Geography	Volume	NumTrans	Flexibility
SinMod	0.666666...	0.333333...	0.957375	0.111111...	1.0	0.8
Int16km	0.333333...	0.333333...	0.886381...	0.263288...	0.769230...	0.45
Int14km	0.333333...	0.333333...	0.886381...	0.263288...	0.769230...	0.45
Int14kmL	0.333333...	0.333333...	0.886381...	0.263288...	0.769230...	0.45
Int14kmLCF	0.333333...	0.333333...	0.886381...	0.263288...	0.769230...	0.45

Figure 4. Logistic Evaluation

Then, as it was described in section 3.3, the global logistic performance of each transport scenario can be estimated by calculating the average of the precedent normalized values (see figure 4). So, the best scenario obtaining the largest logistic index is the road transport with a score equal to 0.64. The four intermodal scenarios obtain a logistic index equal to 0.51. This highlights the competitiveness of the road scenario from a logistic point of view compared to the intermodal scenarios including waterborne transport.

6. The final STPI

6.1 The final ranking

According to the pyramidal structure defined at the beginning of the paper, we use the calculated indexes related to each performance area in order to calculate the final integrated score expressing the global performance of the studied scenarios according to the environmental, economic, logistic and safety impacts.
As illustrated in figure 5, we use directly the indexes obtained in the precedent step. By using the PROMETHEE II methodology, we can aggregate these scores and calculate the final STPI which gives the final ranking (see figure 6) of the studied scenarios on the basis of the four considered performance area.

Evaluation

	Environment	Logistic	Safety	Economic
SinMod	0.4393733555742807	0.6447476851851852	-1.0	1689.0
Int16km	-0.9995528881704528	0.5059280007977208	0.25	1636.0
Int14km	-0.45656996440301983	0.5059280007977208	0.25	1550.0
Int14kmL	0.04342143729256587	0.5059280007977208	0.25	1218.0
Int14kmLCF	0.973328059706626	0.5059280007977208	0.25	1226.0

Figure 5. STPI Evaluation

Just like for the calculation of the environmental and safety indexes, we have to weight the four performance fields in order to reach a single final STPI value. The initial weights were the same ones for the four macro-criteria. That means the importance given to the economic, logistic, environmental and safety aspects is the same. The section 6.2 develops the aspects of varying weights, which can occur as a result of the specific preferences of the person doing the assessment.
Then, on figure 6, we can analyse the final ranking including the four evaluation fields. The largest STPI – 0.38 – associated with the "Int14kmLCF" case means that the use of a large Ro-Ro vessel with the use of a SCR catalyst, a filter and a low sulfur fuel represents the best compromise between the four evaluation fields. It gets the best global performance according to the weights and the preference functions defined. These ones are usual preference functions (see section 3.2).

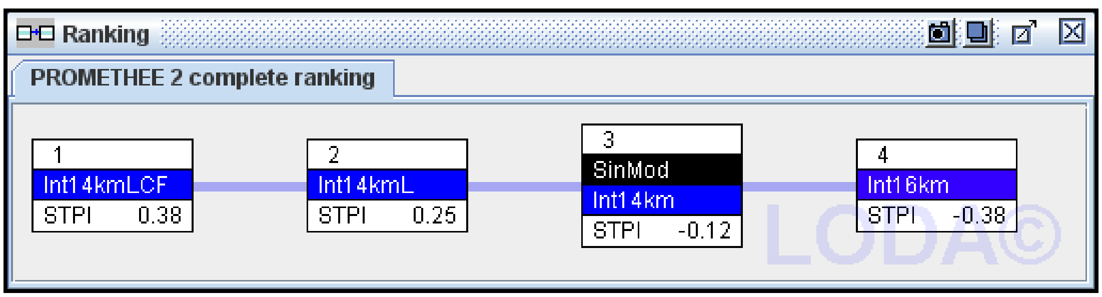


Figure 6. STPI ranking

6.2 Robustness analysis

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 impact the final ranking and in different cases, lead to different recommendations.
A difficult, if not impossible, problem to solve is to find common weights satisfying each decision maker.
Finally, the comparison of the rankings obtained on the basis of different weightings is a way to test the sensitivity of the recommendations. This post assessment analysis is important for providing robust advice. The figure 7 illustrates two alternative weightings to the original weighting. The top part of figure 7 highlights more importance given to environmental and economic aspects. The second part presents an example where the decision makers focus on the logistic aspects. In the two cases, the transport scenario obtaining the biggest STPI value, so the best global performance according to the four evaluation fields, is the same one as in the initial ranking presented in section 6.1. It means that for the three specific highlighted

weightings, the use of a large Ro-Ro vessel with a speed of 14km/h and equipped with specific technologies such as a SCR catalyst, a filter and using a low sulfur fuel seems to be the best compromise to satisfy correctly the three 'judges' with their own feelings about the importance of the evaluation fields.

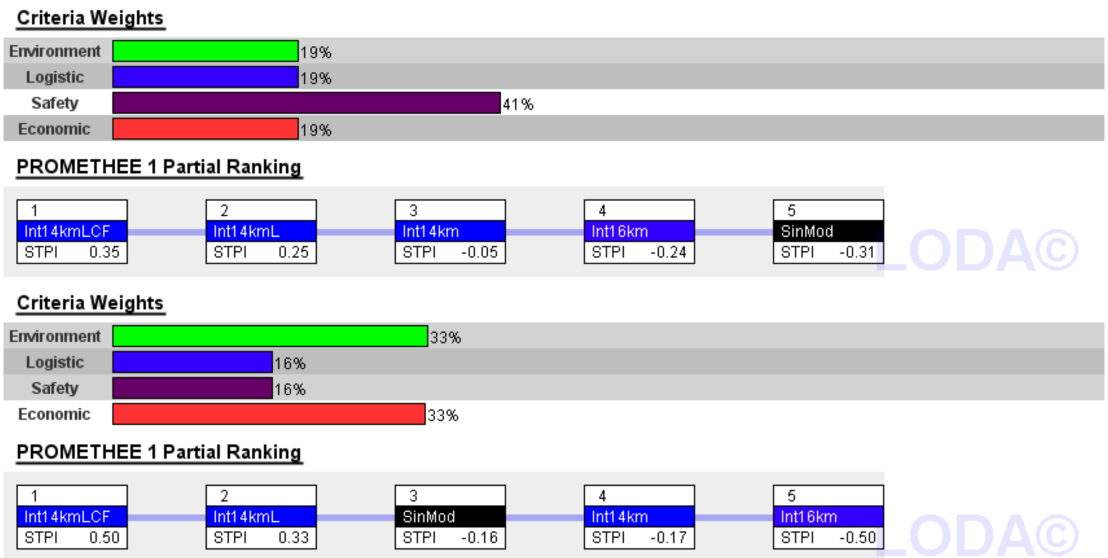


Figure 7. Robustness/Sensitivity Analysis

7. Perspectives and conclusion

This paper presented the development of an integrated framework for the evaluation of the performance of intermodal chains.

First, the authors developed the STPI approach, 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.

These logistic chains were explained and their specific characteristics and parameters linked to the performance area were presented and calculated.

Then, the authors calculated the four indexes related to the environment, the cost, the logistic and the safety, before the final evaluation of the STPI.

The authors discussed the obtained final ranking by highlighting the importance of the allowed weights and presented a brief example of robustness/sensitivity analysis.

The STPI methodology developed in CREATING 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. In a next development step it should be accompanied by the creation of a handbook for ship owners for investment choices, thereby providing insights required to make well-founded choices to optimize the performance of new ships in the various fields. This handbook could deal in detail with the effects of design choices on the operation and exploitation of the ship and could be used as a decision support system for the building of a new ship.

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