BULETINUL Universităţii Petrol – Gaze din Ploieşti	Vol. LXII No. 3A/2010	75 - 82	Seria Tehnică

Methodology for Comparative Analysis of Environmental Performance in Multimodal Transport Systems

Florin Nicolae, Marian Ristea, Adrian Popa

Academia Navală “Mircea cel Bătrân”, Str. Fulgerului 1, Constanța
e-mail: nicolae_florin_m @yahoo.com

Abstract

The object of the comparative study is to gain methodological experience in comparing alternative transport systems in terms of environmental performance. The study has been confined to the operational phase of the transport means both with regard to impacts from mobile subsystems to transportation system and impacts from stationary subsystems to transportation system. This study will focus on emissions, toxic releases, noise and land use. The work has been confined to the operational stage of the transport means. Hence depletion of natural resources, production and scrapping are not included. The subject case study refers to two different intermodal transport systems.

Key words: *environmental performance, LCA, multimodal transport.*

Introduction

This study is based upon the pre-project Globe where the LCA-methodology was tested and evaluated for the inland navigation and maritime transport, [9]. The conclusions from this study imply that LCA is a suitable method to evaluate environmental impacts from a transport mean, but simplifications are necessary since the method is resource consuming. Simplifications can be done with respect to limitation of life cycle phases, subsystems and environmental aspects. One recommendation from the paper is that impact categories for the transport sector in general should be developed, with characterization, normalization and evaluation factors that reflect transport chains, [7]. The paper did not identify complete studies that compared the environmental performance of alternative transport chains. The aim of this study is to provide input to a more comprehensive study in order to further develop the conclusions from the above pre project. The aim of such development work is to establish models and guidelines for the documentation and comparison of environmental performance of different transport chains in a life cycle perspective.

Transport Chains and the Life Cycle Perspective

The goal of this paper is to compare the environmental performance of alternative transport systems, Figure 1, Figure 2. The function of the transport chains is to transport cargo from one place to another based on different routes and transport means. Its primary purpose is to provide a reference which the inputs and outputs can be related to. Such reference is necessary to ensure comparability of LCA-results, and it is particularly critical when different systems are being assessed. When comparing transport chains the distance travelled may differ from one alternative to the other causing differences in environmental performance. Environmental performance should therefore not be expressed per distance unit (km).

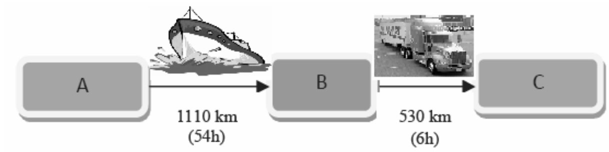

Fig. 1. Transport Chain 1 for general cargo from A to B

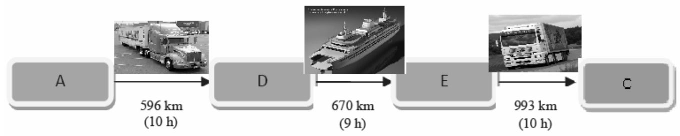

Fig. 2. Transport Chain 2 for general cargo from A to B

The functional unit in this case is defined as 1 ton general cargo transported from point A to point C.
All transport chains include door to door transport of a defined cargo. The two transport chains included in this study are divided into subsystems, Table 1.

Table 1: Transport chains to be compared and their related subsystems

Transport chains	Subsystems	Comment
Chain 1 Water Transport	**General cargo vessel**	Vessel operates between A and B as a part of more extensive route
	Harbours	Harbours in A and B
	Heavy duty vehicle	Operates between B and customer in C
	Road	Road used by heavy vehicle between B and client in C
Chain 2 Road Transport	**Heavy duty vehicle**	Operates between A and D and between E and client in C
	Road	Road used from A to D and from E to C
	Loading terminal	Terminal used for loading general cargo in A
	Car Ferry	The ferry operates between D and E
	Harbours	Harbours for the ferry in D and E

Transport means are represented: general cargo vessel **(**M/V Danube II), Heavy Duty Vehicle (Truck with Trailer), Ferryboat (a ship with 3500 transport units transport capacity), [8]. Every subsystem in a transport chain has its own life cycle; building, operation, maintenance and dismantling. The study is based on a life cycle perspective. The system boundaries determine which unit processes shall be included within the LCA. Several factors determine the system boundaries, including the intended application of the study, the assumptions made, cut-off criteria, data and cost constraints, and the intended audience, [9]. The selection of inputs and outputs, the level of aggregation within a data category, and the modeling of the system shall be consistent with the goal of the study. The system should be modeled in such a manner that inputs and outputs at its boundaries are elementary flow. The criteria used in establishing the system boundaries shall be identified and justified in the scope of the study. LCA studies used to make a comparative assertion that is disclosed to the public shall perform an analysis of material and energy flows to determine their inclusion in the scope of the study.

As shown [4], [5], different system boundaries for different subsystems are defined. This is in accordance with the standard stipulating that the boundaries determine which unit processes shall be included within the LCA. However, the research has not discussed in detail cut-off criteria, data and cost constraints etc., and the criteria used when system boundaries are established. Neither are the effects on the final results by using cradle to gate data evaluated. It is necessary to develop a set of criteria for defining system boundaries for different types of ship transportation.

The relationships between system and subsystems are important aspects to be included in the discussion. Further how much of their material life cycles and their operation areas shall be included in the analyses, hereunder also allocation methods (e.g. amount of reduction for positive effects of recycled materials at the end of the system life cycle, or how to allocate the building of harbours, roads, land use, infrastructure etc. in the evaluation of transportation). One rule of thumb could be that the life cycle boundary is drawn around those activities that may significantly affect the company bottom line and which the company can control.

In the report "Risk factors associated Transport System and their influence on Climate Change,[4], a weighting model developed for mid-European conditions is used (The Eco-indicator 99 model, [1]). The weight factors will vary according to the weight model selected in the analysis program. However, if a set of weight factors are to be developed for the vessel- or trailer operation or for other phases of a transport system, it is necessary to take environmental conditions for different geographical areas into consideration (e.g. do SO_2 and NO_x impact the environment to the same extent in different geographical regions, or is it necessary to use different weight factors based in regional differences).

Laws and regulations differ from one geographical area to the other due to changing condition of the environment. In future different sets of weight factors will most likely be available. e.g. for the Est Europe and Danube River area. Consequently there will be a need for models to analyze and evaluate multivariable problems (emissions to air compared with discharges of heavy metals to river) for different geographical areas.

The alternative transportation systems referred to in this study are intermodal; involving both land based and sea based transport. The main contribution from the mobile sub-systems is: depletion of natural resources, emissions, toxic releases, noise. Since this study has been confined to the operational stage of the transport means, depletion of natural resources is not included. Hence this study will focus on emissions and toxic releases as well as noise and land use. Stationary systems are the: complete infrastructure related to the production, maintenance and scrapping/recirculation system, the infrastructure related to the transport function i.e. roads, terminals, keys, etc. Since this study has been confined to the operational stage of the transport means, production and scrapping are not included. Regarding the infrastructure related to the transport function we focus on land use, which a priori will differ significantly between the two lines of transport selected.

Calculation Methodology

The amounts of substances contributing environmental burdens are calculated by the following formulas. E_i is the total emission of substance i [kg per trip]. Exhaust gas emission may be calculated after (1) or (2):

$$E_i = F \cdot D \cdot e_{ai} \tag{1}$$

where: F is the fuel consumption [kg/km]; D is the distance from point A to point B for each transport means [km]; e_{ai} is the exhaust emission factor for substance i [g/kg fuel].

$$E_i = P \cdot T \cdot e_{di} \tag{2}$$

where: P is engine power (average or detailed power pattern) [kW]; e_{di} is exhaust emission factor for substance i [kg per kWh]; T is time [h]. Dust or particulars are calculated by (3):

$$E_i = F \cdot D \cdot e_{bi} \tag{3}$$

where: E_i is the total emission or consumption of substance *i* (g); -*F* is the fuel consumption (kg/km); -*D* is the distance from point A to point B for each transport means [km]; -e_{bi} is the emission factor for substance i [g/m^2·h]. Leakage of eco – toxic substances from ship antifouling *i* is calculated by (4):

$$E_i = T \cdot A \cdot e_{ci} \tag{4}$$

where:-*T* is time [h]; -*A* is area of wet surface [m^2]; -e_{ci} is the emission or consumption factor for substance i [g/(m^2-h]. Wet surface area can be calculated after formula (5):

$$A = 1{,}7 \cdot L_{pp} \cdot T + \frac{\Delta}{T}[m^2] \tag{5}$$

where: -L_{pp} is lenght of the vessel measured between perpendiculars [m]; -T is depth [m]; -∇-is displacement [m^3].

$$\nabla = L_{pp} \cdot W \cdot T \cdot C_b$$

where: W is breath and C_b is block coefficient for the vessel.

For general cargo vessel and trailer the total emission and consumption are related to the functional unit by dividing by the average exploited capacity of the respective transport mode and multiplying with the amount transported, reflected in the functional unit. E_i^* is the total emission of substance *i* [g/t or per FU] and can be calculated after (6):

$$E_i^* = \frac{E_i}{C} \cdot M \tag{6}$$

where : E_i is the total emitted substance [g]; -*C* is the average exploited capacity per heavy duty vehicle [t]; -*M* is the amount to be transported reflected by the functional unit [t per FU]. For the ferry between D to E the total consumption and emission are allocated to one HDV by dividing on the ferry-capacity and multiplying with the share of the capacity that the HDV occupies (7).

$$E_{trailer,i} = \frac{E_{ferry,i}}{C^*} \cdot U \tag{7}$$

where: $E_{trailer,i}$ is the share of the ferry`s total emission that is allocated to the special cargo transport [g]; $E_{ferry,i}$ is the total ferry emission or consumption of substance i (g) as calculated in equation (1) or (2) above; C^* *is the* exploited capacity for the ferry (measured in private car units); -*U* is the number of private cars units that the heavy vehicle occupies. The emission and consumption ($E_{trailer,i} = E_i$) are then related to the functional unit according to equation (5)

The calculation of land area use is based on the sum of area required at any time during the transport. The land area required for the transport of cargo has to be allocated to the transport chains according to their use of use of the area, e.g. by time used, number of operations, amount of cargo or economic turnover. Occupied land area are according to the time used is calculated by (8).

$$a_r = (B_r + S_{Br}) \cdot (L_r + S_{Lr}) \cdot t_r \tag{8}$$

where: B_r is the breath of the transport mean r (required road/quay) [m]; -L_r is the lenght of the transport means r [m]; -S_{Br} is the safety distance in breadth direction for the transport mean r; -S_{Lr} is the safety distance in length direction for transport mean r; -t_r denote the time used for transport mean r to travel the relevant route described by the transport chain or stay in loading area [h]. The total area use a_n due to noise is expressed as the area exposed to noise levels above 55 dBA. This is the limit set by the the European Federation for Transport and Environment

(T&E) for new buildings and roads, (Nam, 2008). For the movement of the transport means the total area can be estimated by formula (9).

$$a_n = A_{\succ 55dBA,r} \cdot t_r \qquad (9)$$

where: $A_{>55dBA,r}$ is the average area exposed to noise by transport means [m^2]; t_r is the time used for transport mean r to travel the relevant route described by the transport chain or stay in loading area [h]

A rough simplification when the vessel is at quay may be that the noise area taken into account can be calculated after formula (10).

$$A_{\succ 55dBA,r} = \pi R_n^2 / 2 \qquad (10)$$

where R_n is the radius with noise < 55dBA. Land area occupation and land area exposed to noise is related to the functional unit in the same way as formula (6):

$$a^* = \frac{a}{C} \cdot M$$

Input and Output Elements

Data for the general cargo vessel and car ferry transport are based on technical manuals. Data for exhaust gas emission are based on maritime international regulations, [10]. Leakage from antifouling is a continuous emission. Tribytyltin (TBT) is the most extensively used toxic substance and is there for used for the general cargo vessel. The leaking rate depends on the antifouling type applied and the operational profile. As the ship or antifouling specific leak rates are not available, the IMO limit of 4 microgram of TBT per cm^2/day is applied, [11].

The main data collections are:

Data for calculating the general cargo vessel and car ferry fuel consumption and emission related to main engine: distance (km), time (h), fuel (kg/km), emission (CO_2, NO_X, CO, C_XH_Y, PM, SO_X-g/kg fuel) TBT (g/m^2h), capacity (tons), exploited capacity (%), wet surface (m^2), [12].

Data for calculating the general cargo vessel fuel consumption and emission related to two auxiliary engines: time (h), fuel (kg/km), emission (CO_2, NO_X, CO, C_XH_Y, PM, SO_X-g/kg fuel), (RNA, 2009).

Data for calculating general cargo vessel and car ferry area occupation: vessel length, quay with, time in harbour, harbour quay area, traffic flow (vessel/day), etc. Area occupation related to the general cargo ship and ferry harbours is estimated according to the model calculation, [5].

The noise level is related to a ship when moored alongside quay. The noise maps shows the predicted noise levels varying with the distance from the vessel, [2].

Area exposed to noise by the ship is estimated according to the description given in chapter 3. Background information for these approaches: length from ships with noise level equal 55 dBA, ship time in harbor, [2].

The collected data for the HDV transport from A to C is summarized: distance (km), fuel Diesel (kg/km), PM10 (road dust-g/km), exhaust emission (CO_2, NO_X, CO, mmVOC, CH_4, PM_{10}, $PM_{2,5}$, SO_X, N_2O, NH_3, PAH, Benzene-g/kg fuel), capacity (tons), exploited c (%), [13].

Area occupation related to the heavy-duty vehicle is calculated according to the calculation model description given in chapter 3. Background data for these approaches are: vehicle length (m), vehicle width (m), road width (m), average speed (m/s), time on road for chain A or B (hours/vehicle), road length (km), road traffic flow (vehicles/day), (RRA, 2009).

The noise from HDV is caused both by the machinery and rolling. Noise levels from the HDV are predicted according to “The European prediction method for traffic noise”. Area exposed to noise by road transport is estimated according to the description given in chapter 3. Background information for these approaches is: length from HDV with noise level equil to 55 dBA (m), road distance A-B-C, A-D-E-C (km), HDV use B-C, A-D, E-C, road traffic flow B-C, A-D, E-C (vehicles/day estimated based on daily traffic flow in parts of the distance).

Research Results

By using the formulas (1), (2) and (7) the emissions to air are calculated for every substance within each impact category.

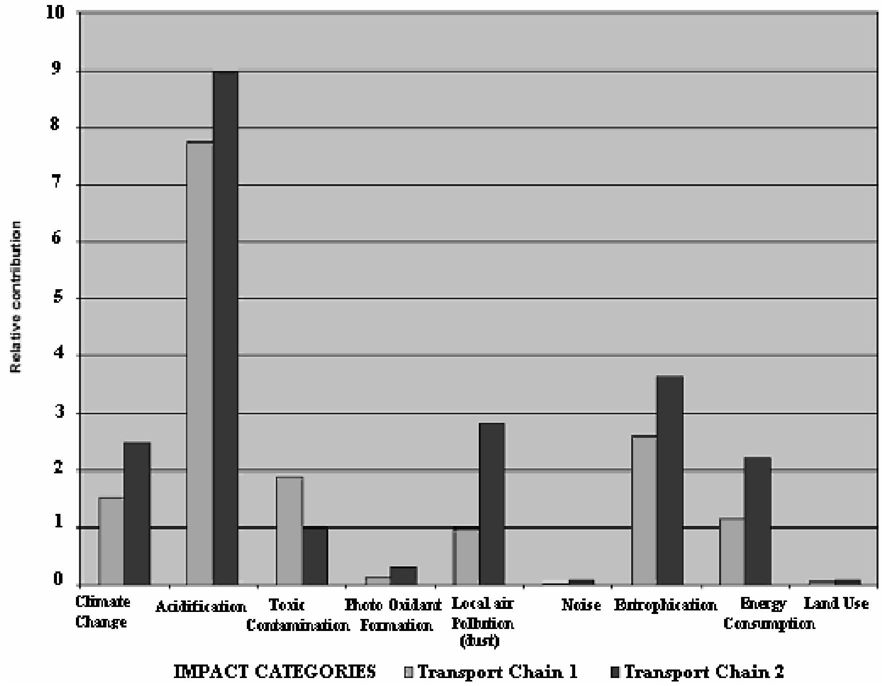

Fig. 3. Normalized inventory results: Chain 1 is mainly waterborne transport, Chain 2 is a combination between trailer and ferry.

The calculations are based on fuel consumption for main machinery systems, auxiliary engines and for vehicle. The TBT-leakage is calculated after formula (4) and (5) by using a leakage-rate of 0,0017 g/(m^2·h). The results are then multiplied by utilized capacity and divided by real capacity and by tons special cargo transported. This gives the leakage per special cargo transported.

The occupied harbor area is calculated by using the vessel length, quay width, time in harbor related to loading/unloading 1 ton special cargo (1 SCU).

The calculations of area occupation due to trailer traffic is based on vehicle length and width, average speed, time on road, number of vehicles per functional unit, see formula (8). The area exposed to noise >55 dBA is based on noise measurements and statistical data. For the trailers it is assumed that the 55 dBA limit is exceeded only when driving. Formula (9) is used and allocation is based on share of total activity.

From each sub-system in the transport chain the total amount of each substance are summarized: climate change (CO_2, N_2O, CH_4), acidification (SO_2, NO_X, NH_3, TBT), local air pollution (dust), photo oxidant formation (NMVOC), noise (area >55 dBA), eutrophication (NH_3), energy consumption (MJ), land use ($m^2 h$), distance (km), exploited c (%). The Figure 3 and Figure 4 indicate that Chain 1 has the best environmental performance within each category except for toxic contamination. In addition to the characterization of different compounds, the environmental impact will in depend on where the emissions take place.

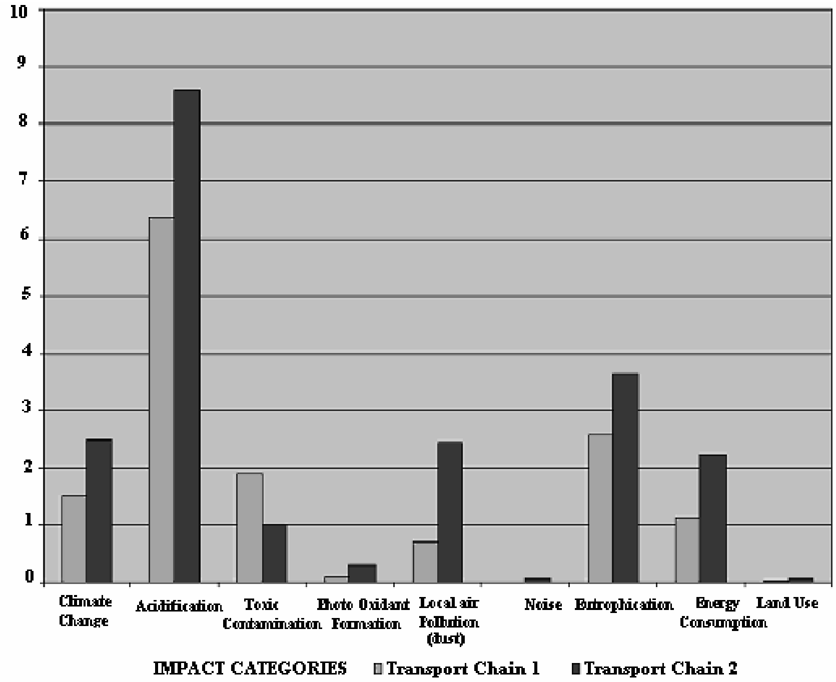

Fig. 4. Normalized inventory results with geographic factors introduced.

Conclusions

In this case study data for two different transport chains has been collected for comparing the environmental performance of transport chains. However, the study does not show how to optimise each chain. This will require more detailed data on machinery systems. It was decided to study only the operational phase since previous studies [4], [5] show that cradle to gate data for fuel contribute less than 10 % to the impact caused by the combustion of the fuel during the life time of a transport means. The building of the subsystems contributes less than 1% to the total environment burdens. Also the maintenance of the transport systems will give minimal contribution. These conclusions depend, however, on the system boundaries chosen. In the main report "Risk factors associated transport system and their influence on Climate Change", the importance of the impact categories is discussed. The impact category toxic contamination (TBT, Pb, etc.) is difficult to evaluate since local impacts are not included in some of the evaluation models used.

The use of land-area and the effects of noise exposure have been evaluated. We see from the Figure 3 and Figure 4 that land use contributes minimal to the total environmental burdens. However, the results show that for chain 2, which to a great extent is a route through densely populated areas, noise should not be neglected as an important impact. The results seem to turn out very similar irrespective of valuation methods used.

The preliminary results are interesting information for further research, for transport companies and governmental bodies in their decision making. The transport companies may use such information to report the environmental performance of transport chains and to plan their logistics. For governmental bodies the information can be used for environmental policymaking ("green" taxation etc.). As a transport means will be a part of an entire transport chain it seems reasonable to put taxes on the entire transport chain and not on a single means. Databases with environmental performance data for transport chains, not only for single transport means, should be developed. Finally the project results are of great value for further research on how to optimize the economic and environmental performance of transport chains, and for the development of ecoefficiency indicators for transportation.

References

1. Goodkoop, M. - *The Eco-Indicator 95*, Final Report, ISBN 90-72130-80-4, 1995
2. Hanna Alve & Jyri Vilko - *Environmental Impacts and Risks in Maritime Supply Chain Route Selection.*Transport Logistics and Energy Efficient Supply Chains across the Borders Compilation of the Results of Two Seminars Held at St. Petersburg and Kouvola, 2010, 5-17..
3. Nam S.K - *Assessment of CO emissions for intermodal freight transport systems and truck-only system: A case study of the Western-Eastern Europe corridor.* Journal of Transport Geography, 2008.
4. Nicolae, F., Bosneagu R - *Risk factors associated transport system and their influence on Climate Change*. Geo-climatic changes on land and sea Dobrogea, GLOBE Symposium 2009.
5. Nicolae, F. - *A mathematical method to determine the energy consumption and pollutant emissions from maritime transport*. NAV-MAR-EDU 2007. ISBN 978-973-8303-84-3, Constantza, 2009
6. Oswald M.,R. - *Rating the sustainability of transportation investments: corridors as a case study*, University of Delaware, 2008.
7. Schau, E.M. - *Environmental Performance of Transport Systems.* NTNU, Trondheim Norwegian University of Science and Technology, Faculty of Social Science and Technology Management, Master Thesis, 2003.
8. CFR - *Personal communication.* Romanian Rail Company (CFR)*,* Ferryboat Dep., 2009.
9. GLOBE - *Influence of geo-climatic changes on global and regional sustainable development in Dobrogea,* Control: 3-PC-3535 Partnerships program in priority areas, 2009
10. IMO - *Prevention of air pollution from ships*, Marine environment protection committee 59th session Agenda item 4 MEPC 59/INF.10 9 April 2009.
11. IMO - *Measures to control potential adverse impacts associated with the use of tributylin compounds in antifouling paints*, MEPC. 46 (30), 2008.
12. RNA - *Personal communication.* Romanian Naval Authorithy (RNA)*,* SAR Pollution, 2009.
13. RRA - *Personal communication.* Romanian Road Authorithy (RRA)*,* Logistics Dep., 2009.

Metodologie pentru analiza comparativă a performanţelor de mediu în transportul multimodal

Rezumat

Obiectivul acestei analize comparative este legat de creşterea experienţei metodologice în studiul sistemelor alternative de transport din punctul de vedere al performanţei de mediu. Lucrarea se referă la etapa de exploatare a mijloacelor de transport atât din punctul de vedere al impactului subsistemelor mobile sau în staţionare asupra sistemului de transport. Studiul se va concentrază asupra emisiilor, zgomotului şi utilizarea spaţiului. Lucrarea se rezumă doar la faza operaţională asociată mijloacelor de transport. Prin urmare, diminuarea resurselor naturale, procesul de fabricare şi reciclare a acestora nu sunt incluse în această analiză. Studiul de caz se referă la două sisteme diferite ale transportului intermodal.