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Panagakos, George; Psaraftis, Harilaos N.

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Model-based corridor performance analysis – An application to a European case

George Panagakos, [a,1] Harilaos N. Psaraftis [a]

[a] *Technical University of Denmark, Anker Engelunds Vej 1, 2800 Kgs. Lyngby,Denmark*

Abstract

The paper proposes a methodology for freight corridor performance monitoring that is suitable for sustainability assessments. The methodology, initiated by the EU-funded project SuperGreen, involves the periodic monitoring of a standard set of transport chains along the corridor in relation to a number of Key Performance Indicators (KPIs). It consists of decomposing the corridor into transport chains, selecting a sample of typical chains, assessing these chains through a set of KPIs, and then aggregating the chain-level KPIs to corridor-level ones using proper weights. A critical feature of this methodology concerns the selection of the sample chains and the calculation of the corresponding weights. After several rounds of development, the proposed methodology suggests a combined approach involving the use of a transport model for sample construction and weight calculation followed by stakeholder refinement and verification. The sample construction part of the methodology was tested on GreCOR, a green corridor project in the North Sea Region, using the Danish National Traffic Model as the principal source of information for both sample construction and KPI estimation. The results show that, to the extent covered by the GreCOR application, the proposed methodology can effectively assess the performance of a freight transport corridor. Combining the model-based approach for the sample construction and the study-based approach for the estimation of chain-level indicators exploits the strengths of each method and avoids their weaknesses. Possible improvements are also suggested by the paper.

Keywords: Sustainable transportation; Freight transportation; Transport corridors; Green corridors; TEN-T core network; Performance assessment

1. Introduction

Despite voices suggesting that modal shifts away from truck may be neither easy to achieve nor significantly effective in reducing total transportation emissions (Nealer et al., 2012), the general view considers shifts from road to intermodal chains as a means for improved environmental performance of freight transportation with regard to greenhouse gas (GHG) emissions (e.g. Janic, 2007; Patterson et al., 2008; Regmi and Hanaoka, 2015). The latest EU White Paper on transport has set the goal of

[1] Corresponding author. Tel.: +45-4525-6514. E-mail address: geopan@dtu.dk

shifting 30% of road freight over 300 km to other modes by 2030, and more than 50% by 2050 (EC, 2011). A basic tool for meeting this target is the 'green corridors,' a European concept denoting a concentration of freight traffic between major hubs and by relatively long distances. Green corridors aim at improving the competitiveness of rail and waterborne transport which, in turn, would enable exploitation of the superior GHG-emission characteristics of these modes in comparison to road haulage. The introduction of the related Rail Freight Corridors (RFCs) in 2010 (EU Regulation No 913/2010) and the TEN-T Core Network Corridors (CNCs) more recently (EU Regulation No 1315/2013) indicates that the corridor approach is gaining popularity as an implementation tool in EU transport policy.

In addition, numerous green corridor applications have popped up at the regional level, especially in the Baltic Sea Region, where this concept has been very popular. Examples include the East West Transport Corridor (Fastén and Clemedtson, 2012), the Swedish Green Corridor Initiative (Wålhberg et al., 2012) and the related GreCOR (Pettersson et al., 2012) and Bothnian Green Logistic (Södergren et al., 2012) corridors, the Scandria Corridor (Friedrich, 2012), the Midnordic Green Transport Corridor (Kokki, 2013) and the Green STRING Corridor (Stenbæk et al., 2014). Outside Scandinavia, examples of important green corridor projects include the Rotterdam-Genoa (Corridor A, 2011) and the Munich-Verona Brenner (Mertel and Sondermann, 2007) corridors, both of which are now integrated into broader RFC and CNC schemes.

A common feature of all these initiatives relates to the need for monitoring the performance of the relevant transport corridors in terms of pre-specified qualities. Although most of these projects define a set of indicators to be used for monitoring performance either explicitly (Mertel and Sondermann, 2007; Corridor A, 2011; Fastén and Clemedtson, 2012; Wålhberg et al., 2012; Pettersson et al., 2012; and Öberg, 2013) or implicitly (Friedrich, 2012; and Stenbæk et al., 2014), very few propose a performance monitoring methodology.

The literature on corridor assessment and evaluation is quite extensive. However, very few articles can be found in the area of continuous monitoring of a multimodal transport corridor. They are either unimodal (road) in scope (Ramani et al., 2011; Muench et al., 2012) or multimodal but focusing on specific transport chains with no aggregation at corridor level (Regmi and Hanaoka, 2012). This kind of aggregation is only attempted in specialised reports produced by international financial institutions like the World Bank and the Asian Development Bank. These studies, however, are rather limited in scope mainly being designed to address bottlenecks related to transport infrastructure and operations between developing countries such as excessive delays in nodes, customs clearance, etc. (Raballand et al., 2008; ADB, 2013).

The present paper addresses this gap by proposing a methodology that was first developed in the framework of the EU-funded project SuperGreen[2] and was subsequently refined and applied along the GreCOR corridor of the homonymous project.[3] The specific objectives of the paper are: (i) to briefly present the methodological approaches identified in the literature for monitoring the

[2] SuperGreen was an FP7 Coordination and Support Action (2010-2013) that supported the European Commission on green corridor development (http://www.supergreenproject.eu/).

[3] GreCOR – Green Corridor in the North Sea Region – was an Interreg IVB project (2012-2015) that promoted the development of a co-modal transport corridor in the North Sea Region.

performance of a transport corridor, (ii) to propose a new method that involves the periodic monitoring of a standard set of transport chains along the corridor in relation to a number of Key Performance Indicators (KPIs), and (iii) to present the results of applying this method on the GreCOR case study.

In an environment of scarce data on freight logistics, the main contribution of our work is a freight corridor assessing methodology that involves decomposing the corridor into transport chains, selecting a sample of typical chains on the basis of transport model results, assessing these chains through a set of KPIs on the basis of stakeholder information, and then aggregating the chain-level KPIs to corridor-level ones using proper weights. Unlike previous attempts, the proposed method combines the merits of a model-based approach in selecting typical transport chains and a study-based approach in estimating the KPI values. The insights provided by the paper can be useful to practitioners who are engaged in implementing corridor schemes as a means of improving the sustainability of freight logistics. They can also benefit researchers interested in advancing policy instruments, as well as educators addressing sustainability in transport related infrastructure and operations.

The rest of this paper is organised as follows. Section 2 briefly reviews previous research and practices on corridor performance monitoring. Section 3 is devoted to the proposed methodology and its evolution through several efforts in the past. The application of the method on the GreCOR corridor, including the construction of the chain sample, the estimation of the KPI values and their aggregation is presented in Section 4. The paper closes with a summary of the main conclusions reached and suggestions for possible future improvements.

2. Literature review

Albeit mainly a transportation theme, the corridor concept is a multidimensional affair striving to integrate diverse sectoral policies in transport, housing, economic development and environmental protection (Priemus and Zonneveld, 2003; Witte et al., 2013). As such, assessing a transport corridor is not an easy task. The relevant literature is extensive and covers a range of perspectives including the modal coverage, focus (micro/macro), scope (infrastructure/operations) and intended use (pre-feasibility, ex ante, on-going or ex post evaluation).

For the purposes of the present paper, we have restricted coverage to performance monitoring methods, which are suitable for sustainability[4] assessments. For the sake of simplicity, only the most important documents published during the ten years elapsed since the introduction of the green corridor concept by the European Commission (EC, 2007) are listed in Table 1. In addition to other areas of interest, Table 1 indicates the number of corridors examined, possible decomposition into transport chains, and the provision of a KPI aggregation method.

Ramani et al. (2011) present a performance measurement methodology designed for highway corridor planning, which addresses the five goals of the Texas Department of Transportation (reduce congestion; enhance safety; expand economic opportunity; preserve the value of transportation assets; and improve air quality). Performance against these goals is measured through 12 indicators. The

[4] Although there is no standard definition for sustainable transportation, there seems to be a consensus that it involves three pillars: economic development, environmental protection and social acceptance (Council, 2006; Ramani et al., 2011; Panagakos and Psaraftis, 2014).

multi-attribute utility theory approach is used for normalising KPI values and aggregating them into a sustainability index using weights developed through a Delphi process in a workshop setting.

A similar approach is followed by Zhang et al. (2015), who present a model aiming at helping the Maryland State Highway Administration estimate the sustainability impact of highway improvement options early in the transportation planning process. This is done through 30 indicators grouped in six categories (mobility; safety; socio-economic impact; cost; energy and emissions; natural resources). Indicator values are calculated by the model on the basis of traffic, road geometry, demographic, economic, land use and GIS data. This feature, also exhibited by Ramani et al. (2011), enables corridor assessment at the pre-feasibility (planning) stage but renders the respective methodologies inapplicable for monitoring purposes.

Two different approaches have been used for ex post corridor assessments. Muench et al. (2012) apply the Greenroads rating system to assess the sustainability of seven road projects funded by the US Federal Lands Highway Program. This is a collection of 48 sustainability best practices, divided into 11 required and 37 voluntary ones. Each voluntary practice is assigned a point value depending on its impact on sustainability. Depending on the sum of points a project scores against the voluntary practices, it earns a certification level (evergreen, gold, silver, certified or none).

The time-cost-distance (TCD) approach[5] is used by three documents for identifying infrastructural and administrative bottlenecks and for assessing and comparing corridor performance. Regmi and Hanaoka (2012) assess the infrastructure and operational status of two corridors in Northeast and Central Asia that offer maritime, road and rail freight services. The paper treats each corridor as a single transport chain consisting of a series of consecutive legs performed by different modes. No aggregation is required for such a setting.

Arnold (2006) provides a detailed description of the TCD approach in outlining the methodology proposed by the World Bank for assessing corridor performance. On the basis that a corridor is generally composed of several alternative routes, the method focuses on measuring the performance of each route. In the absence of more aggregate information, which is usually the case, a sample needs to be constructed. Although the document does not specify the composition of the sample, one can infer from the subsequent steps of the methodology that the sample is composed of transport chains. The indicators suggested are cost, time and reliability. No details are given on how the chain-level indicators are transformed into route-level ones. The comparison with benchmarks leads to the identification of problems on a route basis. As a next step, route problems are translated into performance deficiencies at the links and nodes. No attempt is made to compute indicators at the corridor level. The absence of environmental considerations from the analysis is also noticeable.

Although Raballand et al. (2008) is a World Bank report, it applies a much simpler version of the methodology proposed by Arnold (2006). The report examines the Northern Corridor connecting the port of Mombasa, Kenya with a number of countries in Sub-Saharan Africa. The analysis is restricted to the transit time and reliability of two road connections, as well as the cargo dwell time in the port of Mombasa. The report highlights the serious difficulties encountered in data collection.

[5] The TCD approach consists of composing a chart that displays the changes of time or cost over distance. Distance occupies the horizontal axis, while time or cost occupies the vertical axis.

Table 1. Main features of selected bibliography

Author (Year)	Intended use	Road	Rail	Sea	Focus	Infr.	Oper.	Corr.	Chain	Aggr.	Approach	Data source	Area
A. Articles													
Ramani et al. (2011)	Pre-feasibility	√			Micro	√	√	1		√	Multi-attribute utility theory	Data of the Texas DoT	US
Muench et al. (2012)	Ex post	√			Macro	√	√	7		√	Greenroads framework	Site visits, survey of studies	US
Regmi & Hanaoka (2012)	Ex post	√	√	√	Macro	√	√	2			Time-cost-distance	Site visits, studies, questionnaire	Asia
B. Reports													
Arnold (2006)	Ex post	√	√	√	Macro	√	√		√	√	Time-cost-distance		
Raballand et al. (2008)	Ex post	√			Macro	√	√	1	√		Time-cost-distance	Drivers' forms, studies, interviews	Africa
ADB (2013)	On-going	√	√		Macro	√	√	6	√	√	Cost-time-distance	Drivers' forms	Asia
ETC (2014)	Ex ante	√	√	√	Macro	√	√	1	√		PESTL analysis, Cost-time-distance	Official statistics, studies, interviews	EU
EC (2014)	Ex ante	√	√	√	Macro	√		1			Gap analysis, bottleneck identification	Official statistics, studies	EU
C. Research works													
Fastén & Clemedtson (2012)	On-going	√	√	√	Macro			1	√		Assessment framework	Interviews	EU
Zhang et al. (2015)	Pre-feasibility	√	√		Micro	√	√	1		√	Multi-attribute utility theory	Data of the Maryland DoT	US

In general, the ex post assessments are one-time studies that cannot be used for monitoring purposes. Furthermore, their large scale is often associated with high costs that usually prohibit the frequent repetition required for monitoring operations.

The ETC (2014) and EC (2014) reports for the Scandinavian-Mediterranean (ScanMed) rail freight and core network corridors respectively are exemplary of the specialised Transport Market Studies undertaken for all such European corridors. In addition to providing a detailed description of the existing networks, these massive reports compare the capacity of planned infrastructure to the expected traffic volume in 2030 in order to identify potential bottlenecks to be addressed. The nature of this ex ante assessment is incompatible to the monitoring perspective of the present paper.

This is not the case, however, for the two on-going assessment studies of Table 1. The Corridor Performance Measurement and Monitoring methodology applied by the Asian Development Bank in the framework of its Central Asia Regional Economic Cooperation (CAREC) Program is the most advanced and complete one found in the literature (ADB, 2013). The methodology, applied on six corridors, is based on the TCD approach. The indicators followed are: (i) the cost incurred to travel a corridor section, (ii) the speed to travel along a corridor, (iii) the time it takes to cross a border crossing point, and (iv) the cost incurred at border crossing clearance. Data are collected through CAREC's partnership with 13 national road carrier associations directly from drivers and freight forwarders using actual commercial shipments as samples. Average cost and speed of transport are calculated using cargo tonnage as weights.

Useful methodological insights can also be obtained by the East-West Transport Corridor (EWTC) project, which suggests limiting the on-going assessment to a small number of wisely selected services along the corridor (Fastén and Clemedtson, 2012). In selecting these services, EWTC advises always keeping in mind the purpose of the analysis, selecting corridor sections with a small number of parallel operations enabling effective monitoring, identifying large and stable flows, selecting operations ran by organisations that are willing to share information, and taking advantage of existing systems for data collection including relevant ICT applications like fleet monitoring systems, electronic toll systems, etc. The approach suggested by EWTC is sensible and practical. Its only weakness relates to the fact that, as explicitly stated by Fastén and Clemedtson (2012), the proposed methodology aims to assess selected corridor components (services) rather than the corridor as such.

3. Methodological considerations

3.1 The evolution of the method

The development of a corridor benchmarking methodology was a key objective of the SuperGreen project. The relevant work involved: (i) the selection of a set of corridors to provide a suitable field for testing the methodology, (ii) the selection of a set of KPIs addressing the sustainable development goals of the EU, and (iii) the benchmarking method itself (Panagakos, 2016).

A two-stage approach was followed in selecting the SuperGreen corridors. The pre-selection of the first stage reduced an initial list of 60 potential corridors to 15 on the basis of corridor length, population affected, freight volume, types of goods transported, number and seriousness of bottlenecks, transport and information technology used, and quality of supply chain management. The deeper analysis of the second stage that considered in addition land use aspects resulted in a

recommendation of nine corridors for final selection. An especially arranged stakeholder workshop confirmed this selection with some adjustments (Salanne, 2010).

The SuperGreen KPIs were selected through an elaborate two-phase procedure that drew heavily on stakeholder input. An initial set of 24 KPIs was the output of the first phase, which involved: (i) the compilation of a gross list of indicators, (ii) their grouping into five categories (efficiency, service quality, environmental sustainability, infrastructural sufficiency, and social issues) to combine the three sustainability dimensions with the adequacy of the infrastructure, and (iii) their internal filtering. The feedback received through the five stakeholder / Advisory Committee meetings of the second phase emphasized the need to simplify the indicators into a more concise set, as follows:

- Transport price (€/ton-km);
- Transport time or speed (hours or km/h);
- Reliability (% of shipments delivered within agreed time windows);
- Frequency of service (number of services per year);
- CO_2-eq emissions (g/ton-km); and
- SOx emissions (g/ton-km).

In terms of methodology, we initially suggested: (i) decomposing the corridor into transport chains, (ii) selecting a sample of typical chains, (iii) benchmarking these chains using a set of KPIs, (iv) aggregating the chain-level KPIs to corridor-level ones, and (v) aggregating the corridor-level KPIs into a single corridor rating using proper weights for the averaging (Panagakos, 2016). This second level of aggregation was soon abolished because the weights needed are very much user-dependent constituting a political issue best left for policy makers to decide.

Initially the selection of the typical chains was based on the so-called 'critical segment' of the corridor, the link containing the major geographical barrier of the corridor, on the hope that such a link would have been studied better than other parts of the corridor leading to more detailed data. Based on the early results of SuperGreen, Panagakos (2012) suggested replacing the critical segment as the basis for the sample construction with a corridor study similar in nature to the Transport Market Study foreseen by the RFC Regulation of the EU. The term 'study-based approach' is hereby borrowed from EC (2014) to specify studies as the source of information used in selecting typical transport chains along the corridor under consideration. With the same publication, Panagakos also suggested considering this sample as the 'basket' of transport chains that would be used for monitoring the performance of the corridor on an annual basis, in the same way the Consumer Price Index is calculated around the world on the basis of a 'basket' of goods and services.

Herrero (2015) applied the proposed study-based approach on the ScanMed corridor. The ETC (2014) and EC (2014) documents of Table 1 were reviewed to identify the necessary information. The first one is the Transport Market Study of the ScanMed Rail Freight Corridor. Its main objective is to provide the corridor's Infrastructure Managers with a detailed analysis of freight market development and an estimate of future customer demand. It also provides recommendations for operational and organisational improvements of the rail freight traffic along the corridor. It covers all three modes (road, rail, sea), albeit at varying degrees of detail. In terms of rail freight transport, it provides estimates of the yearly trains between a small number of OD pairs, calculated by extrapolating the number of trains observed during two weeks of year 2012. For road freight traffic, the study analyses the ETISPLUS 2010 database and identifies for each pair of corridor countries and each direction the

three highest volume OD pairs. No maritime connections are suggested by ETC (2014). The second study examined is the Multimodal Transport Market Study of the ScanMed Core Network Corridor (EC, 2014). The objective of this study is to evaluate the future requirements towards the transport infrastructure of this corridor. As such, the study concentrates on infrastructural issues and is of limited use for the application at hand.

It follows that the data provided by these two studies is rather scarce and incoherent for monitoring the performance of a corridor through a comprehensive chain sample. The main difficulties encountered by Herrero (2015) relate to: (i) serious incompatibility problems when combining data from different databases, and (ii) the complete absence of information on maritime chains, for which the author had no option but using model results. His KPI estimates are based on gross assumptions limiting their end value. It became clear that a higher level of consistency would require a different approach.

In view of these difficulties, the present paper proposes to found the construction of the sample on information sourced in the flow results of a transport model ('model-based approach'). The strengths and weaknesses of this approach derive from the nature of modelling. Its main advantage relates to the ability of models to estimate traffic even in the absence of data, which leads to a comprehensive and coherent picture of all flows on the corridor for each segment. The low cost associated with the use of models, once built, is another important advantage. On the negative side, the simplified character of models may lead to estimates that differ from reality. Of course, accuracy improves with a better calibration of the model but this requires extensive use of observed traffic load data, which increases the model development cost. Furthermore, the fact that model results may differ from approved national plans might lead to resistance from certain stakeholders. In order to address these concerns, the proposed methodology involves a sample verification process by appropriate stakeholders prior to KPI estimation.

3.2 The proposed methodology

The proposed methodology consists of the following nine steps (Figure 1):

Step 1. Define the purpose of the analysis: A corridor consists of various types of services offered by competing operators through organised supply chains over a multimodal infrastructural network within an international regulatory and administrative framework. In a complex system like this, setting the exact purpose of the analysis and its intended use is essential. A clear goal statement will assist decision making throughout the analysis and will affect all subsequent tasks. In general, it should be kept in mind that due to resource limitations, there is a trade-off between the width and the depth of analyses of this sort.

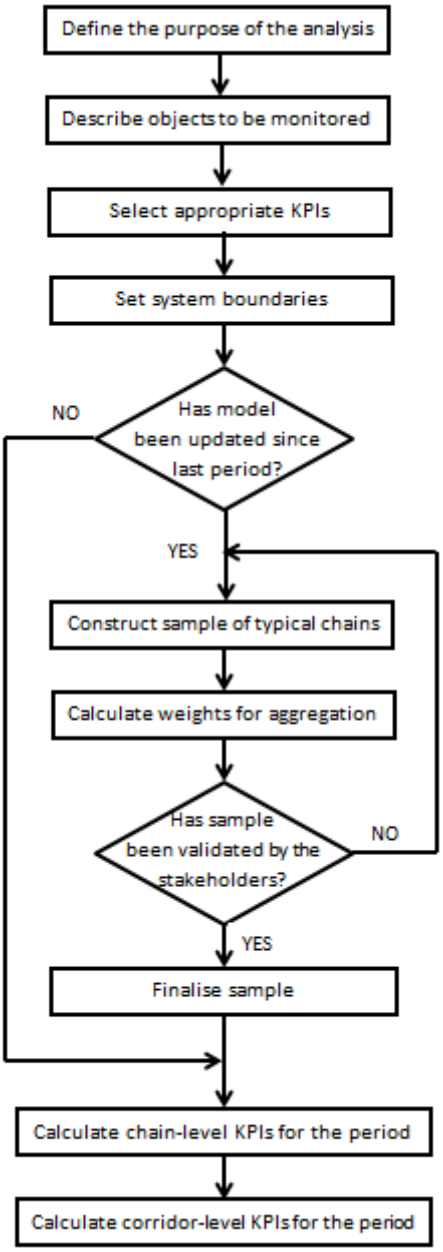

Figure 1. Flow diagram of the proposed methodology

Step 2. Describe objects to be monitored: Corridors tend to be described by locations that represent rather broad geographical areas/places where the corridors start, end or pass through. This has to be translated into a more detailed definition that includes the modes to be examined and the routes comprising the corridor. Each route should be described as a set of designated links, terminals and supporting facilities. Only existing major links should be designated to a route.

Step 3. Select appropriate KPIs: The SuperGreen KPIs of the previous section is an indicative list but, in principle, KPIs should be selected by the corridor management based on the objectives being pursued. Caplice and Sheffi (1994) provide eight criteria for KPI selection: validity (the activities being measured are accurately captured), robustness (similar interpretation by all users/organisations

and repeatability), usefulness (meaningful to decision makers and provision of guidance for actions), integration (all relevant aspects of the process are included and coordination across functions is promoted), economy (benefits outweigh costs), compatibility (with existing information), level of detail (sufficient degree of granulation or aggregation), and behavioural soundness (minimised incentives for game playing). They also identify two primary trade-offs: validity versus robustness (the inclusion of more specific aspects renders the indicator less comparable) and usefulness versus integration (the more coordination across functions is promoted, the less guidance is provided to a particular function manager).

Step 4. Set system boundaries: The boundaries imposed on the analysis need to be defined at this point. The first concerns corridor coverage and relates to the model employed. Ideally, the information needed for sample construction should be sought in models covering the entire corridor area in the same level of detail. If this is not the case, it is safer to delimit coverage to only the part of the corridor lying within the geographical scope of the model used.

A second model-specific feature concerns the catchment area of the corridor defined as the area surrounding the constituent routes of Step 2. As such, the zonal system of the model has a direct bearing on the definition of the corridor catchment area.

A third restriction relates to the length of the chains, which is a decisive factor in modal choice. The dominance of road transport is undisputable for short distances (Janic, 2007; EC, 2011). For EU applications, a restriction aligned to the 300 km limit appearing in the EU modal shift target (refer to Section 1) is a sensible approach.

The final restriction concerns the location of the chains in relation to the catchment area of the corridor. In general, the model chains can be either: (i) totally irrelevant to the corridor under examination; (ii) originating and ending outside the catchment area but still crossing the corridor; (iii) originating or ending within the catchment area; or (iv) originating and ending within the corridor catchment area. With the exception of the first category, all other types of chains have a bearing on the performance of the corridor, the extent of which depends on the actual overlap of the specific route with the corridor network. In order to exclude the possibility of external distortions, the proposed methodology restricts analysis to the so-called 'corridor chains' originating and ending within the corridor catchment area. The term 'corridor chain' is borrowed from the Transport Market Study of the ScanMed RFC (ETC, 2014), which follows exactly the same approach.

Step 5. Construct sample of typical chains: In general, the construction of the sample should exploit all information provided by the model. Given that all comprehensive transport models distinguish freight traffic by commodity and mode/chain type, a sample structure with four levels of aggregation is proposed (

Figure 2). The corridor (Level 1) consists of commodity groups (Level 2), as it is this attribute that basically defines the modes, chain types and vehicles used. Commodity groups are further decomposed into sub-groups based on chain type (Level 3). These sub-groups comprise of individual chains (Level 4).

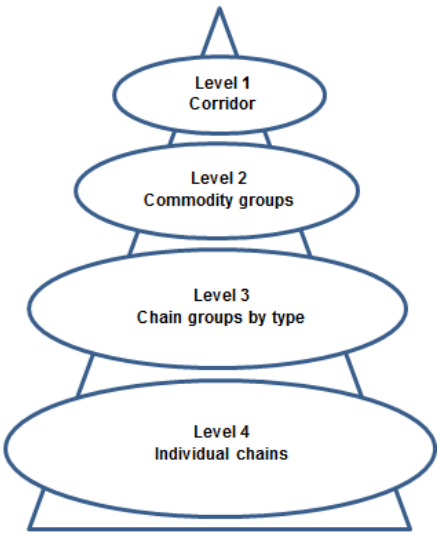

Figure 2. Sample structure

The commodity groups are formed on the basis of the requirements that cargoes impose on transport operations. The following groups need to be distinguished:

- Containerised cargoes moved in reefers (e.g. agricultural products)
- Containerised cargoes moved in dry containers (e.g. manufactured goods)
- Liquid bulk cargoes (e.g. crude oil)
- Dry bulk cargoes (e.g. coal)
- Cargoes requiring special vehicles and handling equipment (e.g. wood products)
- Cargoes that cannot be mixed easily with other cargoes (e.g. waste)
- Cargoes that entail special business arrangements (e.g. mail)
- Other non-containerised cargoes (e.g. fabricated metal products).

The formation of the chain type groups depends on the level of detail provided by the model. Distinction of chain types by mode (road, rail and waterborne) is the minimum acceptable typology.

The general principle guiding the selection of individual chains calls for the best possible representation of the range of services acquired. It is obvious that the fit depends on the number of chains in the sample which, in turn, depends on the available resources. In any case, the following criteria should be taken into consideration:

- The importance of a particular chain type relative to the total traffic. In general, higher importance should be reflected in a larger number of chains in the sample.
- The degree of homogeneity in the range of services provided under a particular chain type. Higher homogeneity should lead to fewer sample chains.
- The degree to which the various services covered by a chain type are subject to different influences and pressures in relation to the KPIs that will be used in the analysis. Higher sensitivity differences require more chains in the sample.
- The likelihood that a particular service will continue to be available for a reasonable period. Unstable services should be avoided.

- The extent to which a service can be defined and described clearly and unambiguously to ensure constant quality of service over time. Inadequately defined services should be avoided.

Step 6. Calculate weights for aggregation: The main advantage of the model- over the study-based approach in sample constructing relates to the possibilities a model provides in calculating the weights needed in the KPI aggregation. Weights measure the relative significance of each chain in the route it belongs and in the entire corridor. These weights need to be fixed to permit historical comparisons.[6] Weights should be adjusted to also account for chain types not represented in the sample.

The weights depend on the particular metric selected for each KPI. Indicators measured on a per tonne-km basis, as are for example the price, CO_2-eq and SOx emission KPIs of SuperGreen, should have weights expressed in tonne-km units. Transport time can only be aggregated if expressed as average speed. The volume of cargo is probably the most suitable weight for aggregating transport time (or speed) and reliability. Frequencies require particular attention. Generally, in serial services it is the least frequent one that determines the frequency of the chain.

Step 7. Finalise sample: As are, the sample chains of Step 5 are not suitable for KPI assessment. Having resulted directly from model output, they connect zonal centroids rather than real addresses. They need to be adjusted to reflect real services offered by providers between locations in the zones of origin and destination through specific terminals and by specific vehicle types. This can only be done by stakeholders, willing to cooperate, who either provide or acquire such services. They also need to avail additional information required for the complete description of the service like shipment size, environmental characteristics of the vehicles used, possible relocation of vehicles/equipment, etc. Only when a service is verified and fully described by a stakeholder can enter the sample. If for any reason this is not the case, the chain has to be replaced by a similar one from the model results, new weights have to be calculated (if needed) and the stakeholder verification process should be repeated.

The finalised sample remains relatively constant as long as the model is not being updated. When this occurs, the entire process has to be repeated. Minor adjustments to the sample may be needed if for any reason a sample service is no longer offered. The provisions of the price index theory for missing data (Pink, 2011) can apply in such cases.

Step 8. Calculate chain-level KPIs for the period: Once a year[7] the participating stakeholders are asked to provide the information required to calculate the KPI values. Average figures calculated from actual data over the previous period need to be reported. In the absence of actual data, the respondent's estimates could be used as good approximations, if they are clearly stated as such.

Price estimates should be market-determined figures. Use of own transport means should be valued at the prevailing hire rates.

[6] In index theory, bilateral indices are used to compare two sets of variables corresponding to two different periods. In the Laspeyres approach, followed here, the two sets of variables are applied on the same sample of services which is the one that was acquired in the first period (Pink, 2011).

[7] Any other interval pre-determined by the corridor management can be used for this purpose. Annual estimates are compatible with both the provisions of the RFC Regulation and the internal reporting procedures of most private companies.

Emission KPIs need to be calculated by a specialised emission calculator. In SuperGreen, the web-based tool EcoTransIT World[8] has been used but, as long as certified footprint calculators are not available, any other model could be used in its position, provided that a relevant qualification escorts the results. The emission calculator permitting, CO_2-eq emissions are preferable to CO_2, as the former accounts for the warming potential of all GHGs. Well-to-wheel emissions should be reported in order to enable meaningful comparisons across modes. The monitoring purpose of the analysis is better served if emissions are calculated on the basis of user specified inputs. Only if this is impossible, the default values of the calculator can be used provided that a relevant qualification is clearly stated.

Step 9. Calculate corridor-level KPIs for the period: Three rounds of KPI aggregation are required to reach the corridor level. The first one concerns the chain types within each commodity group (Level 3 of

Figure **2**) that are represented in the sample by more than one chain. This is done by applying the simple weighted average formula. The second aggregates chain type groups (Level 3) to commodity groups (Level 2). Adjusted weights are used here in order to consider chain types not represented in the sample. The third level of aggregation converts commodity group indicators (Level 2) to corridor KPIs (Level 1) through the direct weighted average method.

The final step of indexing involves a normalisation procedure that allows the comparison of two sets of values either over time (temporal indices) or transport modes (modal indices) for a common commodity or group of commodities. Modal indices are produced by setting the corridor-level values of each KPI to 100.0 and converting all other values proportionally. The same approach is repeated for every subsequent year. For temporal indices, the KPIs of subsequent years are normalised against the corresponding base year indicators that are all set to 100.0.

It needs to be emphasized that the method outlined above permits monitoring of the performance of a single corridor over time. It is not suitable for comparisons between corridors, as it does not consider differences in corridor characteristics that can be decisive in the overall performance of a corridor.

4. The GreCOR application

4.1 Corridor description

The methodology presented above was applied on the GreCOR corridor in the North Sea Region. The road, rail and maritime networks comprising the corridor appear in Figure 3. The exercise aimed at demonstrating the applicability of the method. As such, no specific objectives were set for the development of the corridor and the SuperGreen KPIs of Section 3.1 were selected for the application.

[8] http://www.ecotransit.org/calculation.en.html

Figure 3. GreCOR corridor networks

4.2 Model employed and boundaries of the analysis

In the absence of a pan-European transport model,[9] the analysis was based on the Danish National Traffic Model (LTM) which handles all types of goods movement related to Denmark, i.e. national transports within Denmark; international transports to and from Denmark; transit transports through Denmark; and transport which may be transferred to transit through Denmark, for example by a new fixed link across the Fehmarn Belt. This last feature is important as it extends coverage to flows between Scandinavia and Europe that presently bypass Denmark. Nevertheless in 2010, the base year of LTM, the share of Denmark in the external trade of the UK was about 1% for both imports and exports. Thus, it was decided to exclude the UK from the analysis. Similarly, the Norwegian part Stavanger-Oslo was also excluded limiting the analysis to the Oslo-Randstad segment. Furthermore, the introduction of the ScanMed core network corridor in 2013 induced the re-alignment of the GreCOR networks along the lines of the more basic ScanMed ones. When this new alignment was introduced into the zonal system of LTM, the GreCOR catchment area of Figure 4 was produced. The disproportionate coverage of German, Dutch and Belgian regions in comparison to the Scandinavian areas is due to the much broader definition of LTM zones outside Scandinavia.

[9] The TRANS-TOOLS model (Ibánez-Rivas, 2010) was being updated at the time.

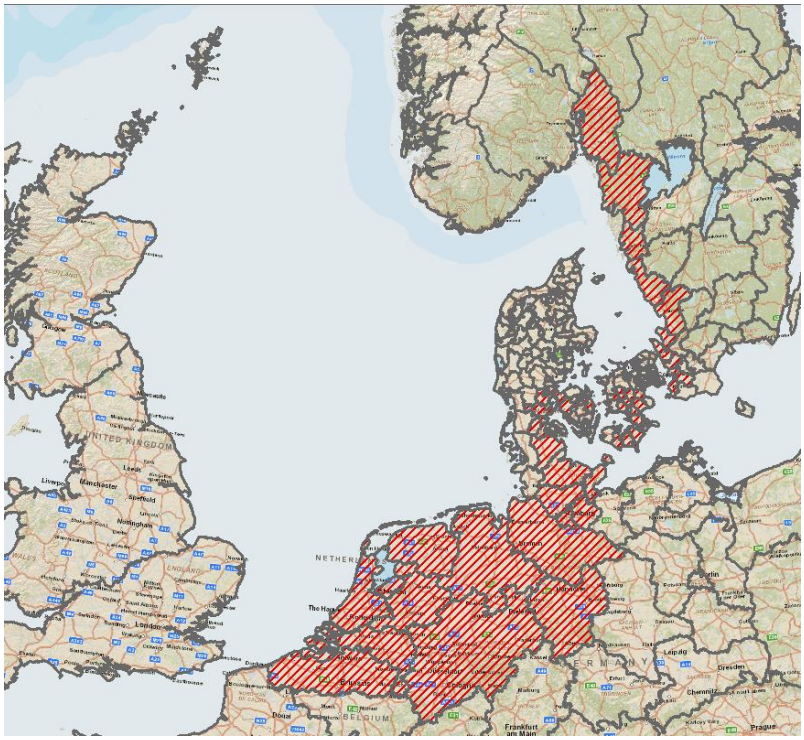

Figure 4. The GreCOR catchment area

The commodities covered by LTM appear in Appendix II together with the corresponding cargo volumes and number of chains. In terms of modes, the model is designed to handle road, rail and maritime transport. For road transport, it distinguishes among seven vehicle types ranging from light goods vehicles to articulated trucks. Three configurations are used for rail transport (conventional train, short wagon train and a combined truck-on-train arrangement) and three more for maritime transport (conventional dry/liquid bulk carrier, containership and a Ro/Ro – ferry – ship).

LTM produces three types of freight flows: (i) between the producer and consumer in the so-called PC-matrix, (ii) the above PC flows broken down into combinations of up to three OD (origin-destination) legs in the so-called chain matrix, and (iii) the separate OD legs in the so-called OD-matrix. The chain matrix is the output type best suited to the present application. Each entry of the chain matrix database corresponds to a transport chain. There are 25 different types of transport chains featuring one, two or three legs each. The chain types used in the analysis are defined in Appendix III.

The results used in this application are those of 2010, which is the latest base (model calibration) year. The database contains more than 2.9 million chains that conveyed almost 507 million tonnes in 2010. For each chain, the model provides general information (commodity type, production zone, consumption zone, annual volume in tonnes, chain type, and containerisation) and leg-specific information (destination zone, destination terminal, mode, consolidation/deconsolidation, and vehicle type).

Three boundaries were imposed on the analysis in order to either reduce the size of the database or exclude irrelevant entries:

- Entries with an annual volume of the cargo flows below 1-tonne were excluded as insignificant

- Domestic flows were excluded as an approximation of the 300 km restriction imposed by the EU modal shift target (refer to Section 1)[10]
- Only 'corridor chains' originating and ending within the corridor catchment area were retained.

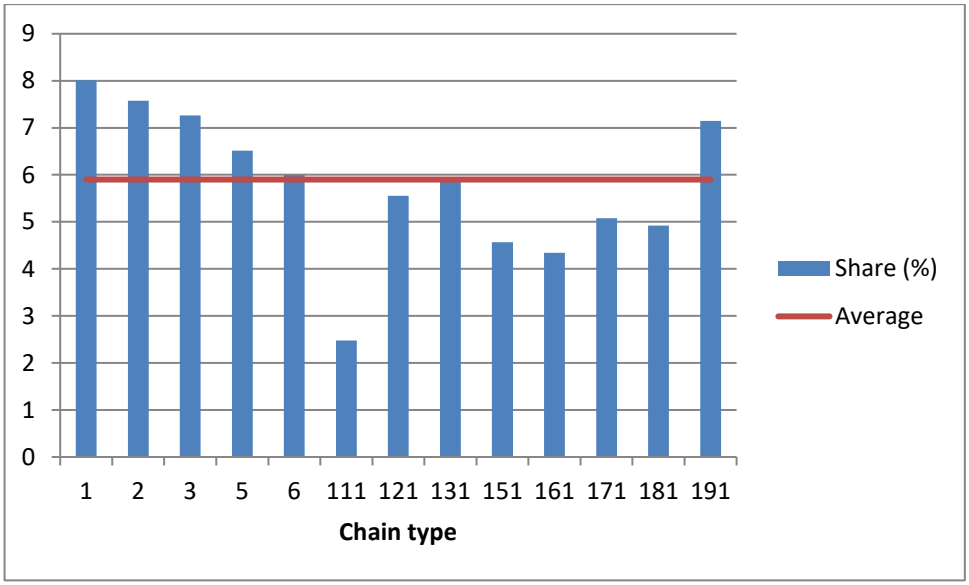

Figure 5. Corridor chains as percentage of international (> 1t) ones by chain type

These restrictions collectively result in 37,446 chains transporting 17.2 million tonnes (refer to Appendix II under the 'final matrix' columns). These figures correspond to 1.3% and 3.4% of the initial values respectively. The percentage share of 'corridor chains' in international ones above 1 tonne by chain type is shown in Figure 5. An interesting observation relates to the fact that although Type 1 (1-leg, 'no crossing' road) exhibits the highest above average share, the corresponding Type 111 (3-leg, 'no crossing' road with feeder services at both ends) displays the lowest below average score. In fact, the same applies to all other road types at a lesser extent. This can be a proof that the design of the GreCOR catchment area (Figure 4) has succeeded in capturing the core services of the corridor, placing less emphasis on the feeder services from/to more remote areas. In any case, the 37,446 chains of the 'final matrix' cover all commodity groups and are still sufficient to ensure a well-designed sample, as they represent 100% of the international chains above 1 tonne in yearly volume that originate and end within the GreCOR catchment area.

4.3 Sample construction

All information provided by the LTM model is taken into consideration for the construction of the sample. Its structure follows the configuration of

Figure **2** and the 23 commodities of Appendix II have been rearranged into 13 commodity groups along the lines proposed in Section 3.2 (Step 5).

[10] This restriction automatically excluded the 2-leg chains which are apparently foreseen only for the domestic trades.

The mechanism followed in building the sample is presented here through the example of Commodity group 22 (fertilizers) which is kept separately due to incompatibility with many other cargoes. The 1,116 chains of Appendix II for this commodity are broken down by chain type in Table 2. The aim is to express the distribution of population chains among the various types with as few sample chains as possible. Having in mind a total sample in the order of 100 chains, we set a tentative target at about 10 chains per commodity group. In the fertilizer case, this would roughly mean selecting one chain per hundred. So, chain types 2 and 3 are represented in the sample with one chain each, while four chains are selected for each one of types 121 and 131. In order to avoid leaving rail and maritime transport uncovered, one additional chain was added in the sample for each of these two types.

Table 2. Sample design for Commodity group 22 (fertilizers)

Chain type		Model results				Corresponding sample		
ID	Description	Annual tonnes	No of chains	Average distance	Tonne*km	No of chains	Adjusted tonnes	Adjusted tonne*km
1	1 leg; road 'no crossing'	2,250	9	453	1,019,240			
2	1 leg; road 'land border'	18,462	100	502	9,275,328	1	21,259	10,889,129
3	1 leg; road 'ferry'	3,515	82	564	1,980,694	1	3,601	2,047,783
5	1 leg; road 'transit DK'	547	2	1,087	594,561			
6	1 leg; road 'direct ferry'	86	1	780	67,088			
111	3 legs; road / road 'no crossing' / road	47	10	423	19,870			
121	3 legs; road / road 'land border' / road	7,335	422	664	4,867,086	4	8,904	6,321,915
131	3 legs; road / road 'ferry' / road	4,539	428	633	2,874,265	4	5,971	3,600,961
151	3 legs; road / road 'transit DK' / road	1,522	12	943	1,434,959			
161	3 legs; road / road 'direct ferry' / road	1,433	13	507	726,696			
171	3 legs; road / rail / road	4,642	16	982	4,556,469	1	4,642	4,556,469
181	3 legs; road / conventional ship / road	9,588	21	684	6,555,747	1	9,588	6,555,747
	Total Commodity group 22	53,964	1,116	630	33,972,003	12	53,964	33,972,003

Once the sample has been designed, the weights (annual tonnages and tonne*km) need to be adjusted to reflect this design. This is done through allocating the weights of types not represented in the sample to the most closely related represented ones under the assumption that their corresponding KPI evolution over time is similar. As such, the weights of Types 1 ('no crossing') and 5 ('transit DK') have been added to the figures of Type 2 ('land border') as the distinction among them is basically geographic, while the Type 3 ('ferry') weights have been increased by those of Type 6 ('direct ferry'). Similar adjustments have been made to the 3-leg road transport chains.

The next step is the selection of individual chains. The type of vehicles employed and the highest annual volume are the criteria for this selection. As an example, Figure 6 shows in light blue the one chain (Fredericia, DK – Borken, DE) selected out of the 100 connections of this chain type. In a similar way, all 156 individual chains comprising the GreCOR sample were selected.

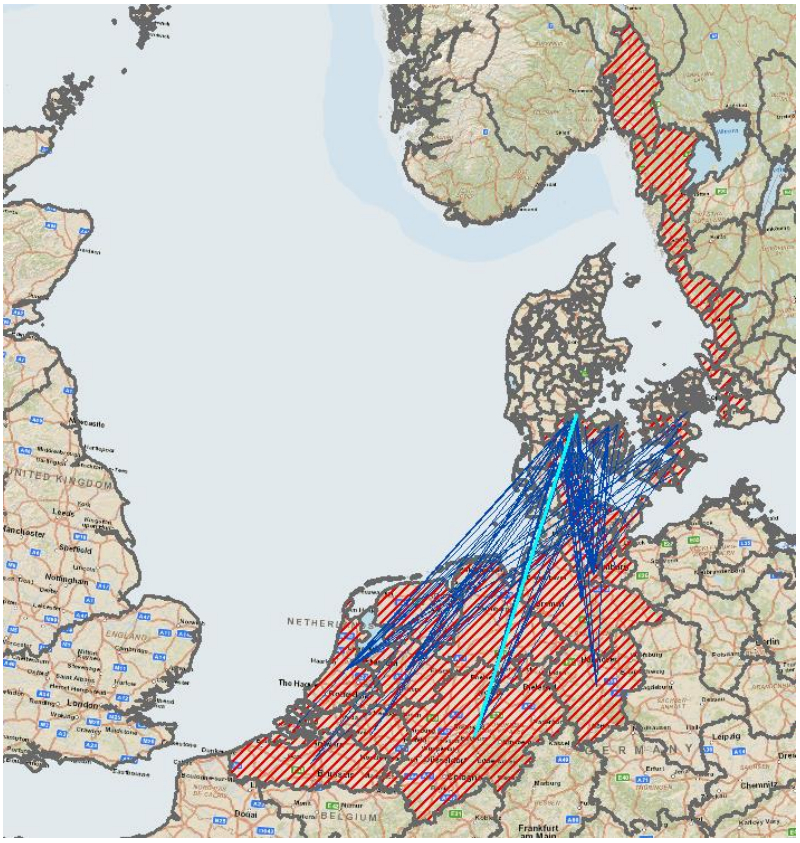

Figure 6. One-leg 'land border' road chains for Commodity group 22 (fertilizers)

4.4 KPI values and their aggregation

The remaining three steps of the proposed methodology involve stakeholder input for verifying the sample chains and providing the information that enters KPI evaluations. Such an undertaking was outside the scope of GreCOR, which only aimed at demonstrating the methodology. In order to display the aggregation mechanism, however, it was decided to apply the methodology based on available default values.

Initially we aimed at the six indicators suggested by SuperGreen, namely the price and speed of transport, the reliability and frequency of service, and the CO_2-eq and SOx emissions. The modal choice function of the LTM model is performed by a logistics sub-model that encompasses default cost and speed estimates for all transport modes. Based on these figures, the values of the relevant KPIs of all sample chains were calculated. Furthermore, the vehicle type information of LTM, in combination with the default values of the EcoTransIT World web-based tool led to the necessary emission estimates. The reliability and frequency indicators had to be dropped due to lack of data.

The resulting corridor indices by commodity group and mode are summarised in Tables 3 and 4 respectively. The variation in KPI values is impressive.

Table 3. KPI values and indices by commodity group

Commodity group	KPI values				KPI indices			
	Cost (DKK/tkm)	Speed (km/h)	CO_2-eq (g/tkm)	SOx (g/tkm)	Cost	Speed	CO_2-eq	SOx
Agricultural products	0.34	12.90	75.38	0.0753	77.4	107.3	107.9	68.2
Coal & lignite	0.18	6.97	29.60	0.0357	41.1	58.0	42.4	32.4
Iron ore & metal ores	0.49	9.22	42.31	0.0497	110.5	76.7	60.6	45.1
Wood & products	0.34	8.73	23.19	0.0333	76.2	72.6	33.2	30.2
Coke & petroleum products	0.16	4.68	10.93	0.0217	35.7	38.9	15.6	19.7
Raw material & wastes	0.30	8.21	18.75	0.0290	66.9	68.3	26.9	26.2
Mail & parcels	1.52	29.29	91.66	0.0965	343.8	243.7	131.2	87.4
Crude oil & natural gas	0.42	6.68	27.34	0.0375	94.4	55.5	39.2	33.9
Fertilizers	1.10	24.47	60.45	0.0683	249.1	203.6	86.6	61.9
Stone & quarry products	0.48	11.83	37.77	0.0449	109.3	98.4	54.1	40.7
All other commodities	0.57	15.93	114.40	0.1912	129.5	132.6	163.8	173.2
Corridor	0.44	12.02	69.84	0.1104	100.0	100.0	100.0	100.0

Table 4. KPI values and indices by mode

Mode	KPI values				KPI indices			
	Cost (DKK/tkm)	Speed (km/h)	CO_2-eq (g/tkm)	SOx (g/tkm)	Cost	Speed	CO_2-eq	SOx
Road	1.52	26.14	79.55	0.0888	344.6	217.5	113.9	80.4
Rail	0.35	18.56	48.54	0.0553	79.0	154.4	69.5	50.1
Shipping	0.19	6.11	46.02	0.1025	42.6	50.8	65.9	92.8
Ro/Ro shipping	0.70	28.11	377.28	0.3145	158.1	233.9	540.2	284.9
Corridor	0.44	12.02	69.84	0.1104	100.0	100.0	100.0	100.0

It should be kept in mind that the results of Tables 3 and 4 refer to door-to-door services that include road feeder services at both ends of the chain. It is confirmed that shipping is by far the least expensive and slowest mode of transport. It is also characterised by the best GHG emission performance. Its SOx emissions score slightly below average but this is only because Ro/Ro shipping, by far the biggest polluter, is excluded from the shipping figures while participating in the formation of the corridor average. It is worth mentioning that the poor environmental performance of Ro/Ro shipping is basically due to the so called 'double load factor effect' and the relatively high sailing speeds of these vessels (Panagakos et al., 2014).[11] It is noted that the SOx emissions of all segments of shipping have been drastically reduced since the beginning of 2015, when the new stricter IMO regulations on the sulphur content of marine fuels in the so-called SOx Emission Control Areas (that include both the North Sea and Baltic Sea of the GreCOR corridor) have taken effect.

Another surprising result regarding Ro/Ro shipping is its higher than road speed. This is because the Ro/Ro shipping chains are basically road services along routes with distances closer to the 'as-crow-flies' routes combined with the fact that the time truck drivers spend on board Ro/Ro vessels is considered rest time by the EU regulations.

Rail transport seems to exhibit positive behaviour in relation to all KPIs examined, as its performance is below average in terms of cost, CO_2-eq and SOx emissions, and above average in terms of speed. From the perspective of the four indicators examined here, the promotion of rail appears to be a win-win solution leading to gains in terms of both economy and environment. It is

[11] By double load factor effect one means the adverse effect on the fuel consumption and emissions of a Ro/Ro ship, when expressed on a per tonne*km basis, caused by the fact that the transport work performed is determined by both the load factor of the ship (in terms of lane meters occupied) and the load factor of the trucks onboard (in terms of the carrying capacity of the trucks taken up by the cargo).

unfortunate that the reliability and frequency indicators, where rail operations trail, could not be included in the analysis.

4.5 Critical review of case study results

It should be stressed that the indices presented above cannot be used for benchmarking as they are based on the default values of the LTM and EcoTransIT models mainly reflecting the composition of the freight flows comprising the corridor sample. It is worth noticing, however, that the corridor wide cost average of 0.44 DKK/tkm translates to 0.0780 USD/tkm (in 2010 prices), which is comparable to the figure of 0.0712 USD/tkm estimated by ADB (2013) for the six CAREC corridors in 2010. In addition to the geographical incompatibility which affects basic cost parameters like labour and fuel costs, this comparison needs to be qualified by the fact that the GreCOR figure would have been much higher if the waterborne trade was excluded as is the case in Asia. On the other hand, the Asian figure almost doubled during the period 2010-2013, a development not paralleled in Europe. To remain in Asia, Regmi and Hanaoka (2012) estimate an average cost of 0.91 USD/TEU/km for the Incheon-Ulaanbaatar corridor, which combines road, rail and sea transport. On the assumption of 12 tonnes of cargo per TEU (Janic, 2007), this is equivalent to 0.0758 USD/tkm, a figure very close to our estimates.

Furthermore, the 0.35 DKK/tkm cost average for rail translates to 0.0467 €/tkm. For the average distance of 1,182 km of our sample journeys involving rail transport, Janic (2007) provides an estimate of 0.0275 €/tkm (in 2000 prices) for rail/road intermodal services in Europe, which is inflated to 0.0337 €/tkm when brought to 2010 denominator. The higher labour costs of Northern Europe can certainly explain a good part of the 39% difference between the two estimates. However, this discrepancy verifies the fact that the proposed method, albeit permitting the monitoring of the performance of a single corridor over time, is not suitable for comparisons between corridors, as it does not consider differences in corridor characteristics that can be decisive in their overall performance (Panagakos, 2012 & 2016).

In terms of speed, the corridor average of 12.02 km/h reflects a significant influence by the tardiness of shipping that sails at an average speed of 6.1 km/h. Road (26.1 km/h) and rail (18.6 km/h) transport in Europe perform better than their Asian counterparts that ran at 22.3 and 12.8 km/h respectively during 2013 (ADB, 2013).

5. Conclusions

5.1 Methodological aspects

The basic conclusion is that the methodology described in this paper can effectively assess the performance of a freight transport corridor provided that the necessary stakeholder input is secured. However, the proposed method is not suitable for comparisons between corridors, as it does not consider differences in corridor characteristics that can affect their overall performance.

The application benefited from the advantages of the 'model-based' approach, namely the provision of a comprehensive and coherent picture of all flows on each section of the corridor. It suffered, however, from the absence of a model offering European coverage, having to rely on the Danish LTM model, which imposed undesirable geographic restrictions (only the Oslo-Randstad part of the

corridor was examined) and led to diminishing accuracy of results as the distance from Denmark increases.

Ensuring reliable data remains a hard problem to address. The service reliability and frequency KPIs had to be dropped due to lack of data. Furthermore, the method will not be complete unless the chain-level KPIs are estimated through raw data obtained from specialised recurrent studies covering specific routes or directly from the stakeholders (shippers, freight forwarders and transport service providers) who use the relevant chains. In addition, the stakeholder input might prove useful in adjusting for any unrealistic model results that might have entered the corridor sample.

It needs to be emphasized here that consistency in raw data solicitation and processing is of utmost importance for ensuring reliability. When it comes to emission estimations, the strict procedures followed in Life Cycle Assessment applications and the provisions of the GLEC framework (Smart Freight Centre, 2016) can be quite inspirational. Data verification by a properly accredited third party can also be considered at a later stage.

With these limitations in mind, the proposed combination of the model-based approach for the sample construction with the study-based approach for the estimation of chain-level indicators exploits the strengths of each method and avoids their weaknesses.

5.2 Directions for further research

In addition to the collection and processing of the stakeholder data that the proper application of the method requires, future research can pursue a number of improvements. Although several criteria were evaluated for constructing the sample, the 'model-based' approach did not permit the identification and exclusion of atypical chains. At the stage of KPI estimation, however, when the chains are looked into more detail, atypical chains may be spotted. At a second iteration of sample composition, which is missing from the present application, such chains should be omitted.

Furthermore, the size of the sample (156 chains) is considered too big, especially if real data have to be collected from stakeholders. In addition to excluding atypical chains, a second iteration could reduce the sample without much loss in its effectiveness. To do so, a sensitivity analysis is required to check the robustness of corridor-level KPIs in relation to specific chains. Stakeholders may also suggest merging some commodity groups together reducing the number of chains in the sample. The dry bulk Commodity groups 2 (coal & lignite), 3 (iron ore & non-ferrous metal ores) and 23 (stone, sand, gravel & quarry products) are possible candidates.

A future revision of the sample might also include the replacement of the exclusion of all domestic chains by the introduction of the chain length threshold of 300 km as suggested by the proposed methodology (Step 4).

A final point relates to the composition of trade. Shipping accounts for 70% of the annual tonnage and 75% of the tonne*km of the 'corridor chains.' Therefore, it plays an extremely important role in forming the corridor indices. It could be of interest to see how the indices look if calculated on land-based modes only.

It follows that improvements can be achieved by: (i) excluding from the sample possible atypical chains identified during the analysis; (ii) revising the sample with the aim of merging commodity groups that use the same type of vehicles and have similar characteristics in terms of the KPIs examined; (iii) revising the sample by replacing the internationality restriction with a length threshold:

(iv) revising the sample with the aim of excluding chains that do not affect the corridor indices (when expressed as one decimal point numbers); and (v) calculating corridor indices excluding shipping (Ro/Ro ships should not be excluded as they serve road transportation).

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Appendix I. Glossary of acronyms and abbreviations

ADB	Asian Development Bank
CAREC	Central Asia Regional Economic Cooperation
CNC	Core Network Corridor (in relation to TEN-T)
CO_2-eq	Carbon dioxide equivalent unit
EC	European Commission
EWTC	East-West Transport Corridor
EU	European Union
FP7	7^{th} Framework Programme of Research and Technological Development (EU)
GHG	Greenhouse Gas
GIS	Geographic Information System
ICT	Information Communication Technology
KPI	Key Performance Indicator
LTM	Lands Trafik Modellen (Danish National Transport Model)
OD	Origin-Destination
RFC	Rail Freight Corridor
SOx	Sulphur oxides (basically SO_2)
TCD	Time-Cost-Distance
TEN-T	Trans-European Transport Network

Appendix II. Composition of the LTM chain matrix by commodity (for base year 2010)

ID	Commodity	Original matrix		Final matrix	
		Tonnes	Chains	Tonnes	Chains
1	Products of agriculture, fish, etc.	40,574,668	245,831	1,475,663	2,760
2	Coal and lignite	19,571,829	7,646	130,093	84
3	Iron ores and non-ferrous metal ores	13,199,566	76,006	336,673	1,339
4	Food products, beverages and tobacco	30,190,571	236,557	2,009,451	3,134
5	Textiles and leather products	3,650,520	200,150	270,242	3,096
6	Wood and products of wood and cork	45,488,712	223,744	1,466,753	2,811
7	Coke and refined petroleum products	62,995,960	27,862	3,449,555	486
8	Chemicals, chemical products, etc.	36,868,486	184,906	2,596,137	2,751
9	Other non-metallic mineral products	15,560,549	203,555	789,124	2,616
10	Basic metals, fabricated metal products	23,458,563	215,847	1,034,014	3,501
11	Machinery and equipment	18,305,567	156,526	130,175	964
12	Transport equipment	4,744,573	125,491	323,634	815
13	Furniture; other manufactured goods	19,993,166	233,532	373,480	3,114
14	Secondary raw materials and other wastes	11,924,412	194,735	526,522	2,454
15	Mail, parcels	6,759,979	176,535	376,253	2,077
16	Equipment utilised in the transport of goods	249,571	16,093	26,621	123
17	Household and office removal goods	1,050,634	74,221	891	59
18	Grouped goods	2,862,862	99,080	392,971	2,198
19	Unidentifiable goods	0	0	0	0
20	Other goods	0	0	0	0
21	Crude petroleum and natural gas	99,275,548	7,945	1,201,714	101
22	Fertilizer, chemical and natural	8,581,166	95,220	53,964	1,116
23	Stone, sand, gravel & other quarry products	41,382,172	133,235	273,223	1,847
	Total	506,689,075	2,934,717	17,237,155	37,446

Appendix III. Definition of chain types used in the analysis

TYPE*	DEFINITION
1	1-leg road chains between Denmark and other Scandinavian countries (irrelevant to a future Fehmarn Belt fixed link)
2	1-leg road chains crossing the land border between Denmark and Germany
3	1-leg road chains connecting Denmark to locations south of the Fehmarn Belt, which involve the use of a ferry
5	1-leg road chains between origins/destinations outside Denmark that cross the country in transit
6	1-leg road chains between origins/destinations outside Denmark that use a direct Ro-Ro connection bypassing Denmark
111	3-leg road chains, where a main chain of Type 1 is combined with feeder road services for the first and last miles.
121	3-leg road chains, where a main chain of Type 2 is combined with feeder road services for the first and last miles.
131	3-leg road chains, where a main chain of Type 3 is combined with feeder road services for the first and last miles.
151	3-leg road chains, where a main chain of Type 5 is combined with feeder road services for the first and last miles.
161	3-leg road chains, where a main chain of Type 6 is combined with feeder road services for the first and last miles.
171	3-leg rail chains, where a main rail transport (Type 7) is combined with feeder road services for the first and last miles.
181	3-leg maritime chains, where a main sea transport (Type 8) is combined with feeder road services for the first and last miles. Containerised cargoes are carried by containerships.
191	3-leg maritime chains, where a main sea transport by a Ro-Ro ship (Type 9) is combined with feeder road services for the first and last miles.
* Types 4 and 141 are intentionally omitted as unrelated to the project.	