UK SUPPLY CHAIN CARBON MITIGATION STRATEGIES USING ALTERNATIVE PORTS AND MULTIMODAL FREIGHT TRANSPORT OPERATIONS

Sanchez Rodrigues V.[1], Pettit S. [1], Harris I. [1], Beresford A. [1], Piecyk M.[2]

1 *Cardiff University Logistics and Operations Management Section*
2 *Heriot-Watt University Logistics Research Centre*

Introduction

Examination of international freight transport chains and supply chains has been highlighted in Sanchez Rodrigues *et al* (2014) who investigated possible options for the use of alternative ports as a way of contributing to supply chain carbon mitigation strategies. This was in contrast to the greater proportion of research into supply chain research which largely relate to the coordination of the chains and the distribution of economic value among supply chain partners (see, for example, Alvarez-SanJaime *et al*., 2013). Further, Alvarez-SanJaime *et al*. (2013) suggests that vertical integration is crucially important to enhance high level of performance in the maritime sector of freight transport chains. However, the literature tends to exclude port selection as a key component of performance improvement in maritime supply chains, since research works on how commodity chains and networks work have concentrated mainly on the management of relationships within supply chains.

Ports are important nodes in global distribution networks and as such they can significantly influence the performance of global supply chains. Even though, in the literature, there is a considerable degree of emphasis in the topic of port selection, the large majority of the research work focuses on economic aspects of port choice, such as market forces and port efficiency (Tongzon, 2009; Steven and Corsi, 2012). Steven and Corsi (2012) analyzed port selection in the context of the United States while Tongzon (2009) focus on the management of inland distribution as a port choice factor. The remit of these studies did not extend to CO_2e reduction or how future changes to the carbon intensity of road freight transport could influence port selection decisions.

This paper therefore extends the work of Sanchez Rodrigues *et al* (2014) in considering whether the use of alternative port gateways, can contribute significantly to an overall reduction in freight transport-related CO_2e emissions in international supply chains. The approach taken in this study refers to that of Liao *et al*. (2010) and Sanchez Rodrigues *et al* (2014): an activity-based CO_2e emission model is used to estimate the cost and CO_2e impacts of five Scenarios, which are described in the paper as the “current situation” and four “proposed Scenarios”. As part of the current work all scenarios were optimized to minimize connection costs. While the paper suggests there is likely to be scope for emissions reduction, the study clearly has boundaries in terms of the assumptions used. It is suggested that the rerouting of containers is influenced by three main variables: total road miles, overall operating costs and overall transport-based CO_2e emissions.

UK Ports and Inland Container Transport

Port capacity expansion decisions for a given region are important in terms of economic development. However, as Sanchez Rodrigues et al. (2014) highlights, the literature on port selection generally focuses on economic and commercial aspects rather than the role of ports in contributing to carbon emission reduction in supply chains. Port selection is a complex problem often studied from an economic perspective (Tongzon, 2009; Steven and Corsi, 2012) and decisions by shipping lines can have an impact creating either congestion or overcapacity (Tongzon and Sawant, 2007; Fan *et al*., 2012), especially when major lines switch ports causing very large numbers of containers to be funneled into a particular port or terminal and large volumes to be lost elsewhere. A study by Chen *et al*. (2014) demonstrates how coastal shipping services can reduce the overall emissions of logistics chains; but the study does not explicitly connect port selection with coastal shipping as an alternative to traditional road freight transport services. A major issue for the UK ports industry in the late 1990s and early part of the 2000s was the forecasted growth in volumes and the associated problem of a lack of capacity at the major UK container ports. Additional capacity was a recognized need and several major developments were proposed to deal with the shortfall (MDS Transmodal, 2006). Only a small number of ports (Liverpool, Felixstowe, Thamesport, Tilbury and Southampton) handled most of the existing volumes and the extra capacity was needed largely in the south and east (Pettit and Beresford, 2009).

With more carefully defined logistics strategies, knowledge of the origins and destinations of containers has become a very important aspect of optimising port choice and total freight transport cost solutions. Thus it seems pertinent to assess the environmental as well as economic impacts of the potential joint transport-based carbon mitigation solutions which can include port selection, mode choice and improvements in the carbon intensity of road freight transport. In respect of the movement of containers, destinations are linked closely to the principal concentrations of industry and population, such as the Scottish lowlands; Northwest and central Northern England; Tyne/Tees; Humber; Midlands; parts of South Wales and Western England; and much of the Southeast (MDS Transmodal 2006). The latter study made predictions regarding the growth of container volumes over the next twenty year and while this cannot be verified, do give some indication of how containerised volumes are likely to be distributed. Previous studies have not included origin to destination movements based on the minimisation of transport freight-based CO_2e emissions through decarbonisation strategies such as modal shift and other relevant road-based carbon mitigation measures. This paper addresses this issue.

Methodology

With reference to the approaches taken by Liao *et al*., (2010) and Sanchez Rodrigues *et al*., (2014), this paper develops a series of new Scenarios designed to model the greater or lesser use of port alternatives. The overall aim of the current paper is to simulate possible CO_2e mitigation strategies along supply chains in the UK. In the methodology, transport movements are analyzed on more disaggregated basis than similar investigations carried out elsewhere. Furthermore this study, for the first time, incorporates a new carbon reduction parameter to address road CO_2e solutions as an alternative to carbon reduction for the UK freight transport sector. New UK port developments such as London Gateway are taken into account in the modelling on the impact of CO_2e emission for container routing.

In order to understand the impacts of port choice on logistics solutions and the potential impact that new solutions may have on the level of CO_2e emissions, three UK port clusters are considered for the analysis. One cluster is located in the ‘southern gateway’ (Felixstowe, London Gateway and Southampton), another two clusters are in the west (Bristol) and in the ‘northern gateway’ (Hull, Immingham and Liverpool). Felixstowe port is an established deep sea port serving the whole of the UK, London Gateway is projected to grow considerably in the next few years and Southampton complements these two ports in terms of capacity and location. Bristol, Hull, Immingham and Liverpool operate at the northern and western limits of possible deep sea vessel calls with various physical or geographical constraints, such as tidal depth and range, effectively capping their capacity and / or growth potential. Bristol was chosen as a potentially viable south-western gateway as it has obtained approval for a new deep-sea container terminal in March 2010 (Port of Bristol, 2013). The six demand regions outlined in the studies by Sanchez Rodrigues (2014) were used to support the main assumptions which form the platform for this paper. Data related to seven ports, which handle 70% of the imported containers in the

UK, used in all modelling scenarios are shown in the Table 1. Those ports are Bristol, Dover, Felixstowe, Hull (including Grimsby and Immingham), Liverpool, London (including Medway and Tilbury) and Southampton (with Portsmouth).

PORT	Imports (000' TEUs)
Bristol	37.4
Dover	1,645.6
Felixstowe	1,861.5
Hull (including Grimsby and Immingham)	1,009.8
Liverpool	569.5
London (including Medway and Tilbury)	950.3
Southampton (including Portsmouth)	894.2
Total import containers for the selected ports:	**6,968.3**
Total UK imports	**9,914.4**

(Source: adapted from Department for Transport (2013))

Table 1. Selected port data for UK import containers (000s TEUs)

Table 2 presents the forecasted demand data for 2015 estimated from the MDS Transmodal report (2006) as the basis for TEUs per destination region. For the Midlands, East England and South East regions, the MDS Transmodal projections for 2010 were recalibrated, using population statistics from the Office for National Statistics (2011). The port throughput and demand datasets are used to calculate the total TEU-kilometers for five Scenarios. In the modelling exercise of the five Scenarios, flows of non-standard containers (e.g. 48′) were not modelled separately because such boxes are still anomalies at most ports; therefore they were considered as 40′ (2 x 20′ TEUs) containers. It is also assumed that the seven ports operate at current capacity for the baseline scenario (Scenario A). In order to build the five Scenarios, origin data in TEUs is allocated to the destination cities considering minimization of distance travelled by road as the primary goal. The five Scenarios used in the modelling exercise are as follow:

- *Base Scenario A*: the baseline Scenario minimizes total TEU-road distance travelled and assumes that the capacity of the seven ports remains constant.
- *Scenario B* is modelled by assuming that the expansion of Bristol, Hull (plus Grimsby and Immingham), Liverpool and London will minimize total TEU- road distance travelled.
- *Scenario C* is estimated by assuming that Southampton can be expanded and that Derby, (representing central northern England), Manchester, Glasgow and Edinburgh can be fed by rail from the port of Southampton.
- *Scenario D* assumes that some expansion of the port of Felixstowe is feasible and that Derby, Manchester, Glasgow and Edinburgh can be fed by rail instead of transporting containers by road.
- *Scenario E* assumes extensive expansion of London Gateway (including Medway and Tilbury) is feasible and that Derby, Manchester, Glasgow and Edinburgh can be fed by rail instead of transporting containers by road.

Each scenario is formulated as the transportation problem that determines the number of TEUs that can be transported to the destination points in order to satisfy all customer demand, subject to capacity constraints while minimizing total road distances travelled. Excel Solver is used to find an optimal solution for each scenario.

The first stage of the modelling process determines the transportation plan for a road-based scenario as discussed in the Scenario A. In scenarios B, C, D and E, we relax all port capacity constraints and force some of the demand locations to be served by a specific rail path. This allows the establishment of the transportation plan and determines capacities needed for each port under consideration. Table 7 illustrates all changes in port capacities as a result of the optimization. After determining an optimum road-based transportation plan we derive CO_2e and cost values for rail and shipping, as discussed below. Data related to differences in distances between ports and the destinations are calculated using an on-line distance calculator (Daft Logic, 2011) and we allocate differences in those maritime distances when a serving port changes from the one that is in Scenario A to a new supply location in Scenarios B, C, D and E. The Isles of Scilly is used as a reference point to calculate the differences in equivalent road miles generated for the sea leg between Scenarios B-E and the actual Scenario A. In scenarios C - E we serve selected demand locations by rail. Derby, Manchester and Glasgow were specified as rail hubs for these rail routes. The locations of these hubs were chosen based on their density of population, freight generation / consumption and geography. Rail route distances from the ports of Southampton, Felixstowe and London Gateway to each rail hub were calculated. No additional road kilometers were added to the rail kilometers in those scenarios because the freight that could be moved by road is transferred by rail from Southampton, Felixstowe and London Gateway by rail.

Destination Region	Reference City	000' TEUs	Destination Region	Reference City	000' TEUs
Scotland	Glasgow	120.46	North West	Liverpool	441.79
	Edinburgh	120.46		Manchester	441.79
North East	Newcastle	156.66	Wales	Swansea**	56.40
York & Humber	Leeds	250.66	South West	Exeter	131.60
	Sheffield	250.66	East England	Northampton	907.07
Midlands	Derby*	1,558.67	South East	London	2,532.11

(Source: Author's estimates based on population consumption estimates)

*- Derby is use as a representative of a Midlands location although in practice it is in Central-Northern England

** - Swansea is taken a mid-point for South Wales

Table 2. TEUs allocation by destination region

The modelling follows the approach recommended by McKinnon and Piecyk (2009). Table 4 shows the factors recommended by Department for Environment, Food and Rural Affairs (2013) as well as the costs per TEU-Km for each of the transport modes suggested by Department for Transport (2012).

CO2e parameters	Cost parameters
Kg CO_2e per TEU-km (Road transport): 1.0166	Road Freight Cost (TEU-km): £0.99
Kg CO_2e per TEU-km (Maritime transport): 0.17655	Rail Freight Cost (TEU-km): £0.62
Kg CO_2e per TEU-km (Rail transport): 0.33693	Maritime Freight Cost (TEU-km): £0.31

Table 4. CO_2e and cost parameters used in the study.

In the modelling exercise, a road-based CO_2e reduction parameter was included to assess the sensitivity of the output variables, namely overall CO_2e emissions and total freight transport cost, to changes in this factor. The five Scenarios have been modelled with six values of this parameter: 0%, 10% 20%, 30%, 40% and 50%. According to Piecyk and McKinnon (2010), in the absence of any new policy initiatives (i.e.

business-as-usual scenario) GHG emissions from road freight transport in the UK should decline from around 10% from the 2007 baseline, and in the optimistic scenario, a reduction of up to 56% can be expected. The paper uses six parameters for road-based CO_2e reduction initiatives and it incorporates pessimistic values of road-based CO_2e reduction rates to allow for the impacts of the recent economic downturn and acknowledge that the resources available to logistics operators to improve their carbon efficiency may still be sparse.

Findings from the modeling of the five scenarios

As discussed in the methodology section, five Scenarios were analyzed and the freight transport costs and CO_2e calculated for each scenario using the assumptions discussed above. Figure 1 illustrates a summary of the findings obtained in the study and the results show that Scenario C has the lowest values for total freight transport cost and CO_2e emissions starting from a 30% reduction of road freight transport CO_2e outputs. Scenarios D and E, that use rail based options from Felixstowe and London Gateway produce similar results, hence they are closely aligned in Figure 1. This is due to their relatively similar distances from the key destinations.

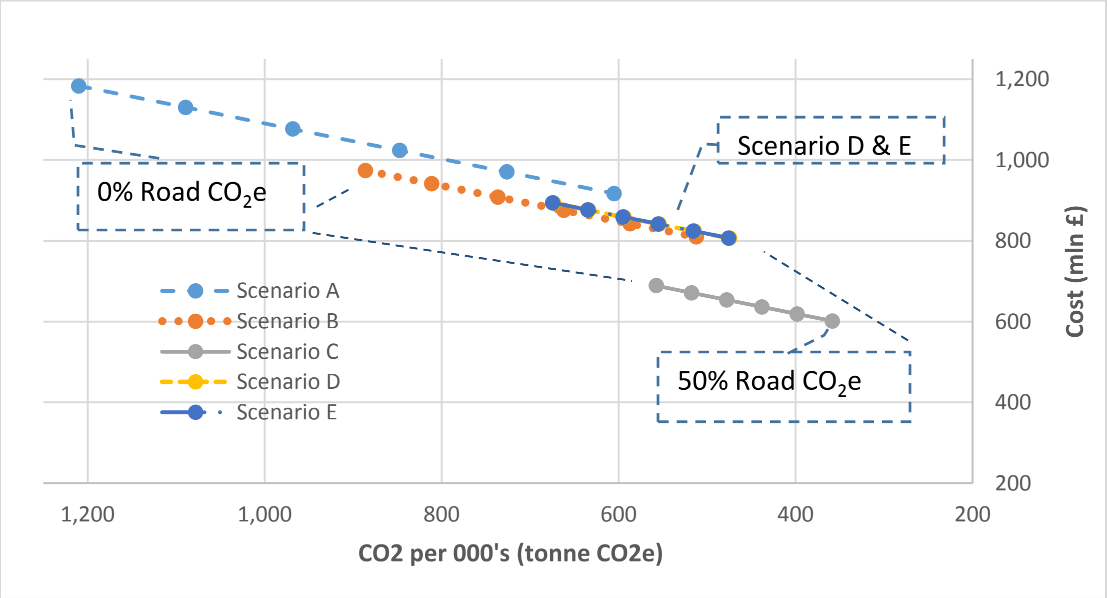

Figure 1. Comparative results of five scenarios

According to the findings, as can be seen in Table 5, Scenario C seems to be the least carbon intensive and most economical scenario with outputs of 557 thousands of Tonnes of CO_2e emissions and a cost of £689 million, which represents a reduction of CO_2e emissions and cost, relative to Scenario A, of 54% and 42% respectively. Scenario C assumes that Southampton can be expanded and that Derby, Manchester, Glasgow and Edinburgh can be fed by rail from the port of Southampton. The findings show even with a road-based reduction factor value of 50% Scenario A will not reduce to equal the total CO_2e emissions and cost of Scenario C i.e. even in a very optimistic future carbon reduction scenario for road freight transport. Similarly, Scenarios D and E assume feasible expansions of the ports of Liverpool, Bristol, Felixstowe and London, and that Derby, Manchester, Glasgow and Edinburgh can be fed by rail from these ports. These scenarios will have better values for CO_2e outputs and total costs compared to a 50% improvement in the road-based scenario. These two Scenarios present considerably lower outputs of cost and CO_2e emissions, respectively £894 million and above 670 thousand Tonnes of CO_2e emissions; nevertheless, their total cost and CO_2e emissions are not as low as the ones estimated for Scenario C.

% Road Reduction	Scenario A (Base)		Scenario B		Scenario C		Scenario D		Scenario E	
	Cost (£ Million)	CO2e (000's Tonne CO2e)	Cost (£ Million)	CO2e (000's Tonne CO2e)	Cost (£ Million)	CO2e (000's Tonne CO2e)	Cost (£ Million)	CO2e (000's Tonne CO2e)	Cost (£ Million)	CO2e (000's Tonne CO2e)
0	1,183	1,210	974	886	689	557	894	673	894	674
10	1,130	1,089	941	811	671	517	876	634	876	634
20	1,077	968	908	736	654	478	859	594	859	595
30	1,024	847	875	661	636	438	841	554	841	555
40	970	726	843	587	619	398	824	514	824	515
50	917	605	810	512	601	358	806	474	806	475

Table 5. Total costs and CO_2e emissions for five scenarios

On the other hand, Scenario B shows that the total freight transport cost and CO_2e emissions are lower than in Scenario A, but the reductions in cost and CO_2e emissions are not as significant as in the cases of Scenarios C, D and E. Scenario B presents reductions of total freight transport cost and CO_2e emissions relative to Scenario A of 18% and 27% respectively. Nevertheless, Scenario A could have a lower value of CO_2e emissions if the road-based CO_2e reduction factor is just below 30%. With this finding, it can be concluded that for a feasible reduction of below 30% of the CO_2e output for road freight transport, it would be more carbon efficient to improve the intensity of road freight transport operations through technological advancement rather than shifting cargo to maritime-based modes.

The required change in the capacity of the ports included in the study is a fundamental aspect which needs careful attention. As Table 7 shows, Scenario B involves significant increases in capacity at Bristol, London, Liverpool and Hull.

Port	Scenario				
	A (Base Scenario)	B	C	D	E
Hull	0%	94.7%	-59.7%	-59.7%	-59.7%
Liverpool	0%	141.5%	21.6%	21.6%	21.6%
Bristol	0%	402.7%	402.7%	402.7%	402.7%
Dover	0%	-100%	-100%	-100%	-100%
Southampton	0%	-100%	150.7%	-100%	-100%
Felixstowe	0%	-100%	-100%	20.4%	-100%
London	0%	261.9%	261.9%	261.9%	497.8%

Table 7. Overall capacity change of selected seven port

In particular, the capacity of the port of Bristol requires an increase of 402%. Furthermore, Scenario C requires significant capacity increases of 262% and 403% at the ports of London and Bristol respectively. These capacity changes may have significant impacts on the CO_2e emissions of the Scenarios included in the paper if construction-based carbon emissions were estimated. Moreover, reductions in the total numbers of TEUs or complete closure of some ports such as Felixstowe, Southampton and Dover would be required in Scenarios B, C, D and E, as idle capacity would be generated at these ports. This is a significant issue which needs to be considered in the expansion plans of the ports of Southampton and London. For Scenarios D and E, while they have similar costs and CO_2e emissions they have very different port expansion and closure outcomes. For Scenario D Felixstowe would see only a small increase in capacity of around 20% whereas in Scenario E there would be a total closure of the port. London Gateway would however be expanded in both Scenarios by 262% and 498% respectively. In all 4 scenarios the port of Bristol would be expanded by over 400%.

Conclusions

Traditionally, research on the topic of port choice focuses on economic aspects of port choice, such as market forces and port efficiency (Tongzon, 2009; Steven and Corsi, 2012). More recently, Sanchez Rodrigues *et al*. (2014) demonstrated that rerouting containers away from traditional large ports in the UK southeast could significantly reduce the overall CO_2e emissions generated by marine-based container transport. This would be achieved by using ports in the north and north-west ports and/or shifting freight from road to rail in container movements between ports and inland origins/destinations. The Sanchez Rodrigues *et al*. (2014) study, however, did not include likely future reductions in the rate of CO_2e emissions generated from road freight modes. Moreover, previous studies did not link carbon mitigation strategies to the import of containers, nor did they consider the reallocation of import containers between alternative gateway ports. This paper addresses these shortcomings. The paper contributes to the academic literature by demonstrating how CO_2e reduction can be a significant factor in the selection of ports in maritime-based supply chains. The paper demonstrates that reductions in CO_2e emissions achieved by freight transport operations in maritime-based supply chains can be driven by changes in the structure of freight transport chains as well as potential future road-based CO_2e reduction initiatives driven by technology and process advancements.

Specifically, this paper compares five different Scenarios that link UK import container flows with inland freight transport movement. A methodology based on road TEU-Km minimization was applied to the five Scenarios. A CO_2e reduction parameter is used to assess the sensitivity of the five Scenarios to likely reductions in the carbon intensity of road modes. Two main output variables were used to compare the five Scenarios: overall CO_2e emissions and total freight transport cost. For all values of the road-based CO_2e reduction parameter (0% to 50%), Scenario C is the least carbon intensive and most cost effective. However the outcome is that additional capacity is required at four ports including a 150% expansion at Southampton. In the case of Scenario D, even though the total CO_2e emissions and freight transport are higher than in the case of Scenario C, there is the requirement for additional capacity at Liverpool, Bristol and London, and a small expansion at Felixstowe. The results obtained from this study are a starting point for further research in a number of areas. Firstly, the approach adopted by the study can be replicated in another geographical context at continental or domestic level to explore how geographic partners can impact on the carbon reduction strategies tested in the study. Secondly, the modelling approach applied in the study can be used to assess the climate change adaptability of continental/domestic freight transport networks have. Thirdly, additional parameters can be introduce in the model used in the paper, in particular, carbon reduction rates for water and rail modes can be introduced to explore the sensitivity of the findings to potential future reductions in the CO2 emissions rates of ships and trains.

References

- Alvarez-SanJaime, O., Cantos-Sánchez, P., Moner-Colonques, R., Sempere-Monerris, J., 2013. Vertical integration and exclusivities in maritime freight transport. Transportation Research Part E: Logistics and Transportation Review 51, 50–61.

- Cheng T.C.E., Ke-hung Lai, Y.H, Lun V, Wong CWY. 2013. Green shipping management. Transportation Research Part E: Logistics and Transportation Review 55, 1–2.
- Chen, K., Yang, Z., Notteboom, T., 2014. The design of coastal shipping services subject to carbon emission reduction targets and state subsidy levels, Transportation Research Part E: Logistics and Transportation Review 61, 192–211.
- Daft Logic, 2011. Google Maps Distance Calculator, Available at http://www.daftlogic.com/projects-google-maps-distance-calculator.htm. [accessed: December 2011]
- Department for Environment, Food and Rural Affairs, 2013. Guidelines to DEFRA's GHG conversion factors for company reporting, Available at <http://www.defra.gov.uk /environment/business /reporting/pdf/conversion-factors.pdf> [accessed: March 2013]
- Department for Transport, 2013. Transport Statistics Bulletin – Provisional Ports Statistics 2012, Available at <http://www.dft.gov.uk/adobepdf/162469/221412/221658/374865/ provportstats2009.pdf > [accessed: March 2013]
- Department for Transport, 2012. Delivering a Sustainable Railway, Available at <http://webarchive. nationalarchives.gov.uk/+/http://www.dft.gov.uk/about/strategy/ whitepapers/whitepapercm7176/whitepapersummarybooklet.pdf> [accessed: March 2013]
- Fan, L., Wilson, W., Dahl, B., 2013. Congestion, port expansion and spatial competition for US container imports, Transportation Research Part E: Logistics and Transportation Review 48, 1121–1136.
- Liao, C-H, Tseng, P-H, Cullinane, K., Lu, C-S, 2010. The impact of an emerging port on the carbon dioxide emissions of inland container transport: an empirical study of Taipei port. Energy Policy 38, 5251 – 5257.
- McKinnon, A., C., Piecyk, M., I., 2009. 'Logistics 2050: Road Freight Transport in a Low Carbon World' in Sweeney, E. (ed), Supply Chain Management and Logistics in a Volatile Global Environment, Blackhall Publishing, Dublin.
- Piecyk, M., I., McKinnon, A., C., 2010. Forecasting the Carbon Footprint of Road Freight Transport in 2020. International Journal of Production Economics, 128(1), 31-42.
- MDS Transmodal, 2006. UK Port Demand Forecasts to 2030, Department for Transport, London.
- Office for National Statistics, 2011. Population Estimates for UK, England and Wales, Scotland and Northern Ireland, Mid-2010. Available at <http://www.ons.gov.uk/ons/ publications/re-reference-tables.html?edition=tcm%3A77-231847.> [accessed: July 2012]
- Pettit, S., J., Beresford A., K., C., 2009. Port Development: From Gateways to Logistics Hubs. Maritime Policy and management 36 (3), 253- 267.
- Port of Bristol, 2013. The Bristol Port Company. Available at <http://www.bristolport.co.uk/ about[accessed: 28th August 2013]
- Robinson, R., 2002. Ports as elements in value-driven chain systems: the new paradigm. Maritime Policy Management, 29 (3), 241-255.
- Sanchez-Rodrigues, V., Beresford, A., Pettit, S., Battacharya S., Harris, I., 2014. Assessing the cost and CO_2e impacts of rerouteing UK import containers. Transport Research Part A: Policy and Practice 61, 53-67.
- Steven, A., Corsi, T., M., 2012. Choosing a port: An analysis of containerized imports into the US. Transportation Research Part E: Logistics and Transportation Review 48, 881–895.
- Tongzon, J., L., 2009. Port choice and freight forwarders. Transportation Research Part E: Logistics and Transportation Review, 45, 186–195.
- Tongzon, J., L., Sawant, L., 2007. Port choice in a competitive environment: from the shipping lines' perspective. Applied Economics 39 (4), 477-492.