ASSESSING THE COST AND CO_2e IMPACTS OF REROUTEING UK IMPORT CONTAINERS

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Abstract

Among the most important trade-related issues currently confronting the UK are the environmental implications of very large volumes of containerised freight being handled at a small number of ports while there appears to be significant potential for using other ports and water-rail intermodal connections. Six UK ports are selected for the analysis: Hull/Immingham, Liverpool, Felixstowe, Southampton, Dover and Bristol. Through an origin-destination analysis, the cost and CO_{2e} impacts of UK port trade patterns are compared using the actual situation against three proposed Scenarios: (1) the re-direction of containers by a combined expansion of Hull and Immingham; Liverpool; and Bristol, (2) moving containers by rail facilitated via expanded capacity at Southampton, and (3) moving containers by rail through expanded capacity at Felixstowe. The research found that transporting containers from Felixstowe and Southampton to the northern regions by rail has the lowest CO_{2e} impact, and is the most feasible option, although constraints exist in terms of infrastructure provision, water depth and rail network capacity.

Keywords: UK Port Capacity, Northern Gateway, Economic and Environmental Cost

1. Introduction

The development of ideas about how commodity chains and inter-organisational networks ultimately link regions and countries together has, over time, extended to include the breadth of supply chains from product development to final consumption (Leslie and Riemer, 1999; Hopkins and Wallerstein, 1986; Gereffi, 1994). As Oro and Pritchard (2011) suggest, the principal concern of such research is how such chains are ‘coordinated across space, and how economic value is distributed among participants'. Further, they propose that governance, whereby forward and backward chain linkages are coordinated, establishes how economic factors within the chain operate. Earlier work by Gereffi *et al* (2005) categorised such governance into five variants: market based, modular, relational, captive and hierarchical. The conceptual development in understanding how commodity chains and networks work has thus focused primarily on the underpinning logic of relationships. Product and commodity systems have been further defined in a relational spatial context as how economic actors operate in, for example, network arenas (Yeung, 2005; Bathelt, 2006).

Ports are often key contributors to economic development and key facilitators of international trade. As such they can be used to promote the economic cohesion of different regions. Ports are also important nodes in logistics chains and the location and efficiency of ports contributes significantly to economic competitiveness, and there has therefore been a continuous focus on the efficiency of ports in the academic literature (Suykens and Van de Voorde, 1998; Tongzon J, 2001; Gonzalez and Trujillo, 2008). Further, over time competition between ports has intensified, port hinterlands have expanded and port intermodal facilities have been improved, thus allowing carriers to focus their activities on fewer and larger ports. Shipping lines make decisions both about the deployment of vessels to routes and ports, and the assignment of shipments to vessels. The combination of these two activities determines in part which ports will be used on any particular route (Malchow and Kanafani, 2004). What has not been taken into consideration by shipping lines in their port selection criteria however has been the overall environmental impact of the port choice decision, although Emission Control Areas (ECA) specified under MARPOL Annex VI have led to some operational changes by shipping lines in order to comply with legislative imperatives(Fathom Shipping, 2013).

One of the key aspects of improving the environmental performance of supply chains is the transfer of freight from road to less carbon intensive freight transport modes such as water-borne transport and rail. Closely linked to the transfer to water modes is the requirement to select ports which are close to the market under consideration, thereby providing the shortest land route possible: essentially following the 'sea-maximising-land minimising' principle. One of the first studies undertaken in the area of port traffic volumes in relation to location was that of Chisholm (1985) who looked, in particular, at the accessibility of trade generating regions and the level of economic development in Britain. However, no detailed analysis of origin – destination flows through the ports was presented. Further, no reference to the carbon footprint of particular freight routeings was incorporated into the study. Although freight transport corridors were highlighted in the Chisholm (1985) study, the approach taken left considerable room for a more disaggregated analysis. Another early study by O'Connor (1987) examined the way in which related services accrete onto large port cities where there are synergies between the cargoes and regional trades. More recently, Notteboom (2009) considered the complementarity and substitutability of container ports across a range of port regions. Again, however, these studies did not extend to include the broader aspects of how consignment routeings through alternative ports could contribute to improvements in the performance of supply chains in the area of CO_2 reduction.

This paper therefore endeavours to address the issue of whether re-engineered supply chains, using alternative port gateways, can contribute significantly to an overall reduction in freight transport-related CO_2 emissions. In terms of the impact of economic activity on the environment, evidence from the Mauna Loa observatory in Hawaii indicates that CO_2 levels in the atmosphere now stand at 387 parts per million (ppm), up almost 40% since the industrial revolution and the highest for at least the last 650,000 years (NOAA, 2012). At a national level, according to DEFRA (2006), in the UK freight transport contributes 6% of the total annual CO_2 emissions of the UK. Within the transport sector, road freight transport typically represents around 22% of the total UK annual CO_2 emissions. Additionally, in regards to UK domestic Tonne-Km, rail transport contributes 9% of total CO_2 emissions and shipping 20%. (Department for Transport, 2007). Hence, freight transport has become an extremely important supply-chain function not least because of its impact on the environment.

A major cause for concern is that CO_2 emissions derived from road freight transport are increasing at a faster pace than the emissions generated by cars and buses. CO_2 emissions from truck movements are anticipated to exceed those derived from passenger transport by the beginning of the 2020s (WBCSD, 2004). Considerable efforts are being made by governments, and by the European Union (EU), to decouple the growth in carbon emissions from growth in Gross Domestic Product (GDP). To support these efforts, it is essential to evaluate in detail how supply chains can meet the challenge of more successfully managing their emissions performance. Woodburn and Whiteing (2010) recommend modal shift as one of the most effective strategies to reduce the carbon footprint of freight transport networks within supply chains. This paper aims to explore how the redistribution of freight handled by the main UK ports of entry combined with a shift of freight from road to rail for inland movements could reduce the total carbon footprint of the UK freight transport sector. The approach taken in this study is similar to that of Liao et al (2010): an activity-based CO_2 emission model is used to estimate the cost and CO_2e impacts of four Scenarios, which are described in the paper as the "current situation" and three "proposed Scenarios". However, in order to run the model, a more disaggregated analysis than that implemented by Liao *et al* (2010) has been undertaken. While there is likely to be considerable scope for emissions reduction, the study that follows clearly has boundaries in terms of the assumptions used. Changes to the throughputs at different ports will have repercussions along the supply chain and could negatively influence the savings that could be made, and therefore it could be more difficult to realise the total overall potential reductions than suggested. In this paper, it is hypothesised that the rerouting of containers away from traditional large ports in southeast England and into northern / north-western ports would significantly reduce the overall carbon footprint of marine-based container transport for British trade.

In order to keep the modelling exercise manageable, the flows of empty containers and exported freight are excluded from the analysis. Export volumes are lower and empty container flows do not drive the logistics system in the way that loaded containers do; empties also follow a wide variety of paths through the system with the result that their patterns of movement have less coherence. Thus, the Scenarios presented in this paper only include loaded import containers through the ports moved via rail or road. In practice, however, the logistics of container movements is further complicated by indirect routeing of a significant proportion of containers via Inland Container Depots which act as sinks for rail-hauled containers to / from, for example, Leeds, Glasgow, Manchester and outer London. Local distribution and collection is performed by truck, hence these movements are already 'intermodal'. In Scenarios 2 and 3, three main locations have been selected for the transfer of containers from road to rail, being Derby, Glasgow and Manchester. In the case of Derby and Manchester recent distribution centre developments have improved the intermodal links with the provision of Rail Terminals. One such example is the Daventry International Rail-Freight Terminal which consists of about 2 million sq ft of rail-connected distribution facilities (PROGIS RFI, 2013). This provides the option for users of the terminal to expand the use of rail transport. Similarly, Glasgow was selected as a rail freight terminal location in order to minimise road TEU-Kilometres in freight movements of Scottish imports. Further, the new port at London Gateway could have major implications for container re-routeing as it will offer 3.5 million TEU capacity when fully operational. However, as the port is not yet handling containers on a commercial basis, it was not included in this analysis which is restricted to selected established ports which are fully operational.

2. Port Selection Criteria

Port selection in supply chains has not, to date, focused on the requirement for supply chains to reduce the overall level of CO_2 emissions. Rather, port selection criteria have focused more closely on commercial considerations such as, for example, least-cost through handling improvements. Further, substantial changes in trading patterns have been a recurring feature of Britain's history. As Asteris and Collins (2007) discuss, port-capacity enlargement decisions and major infrastructure upgrades for a given region, are important both in terms of economic development and regional politics. Potential impacts have been exacerbated by increases in vessel size which 'together with the mobility available to freight in unitised form' have resulted in container lines using hub-and-spoke systems with a preference for ports in southeast England. Fundamental changes in cargo handling and increases in ship size led to redundant ports unsuitable for conversion to modern container handling requirements with new ports or port areas developed to accommodate such changes (Pearson and Fossey, 1984, UNCTAD, 2011). The issue of port selection is further complicated by the selection criteria used by the shipping lines. Most port operators design their strategies based on the 'stated preference' of shipping lines, and this 'geo-economic' approach may be fundamentally flawed as shipping lines tend to overstate their demands for port services. This can therefore lead to overcapacity being promoted (Tongzon, 2002; Tongzon and Sawant, 2007).

Whatever the reason or approach taken for deciding which ports are used, port selection is a complex and under-analysed issue. Many authors have studied port selection with most leaning towards 'achieving scale economies' and 'time compression' as primary port choice factors over 'proximity to the market' (Slack, 1985; Lirn *et al*, 2004; Ugboma et al, 2006). Robinson (2002) indicated that port selection depends on a port's inclusion in logistics chains while Malchow and Kanafani (2004) concluded that port selection has been modified mainly by the development of inter-modal transport. Bichou and Gray (2005) and Yap and Lam (2006), on the other hand, tie port selection back to the economic, political and social environment.

What is clear from the above discussion is that ideas related to port selection predate the arguments that CO_2 emissions are an important consideration in transport decision-making. The criteria relating to port selection have primarily focused on inland transport minimisation and the extant literature has paid little attention to the problems of CO_2 emissions because port selection, as with modal choice, has been treated as a purely economic / commercial decision. In the recent past, however, issues pertaining to CO_2 emissions have become more focused on the role of the global community in the generation of carbon emissions awareness. This has led to increased pressure on modes with disproportionately high carbon output such as road, with the development of ideas about the transfer of cargoes to modes where emissions are, pro-rata, lighter. Ports are ideally placed to play their part in reducing in transport-related CO_2 emissions through their contribution to the redesign of supply chains.

3. UK Ports

During the 1990s, container handling capacity in the major British ports was recognised as being unable to cope with predicted growth in volumes. There was also increasing concentration of existing volumes into the larger ports including Liverpool, Felixstowe, Thamesport, Tilbury and Southampton (Dawe, 2001). Successive studies by, for example, the Department for Transport (2009) and MDS Transmodal (2006) confirmed both the need for additional port capacity in the UK and the fact that extra capacity would be required primarily in the south and east (Pettit and Beresford, 2009). The complexities of container feedering from a mainland European port, e.g. Rotterdam, are such that it may be more cost-effective to serve the Midlands and Scotland via other ports such as Hull, Immingham, Liverpool and Bristol, rather than via mainline direct call at Felixstowe or Southampton with inland transport mostly by road (Pettit and Beresford 2007). With more sophisticated pricing and 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. It seems pertinent to explore the potential water-rail intermodal connections between southern UK ports and the midlands and north of the UK. However, it is important to estimate the effects that these initiatives have on the economic and environmental costs of the freight transport movements of the maritime, rail and road legs of such cargo movement.

In order to more fully understand the impacts of port choice on logistics solutions and the potential impact that this will have on the level of CO_2e emissions, two UK ports located in the southern gateway (Felixstowe, Southampton), one in the west (Bristol) and three in the northern gateway (Hull, Immingham and Liverpool) were selected for analysis. Felixstowe is an established deep sea port serving the whole of the UK and Southampton complements it in terms of capacity and location. Bristol, Hull, Immingham and Liverpool operate at the northern and western limits of possible deep water, restricted access and limited demand. As indicated earlier, while London Gateway could have major implications for container re-routeing it was not included in this analysis which is restricted to selected established ports which are fully operational.

Pettit and Beresford (2007) used a mapping tool to quantify inland freight movements by distance and cost from selected ports including Felixstowe, Hull and Immingham. Based on this work three Scenarios are tested: (1) the re-direction of containers by a combined expansion of Hull, Immingham, Liverpool and Bristol, (2) moving containers by rail facilitated by the expansion of the port of Southampton, and (3) moving containers by rail facilitated by the expansion of the port of Felixstowe. In order to simplify the study and to keep the analysis manageable, the option of coastal shipping has also not been considered as a scenario in this paper. Real time container origins and destinations are used as a key proxy for port-inland flows.

4. Modal shift as an enabler for the decarbonisation of freight transport

McKinnon *et al.* (2007, 2010) developed an analytical framework for green logistics which focuses on guiding the decarbonisation of road freight transport sectors and networks. The framework includes seven parameters being: modal split, average handling factor (or the average number of nodes in supply chains), the average length of haul vehicles travel, the average load on laden trips, the average empty running per trip, energy efficiency and emissions per unit of energy used. Tacken *et al* (2011) linked these parameters with four key areas where road freight transport operations could focus in order to reduce emissions being modal split, logistics efficiency, vehicle fuel efficiency and carbon intensity of fuel used. The focus was on how the use of road transport can be reduced by adopting a modal shift programme at a macro level. The UK was used as a case study to demonstrate how the carbon footprint of the freight transport sector can be reduced by establishing road freight miles reduction as a key objective to be taken into account when deciding the port of entry selected depending on the location of the final destination.

According to Woodburn and Whiteing (2010), in the UK, road haulage increased its market share from 65% in 1976 to 69% in 2006, and in contrast to this, the rail and domestic water sectors have had relatively smaller market shares, e.g. 9% and 22% in 2006. Rail and waterborne modes of transport are less damaging to the environment than road haulage, with typical emissions from waterborne freight four or five times less per tonne-km than for road, and seven times lower for rail (McKinnon 2007, Woodburn and Whiteing 2010).

A number of authors have discussed measures which could be applied to enable the adoption of modal shift in the UK. Woodburn *et al* (2007) identified four types of measure which could be adopted to incentivise modal shift in the UK and the rest of EU countries. These measures can be categorised as fiscal, regulatory, supply-based organisational and demand-based organisational. Examples of fiscal measures are the single sustainable distribution fund operated by the UK government from April 2007 (Department for Transport, 2006) and taxing the external cost of each mode of transport (Westermark, 2001). Furthermore, regulatory measures have been adopted at UK and European Union levels to enable the liberalisation of, and access to, international rail freight corridors and which aim to further increase volumes transported by rail (Cantos & Maudos, 2001; Woodburn *et al.*, 2007). In relation to the focal aim of this paper, fiscal and regulatory measures play a crucial role in the redistribution of ports of entry in the UK as well as in the increase of freight that is moved from South Western ports to the Midlands and Northern UK regions.

In addition, as Woodburn *et al* (2007) emphasise, supply-based organisational measures refer to initiatives that improve the provision of transport in non-traditional modes such as rail and water. Examples of such initiatives include new or improved infrastructure, innovative service provision, changes in operating practices and better integration of rail and water with road. This paper illustrates the cost and CO_2e impacts of redirecting freight to non-traditional ports and rail routes to reduce the total road freight tonne-kilometres. Two of the main enablers of this are the commissioning of new or improved port and inland intermodal hubs and better integration of water and rail with road. An important contributor to improving the integration of water and rail with road is multimodal transport. For short-distance transport, especially internal land-based transport, solutions are usually clear-cut and simple; but over medium to long hauls modal combinations can be varied and complex, especially for very high value cargoes (Beresford, 1999). The door-to-door benefits of road haulage are thus compatible with a range of possible multimodal transport solutions (Lalwani et al, 1991;

Hensher and Brewer, 2001; Lowe, 2005). The economies of scale of the respective transport modes: air, sea, waterway, rail and road, form the basic framework for freight carriage and for supply chain structure optimisation from a transport perspective (Gilman, 1980, 1983; Stopford, 2009). Indeed, the ever decreasing pro rata unit costs over time of shipping, derived primarily from steadily increasing ship size and from parallel developments in cargo unitisation and containerisation, have been cited as decisive components in the globalisation of the world economy (Dicken, 2007). By restructuring modal combinations based around the port of entry alternative solutions to the existing limitations of multimodal transport solutions can be suggested. Thus, at UK domestic level, if more efficient water to rail and inland rail to road combinations are selected the total carbon footprint of the UK road freight sector could potentially be substantially reduced.

The other type of modal shift measure proposed by Woodburn *et al* (2007) is demand-based organisational measures taken by the freight transport users, including producers, manufacturers and retailers across all the UK economic sectors. When large companies such as Tesco, Sainsbury's, Coca-Cola, Nestle, Corus and IKEA incorporate rail and water modes of transport, as well as road, into the weekly and long-term planning of their freight transport networks, they can achieve a dramatic reduction of their inland road freight miles and ultimately of their carbon footprint. As Woodburn and Whiteing (2010) argue, forward-looking companies are attempting to 'future-proof' their supply chains by ensuring that they have a choice of modes available to them by anticipating the risks associated with using road exclusively, e.g. major fluctuations in fuel prices or an interruption to the availability of fuel. The impact of the adoption of a more integrated approach to multimodal transport planning in the UK freight transport sector, taking inland road freight miles reduction as a principal objective could provide substantial gains in terms of CO_2 reductions for supply chains.

5. Inland Container Transport

An assessment of the movement of containers throughout the UK based on a spatial model using Microsoft Excel and a sensitivity analysis was recently undertaken by Pettit and Beresford (2007). This enabled the relative competitive positions of the respective ports from a distribution/cost matrix point of view, to be compared. The distribution of import containers from the ports of Hull, Immingham, Southampton, Felixstowe and London Gateway was analysed. From data obtained from shipping lines the principal container destinations in Great Britain were mapped using a five point intensity scale to show the spread of container destinations throughout the country (1). The destinations relate closely to the principal concentrations of industry and population. Prominent are: the industrial axis of the Scottish lowlands; Northwest and central Northern England; Tyne/Tees; Humber; Midlands; parts of South Wales and Western England; and much of the Southeast. Large areas of the country receive only a few containers: most of Scotland, the borders and Cumbrian areas of Northwest England, Lincolnshire, most of Wales and Southwest England. The key container concentrations are: the Glasgow area; Teeside; Manchester/Liverpool; Leeds/Sheffield; West Midlands; East Midlands; Greater London; and the Southampton area. Great Britain is polarised into two separate major markets in terms of import container destinations: Southeast England from Southampton to Norwich and Wales/Northern England from South Wales to Humberside. The percentage market share of the container destinations attributable to these key regions is shown in Table 1. However, previous studies have not included origin to destination movements based on the minimisation of road tonne-kilometres generated by container movements. This paper addresses this issue.

Table 1: Import Containers: Regional Markets by Percentage

Zone	Region	Regional Container Destination Market Share
1	Northern and Western Scotland where demand is low and widely dispersed.	1%
2	Central Scotland (Clyde, Edinburgh, Dundee, Perth, Aberdeen) where demand overall is less dispersed and medium volume.	8-9%
3	A large area of Borders and North England down into North Mid and West Wales where demand is again low and widely dispersed.	2%
4	A 'box' bounded by Tyne, Leeds, Liverpool, South Wales, Bristol, Oxford and Lincolnshire which is generally medium to high volume.	41-43%
5	South West England, Central Southern England into Northern East Anglia where demand is generally low and rather dispersed.	7-8%
6	South East England where demand is high and concentrated.	39-40%

Source: Pettit and Beresford, 2007

The work of MDS Transmodal (2006), however, suggests that Great Britain splits into nine regions in terms of container destinations / origins (ODs), as shown in Table 2. It is notable that the MDS Transmodal data appears to absorb London ODs within the East England and South East statistics. This makes it impossible to identify specific ODs on a fine grid basis such as a town-wise grid. However it is clear that east England, the South East and London

1 For reasons of confidentiality it is not possible to attribute individual container movements to a specific port.

are together dominant, accounting for around 70% of Britain's total, although this in itself is oversimplified as transhipment complicates the pattern of container distribution still further. Some confirmation of the MDS data can be taken from Table 1 which also indicates that about 70% of box movements finish or start in zone 6 or the eastern part of zone 4. While the forecast data provided in Table 2 cannot be verified, it gives some indication of how containerised movements will be regionalised over the next twenty years.

Table 2: Forecasts for GB forecast containerised traffic (teu) to 2030 by GB port region

	2005	**2010**	**2015**	**2020**	**2025**	**2030**	**Growth**
North East	150	225	312	365	428	366	3.6%
Yorks. & Humber	506	720	851	984	1,098	1,225	3.6%
East Midlands	22	32	38	44	49	54	3.6%
East England	3,442	4,516	5,538	6,461	7,724	9,376	4.1%
South East	2,126	2,630	3,392	3,959	4,676	4,920	3.4%
London	-	-	-	-	-	-	-
South West	112	189	197	228	255	355	4.7%
North West	604	1,269	1,315	1,540	1,719	2,586	6.0%
Wales	57	81	96	111	124	139	3.6%
Scotland	194	346	408	475	560	707	5.3%
Total	7,213	10,009	12,146	14,167	16,633	19,728	4.1%
Total ex. transhipment	7,003	10,009	12,146	14,167	16,633	19,728	4.2%
Container Units	4,401	5,881	6,941	8,095	9,505	11,273	3.8%

Source: interpreted from MDS Transmodal (2006)

Specifically, MDS Transmodal (2006) suggests four Scenarios regarding container traffic growth, port call patterns and possible terminal expansion projects. Scenario One embraces the 'business-as-usual' case, and a need for extensive expansion of feeder ship berths would be required. The overall impact on the economy would be generally negative with significantly higher transport and hence 'end user' costs. Scenario Two, referred to as a 'greater southeast plus Liverpool' approach reduces user costs significantly over the 'business-as usual' approach referred to in Scenario one. Scenario Three involving the development of extra deepwater capacity beyond the greater southeast region produces similar transport efficiency results to the 'more feeder berths' approach. In practice, the extra deepwater berths would in reality cater for both mainline and feedership calls.

The final strategy, 'Scenario Four', involves construction of extra capacity in the greater southeast instead of on the west coast or in the northeast. Some rebalancing of costs would result, but overall user costs would rise by around £80 million per annum. Interestingly, the report suggests that, as container traffic increases and southeast capacity becomes fully utilised, some of the deep sea traffic would be attracted to regional ports via direct call, suggesting a ripple effect. Some of the implications for container transport derived CO_2 emissions of these Scenarios are discussed below.

6. Methodology

The methodology employed here broadly mirrors that followed by Liao et al (2010) who present Scenarios based on the greater or lesser use of Taipei port *vis-a-vis* alternatives. Trade is presented as flows taking the form of maritime and inland transport segments with ports acting as the interface. Here however transport movements are analysed on a more disaggregated basis. Six major UK ports were used for this study: Felixstowe and Southampton were chosen for the southern gateway, Hull, Immingham and Liverpool as northern gateways. Bristol was selected as a western gateway as the port has been developing its strategy to act as a major container gateway since 2004 (Port of Bristol, 2013) and received approval for a 1.2km quay deep sea container terminal capable of handling 1.5 million TEUs in March 2010 (DfT, 2010). Moreover, the six regions used in the studies undertaken by the Port of Bristol (2013), Pettit et al. (2005) and Pettit and Beresford (2007) have been used to support the main assumptions in the study. Six ports were included in the estimation of the origin data as shown in Table 3, being Bristol, Dover, Felixstowe, Hull plus Grimsby and Immingham, Liverpool and Southampton plus Portsmouth. These ports were included in the study because they jointly handle about 63% of the total UK imports. Table 3 shows the baseline data, being cargo volumes in thousands of TEUs (including both Lift-On Lift-Off (Lo-Lo) and Roll-On Roll-Off (Ro-Ro)) through the relevant ports, gathered from Department for Transport (2009). As can be seen, the Southern UK ports represent over 73% of the total imports handled by all six ports.

Table 3: Baseline data for UK import containers, selected port of origin (000s TEUs)

Port	(000s TEUs)	Market share (%)
Bristol *	29	1
Dover **	1,910	36
Felixstowe *	1,257	24
Hull (plus Immingham) ***	832	16
Liverpool *	591	11
Southampton * (plus Portsmouth) **	667	13
Total Imports for Ports included	**5,286**	**63**
UK total imports ***	**8,425**	**100**

***- Mainly Lo-Lo; ** - mainly Ro-Ro; *** Mix of Lo-Lo and Ro-Ro**
(Calculated from Department for Transport (2009)

Table 4 shows the nine UK destination regions proposed by MDS Transmodal (2006), which have been used to estimate the total TEUs per region. The forecast data for 2010 from the MDS Transmodal report were used for the estimation of the destination data. Nevertheless, as Table 4 shows, for the Midlands, East England and South East regions, the MDS Transmodal data for 2010 were recalibrated, since in the original dataset, East England and the South East statistically absorb most of the Midlands' TEUs. TEU data for these three regions was recalibrated using population statics from the ONS (2010) for the cities located within them. Subsequently, the percentage of TEUs per region and the total UK imports handled in the six ports included in the study were used to calculate the total imports for each destination region, which represents 63% of the total number of containers handled by all UK ports. Also, for each of the regions included in the study, a reference city was selected to calculate the total miles from ports of origin to each of the regions. The main assumption used for estimating the destination data per region is that these cities concentrate all primary despatches for their respective vicinities.

Table 4: Re-allocation of UK imports per city in TEUs (000s)

UK destination area	Reference City	Original MDS Transmodal data (000s TEUs)	Re-allocation of MDS Transmodal data (000s TEUs)	% of TEU	Destination data from sampled imports (000s TEUs)
North East	Newcastle	225	225	2.2	119
York & Humber	Leeds	720	720	7.2	380
Midlands	Derby	32	2239	22.4	1182
East England	Northampton	2630	1303	13.0	688
South East	London	4516	3637	36.3	1921
South West	Exeter	189	189	1.9	100
North West	Manchester	1269	1269	12.7	670
Wales	Swansea	81	81	0.8	43
Scotland	Edinburgh and Glasgow Average	346	346	3.5	183
Total (000s TEUs)		10008	10008		
Sampled imports (000s TEUs)			5286		
% of imports included			63		

Source: Calculated from MDS Transmodal (2006)

This data set together with the destination data set was used to calculate the TEU-kilometres for four Scenarios. While there are clearly areas where efficiency could be improved, for example increasing the utilisation of containers would potentially reduce the total number of TEUs necessary thus reducing total TEU-kilometres and the need for port expansion. Such changes were considered to be outside the scope of this paper, however. The estimation of the actual Scenarios was made by assuming that the six ports selected operate at total current capacity. In this Scenario, the allocation of origin data in TEUs has been allocated to the destination cities considering minimisation of distance travelled by road as the primary goal: The four Scenarios are:

- Scenario (0): Estimation of the actual Scenario; Dover, Felixstowe and Southampton handle about 73% of the UK import containers included in the study. This Scenario is constructed around the minimisation of cargo transport by road distance, and the assumption that the capacity of each port remains constant.

- Scenario (1) is estimated by assuming that the ports of Bristol, Hull plus Grimsby and Immingham and Liverpool can be expanded to minimise road distance travelled. The main aim is to reduce CO_2e and costs generated due to UK freight transport movements at a macro level as well as reducing traffic congestion. This Scenario could arise from increasing pressures for change, over and above those which already exist, for example from government commitments to reduce CO_2e outputs to a greater extent than current commitments. Using ports more proximate to the market destination for the cargo would contribute to meeting this requirement.
- Scenario (2) is estimated by assuming that an expansion of the port of Southampton is feasible and assuming that Derby, Manchester, Liverpool, Glasgow and Edinburgh can be fed by transporting containers by rail from the port of Southampton to these cities instead of transporting containers by road. . This Scenario could occur if strategy changes are implemented by the Liner shipping companies regarding their UK port of call. Additionally, further investment in the UK rail network to support the transfer of cargoes to rail routes from Southampton may have taken place.
- Scenario (3) is estimated assuming that an expansion of the Felixstowe port is feasible and assuming that Derby, Manchester, Liverpool, Glasgow and Edinburgh can be fed by transporting containers by rail from the port of Felixstowe to these cities instead of transporting containers by road. The most likely reason for this Scenario developing is that Liner shipping companies continue to develop increasingly large vessels that have limited options in terms of their port of call. Felixstowe, being one of the only ports that accept vessels of the Maersk E Class or equivalent, permits this Scenario to exist. The coming on-stream of London Gateway over the period 2014 to 2016 will ultimately allow further reworking of this Scenario. Container volumes listed in Table 4 were re-allocated to regions based on estimates of container origins and destinations derived from industrial output and regional population data.

Distance data (as shown in Table 5) was calculated using an on-line distance calculator (Daft Logic, 2011). This distance data together with the origin and destination data sets in TEUs have been used for the estimation of the actual Scenario and proposed Scenarios 1, 2 and 3. The two shortest distances between origins and destinations have been identified as the two least carbon intensive routes to move freight by road as a guide for the calculations for the four Scenarios. The rail route used for estimating the rail kilometres in Scenarios 2 and 3 includes three main rail hubs, Birmingham, Manchester and Glasgow. The locations of these hubs were selected based on their concentration of population, freight generation / consumption and geography. Rail route distances from the ports of Southampton and Felixstowe to each rail hub are shown in Table 6. No additional road kilometres were added to the rail kilometres in Scenarios 2 and 3, because of the fact that the freight that was transferred from road to rail was freight that needed to be moved from Southampton and Felixstowe to Derby, Manchester/Liverpool and Glasgow/Edinburgh.

Table 5: Origin-to-destination distance data (Km)

		Destination											
	Region	Scotland		North East	York and Humber		Midlands	North West		Wales	South West	East England	South East
	Reference City	Glasgow	Edinburgh	Newcastle	Leeds	Sheffield	Derby	Liverpool	Manchester	Swansea	Exeter	Northampton	London
Port of origin	Hull (+ Grimsby and Immingham)	427	404	230	97	105	150	203	153	467	483	243	345
	Liverpool	353	354	282	153	129	156	3	58	391	411	242	343
	Bristol	599	601	473	335	290	217	291	283	129	105	148	190
	Dover	787	789	565	451	406	346	477	475	435	391	238	122
	Southampton	687	692	526	388	343	277	383	377	279	151	153	129
	Felixstowe	676	650	475	346	319	283	417	411	460	478	198	150

Source: Daft Logic (2011)

Table 6: Origin-to-destination distance data (Km)

		Rail hub destination		
	Reference City	Glasgow	Birmingham	Manchester
Port of origin	Southampton	447	141	224
	Felixstowe	449	143	226

Source: Travelfootprint, 2011

Furthermore, the differences in equivalent road kilometres generated for the sea leg between Scenarios 1 and 2 and the actual Scenario were calculated using the Isle of Scilly as a reference point and by assuming that most of the cargo which goes to the ports of Bristol, Felixstowe, Liverpool and Southampton moves in from the Atlantic Ocean. Table 7 shows these differences (Daft Logic, 2011).

Table 7: Equivalent road km differences between sea legs of Scenarios 1, 2 and actual

Scenario	Original port	Equivalent road kilometres	Scenario	Alternative port	Equivalent road kilometres	Difference (equivalent road kilometres)
0	Felixstowe	700	1	Liverpool	650	-50
				Hull and Immingham	1000	300
				Dover	650	-50
				Bristol	445	-255
			2	Southampton	400	-300

Source: DaftLogic, 2011

Table 8 shows the CO_2e emissions and transport cost factors used to convert the TEU kilometres to tonnes of CO_2e emissions and GB pounds. The CO_2e emission factors for freight transport recommended by Defra (2007) and the transport costs of moving products by road, rail and water recommended by the Department for Transport (2009) are used for this conversion. It should be noted that the emission factors used may be based on different loading assumptions which may not reflect the actual conditions which occur on the ground. However, the factors used here are generally accepted as being representative in most cases.

The costs incurred due to the expansion of different ports were not included in the study, since it is difficult to estimate such costs in an accurate manner. For the same reason, no calculations were made for using the very large (and potentially very influential) future port of Thames Gateway or for the impact of Emission Control Areas which could lead to operational changes by shipping lines such as slow steaming or the use of different fuels (Fathom Shipping, 2013). Furthermore, the cost of transferring TEUs from ports to lorries is typically £100 per TEU and the cost of performing local distribution of a container from ports to rail hubs and then from rail hubs to the destination is on average £150[2].

Table 8: Costs and CO_2e emissions factors used

Transport mode	Cost (£ per TEU-Kilometre)	Kg of CO_2e per Tonne-Kilometre	Kg of CO_2e per TEU-Kilometre
Average lorry	1.00		1.07897
Average train	0.32	0.03692	0.7384
Average container ship	0.31	0.01877	0.3754

Source: DEFRA, 2007

After estimating the transport costs and tonnes of CO_2e emissions, the barriers to expanding the capacity of the ports of Bristol, Hull, Liverpool and Southampton were investigated. This was achieved by consulting various government sources and the port operators themselves. Reports were found on each of the Ports' websites as well as a government site on the expansion of Bristol. The barriers to increasing the capacity of the UK rail network were also investigated (DfT, 2007; 2009).

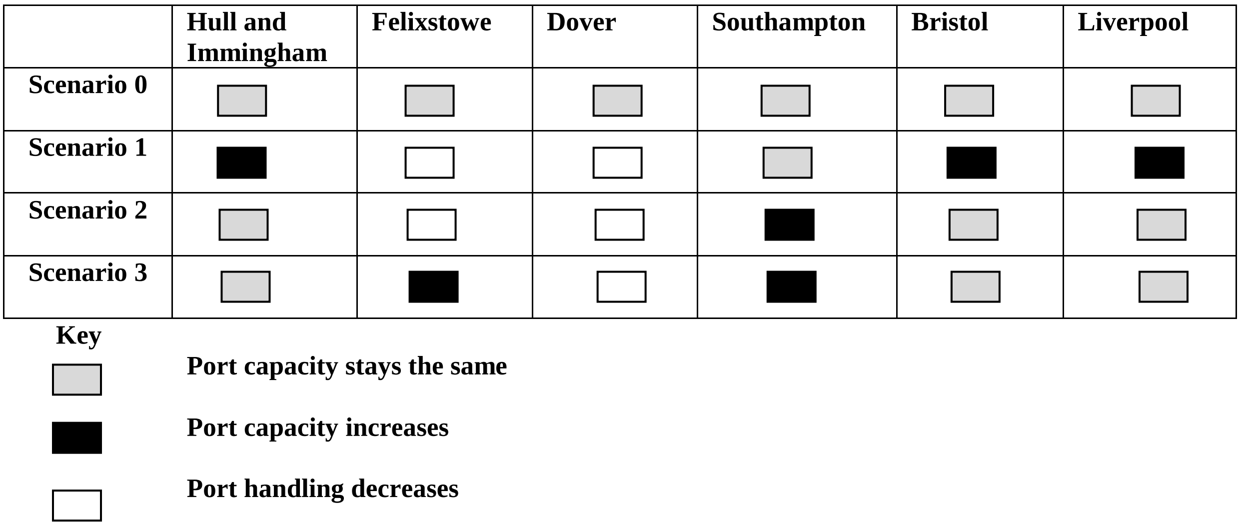
7. Port Capacities: the four Scenarios

In order to undertake the exercise, as explained in the methodology section, four Scenarios were identified and the freight transport costs and CO_2e generated in each of them estimated by applying the assumptions discussed previously. A visual portrayal of the four Scenarios is presented in Figure 1. The main aim is to assess how these four Scenarios affect CO_2e emissions from freight transport, as well as costs, assuming that rail and water are significantly less carbon intensive and are often cheaper per unit than road transport (Beresford, 1999). The main independent variable used to generate the four Scenarios is distance and the main purpose for the estimation of the four Scenarios is the minimisation of

2 These two parameters were gathered from confidential commercial sources.

the road distance from origin to destination. The feasibility of expanding the capacity of ports and the UK rail network is not considered in estimating the costs and Tonnes of CO_2e generated in the four Scenarios, but is discussed after presenting the findings. The Emissions Control Area affecting total CO_2e emissions in freight flows moved through the North Sea has not been included in this paper, since the paper proposes scenarios which could lead to significant reductions in the total freight-transport based CO_2e emissions.

Figure 1: The four Scenarios for port capacity development



Source: Authors

From the calculations performed for the four Scenarios, Scenario 2 (an expansion of the port of Southampton and the use of the rail network from this port and the cities of Derby, Manchester and Glasgow) is the least carbon intensive option with a saving in CO_2 emissions of 29% in comparison to Scenario 0 (See Table 9). Scenario 2 is the second most cost-effective option and represents a net financial saving of about £112 million (7.8% cost saving), slightly less than Scenario 1 which represents a net cost saving of £136 million (10.5% cost saving) and slightly more than the net savings in Scenario 3, £111 million (7.7%). These savings can be explained by the fact that most of the TEUs re-directed from Felixstowe to Southampton to feed the cities of Derby, Liverpool, Manchester, Glasgow and Edinburgh are transported by rail instead of road, which is about 30% less carbon intensive and more cost effective than the equivalent road routes for high volume flows. Furthermore, the fact that Scenario 1 is more cost-effective than Scenarios 2 and 3 can be explained by the fact that the addition of an intermodal hub to the routes used in these Scenarios increases the cost of transferring TEUs by £50 per TEU.

In addition, as Table 9 depicts, Scenario 2 offers a significant cost saving of £112 million and a reduction of 120,000 Tonnes of CO_2e. On the other hand, the total road movements in Scenario 1 are more carbon intensive but slightly more cost effective than the Scenario 2, the additional water movements run in Scenario 1 offset the reductions in CO_2e and costs. Moreover, in the case of Scenario 3, there are slightly more savings in CO_2e emissions (16%) than in the case of Scenario 1; however the cost savings of Scenario 1 (10.5%) are slightly more than the cost savings in Scenario 3 (7.7%). The main reason is that, as in Scenario 2, Scenario 3 implies having an additional cost of £50 per TEU as a result of transferring TEUs from rail to road.

Table 9: Estimated costs and Tonnes of CO_2e emitted in the four Scenarios

Scenario	000' TEU-Road Km	Transport costs (£ Million)							Freight transport CO_2e emissions (000' Tonnes)				
		Road	Additional water	Additional rail	Transfer from water to road	Transfer from water to rail to road	Total	% of savings	Road	Additional water	Additional rail	Total	% of savings
0	908	903			529		1,432	-	980			980	-
1	711	707	60		529		1,296	10.5	767	73		840	14
2	521	517	(-) 100	219	417	167	1,320	7.8	562	(-) 121	260	700	29
3	521	517	-	220	417	167	1,321	7.7	562	-	262	824	16

Source: Authors

A key aspect requiring consideration is the additional port capacity required and the number of ports which may require expansion in the three Scenarios. This is shown in Table 10. Scenario 1 would require a significant expansion of the port of Bristol (by around 390%), and less significant but still considerable expansions of Hull and Immingham and Liverpool, 102% and 44% respectively. Moreover, this would lead to a reduction in required capacity at the ports of Dover and Felixstowe. Furthermore, Scenario 2 represents an expansion in capacity of the port of Southampton of 187% while at the same time there is a reduction in required capacity at the other two South East UK ports. This is less significant than the expansion of port capacity required in Scenario 1, although still considerable. Hence, the costs and CO_2e impacts of Scenarios 1 and 2 would need to be calculated carefully, since these two Scenarios are likely to require a considerable investment cost and generate additional construction-related CO_2e emissions.

Table 10: Overall capacity change of the six Ports selected in the four Scenarios tested

Scenario	0	1	2	3
Rail capacity required	The same	The same	Increased	Increased
Port capacity and capacity utilisation changes (%)				
Hull and Immingham	0	102	0	0
Liverpool	0	44	0	0
Bristol	0	390	0	0
Dover	0	-50	-50	-50
Southampton	0	0	187	20
Felixstowe	0	-40	-29	17

Source: Authors

Furthermore, the expansion in capacity required at the ports of Southampton and Felixstowe under Scenario 3 is significantly less, 20% and 17% respectively, than the expansion required in the port of Southampton (187%). This difference in terms of port growth required in the two Scenarios needs to be considered when selecting the preferred Scenario due to the potential investment costs and CO_2e emissions which could be generated by building more capacity at these two ports. In addition, the barriers to the expansion of the ports of Bristol, Liverpool, Hull and Immingham required in Scenario 1, and of Southampton and Felixstowe and the increase in the UK rail network required in the case of Scenarios 2 and 3 respectively, needs to be taken into account when analysing the findings from the estimation of the four Scenarios. An example of a significant barrier is the required increase in rail capacity at, or close to, the major gateway ports and this is discussed in more detail in the next section.

8. Barriers to Expansion

While the study demonstrates that for economic and environmental benefits, the ports of Liverpool, Hull and Bristol should be expanded and used for handling cargo destined for Scotland, Northern England and the Midlands, in practice there are major barriers to consider. Over the last two decades a notable development in container trade has been the growing size of ships which now rely heavily on economies of scale, as the operator's profit margin improves when containers are transported on larger ships. Until around the mid-1990s the largest container ships were in the range of 4,500 TEUs. Since then the size of container ships has been steadily rising; from 5,000 – 8,000 TEUs in the 1990s to 14,000 + TEUs from 2006 onwards. The trend has continued further; in November 2012 the capacity of the largest container ship in service increased to 16,200 TEUs which was surpassed with the introduction of an 18,270 TEU capacity vessel in July 2013 (Cullinane and Khanna, 2000; Martin et al, 2013; Brett, 2013; Kremer, 2013; Rodrigue 2013). The latest data available suggests that the recently launched Maersk Triple E Class vessels, with a full load of 18,000 TEU, steaming relatively slowly at 16 knots, will save up to £750,000 in fuel costs on a typical journey from Shanghai to Rotterdam compared with express-service fast-steaming ships. It would also emit only 3g of CO_2 to transport one tonne-kilometre. Maersk alone plans to construct further 19 similar sized ships over the next two years (Kendall, 2013). In order to meet the demand for handling larger ships container ports and terminals have also had to increase capacity. Such expansion has required them to increase the water depth of the approach channel and at the quay, provide larger container storage capacity, larger quay-side and gantry cranes among many other major investments (Tongzon, 2002; Notteboom and Rodrigue, 2007).

However, not all ports have been able to expand and keep pace with the growing size of container ships. The ports of Hull, Bristol and Liverpool, which are located on the banks of a river or in an estuary, unfortunately belong in this category. The limitation of water depth alongside the docks compels the three ports to rely on tides and the use of lock facilities. Locks, located between the river or estuary and the enclosed dock basin used for cargo operations, help maintain a suitable depth of water within the dock facilities at a height roughly equivalent to the level of high water in the adjacent river or estuary. Thus a ship takes advantage of high water when transiting the approach channel and remains protected from tidal fluctuation when it is docked for cargo handling. Use and awareness of available water depth is especially critical in the case of the port of Bristol where the tidal range is up to 15 metres during the spring tide (Tym, et al, 2004). However, such tide-dependent ports and lock facilities also limit a port's efficiency. Ships calling at these ports can use the approach channel only during favourable tidal periods and are further constrained by the dimensions of the lock. Moreover the whole process of passing through a lock increases a ship's turnaround time (Alderton, 2008). Thus, increasing the capacity of these three ports would mean a significant investment in dredging the approach channel and at quay side, expanding the size of the locks as well as increasing the container handling capacity in the dock. Such extensive upgrading of ports is not only capital intensive and impracticable but arguably also environmentally unfriendly.

At present, none of the three case ports (Hull, Bristol or Liverpool) is able to accommodate ships in the range of 5,000 TEUs through their locks or alongside the terminals due to size restrictions. These ports in their current form therefore are more suitable to handle UK's short-sea shipping needs, such as coastal trade and trade with the neighbouring EU ports. The trading pattern in the port of Hull in particular supports this argument, where in 2010 all of the 203,000 TEUs handled from international trade was with ports in the EU (TSO, 2012). The specifications of the ports are detailed in Table 11 (below) and the ways in which these features hinder their expansion potential are now discussed.

The port of Hull, which is around 20 miles inland along the Humber Estuary, is depth-constrained as follows: ships with a maximum draught of 11 metres can call at the Queen Elizabeth container terminal. The infrastructure and superstructure of the port are also commensurate with its nautical features; the port can offer only 300 meters of quay with three ship-to-shore gantry cranes (GPE, 2008; Port of Hull, 2013). Due to this limitation, relatively small ships of a maximum of 34,000 tonnes deadweight, which is roughly of the size of a 2,500 TEU container ship, can call at the port. The 2010 statistics show that a total of 313 container ships called at the port, each one of which was less than 20,000 DWT tons in size (which roughly equates to 1,800 TEUs) (Alderton, 2008). The aggregate DWT tonnage of all container ships which called at the port was only 2.2 m tons (TSO, 2012).

The port of Bristol, which is made up of the ports of Portbury and Avonmouth, also suffers from nautical constraints and in particular from infrastructural restrictions. In 2010, it handled only 69,000 TEUs, which was less than 1% of the total 8.2 m TEUs handled in the UK. Its limited container handling record was also evident in terms of ship calls; only 115 container ships called at the port, and of these only 29 were of 20,000 DWT tonnes or more. The reason for the limited container handling facilities is, in part, located in the port's focus on other forms of trade, such as coal, coke, animal feed and automobiles. In fact the allocated land area for handling containers is only around 2.5 per cent of the total port land area (TSO, 2012; GPE, 2008; Port of Bristol, 2013; Tym et al, 2004).

The port of Liverpool, although bigger than the ports of Hull and Bristol, is also constrained by its nautical accessibility and thus has not been able to compete with leading container ports. The port handled 662,000 TEUs in 2010 and was the fourth busiest container port in the UK. Its trade was better balanced between deep sea and the EU ports which was carried on a total of 644 container ships – nearly equally divided between ship size of less than 20,000 ton DWT and of 20,000 ton DWT and above. The maximum depth at its Seaforth container terminal is 12.8 meters which has 1,100 meters of quay. Currently the port has an annual capacity to handle around 700,000 TEUs. The main constraining factor is its locks which restricts the maximum size of container ships to 'Panamax', i.e. around 4,500 TEUs (TSO, 2012; GPE, 2008; Port of Liverpool, 2013).

Table 11: Overview of the cargo handling capacity of the ports of Hull, Liverpool, Bristol, Felixstowe and Southampton

Port Features	Hull	Bristol (Portbury/ Avonmouth)	Liverpool	Felixstowe	Southampton
Total DWT (in m tonnes) of fully cellular container ships in 2010	2.2	1.4	13.9	122.8	51.9
TEUs handled in 2010 (in '000)					
Total TEUs	203	69	662	3415	1564
Deep-sea TEUs	0	18	291	2426	1369
EU TEUs	203	44	284	431	77
No. of container ships called at port					
DWT < 20,000 tonnes	313	86	331	619	278
DWT ≥ 20,000 tonnes	0	29	313	1713	555
Lock restriction: maximum Length x Breadth (meters)	199x 25.5	210/290x 30.0/41.0	292x 32.6	None	None
Approx. max draught (metres)	10.4	14.5 / 11.0	12.8	15.0	15.5
Approx. quay length (metres)	300	600 / 450	1050	2354	1350
Estimated largest container ship handled (in TEU)	2500	6000 / 3500	4500	14,000	14,000

Sources: TSO (2012); GPE (2008)

The infrastructural constraints faced by the larger container ships have led to major expansion schemes being currently being considered at two of these ports: Bristol and Liverpool. In Bristol, a new container-operating facility with a capacity of 1.5 million TEUs which could accommodate ships of 16 meters draught has been proposed (Department for Transport, 2009; Port of Bristol, 2013). The development of this terminal is intended to address a shortage of container handling infrastructure to accommodate bigger ships at any condition of the tide, and to eliminate the need for ships having to pass through locks. While the plans are approved construction work has not yet commenced. The development of a new container terminal at the Port of Liverpool, on the other hand, began in mid-2013 and is expected to be completed in 2015. This will increase the port's capacity by 600,000 TEUs per annum and the terminal will be able to handle container ships with a maximum of 16 metres draught and a capacity of 13,000 TEUs. The handling of the largest vessels will be restricted to a short time-window either side of high water. On a more regular basis the new terminals at both ports are designed to accommodate ships of around 6000-8000 TEUs (Port of Bristol, 2013; Port of Liverpool, 2013; Drewry, 2013). While these developments may alleviate some of the capacity limitations, such major infrastructural investments on greenfield sites are not without environmental concerns (Hailey, 2010; Osler, 2010). Moreover, as the calculation above has shown, even when the facilities are fully operational they would not provide the necessary capacity required without support from the ports of Southampton and Felixstowe.

Conversely, the ports of Felixstowe and Southampton have flourished largely due to their geographical and hydrographical advantages, enabling them to accommodate some of the largest container ships. Currently both ports can handle 14,000 TEU ships (Port of Felixstowe, 2013; Port of Southampton, 2013). With the help of regular dredging vessels with 14.5 metres of draught can navigate into the port of Felixstowe. In 2010 it almost reached its handling capacity of 3.5m TEUs per annum. Its expansion is on-going and the current plan is to increase the capacity of the port to handle 7.3 million TEUs per annum by increasing quay length to five kilometres and terminal water depth to 16 metres (Port of Felixstowe, 2013). At Southampton the approach channel has a depth of 14.5 metres while the maximum depth alongside the container terminals is approximately 15.5 metres with plans to dredge to 16.0 metres. In 2010 the port handled 1.56 m TEUs which is expected to increase to over 2.6 m TEUs in 2020 and to over 4.2 m TEUs in 2030. It is estimated that the current infrastructure of the port will be at saturation point by 2021 and the port will need to expand into the Dibden Bay Reclamation area. By 2030, the new development would be expected to handle between 0.5 and 0.8 million TEUs containers annually (ABP, 2010).

These natural advantageous features of Felixstowe and Southampton are therefore the main factors that have enabled them to keep pace with growing volume demands and the increasing size of container ships, and they are better placed to meet these demands. However, expanding ports such as Hull, Bristol and Liverpool, may be more economically effective overall and have less environmental impact once made ‘operational’. However, new construction will inevitably cause one-time environmental pollution which has not been included in the calculation of the four scenarios in this study. While it is true that the two new developments in Liverpool and Bristol will alleviate some of the stress on the two main southern UK ports, it is also evident that even when they operate at peak capacity, they would not be able to meet the target of Scenario 1 as hypothesised.

9. Discussion and Conclusions

As was highlighted in the introduction to this paper, work previously undertaken on the role of ports in supply chains has addressed relational issues and the alternative approaches which may benefit chain or network players and improve environmental performance. Key to improving the environmental performance is the transfer of freight from road to less carbon intensive freight transport modes and the increased use of ports closer to the final cargo destination (Chisholm, 1985; O’Connor, 1987; Robinson 2002; Notteboom, 2009) as well as the development of inter-modal connections in the ports (Malchow and Kanafani, 2004). It was hypothesised that the rerouting of containers away from traditional large ports in southeast England and into northern / north-western ports and/or shifting cargo from road to rail when moving containers between ports and inland origins / destinations could significantly reduce the overall carbon footprint of marine-based container transport. Nevertheless, international supply chain structures are almost invariably driven by economic and commercial imperatives; this is especially true when markets are depressed and profit margins are extremely tight or even negative. The findings presented in this paper will therefore be influenced by changes in market cycles and at what point in the cycle predictions are made. This will be particularly relevant in the area of port development where the proposed capacity changes, which are generally in the form of ‘lumpy’ medium-term investment, could have implications for port efficiency and productivity in less buoyant periods. In this context, additional incentives, such as government grants and subsidies aimed at encouraging greater use of rail for freight movement, would be required to encourage shipping companies to reconsider their selection of a particular port. This could work in favour of those ports which potentially provide opportunities for modal shift. Further, if a port were to expand during a growth phase in the economic cycle, the risk would be that the port would be under-utilised and hence less efficient during periods when demand falls. This is a problem of inbuilt overcapacity which could influence decisions on modal changes.

The overall contribution of this paper therefore, is that it demonstrates how changes in the structure of freight transport networks which support supply chains at national or continental levels can significantly reduce the level of CO_2 emissions. As has been shown in this study, from an environmental perspective, mainland Great Britain could be better served by operating, at the very least, a two-port gateway system, or possibly a multiport system with shipping lines calling at least twice at British ports. This contradicts current commercial thinking which invariably sees Great Britain as worthy of one call only by the major container lines with road haulage or rail-road intermodal often doing long-haul inland distribution.

Specifically, this paper compared four different Scenarios that link UK import container flows with inland freight transport movement. A methodology based on road kilometre minimisation was applied to the four Scenarios. The four Scenarios were compared based on the total transport operating costs and total CO_2e emissions generated. Scenario 2, the expansion of Southampton combined with an expansion in capacity in the rail links between Midlands and UK Northern regions, has the second lowest operating costs (a 7.8% net saving in operating cost) and the lowest CO_2e emissions (a 30% net saving in CO_2 emissions). Furthermore, Scenario 1 has the lowest operating cost with a net saving of 10.5%. From a purely economic point of view, Scenario 1 has the lowest operating cost, but from an environmental point of view Scenario 2 is the least carbon intensive. Nevertheless, Scenarios 1 and 2 would need a significant investment and generate additional construction-related CO_2e emissions due to building additional capacity in the port of Southampton and the ports of Bristol, Liverpool and Hull respectively. Hence, further research on the economic and environmental feasibility of Scenarios 1 and 2 is pertinent. Additional research is required to estimate the economic and ecological implications and the payback period of such expansion. The findings on CO_2 emissions of the four Scenarios are based on carbon conversion factors recommended by Defra (2010). Although these factors are widely accepted in the literature, they could change in the future if technological advances are adopted in each mode of transport. Hybrid fuel systems, for example, could theoretically transfer from passenger vehicles to trucks, having major implications for the carbon-intensity or road-haulage of containers. Nevertheless, the figures represent the current carbon intensity of each mode of transport including in the modelling presented in the paper. Future research could assess long-term carbon reduction Scenarios which could include technology improvements as an alternative option to model shift. Finally, it is also acknowledged that shipping tends to have higher levels of sulphur emissions than other transport modes which could lead to unwanted impacts related to health (such as respiratory illness) and the environment (acidification).

Scenario 3, container distribution with the combined expansion of Felixstowe and Southampton, yields a significant reduction in cost (a 7.7% net saving in operating cost) and in CO_2 emissions (a 16% net saving in CO_2e emissions). The combined expansion of Felixstowe and Southampton would provide a good option for freight flow adjustments from two points of view. Firstly, they form very competitive entry points for serving the South and South East UK regions which are the most important markets for unitised freight. Data from MDS Transmodal (2006) consistently show that southeast and eastern England account for around 70% of container origins and destinations. Thus Felixstowe provides an effective and competitive access point to many of the principal destinations in the UK, in terms of total inland transport cost, compared to other UK ports. Nevertheless, in terms of CO_2e outputs and operating costs, the argument against using the port appears to be relatively strong. Southampton offers a significant advantage by reducing the total costs and CO_2e burden derived from road and sea borne container transport. However, Scenario 3, the expansion of the ports of Felixstowe and an increase in capacity in the rail route between Felixstowe and Glasgow could be considered as the most feasible, since it does not require as much investment as Scenarios 1 and 2.

Three Scenarios were compared to the current Scenario for inland container distribution based on six main UK ports and current rail links between South East UK ports with more Northern locations; however, the impact of expansion of the London Gateway port has not been considered in the study. The sheer size of London Gateway (around 30% of the UKs total container capacity) could bring about major port call / inland logistics changes. Furthermore, an additional Scenario should be run to include coastal shipping as a means of connecting the South East UK ports with more Northern cities. Hence, further research considering Scenarios in which London Gateway and coastal shipping are included need to be undertaken. Such Scenarios could form alternative options to Scenarios 2 and 3. Moreover, the approach adopted in this study could be replicated in other countries, or indeed continents, such as Europe or North America in order to estimate the impact of port selection at a much larger scale and in a generic way; this would enable researchers to compare regions, identify differences and to validate the approach taken.

While there is clearly scope for emissions reduction, this study was constrained by the assumptions made and discussed in the methodology. Changes to the throughputs assumptions have repercussions along the supply chain and could negatively influence the savings that could be made, and therefore more difficult to realise the total overall potential reductions postulated. The sensitivity of emissions savings (and cost savings) to routeing variations is an important area for further research but was outside the scope of research for this paper. Also, for the sake of simplicity, flows of empty containers were not included in the discussion. While a reduction in total TEUs transported by road should include imports, exports and empty containers, the Scenarios presented includes exported freight moved from origin to ports at close proximity and/or via rail to Southern UK ports. This logic also applies to empty containers and hence the total TEU moved by road is still minimised in the alternative Scenarios presented.

Furthermore, global policy initiatives such as the ECAs which reach into Europe, e.g. in the North Sea area, have not been considered within the scenarios proposed in this paper, since the alternative scenarios are based on the minimisation of CO_2e emissions and the freight transport cost of the UK freight transport sector as a whole. Nevertheless, the findings of the paper have significant implications on policy frameworks such as the ECA area established for the North Sea, and these implications leave further avenues of research. In addition, proposed policy changes at the EU level, are also likely to trigger a reconsideration of the potentially important role of ports in supply chain decarbonisation (EU, 2013).

Finally, this research was undertaken by applying a number of assumptions in terms of total weight in TEUs per destination city. Also, average parameters have been used to calculate the costs and CO_2e emissions from origin to destination. One problem with this is that even though this approach is a good representation of the economic and carbon intensity of UK freight transport sector, it does not reflect the reality of different sectors, such as steel, automotive, food and textile. Freight transport operations within each of these sectors will be planned and run based on different decision-making rules. Hence, it is important to run sector-specific case studies to assess the feasibility of the three Scenarios proposed in this paper, considering barriers such as demand uncertainty, restrictions of using rail and water as an alternative to road. Also, the opinion of transport users in these four sectors should be consulted to evaluate the applicability of Scenarios 1, 2 and 3 specific to their operations.

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