

Operational measures to mitigate and reverse the potential modal shifts due to environmental legislation

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Operational measures to mitigate and reverse the potential modal shifts due to environmental legislation

Abstract

On 1 January 2015, the sulphur upper limit for marine fuels used within Sulphur Emission Control Areas (SECA) was lowered from 1% to 0.1%, with which vessels can comply only through using pricier ultra-low sulphur fuel, or investing in abatement technologies. A potential increase of fuel prices could lead to closures of services due to the combined effects of loss of market due to higher freight rates, and increased operational costs. This paper builds on previous work allowing the modelling of modal shifts between sea and landbased options, and assesses the potential of operational measures that ship-owners can deploy to cope with the threat of the low sulphur requirements. The measures include speed reduction, change of service frequency, use of alternative fuels such as LNG, investments in scrubber systems, and improved fleet assignment. The proposed measures are tested on a set of case studies for services that are part of a short sea shipping (SSS) network of a leading Ro-Ro operator. The results of this work can be useful to practitioners seeking to design new strategies that improve the resilience of their network, as well as to regulatory bodies designing new regulation that could have negative implications on certain sectors.

Keywords: maritime logistics; Ro-Ro shipping; shipping emissions; short sea shipping; sulphur legislation

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Introduction

Maritime transport moves approximately 80% of the total worldwide cargo (UNCTAD, 2016), offering significant economies that allow cost-efficient transportation of goods. The ever-growing sizes of vessels, as well as technological improvements have established maritime transport as the most fuel efficient mode of transport per ton-kilometres of transported cargo. At the same time, it is in the interest of ship operators to reduce their operating costs in order to be competitive against other ship operators, and in certain cases other transportation modes. This is often hindered by the increasing regulatory pressure that can raise operating costs (Schinas and Stefanakos, 2012).

Emissions from the maritime sector

The contribution of the transportation sector on the world CO₂ emissions was estimated at approximately 20.4% during 2014 (The World Bank, 2017) whereas the maritime sector accounted for 2.2% (IMO, 2014). Considering only Europe, the respective figures for CO₂ were estimated at 20.1% in 2014 for transport, and 4% for maritime sector (Eurostat, 2015). Therefore, in terms of carbon intensity it is evident that maritime shipping outperforms competing transportation modes. However, marine engines are using bunker fuels (such as heavy fuel oil – HFO) that generates higher level of emissions of harmful pollutants. In-between 5 and 8% of the global SO₂ anthropogenic emissions are attributed to the maritime sector (Eyring et al., 2005), due to the higher sulphur content in fuel used. A more recent estimate on sulphur emissions can be extracted from data provided by the Organization for Co-operation and Development (OECD). For 2015, OECD estimates that transportation (mobile sources) accounted for 3.45% of the total sulphur oxides emissions within the OECD countries, 14% of which was attributed to road transport (OECD, 2017). Vessel activity results in the generation of black carbon (BC) and particulate matter (PM) emissions, that have negative effects in the health of affected population residing near coastlines and ports (Zis et al., 2014). Effects of vessel emissions near residential centres have also been linked with fatalities (Corbett et al., 2007) and are responsible for very high external costs of transportation (Tzannatos, 2010). On the environmental aspect of ports, Cui (2017) notes it is becoming a greater concern particularly with regards to CO₂ emissions which is characterized as a key undesirable output of a port's function.

Relevant regulation on sulphur emissions, abatement options, and impacts

The IMO has set maximum limits on the sulphur content allowed in bunker fuel used by ships through the revised MARPOL Annex VI, differentiating between activity within and outside SECAs (where stricter limits apply). SECAs currently include the North and Baltic Sea, the majority of US and Canadian coasts, and the US Caribbean. January 2015 was a turning point as the regulation enforced the use of ultra-low sulphur fuel with a content of a maximum of 0.1% within SECAs. In July 2017, during the 71st session of the Marine Environment Protection Committee (MEPC), the IMO confirmed that the global sulphur limit (outside SECA) at 0.5% will be enforced from January 1st 2020.

In order to comply with the low sulphur limits, ship operators have to either use pricier ultra low-sulphur fuels (for example Marine Gas Oil – MGO, or hybrid low-sulphur HFO), LNG, or invest in other abatement technologies such as scrubber systems which however require significant capital costs (Cullinane and Bergqvist, 2014). Therefore, an immediate repercussion of the lower sulphur limits would be the increase of costs for the ships operating within SECAs. The increased costs may prompt ship operators to increase freight rates in response. As a result, certain services may lose transport volumes to competing services that are not affected directly by such regulation. The SSS sector may be particularly affected and lose market shares to competing landbased modes that have traditionally higher monetary costs but are more competitive in travel times (Suárez-Alemán, Trujillo, and Medda, 2015). The profitability of a shipping service will therefore be affected by both an increase in operating and/or capital costs, as well as a decrease in transported volumes. Considering that the European Union has set the promotion of SSS as a priority, it is vital to suggest actions that regulatory bodies and affected ship operators can utilize so mitigate the negative effects of such regulations.

Prior to the new limit, several academic and technical studies anticipated that the sea-based cost for transport would increase by up to 20% in certain affected short sea shipping

services (Odgaard et al., 2013). This could lead to potential closures of routes due to reverse modal shifts towards competing landbased options (Sys et al., 2016). The exact repercussions of the new sulphur limits are difficult to identify in the wake of the unexpectedly low fuel prices for both low-sulphur and heavy fuel oil throughout 2015. These low prices actually led to lower freight rates for most shipping operators due to the link of fuel prices and freight rates via bunker adjustment factors (BAF). Recent work in the aftermath of the new limit has shown that despite the low fuel prices, that the lower limit has had negative effects on Ro-Ro shipping and it can pose a significant threat to the sector should fuel prices increase again (Zis and Psaraftis, 2017). In such an event, it is necessary to deploy operational and policy measures that can help the sector cope with the increased regulatory pressure, and not lose out to competing landbased or unaffected maritime options.

Structure of the paper

This paper examines the extent of the economic and environmental repercussions of the stricter SECA limits to the Ro-Ro sector, and how the ship operators can cope with the increasing operating costs. The paper considers as a benchmark the year before the new limits kicked in, and analyses the effects of the regulation and the proposed operational measures in the first year of the new limits. It builds on an established methodological framework that allows the estimation of modal shifts because of the lower sulphur limits. Subsequently, a set of measures that ship operators can take to ensure the viability of their services is presented. The proposed measures can either lower the operating costs of a service, or improve the revenue generation of a service. Three main fuel price scenarios are considered and the efficacy of the proposed measures is tested on a set of case studies using data from services within SECAs, of a leading Ro-Ro operator. The methodology developed in this work allows the quantitative economic assessment of such measures, considering the environmental balance of the system and the profitability of a route. The paper concludes with a discussion on examined measures according to their efficiency considering key route characteristics including sailing distance, ship type, sailing frequency, and value of transported cargo.

Modelling modal shifts

This section summarizes the underlying modelling framework used to estimate modal shifts that occur as a consequence of the low sulphur requirements. A two-stage nested logit model is utilized to estimate the new probability of choosing a particular mode after a change in the generalized cost of any of the available options for a shipper.

Required data

In order to construct a modal split model to estimate shifts because of any changes in the available options of a shipper, it is necessary to acquire representative data. Most discrete choice use revealed preference data to predict aggregate market behaviour (Ben-Akiva et al., 1994), and require information on the key explanatory parameters. Another approach is the use of stated preference data, which revolve around observations on hypothetical choice behaviour, typically collected through surveys, interviews or focus groups. For all cases, the necessary data require the acquisition of information on the market share of each of the available options (e.g. how many select each option) to model the probability of making a selection. Subsequently, one has to

decide which the explanatory variables are in the model that will be used in the model calibration stage.

Most discrete choice models used in transportation are focusing on the behaviour of passengers or drivers, and differentiate between the various transportation modes that are available to them. Ortúzar and Willumsen (2011) classify the factors influencing mode choice in three groups, that include among others travel cost, travel time, number of transit changes, weather, comfort, vehicle availability, trip purpose, income, time of day. In contrast, for freight transport the shipper usually has to decide based on fewer influencing factors, mainly the total travel cost and overall time, taking into consideration the reliability of service. Nam (1997) considers as explanatory variables for freight transport the shipment weight, freight charge, commodity type, distance, travel time, and frequency of service, that can be transformed into cost and time for each option. In this paper, the focus is on modelling the mode choice of shippers when one or more short-sea shipping modes are available and compete with each other and with one or more landbased modes. It is assumed that the decision is based on information about total travel cost and time, as these are the explanatory variables that are heavily affected by changes in policies (such as the requirement to use low-sulphur fuel since 2015) and the examined operators' measures.

A hierarchical logit model

For some of the services examined in this paper there are more than one alternative transportation modes. To capture this fact, a hierarchical (nested) logit model is used to simulate the shippers' decision making process (Ortúzar and Willumsen, 2011). It is assumed that the shipper first has to decide whether to utilize a maritime mode or prefer a landbased option. In the second step of the process, the shipper will have to decide which option to use within this mode (e.g. which maritime option if there are more than one available). The shipper is assumed to decide based on information on the cost of transport, and the total travel time taking into account all waiting times for intermodal options. This assumption simplifies certain aspects of the modelling part.

The generalized cost of transport

In general, discrete choice modelling methodologies consider that a selection is based on maximizing the utility (or minimizing the disutility) associated with each option. As a result, it is necessary to link cost and time in a single function of disutility. This can be the generalized cost of transport, which increases at higher transport costs, and travel times; both considered as undesirable and thus the preference for using the term disutility. Travel time and costs can be linked using the value of cargo and its depreciation as a means to convert time into monetary costs. This conversion can be considered as a representation of the value of time of a certain cargo which will vary for different cargoes. Considering that for at least the maritime options the freight rates are a function of the shipment size (costs are given in monetary units per lane-meter transported), it is not only the value of cargo that affects the generalized cost of a shipment but also its physical characteristics.

This paper uses a simplified formulation of the generalized travel cost of mode i as in the work of Zis and Psaraftis (2017), shown here in eq. 1:

$$GC_i = TC_i + a \cdot TT_i \quad (1)$$

where TC_i (€/lanemeter-lm) is the monetary travel cost for mode i and TT_i (hours) is the respective travel time. The parameter α is a positive constant which depicts the monetary value of time in units (€/lm/hour). This formulation can facilitate comparisons between different shipping options, and additionally compare the effects of a change in a specific parameter of the problem (e.g. fuel price, change in the frequency of a service, introduction of an additional tax etc.).

The calibration steps

The model considers the general case where there are N transportation modes available to a shipper. The probability of choosing option $i \in \{N\}$ will depend on the generalized cost of each option GC_i . The first split assumes that there are j nests denoted as M maritime and L landbased modes (where $\{M\}, \{L\} \in \{N\}$). The probability of choosing a maritime mode is given by equation 2.

$$P_j = \frac{e^{-\lambda_1 \cdot GC_j}}{\sum_{j=M,L} e^{-\lambda_1 \cdot GC_j}} \quad (2)$$

Where λ_1 is a dispersion parameter to be estimated that acts as a weight attached in the choice to the generalized cost. The larger the value of λ_1 , the greater the implication of a change in the cost of one option to the decision. Equation 2 introduces GC_M known as a composite generalized cost, which is a function of the generalized cost of all $i \in \{M\}$ alternatives of available maritime modes.

After the shipper has decided which general transportation mode to use (e.g. which 'nest'), the next step is to decide which of the available options within this nest. The probability $P_{i/M}$ of choosing option $i \in \{M\}$ is given by equation 3.

$$P_{i/M} = \frac{e^{-\lambda_M \cdot GC_{i/M}}}{\sum_{i \in M} e^{-\lambda_M \cdot GC_{i/M}}} \quad (3)$$

Where λ_M is a dispersion parameter for the secondary split within the maritime nest. This can be used to estimate the composite generalized cost of the maritime nest if the generalized cost $GC_{i/M}$ and the respective market shares of each option i are known.

$$GC_M = \frac{-1}{\lambda_M} \log \left(\sum_{i \in M} e^{-\lambda_M \cdot GC_{i/M}} \right) \quad (4)$$

A similar process can be used if there are more than one options within the second nest (L) that represents landbased options. However, in this paper only one option is considered for cases where there are landbased alternatives.

Available data and underlying assumptions

In summary, to examine the impacts of any changes on a specified Ro-Ro service, the following steps must be followed to calibrate a modal shift model before the introduction of changes:

- Compile a list of all competing modes (maritime and/or landbased)

- Select origin – destination (O-D) pairs for shipments that may use the Ro-Ro service
- Estimate of the total travel time for each available option in the transportation system
- Retrieve information on freight rates to estimate total transportation cost for each option
- Identify transported volumes for each option and express as market shares for each mode

The ideal data set would comprise of all O-D pairs for all cargoes, including information on value of cargo for each shipment, total travel time, and travel cost paid by the shipper. Ro-Ro ship operators are setting their freight rates in € per lanemeter (lm), so essentially as a function of volume that the cargo takes on-board the vessel. Typically freight rates are confidential and negotiated on an individual customer level (with provision of bulk discounts etc.). In this work, we use the average freight rate (€ per lane meter) that the shipping company was charging for each of the examined routes. A drastic discount to a large supplier could result in an all or nothing assignment between the available options. Occasionally a shipper may have a strong preference on a mode or service provider and thus be more reluctant to switch despite a small increase in the cost of one of the options. However, this paper is considering the aggregate case in order to estimate the effects of the regulation from a wider perspective. Focusing on specific disaggregate level shipments would require data collection at a very microscopic level that may actually not be available.

The weight of the cargo is not known to the ship operator and as such one lanemeter of cargo is considered as the modelled unit of transport for all competing modes in the analysis. The ship operators may also not be aware of the initial origin and final destination of cargoes they are carrying. Finally, disaggregate level information on freight transport flows for the full European road network is not available. For the calibration of the logit model a simulation approach was utilised where sensitivity analyses around central values for key characteristics (freight rates, travel distances, market shares) were performed.

Operators' measures and selected services

This section will present the measures that a ship operator can use to improve its position in the aftermath of the lower sulphur requirements as of 2015. The set of services that will be examined in the analysis section is shown along with an aggregate level data summary of relevant financial information on the Ro-Ro operator that provided data for this work. The measures were selected and tailored in a way to be transferable to other types of shipping, and not limited to only Ro-Ro operations.

Speed reduction

Lowering the sailing speed even by a small amount can lead to significant fuel consumption reductions in each journey. Therefore, for routes that are struggling with low traffic it may be an option to maintain a service financially viable. Unlike other types of shipping, Ro-Ro services are relatively fast and due to the high sailing frequency (multiple sailings per week, and in certain cases per day); there are additional constraints

that do not allow very low sailing speeds. Due to the nature of the sector, most sailings last an integer number of hours, or integer multiples of 30 minute periods, while also departures and arrivals of most sailings are at sharp or half-past times. This facilitates the planning of cut-off times for the embarkation of goods and passengers.

Sailing frequency

For certain services where profitability may be hindered due to loss of cargo volumes, an option may be to reduce the number of weekly sailings. Instead of shutting down a service completely, the sailing frequency may be adapted by either reducing the number of deployed vessels, or simply reducing the number of weekly sailings. While the market share will drop in such an event (as this is increasing the average travel times), it is expected that it will increase the utilization rate and thus improve the profitability of the route.

Fleet reconfiguration

This measure is essentially an adaptation of the sailing frequency option that the Ro-Ro operator has. Instead of altering the number of sailing frequency, the Ro-Ro operator can consider changing the fleet assignment between the different routes served by assigning vessels optimally according to their key technical characteristics in terms of capacity, speed, and fuel consumption. There are certain constraints for the implementation of this measure. Vessels are assigned to existing services based on their type (pure cargo, or cargo + passenger vessels) and thus vessels can be swapped only between similar type services.

Technological investments

The ship operator can opt to switch into MGO or low-sulphur HFO fuel when sailing within SECA. This option has the advantage that it does not require a significant capital investment (for retrofits), but is using more expensive fuel in the regulated areas. In addition, MGO has a lower viscosity than HFO, and as a result additional lubrication is required to prevent damage in the engine's pumps (MAN, 2014). Differences in fuel temperatures can also harm the cylinders of the engine thus also increasing operating costs due to potential technical problems. The exact costs of such technical impacts due to fuel switching to low sulphur fuel are not as straightforward to calculate, and in the scope of this paper we limit our cost analysis on the fuel price differential with HFO. Besides using low-sulphur HFO and MGO fuel types, the ship operator can also use liquefied natural gas (LNG) as fuel is an alternative option of complying with the SECA limits. However, this may require significant technological investments to retrofit the vessel, and access to LNG bunkering ports, the number of which is currently limited (Patricksson and Erikstad, 2016). On the potential use of LNG as fuel, Nikopoulou (2017) notes that LNG is not competitive as an abatement solution for Ro-Ro vessels. Alternatively, the ship operator may also invest in scrubber systems that allow the use of regular HFO which is cheaper. For both options, a discussion on the financial merit of such investments will follow in the analysis section.

The examined services

This paper considers seven routes from a leading Ro-Ro operator with services within SECAs. The routes comprise of a mixture of cargo-only services (Ro-Ro), services that also carry passengers (Ro-Pax), and predominantly passenger services with limited cargo capacity (Pax). The Ro-Ro operator provided information on transported volumes, freight rates, passengers on-board (for Ro-Pax services), fleet deployment, and fuel consumption for each vessel on each service for 2014 and 2015. The seven routes are a representative subset of the full Ro-Ro network that the operator is serving. The selection of the seven routes was based on balancing the following criteria:

- Sailing distance
- Sailing frequency
- Deployed capacity
- Cargo types
- Vessel types (Ro-Ro, Ro-Pax, Pax)

Based on these criteria, the examined services are the following:

- Gothenburg – Ghent (Ro-Ro – North Sea)
- Esbjerg – Immingham (Ro-Ro – North Sea)
- Rotterdam – Felixstowe (Ro-Ro – North Sea)
- Copenhagen – Oslo (Pax – North Sea)
- Klaipeda – Kiel (Ro-Pax – Baltic Sea)
- Klaipeda – Karlshamn (Ro-Pax – Baltic Sea)
- Dover – Calais (Ro-Pax – Cross Channel)

Their key characteristics along with an aggregate data summary for 2014 and 2015 is shown in Table 1, showing only percentage changes between the two years (and not exact values) due to a confidentiality agreement with the shipping company.

Table 1. Overview of examined services and changes between 2014 and 2015. Source: own compilation from data provided by operator

Route	Distance (NM)	Sailing Speed (knots)	Frequency (sailings/week)	Fleet and Abatement	Year	Trips Total	Transported Cargo Volume change (%)	Cargo Rate change (%)	Revenue Change (%)	Annual Fuel Cost Change (%)																																																																					
Gothenburg – Ghent	577	18.1	6	Scrubbers (3 vessels)	2014	553	6.06	-5.62	0.09	-52.89																																																																					
					2015	569					Esbjerg – Immingham	326	18.1	6	1 Scrubber 1 MGO	2014	512	19.46	-0.5	18.85	-15.29	2015	580	Rotterdam – Felixstowe	121	16.1	16	2 Scrubber 1 MGO	2014	1514	15.13	0.5	15.71	-24.34	2015	1637	Copenhagen – Oslo	272	15.5	7	1 Scrubber 1 MGO	2014	687	-5.82	1.58	4.28	-9.36	2015	702	Klaipeda – Kiel	397	18.4	6	2 Scrubber	2014	611	-4.64	-7.71	-8.89	-30.05	2015	615	Klaipeda – Karlshamn	223	17.2	7	1 Scrubber 1 MGO	2014	717	3.64	-2.32	3.73	-22.99	2015	710	Dover – Calais	26	15.3	99
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Calibration of modal split model for each examined route

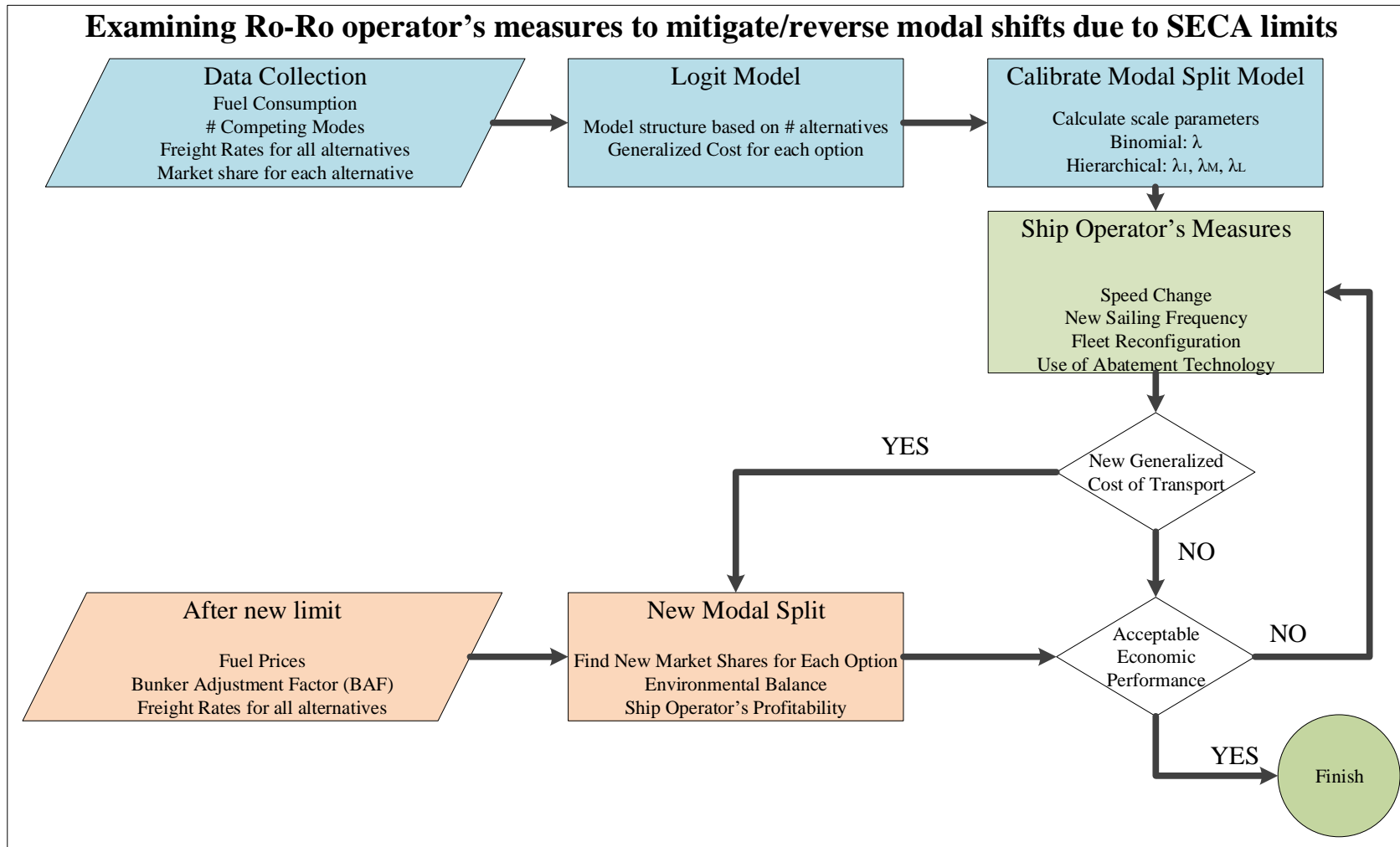
Using the modal split methodology presented in section 2, a modal split model was calibrated based on the data for 2014 as provided by the Ro-Ro operator. To address the issue of market shares for all options, an approach using reasonable ranges based on aggregate-level statistical data (Eurostat, Shippax journal) and also following discussions with relevant experts was used. The calibration results are shown in Table 2 considering only cargo flows for all routes.

Table 2. Calibration results for the examined services

Route	Market Share (%)			Scale parameter		
	<i>Maritime</i>	<i>Maritime competitor</i>	<i>Land</i>	λ	λ_I	λ_M
Gothenburg – Ghent	24-30	21-29	39-49	NA	0.027	0.025
Esbjerg –Immingham	60-70		30-40	0.08	NA	
Rotterdam – Felixstowe	30-40		60-70	0.14		
Copenhagen – Oslo	20-25	NA	75-80	0.108		
Klaipeda – Kiel	51-61	NA	39-49	0.019		
Klaipeda – Karlshamn	67-77	23-33	NA	0.08		
Dover – Calais	39-49	NA	51-61	0.015		

The average values are shown as these will be used in the analysis. The values agree with the dispersion parameters for freight transport in previous studies (Lemper et al., 2009; Panagakos et al., 2014). Larger values for λ indicate a bigger shift potential for the same change in the disutility function modelled. Therefore, if the generalized cost of all services increases by the same amount as a consequence of the mandatory use of low-sulphur fuel, then the route with the higher dispersion parameter will lose a greater market share to competing modes. This route may therefore be at a higher risk and in greater need of the deployment of appropriate operating measures to reduce the potential market share loss. Figure 1 below summarizes the methodological process used in this work in the form of a flowchart. The effects of utilizing one of the suggested measures on shipper's choice is modelled using the calibrated modal split model.

Figure 1. The methodology used in this work



Analysis

This section presents the three fuel case scenarios used in the analysis, and then proceeds to evaluate the impacts of the suggested measures on the route profitability of a service, and the new modal split. While there could be a combination of measures for most cases (e.g. using scrubbers with a different sailing speed, or combining a new sailing frequency with vessel swaps), each measure is deployed on its own.

Fuel price scenarios

The calibration for all scenarios was conducted based on data for 2014, which was the last year where a maximum sulphur content of 1% was allowed. Prior to 2015 there were concerns that the anticipated increase in fuel prices due to the new requirement could lead to several service closures. However, fuel prices were significantly reduced in 2015 to the point that MGO (2015 price) was actually cheaper than what HFO 1% was before the new limits (2014 price). As a result most shipping operators saw a very profitable year, which masked the negative effects of the regulation. Zis and Psaraftis (2017) conducted a simulation analysis that showed that if the fuel prices would revert to previous high levels, the maritime modes would lose significant market shares that could threaten their service. At the same time, their analysis illustrates that if the regulation was not present, the maritime modes would have enjoyed much higher transport volumes due to the very low fuel prices for HFO, and their profits would be greater. This work considers a similar mixture of fuel price scenarios, to test the efficacy of operators measures on modal shifts and route profitability, comparing with the actual 2015 baseline case (no operator's measures used). Case 1 considers the actual prices as experienced in 2015, Case 2 is a pessimistic scenario with high fuel prices as in early 2014, whereas Case 3 is a hypothetical scenario during which HFO with 1% sulphur is still allowed as before the regulation, with the 2015 prices.

Implications of travel time and travel cost on shipper's choice

Most of the examined measures will affect either the sailing time of a service and/or the waiting times due to changes in sailing frequency. Other measures may have an impact in the freight rates that the shipper will have to pay. Santos and Guedes Soares (2017) develop a methodology to determine the optimal characteristics of a Ro-Ro route in terms of freight rate and sailing speed, and show that the optimum point of operation from the shipping company's perspective is different to what shippers prefer. The modal split model used in this work is based on the generalized cost of transport as its utility function. Therefore, it is important to note the impact of each additional hour of travel time on the generalized cost, which depends on the cargo value. This can be calculated for all routes for an indicative set of different cargo values using equation 1. For high depreciation rates, and for relatively shorter journeys, the increase in sailing time by 1 hour can be significant leading to increases in the generalized cost of up to 11% certain cases, not considering Dover – Calais due to the very low sailing time. For lower value cargoes travelling on longer routes, the one extra hour is relatively indifferent to the shipper making up of less than 0.1% in certain cases.

The examined measures tailored for each route

In the previous section, measures that are at the disposal of the ship operator were presented in qualitative terms. This section shows the format under which these measures were considered for each of the seven routes examined in the context of this paper. The measures are presented in a matrix form where each row depicts each of the seven services, and each column represents the examined measure. Table 3 contrasts the status of each service in 2014 just prior to the implementation of the 0.1 % limit. A short description of the ex-post measure is given in the matrix.

Table 3. The examined measures for the services

Route \ Measure	Speed Reduction		Sailing Frequency		Fleet and network reconfiguration	Use of LNG as fuel	Use of scrubbers in more vessels
	Baseline (hours)	New (hours)	Current (#/week)	New (#/week)			
Gothenburg Ghent	32	+ 1, 2	Not applicable due to long-term contracts with clients		Six sister ships, one with lower capacity	Not route specific. Conceptual discussion and performance of a cost benefit analysis (CBA) assuming no changes in schedule	None of these routes has a vessel that can be retrofitted. A simple CBA is conducted for the MGO vessel of the Ro-Ro operator with the highest fuel consumption, assuming no changes in schedule
Esbjerg Immingham	18.5	+0.5, 1	6	5 (cut Saturday)	Swap vessels between these two routes		
Rotterdam Felixstowe	7.5	+0.5, 1	Not examined				
Copenhagen Oslo	17	+0.5, 1 (increased onboard revenue)	Not applicable due to being a passenger oriented service		Not possible dedicated vessels		
Klaipeda Kiel	20	-1.5 (speed increase) 0.5	7	6	Swap vessels between these two routes		
Klaipeda Karlshamn	13	+1,2	10	8			
Dover Calais	Not relevant due to low sailing time		99	75	Not possible dedicated vessels		

A summary of results

This section will present the main findings on the effectiveness of the previous measures in the services. Due to space limitations, only a summary of results will be shown.

Speed reduction

The effects of speed reduction in the fuel consumption of vessels deployed in the applicable services are shown in Table 4. The average fuel consumption of the deployed vessels that were used in each route in the examined period is shown.

Table 4. The effects of a new sailing speed on fuel consumption

Route	Hours at berth	Hours sailing	Weekly fuel consumption (tonnes)	Change (%)
Gothenburg – Ghent	Baseline Sailing Speed 18.06 knots			
	38	130	286.9	NA
	Increase Trip by 1 hour, New Sailing Speed 17.3 knots			
	32	136	259.3	-10.7
	Increase Trip by 2 hours, New Sailing Speed 16.5 knots			
	26	142	235.5	-21.8
Esbjerg – Immingham	Baseline Sailing Speed 18.11 knots			
	60	108	292.4	NA
	Increase Trip by 0.5 hours, New Sailing Speed 17.6 knots			
	57	111	274.1	-6.3
	Increase Trip by 1 hour, New Sailing Speed 17.1 knots			
54	114	257.4	-11.9	
Copenhagen - Oslo	Baseline Sailing Speed 15.5 knots			
	45.5	122.5	271.3	NA
	Increase Trip by 0.5 hours, New Sailing Speed 15.1 knots			
	42	126	257.9	-4.9
	Increase Trip by 1 hour, New Sailing Speed 14.7 knots			
38.5	129.5	245.9	-9.4	
Klaipeda – Kiel	Baseline Sailing Speed 18.4 knots			
	26.5	129.5	321.1	NA
	Decrease Trip by 1.5 hour, New Sailing Speed 19.8 knots			
	35.5	120.5	373.8	+16.4
	Increase Trip by 0.5 hours, New Sailing Speed 18 knots			
23.5	132.5	305.9	-4.7	

It has to be noted that in the estimation of the fuel consumption at different sailing speeds, the assumption is that any changes in cargo volumes loaded are not considered. In reality, if due to the lower sailing speed the demand is reduced, this will result in a slightly lower fuel consumption due to the lower deadweight. The next step of the analysis

is to understand the effect of the lower sailing speed into modal choice, considering that no other change is introduced (e.g. the freight rates are remaining the same for all three Fuel Case scenarios as in the baseline). The runs are performed for average cargo values and depreciation rates. For all speed reduction scenarios a minor loss of cargo is observed, which is due to the very low effect that the extra time has on the generalized cost of transport. It must be stressed that if a very high depreciation rate is used and/or cargoes of very high values, then the loss due to slow steaming would be higher. There are however practical constraints on how much speed can be changed, due to scheduling issues with ports, as well as a minimum turnaround time at each port for loading and unloading. An overall observation is that the revenue remains relatively unchanged, whereas the cost of fuel is changing dramatically for lower speeds for all fuel case scenarios. For cruise routes, a side benefit of a higher sailing times is an increase in revenue from on-board spending (passenger facilities such as casinos, restaurants, bars). In terms of capacity utilization (which is confidential information), fuel price plays a crucial role in its value whereas an increase in sailing time has a trivial effect.

New sailing frequency

The effects of a new sailing frequency on transported volumes, generated revenue and fuel costs is shown in Table 5 for the Esbjerg – Immingham route. The hourly fuel consumption for the two vessels that were used in this route in the examined period is shown for the different activity phases. For the pessimistic fuel case scenario (increased price) the option of removing one weekly sailing is considered, whereas for the low fuel price scenario one extra sailing.

Table 5. Baseline case and effects of a new sailing frequency (Esbjerg- Immingham)

Ship	Average Fuel ME (tonnes per hour)	Average AE (tonnes per hour, cruise)	Average Fuel port (tonnes per hour, berth)		
Baseline Sailing Speed 18.11 knots					
Ship E	2.158	Included in ME	0.392		
Ship F	2.520		0.400		
Hours at berth (both vessels)	Hours sailing (both vessels)	Fuel consumption (tonnes/week)			
120	216	553			
	New sailing frequency	New Transported	Capacity utilization	Δ Revenue (€)	Δ Fuel Cost (€)
Fuel Case 2	5	-6%	+20% undesireable	-110000	-33500
Fuel Case 3	7	+1%	-4.5%	40000	16500

It can be seen that the drop in demand as a consequence of the reduced frequency, is not enough to reduce the capacity utilization to a reasonable range and the average capacity utilization of the vessel increases by 20% as compared to an already high baseline case. The reduction in revenue is higher than the reduction in fuel costs, and unless the reduction in other costs (salary, port fees, and depreciation of vessel) is higher than this difference the company will be worse off by reducing the service. Thus, it can be concluded that the reduction of sailing frequency should be used only for an extreme drop in demand in this route. For the optimistic case where an additional sailing is launched, the capacity utilization is lowered to a more robust level, while the transport

demand is also slightly increased. The net difference between the additional revenue and the additional fuel costs is approximately €23000 per week, which needs to be higher than the extra salary costs, port fees, and wear of the vessel for the extra weekly sailing.

Fleet reconfiguration

In this scenario, the option examined is swapping vessels between two Baltic Sea routes. This swap can be considered if there is a drop in transport demand in one route and a smaller vessel is assigned to it. The highest fuel benefit is approximately €23000 per week observed for the high fuel price scenarios. The capacity utilization would remain for all scenarios at an adequate level. The underlying assumption is that a vessel swap would not affect the transportation demand for the service, considering that the vessel would sail at the same sailing speed and frequency. For low fuel price scenarios, the fuel cost benefit is small while there is a risk that vessels are loaded extremely close to the maximum capacity and could in theory lead to loss of revenues for not picking up cargoes. It should be noted however that EU rules are restricting swaps between vessels that have been subsidized for a scrubber retrofit, and force the deployment of the vessel to a dedicated route.

Technological investments

In this scenario, the option is the installation of a scrubber system in one of the vessels that has not been retrofitted in the examined routes. The Ro-Ro operator has invested heavily in scrubber systems since 2010 to retrofit its fleet and continues to do so. Jiang et al. (2014) conducted a CBA analysis on the merits of installing scrubbers as an abatement option for the SECA requirements for a container vessel. They conclude that an investment in scrubber systems is more attractive when the price differential is more than €233/ton. Zis et al. (2016) considered a CBA for scrubbers at different fuel price scenarios and for different vessel types sailing in and out of SECAs. In their analysis, it is shown that a scrubber investment has doubled its payback period in the aftermath of the very low fuel prices observed. In this section, a Ro-Ro vessel deployed in Esbjerg – Immingham and is still running on MGO will be considered for an investment in scrubbers. Using an estimated retrofit cost of €250 per kW of installed main engine power (EMSA, 2010), the capital cost of investment would be in the region of 4.8 M€. The total weekly fuel consumption for the vessel reaches 303 tons. Following an installation of scrubbers, the additional fuel consumption is assumed to be 3% to cover the scrubber's energy requirements. The operating cost savings will depend on the fuel price differential of HFO and MGO. Considering several fuel price differential as the points in time to decide which option to use, the payback period of the investment can be estimated through a simplified CBA analysis.

Assuming a constant fuel price differential (which is a crude assumption to facilitate comparisons) for the calculation, there is a significant variation in the payback period of the scrubber. At the highest fuel prices observed in the two years between 2014 and 2015, the investment in scrubber systems would seem as very promising with returns in less than 2 years. However, taking into account the lowest fuel prices observed in the end of 2015, the payback period increases to 4.3 years e.g. 2020. At that point in time, the global sulphur cap will be enforced and potentially new technologies will be available that would constitute investing in scrubbers in 2016 less appealing. Considering these simplistic calculations, the age of the vessel should also be taken into account as if a vessel has less than 5 years of remaining service, investing in scrubbers may not make sense.

The use of LNG as fuel has been considered in recent years as a potential alternative to low-sulphur fuel or use of scrubber systems, due to the zero content of sulphur in LNG,

as well as the better fuel economy offered by LNG engines and the lower carbon emission factors. There is however, some scepticism concerning LNG on both environmental grounds due to the potential methane slip, as well as techno-economics due to the limited number of LNG bunkering ports. Holden (2014) notes that as of 2014, very few ports within ECAs offered LNG bunkering facilities.

The Danish Maritime Authority (DMA) conducted a feasibility study on LNG as a potential solution for new-builds and retrofits (DMA, 2012). The DMA considers that the funds required to retrofit an engine to use LNG on a Ro-Ro vessel with a main engine of installed power of 21000 kW would require an investment €339/kW and an additional installation cost €150/kW (main and auxiliary engine). The total capital investment costs can therefore reach 10.5 million Euros. Unlike a scrubber investment that allows the use of HFO instead of MGO, the price of LNG is not guaranteed to be much lower than MGO. However, the specific fuel oil consumption (SFOC, g of fuel per kWh) is lower for gas turbines in comparison to internal combustion engines. Kristensen (2012) suggests that LNG powered turbines have a SFOC that is typically 18% lower than marine diesel engines. Assuming that LNG bunkering facilities were available in the visiting ports, the analysis for retrofitting the vessel on Esbjerg – Immingham shows a lengthier payback period for all fuel price scenarios.

Conclusions and further work

This paper considered certain measures that a Ro-Ro operator has to cope with the higher costs due to compliance with the lower sulphur requirements in SECAs. The paper built on an existing modelling framework that estimates modal shifts as a consequence of changes in the generalized cost of transport in any of the available options that a shipper has. This modelling framework has been extended to facilitate the assessment of the suggested operational measures. The measures considered changes in the sailing speed of the vessels at each of the examined routes for three fuel case scenarios.

The results indicate that the option of reducing sailing speed should be performed for high fuel prices, as the cargo losses would be minimal, while the hours at the port would also be reduced. However, the latter fact may require additional resources in order to ensure the efficiency of loading/unloading operations and the on time departure of the vessel to the next port. The model was tested for changes in the sailing frequency of the vessels. For these scenarios, the fuel savings are higher than the loss of revenue. However, the utilization factor of the vessel may be reduced. Changes in sailing frequency have important impacts on the utilization factor. The Ro-Ro operator can use this measure as a mechanism to cope with either

- too high utilization factors (that pose the threat of transport demand exceeding the capacity of the vessel and thus cargoes left at the port for the next sailing)
- too low (with negative environmental impacts due to the resulting high emissions per transported NM-lm).

Swapping vessels between routes was also examined under the assumption that the schedule in that case would not be altered, and thus the transport demand would stay fixed.

Finally, the option of further investing in scrubbers or LNG technology was considered for a conceptual retrofit scenario in one of the most fuel demanding vessels. The analysis showed that the current low fuel prices constitute the investment less appealing in comparison to the previous years. The payback period of the investment in

scrubbers is shown to have doubled in comparison to what it would have been in 2014. It would be even higher for other vessels that have a lower fuel consumption.

The overall conclusion is that selecting the right measure can prove critical in ensuring the viability of a service that strongly competes with land-based modes. The methodology allows the conduct of sensitivity analyses on key parameters for each measure proposed. Next steps in this research will include the examination of these measures in the full network of the Ro-Ro operator, as well as through the use of combined measures. For example, a vessel that has a scrubber can sail faster, whereas for options where the sailing time is increased, a higher frequency could be offered. Finally, it is important to consider also regulatory measures that can be used to demotivate modal shifts to landbased modes in accordance with the targets set by the European Union. These may include the provision of subsidies to ship operators for investments in abatement technologies, subsidies to shippers to use maritime modes, or introduction of additional taxes on landbased freight modes.

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