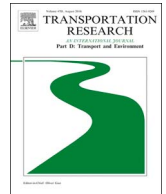




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# Transportation Research Part D

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## Optimization of a container vessel fleet and its propulsion plant to articulate sustainable intermodal chains versus road transport

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### A B S T R A C T

The recent European regulations on emissions from heavy duty vehicles (Euro VI) along with the enforcement of ECA regulations have represented an additional challenge for the sustainability of the motorways of the sea. The main aim of this paper is to identify the optimal sizing and the most adequate propulsion plant for a fleet of feeder vessels that, by operating under motorways of the sea conditions, is able to articulate competitive intermodal chains versus the road for the door-to-door transport by ensuring the sustainability of the intermodality in the current normative framework. Thus, a mathematical model is developed to evaluate, aside from the total costs and the time invested in the transport, the environmental costs of the unimodal transport and of intermodal chains with different sizing and technologies for the vessels. The resolution of this multiobjective model was carried out with an NSGA-II algorithm in an application to a transport network between Spain and France. This application concluded that fast and small vessels with LNG propulsion plants are the most convenient to maximize the competitiveness advantage against the road alternative. Likewise, the analysis of the environmental performance of both transport systems in the application case from 2010 to 2015 shows an unfavourable environmental evolution for the intermodality.

### 1. Introduction

Maritime transport was traditionally shown to be a sustainable solution for transportation needs. Proof of this is the institutional support of the European Union (EU) from the White Paper on European Transport Policy for 2001 to the intermodal chains articulated through Motorways of the Sea (MoS) (Gesé and Baird, 2013). Since then, significant European efforts have aimed at improving the opportunities for the success of intermodal chains versus road transport in terms of time and cost of the ‘door-to-door transport’ (Martínez-López et al., 2015c).

Despite evident EU interest in boosting Short Sea Shipping (SSS) (Medda and Trujillo, 2010) and specifically, the MoS, over the years, this alternative solution has faced an unbalanced competitive situation compared to truck transport due to, among other

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reasons, the public financing of road transport by the member states (Baird, 2007; Gesé and Baird, 2013); the lack of internalization of the external costs by the transport modes (Jugovic et al., 2014), such as the costs of traffic accidents, noise or traffic congestion; and the unequal treatment of the environmental requirements demanded established by the EU for each transport mode (Culliane and Culliane, 2013).

This has motivated that the environmentally friendly label traditionally given to SSS in comparison to other transport systems has been under discussion in recent years (Hjelle and Fridell, 2012; Hjelle, 2010, 2014). Consequently, a number of previous studies have tackled the environmental impact of unimodal transport for a specific door-to-door route, versus the intermodal transport through SSS. The results obtained show an environmental advantage of intermodality when the routes are covered by container vessels (Lee et al., 2010; Chang, et al., 2010; Usabiaga et al., 2013; Martínez-López et al., 2016) and a disadvantage when they are covered by Ro-Ro vessels (Usabiaga et al., 2013). However, these studies are based on vessels with conventional propulsion plants (Tier II fuel-based engines) and trucks with technology below Euro VI, that is, they have not considered the most recent applicable technology for these two transport alternatives. This is a key issue as the technological development in the reduction of pollutant emissions has clearly been slower in the maritime sector (Culliane and Culliane, 2013) than land transport in recent years.

In light of the above, considerable uncertainty remains regarding the sustainability of intermodality by operating with the current applicable technology in seaborne transport, in comparison with the trucking alternative. Therefore, in order to fill this knowledge gap, this paper tackles the environmental competitiveness of intermodal chains (articulated through MoS) in comparison to road transport, with the optimization of container vessel fleets by assuming compliance with the EU's environmental requirements: Euro VI technology for trucking, and the current technical possibilities to accomplish with Emission Control Area (ECA) regulations (MARPOL 73/78) in seaborne transport: heavy fuel oil (HFO) engines (Tier III) with scrubber, marine gas oil (MGO) engines (Tier III) and gas engines operating with LNG (Bengtsson et al., 2014; Brynolf et al., 2014).

This introduction is followed in the next section by a brief discussion of the development of the environmental normative for transport modes in the EU. Section three describes the mathematical model which has been developed to evaluate the environmental impact of unimodal transport and the intermodal alternative according to the features of the container fleets obtained during the optimization process. Section four introduces an application of the model to a particular case. The results obtained from this process are discussed in section five where the utility of the model as a support decision tool about the sizing, and the technical and operative features of the vessels (especially the setting up of propulsion plants and the most suitable combustible) is assessed. Finally, section six provides the conclusions and directions for further research, which will be useful not only for shipowners but also for policy makers who can evaluate the consequences of the unbalanced situation in the environmental regulation among transport modes and make decisions about future transport strategies in the EU.

## 2. The regulatory regime in E.U for environmental compliance

Since the 1990s (Directive 91/542/EEC, amending Directive 88/ 77/EEC), the EU has limited the pollutant gas emissions of vehicles by imposing compulsory standards (Euro I to Euro VI), which forced the development of technology to meet these requirements. Currently, since January 2014, Euro VI technology has been required in the EU for heavy duty vehicles (Regulation EC N 595/2009 as amended by Regulation 582/2011), category N3 (Annex II, Directive 2007/46/EC). These vehicles are industrial trucks able to carry loads above 12 tonnes. The Euro VI emission standards involve a 50% reduction of particulate pollutants and a 77% reduction of NO<sub>x</sub> emissions, compared to Euro V (Regulation 582/2011).

In the maritime context, the publication of Technical Report No. 4/2013 by the European Environment Agency (EEA) showed a concerning situation regarding the share of contribution to worldwide greenhouse gases by European maritime transport. As a consequence, the European Commission adopted a 'step' strategy, COM (2013) 479, focused on the harmonization of the maritime transport greenhouse emissions with the CO<sub>2</sub> emissions targets collected in the White Paper on Transport (2011). The first step sought to monitor the CO<sub>2</sub> emissions of vessels operating in the ports of Member States. This step was finally collected in Regulation (EU) 2015/717 of the European Parliament, which enforced the setting up of Monitoring, Reporting, and Verification (MRV) systems for CO<sub>2</sub> emissions in vessels; with the first reporting period scheduled for 2018. The second step of the strategy deals with greenhouse gas reduction targets; this has not yet been reflected in the European regulations.

Additionally, the European Parliament [Directive (EU) 2016/802] will drastically limit Sulphur emissions in all European territorial seas and Exclusive Economic Zones from 2020, according to the International Maritime Organization (IMO) requirements, with the expectation that the Mediterranean will be classified as a Sulphur Emission Control Area (SECA) zone by the IMO in the short term (Panagakos et al., 2014). Nowadays in Europe only the Baltic Sea, the North Sea, and the English Channel are classified as SECA zones. These zones are defined by the International Convention for the Prevention of Pollution for ships (MARPOL 73/78) Annex VI (Regulations for the Prevention of Air Pollution from Ships), and its classification implies that, since January 2015, the Sulphur content of the combustibles used in these zones must not exceed 0.1% on a mass basis.

In recent years, aside from the attention paid to the emissions of acidifying substances (SO<sub>2</sub>) and greenhouse gases (CO<sub>2</sub>) in maritime transport, the conclusions published by other technical reports motivated additional studies about other pollutants. Thus, concern about the ozone precursors (NO<sub>x</sub> emissions) drastically increased when the Technical Report No. 4/2013 concluded that, NO<sub>x</sub> emissions in the EU from maritime transport will be equivalent to the land NO<sub>x</sub> emissions in 2020. This pollutant is especially concerning in SSS traffic (Bengtsson et al., 2014), due to its local and regional impact.

In recent years, the EU's SSS has gained particular relevance in terms of pollution. In 2010 the Norwegian Pollution Agency, for example, reviewed the existing exhaust emission factors for the Norwegian domestic maritime sector (Nielsen and Stenersen, 2010). Due to the significance of the factors found (NO<sub>x</sub>, CH<sub>4</sub> particulates and black carbon), these were used in the national emissions

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