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Maritime routing and speed optimization with emission control areas

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ABSTRACT

Strict limits on the maximum sulphur content in fuel used by ships have recently been imposed in some Emission Control Areas (ECAs). In order to comply with these regulations many ship operators will switch to more expensive low-sulphur fuel when sailing inside ECAs. Since they are concerned about minimizing their costs, it is likely that speed and routing decisions will change because of this. In this paper, we develop an optimization model to be applied by ship operators for determining sailing paths and speeds that minimize operating costs for a ship along a given sequence of ports. We perform a computational study on a number of realistic shipping routes in order to evaluate possible impacts on sailing paths and speeds, and hence fuel consumption and costs, from the ECA regulations. Moreover, the aim is to examine the implications for the society with regards to environmental effects. Comparisons of cases show that a likely effect of the regulations is that ship operators will often choose to sail longer distances to avoid sailing time within ECAs. Another effect is that they will sail at lower speeds within and higher speeds outside the ECAs in order to use less of the more expensive fuel. On some shipping routes, this might give a considerable increase in the total amount of fuel consumed and the CO_2 emissions.

1. Introduction

Ocean-going vessels carry more than 90% of global trade (IMO, 2014), and shipping is considered environmentally efficient. However, there are still significant emissions associated with the operations. Emissions from the shipping industry are closely correlated to its consumption of fuel, which has been estimated to be between 279 and 400 million tons (Cullinane and Bergqvist, 2014). Since ships move between different jurisdictions, there is a need for international regulations. The International Maritime Organization (IMO), a specialized agency of the United Nations, is responsible for, among other things, regulations on the safety and security of shipping and the prevention of maritime pollution by ships. MARPOL is the main international convention concerning prevention of pollution of the marine environment by ships, and in 1997 the convention was updated with Annex VI, which more specifically considers air pollution from ships and sets limits on the emissions of both NO_x and SO_x from ship exhausts. In 2008 the IMO agreed on the latest version of Annex VI setting a global limit on the sulphur content of a ship's fuel to 3.50% (from 2012) followed by a reduction to 0.50% from 2020 (though subject to a review to be completed by 2018 which may conclude to prolong this stricter requirement to 2025).

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Four Emission Control Areas (ECAs) have also been defined by MARPOL, as shown in Fig. 1. These are the Baltic Sea, the North Sea and English Channel, and the North American and the US Caribbean coasts. Within these ECAs there is even more stringent control of the sulphur emissions with a limit of 0.1% sulphur content in the ship's fuel from January 1, 2015. The North American and US Caribbean ECAs also regulate NO_x emissions. In addition, the EU has adopted legislation transposing the IMO regulations into EU law, the latest version of which is Directive 2012/33/EU (also known as the sulphur directive). The sulphur directive is more stringent than MARPOL Annex VI, as irrespective of the outcome of the proposed IMO review in 2018, a reduction to a cap of 0.50% sulphur content will be unilaterally implemented in the EU on 1 January 2020 and also all passenger ships in the EU's non-ECA waters will have a maximum 1.5% sulphur content until that time.

There are mainly three ways shipping companies can achieve compliance with the ECA sulphur regulations, i.e. fuel switching, scrubber and using liquefied natural gas (LNG) as fuel. In this paper we will focus on fuel switching. For a ship entirely operating within an ECA, the capital cost of converting to burning low sulphur fuel such as MGO is between 10,000 and 100,000 USD, depending on the ship. For ships that operate both within and outside ECAs, fuel switching is a straightforward compliance alternative. This means that the ships burns marine gas oil (MGO) within ECAs, while the more commonly used and cheaper fuel type, heavy fuel oil (HFO), is used outside. The ability to switch fuels is a necessity for deep sea vessels that cross in and out of ECAs, so these ships need to keep two sets of segregated fuel tanks, one for HFO and another for MGO. Segregating the fuel tanks would involve retrofitting the vessel. Modifications should also be made in the fuel pump system and would also involve installing a fuel switch and a cooler, as HFO is preheated whereas MGO should be injected cold. The corresponding investment costs are ship dependent but in any event are about an order of magnitude lower as compared to the other two compliance options (see below).

The second option is to install a scrubber, which is a filtering/cleaning system to remove the sulphur from the exhaust. This permits the ship to use HFO in ECAs. Such solutions are used by some short sea ferry operators, such as for instance DFDS Seaways, which has embarked upon a massive scrubber installation program, with an investment cost of about 125 million USD for 21 ships. The scrubber solutions are usually not considered cost effective for deep sea vessels as the portion of time they spend in ECAs is low.

The third alternative involves using liquefied natural gas (LNG) as fuel. This reduces emissions of sulphur and potentially many other substances such as nitrogen oxides. This involves high investments for retrofitting the ship so that it can store and burn LNG, and also making sure there are adequate shoreside LNG supply facilities at the ports in which the ship will refuel.

Compliance with ECA regulations has received significant attention lately, both from shipping companies and from the research community. Schinas and Stefanakos (2012) propose a stochastic programming model for determining the mix of a fleet of ships operating in ECAs. The recent special issue in Transportation Research Part D (Cullinane and Bergqvist, 2014) focuses more on the technical options to comply with the ECA regulations. Jiang et al. (2014) perform an economic analysis to compare scrubbers and fuel switching. Their analysis shows that which of these two options that is preferable depends on the price spread between MGO and HFO. Yang et al. (2012) assess all three alternatives according to a number of criteria, such as capital and operational costs, operational difficulty and maintenance requirement. Findings show that fuel switching is preferred for SO_x control, while scrubbers may become more important with stricter future limits. Brynolf et al. (2014) and Balland et al. (2012, 2013)) also analyze SO_x compliance in combination with NO_x abatement.

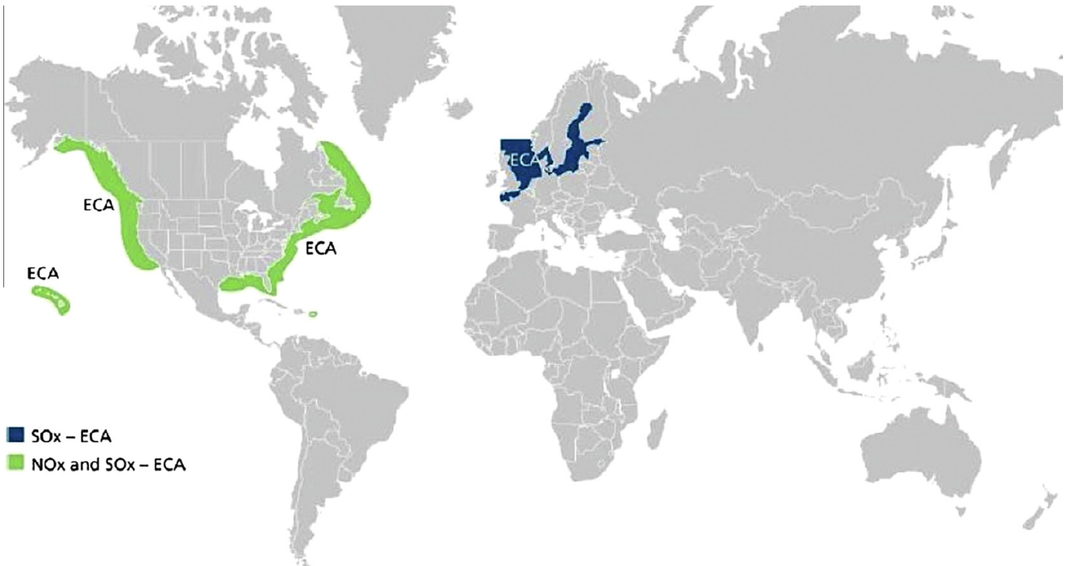

Fig. 1. Map over current emission control areas.