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A framework for real-time monitoring of energy efficiency of marine vessels

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ABSTRACT

Sea shipping is one of the most widespread transport modes. Therefore, the improvement of energy efficiency and further curbing of Carbon Dioxide emissions by marine vessels is important both economically and environmentally. During the sixty ninth Marine Environment Protection Committee session in April 2016, the International Maritime Organization approved mandatory requirements for ships to report their fuel consumption, which is the first of the three-phase approach to derive a standardized measure for energy efficiency tracking of marine vessels. Under the International Maritime Organization Data Collection System, emphasis has been placed on verification of the collected fuel consumption data so that vessels' energy efficiency could be benchmarked and improved. To optimize the operational efficiency of marine vessels, this paper proposes the Real-Time Energy Efficiency Operating Index and the framework to implement it. The proposed scheme can be used to verify fuel consumption and carbon dioxide emission data reported by individual ships. It also provides an approach to automatically and remotely estimate the transport work in real time. The proposed architecture mainly relies on the Automated Identification System and a constructed vessel database. A proof of concept prototype is deployed that monitors the energy efficiency of vessels along the Singapore Strait.

1. Introduction and motivation

Although sea-transportation is the most fuel-efficient way of shipping goods, fuel consumption constitutes the major component in the operating costs of shipping line companies and for the maritime industry in general [1]. With increased transport demand, there is an increasing need to curb fuel consumption and Green House Gas (GHG) emission [2]. In this regard, the IMO has recently raised concerns on the need to further improve the energy efficiency of sea going vessels. To promote and sustain this need, several measures have been implemented targeting the design of new vessels. One prominent measure is the regulation of the Energy Efficiency Design Index (EEDI) for new ships [3]. The Ship Energy Efficiency Management Plan (SEEMP) is another important regulation for all ships to manage the ship's efficiency performance over time. In it, it also recommends the voluntary use of the Energy Efficiency Operating Index as a monitoring tool. With this need to reduce GHG emissions, several studies have been done on the additional technical and operational measures that can further improve the design and operational efficiency [4].

1.1. Relevant literature

The EEDI has had great impact in the definition of regulations and, as a result, it has boosted a significant amount of literature on the evaluation of such index for several categories of vessels. [5] analyzed the potential powering options for LNG carriers under the EEDI requirements, and [6] studied the effect of correction factors in the EEDI on the emissions of the general cargo vessels. Moreover [7], highlights the importance of accurate data in order to improve the effectiveness of the EEDI computation, and it proposes enhancements in the modeling of consumption due to the motion of vessels in real navigation conditions. The EEDI however is a static design based index that does not capture the operational efficiency performance over time. In this regard [8], analyzed the operational efficiency for inland river ships in order to understand the impact of the dynamic navigation environment (e.g., calm waters versus real

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List of abbreviations and acronyms

AER	Annual Efficiency Ratio
AIS	Automatic Identification System
ASSIST	Access Controlled Ship Identification Streams
CO_2	Carbon Dioxide
DCS	Data Collection System
EEDI	Energy Efficiency Design Index
EEOI	Energy Efficiency Operating Index
EHS	Energy per Hour in Service
FORS	Fuel Oil Reduction Strategy
GHG	Green House Gas
GPS	Global Positioning System
GT	Gross Tonnage
HFO	Heavy Fuel Oil
IMO	International Maritime Organization
ISPI	Individual Ship Performance Indicator
MARPOL	The International Convention for the Prevention of Pollution from Ships
MDO	Marine Diesel Oil
MEPC	Marine Environment Protection Committee
MMSI	Maritime Mobile Service Identity
MPA	Maritime Port Authority of Singapore
MRV	Measure Reduce Verify scheme
SEEMP	Ship Energy Efficiency Management Plan
STEAM	Ship Traffic Emission Assessment Model
SOLAS	Safety of Life At Sea convention
RT-EEOI	Real-Time Energy Efficiency Operating Index
VHF	Very High Frequency

time navigation conditions). Similarly [9], developed a model for the prediction of the fuel consumption and emission for large ships, and [10] proposed an innovative framework to evaluate ship air emissions based on Life Cycle Assessment. In addition to the evaluation of the design and operating efficiency indices, the literature has also focused on the effect of policies and operational measures on lowering emissions. [11] studies how the speed, size and slenderness in design reduces emissions and costs. [12] provides a comprehensive review of technical and operational measures and their emission reduction potentials, and [13] discusses the implementation of several technical measures on emissions. [14] studies the impact of route and port selection on reducing CO_2 emissions and [15] analyzes the impact of the use of LNG as an alternative fuel for propulsion.

In the current literature on operating emissions and efficiency, most are focused on retrospective yearly emission/efficiency measures, ignoring the real time behavior and the spatio-temporal dynamics of the emissions. Despite the indisputable importance of providing aggregate benchmark measures for periodic estimation of emissions, real-time monitoring is becoming increasingly relevant to ports as well as global authorities such as IMO and it can represent the basis to develop policies for efficiency optimization and emission minimization. In Ref. [16], a real time optimization of ship energy efficiency is proposed. However, the approach focuses on the optimization of the operations of a single vessel rather than global measures for fleet efficiency and benchmark for different vessels.

In the direction of obtaining estimates on fleets of vessels, especially in real-time, the availability of data becomes a key issue. The Automated Identification System (AIS) represents a promising source in this direction. In relation to AIS data, Gutierrez et al. [17] uses this source to provide a comprehensive analysis and comparison between various bottom-up approaches to estimate emission inventory and fuel consumption of ships. Smith et al. in Ref. [18] propose the application of AIS data to measure vessel energy efficiency employing both top-down and bottom-up approaches. In fact, while both contributions show the viability of employing AIS data for analysis of emissions retrospectively, and succeed in identifying clear patterns in the behavior of fleets and ship types with respect to CO_2 emission and energy efficiency, they do not allow for real time energy efficiency computation, thus hindering the possibility for the controlling bodies (either port or global organizations) to interact with the vessels and mandate improvement measures like speed adjustment [19].

1.2. Challenges to achieve real-time energy efficiency estimation

In fact, to enable automatic real-time tracking, additional methodologies and architectures are required.

A challenge for the implementation of such methodologies is the availability of data and an architecture to process and analyze them automatically [17]. In this direction, regulatory bodies like the European Union are actively promoting regulations for the shipping sector to report and verify vessel emissions and energy efficiency. However, the proposed Measure-Reduce-Verify (MRV) scheme is still based on data to be reported on a per-voyage or annual basis [20]. This hinders the potential to track and control vessel emissions in real time. Concerning data reporting and availability, during the 69th Marine Environment Protection Committee (MEPC) session in April 2016, IMO has approved mandatory requirements for ships to record and report their fuel consumption, which is intended to be the first step of the three-phase approach to derive a mandatory standard for energy efficiency tracking of marine vessels. Per this scheme, ships of 5000 gross tonnage and above will be required to collect consumption data for each type of fuel they use, as well as other specified data including proxies of the transport work [21]. These data can be collected retrospectively from shipping logs, but is tedious to compile and consolidate. In addition, to derive energy efficiency measures, data concerning the cargo mass being transported should be collected as well, but this is sensitive information that shipping companies do not want to publicly report. How to estimate this information without voluntary reporting by individual vessels is part of the challenge faced.

1.3. Contribution

In this paper, a novel software architecture which can gather real-time data from several sources including AIS is designed. And a new methodology is proposed for the fast computation of real-time energy efficiency of vessels which does not require any manually input information and can be done remotely on shore side. The resulting framework represents a first step towards a robust real-time system for vessels efficiency tracking. This is in line with IMO's agenda to enforce the Data Collection System (DCS) requirements in 2018 for benchmarking energy efficiency of marine vessels [21], and the framework proposed can enable independent verification of data submitted through DCS. In this contribution, the use of the framework is illustrated, while highlighting potential issues and limitations characterizing this first proposal.