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Applying Multi-Class Support Vector Machines for performance assessment of shipping operations: The case of tanker vessels

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ABSTRACT

Energy efficient operations are a key competitive advantage for modern shipping companies. During the operation of the vessel, improvements in energy use can be achieved by not only by technical upgrades, but also through behavioural changes in the way the crew on board is operating the vessels. Identifying the potential of behavioural savings can be challenging, due to the inherent difficulty in analysing the data and operationalizing energy efficiency within the dynamic operating environment of the vessels. This article proposes a supervised learning model for identifying the presence of energy efficient operations. Positive and negative patterns of energy efficient operations were identified and verified through discussions with senior officers and technical superintendents. Based on this data, the high dimensional parameter space that describes vessel operations was first reduced by means of feature selection algorithms. Afterwards, a model based on Multi- Class Support Vector Machines (SVM) was constructed and the efficacy of the approach is shown through the application of a test set. The results demonstrate the importance and benefits of machine learning algorithms in driving energy efficiency on board, as well as the impact of power management on energy costs throughout the life cycle of the ships.

1. Introduction

There are strong economic and environmental incentives in reducing the fuel consumption of the shipping industry. The need to curb the increase in the global average temperatures, together with the designation of new emission control areas in China underline the importance of energy management on board modern vessels.

Interestingly, within energy management systems, shipping has attracted limited attention. In a recent review by Lee and Cheng (2016) the authors argue that although energy management systems have been extensively studied for over 40 years, the majority of studies are focused on either buildings or industrial and factory energy management systems with no studies on shipping. In the shipping literature a number of works have attempted to develop models that simulate the performance of the ship energy systems and identify energy consumption patterns. Trodden et al. (2015) propose a data analysis methodology to isolate the steady-state free-running condition of a harbour tug. The developed algorithm separates the data-stream, as output from monitoring devices, into periods associated with steady-state, free-running condition, and non-steady-state free-running condition and shows that the tug is being operated in a fuel efficient manner, making the most of a retrofitted economy engine speed selector. Cichowitz et al. (2015) discuss the use of Dynamic Energy Modelling (DEM) for realistic simulation of ship energy systems. DEM captures holistically the transfer, conversion and storage of energy on board a ship as a function of its operational profile and over long periods of time or during its commercial life-cycle. Simulation using DES is presented for four hypothetical scenarios that illustrate the feasible operational space for the case of a container ship. Similar studies can be found on other industrial sectors such as household equipment (Murray et al., 2016) and hybrid vehicles (He et al., 2016).

All studies that were just described acknowledge the growing importance of data and data analysis, and their potential in operationalizing performance management across the shipping industry. In a study of the digital transformation conducted by the MIT centre for digital business, Westerman et al. (2011) argue that performance management is one of the building blocks of the ongoing digital transformation. In the oil and gas industry, DNV – GL claim that if the oil and gas industry could analyse and understand all the data it is currently producing in a more coordinated manner, operational efficiency could be boosted by as much as 20%. However the same report warns that the potential of big data is hampered by a lack of

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resources, lack of experience and the increasing volume of data (DNV, 2016).

However, simply measuring fuel consumption is not enough in driving energy efficiency. Trodden et al. (2015) argue that while data monitoring devices are relatively inexpensive, the process of analysing data can be complex, particularly when a ship's activities are diverse. In their study of the German and Danish shipping industry, Poulsen and Johnson (2015) conclude that the lack of information on energy efficiency and lack of time to produce and provide reliable energy efficiency information cause energy efficiency gaps.

Data-related challenges are not confined to shipping. A recent analysis from the McKinsey Global Institute argues that even in established organizations where core processes are centred around data analytics, management-approval processes have not kept up with the advancements in data analytics (Court, 2015). However, the shipping industry exhibits certain characteristics that further complicate data analysis. The different characteristics of power generation systems and consumers for vessels in operation require careful consideration and adjustment of energy consumption profiles to ship-specific characteristics. Especially in the tramp shipping market that is driven by the complex balance of supply and demand (Stopford, 2009), operating profiles can change rapidly. Energy consumption patterns are also influenced by safety considerations. For example, specific equipment according to the ship safety plan might be turned on when transiting high risk areas (NATO Shipping Centre 2016). But most importantly, as vessels engage in a multitude of operational activities, energy consumption patterns need to be associated to those particular activities (Trodden et al., 2015).

Challenges towards data analysis can also stem from the various ship management models that appear in the shipping industry. Information and incentives are often fragmented, as fuel consumption is a performance measure of the commercial department – reflected in the Time Charter Equivalent (TCE) - and often outside of the sphere of influence of the technical department, which is often primarily measured on Operational Expenses (OPEX). This paradox is even more prevalent in third party ship management, where information regarding fuel saving potential is not readily provided and shared by decision makers at sea and ashore (Poulsen and Sornn-Friese, 2015). This situation creates data silos in shipping companies and invites for one of the key business challenges of the modern age according to Thompson (2012), which is to recognize and use the valuable information that is scattered around the organization.

In light of the above mentioned challenges, we believe that these limitations can be overcome by a methodological shift to multivariate machine learning techniques. To the best of our knowledge, machine learning techniques have not been applied on power management in shipping – at least not in the open literature. However, machine learning has been extensively used for power management in other industrial sectors, with particular focus on prediction. In a recent review of forecasting approaches for the building sector, Chalal et al. (2016) argue that Support Vector Machines (SVM) and artificial neural networks models (ANN) are the most common tools, to develop energy prediction approaches, which in turn support physical improvement strategies. Especially SVMs have been used for time series predictions, particularly in financial time series and electrical load forecasting (Sapankevych and Sankar, 2009).

Given their wide adoption and alleged benefits, we investigated the efficacy of Support Vector Machines in eliciting the correct information from the energy consumption patterns. Based on the results of that analysis, we assess the potential savings from behavioural improvements. This article proposes a supervised learning model for identifying the presence of energy efficient operations, as a basis for developing an energy management methodology. Focus is on the production of electricity on board a group of tanker vessels. Production of electricity on board from generator engines comprises between 9% and 25% of the total fuel consumption of a tanker vessel (Fig. 1). Through ship-specific adjustments, the proposed methodology evaluates operational practices between different vessels, thus providing an informed picture of the behaviour-driven efficiency on-board. The performance and accuracy of the classifier was evaluated by means of 5-fold cross validation. The development and scope of the methodology, while novel in the shipping literature, follows extant directions for future research to identify actual effects of fuel initiatives (Poulsen and Johnson, 2015), measured under comparable conditions (Trodden et al., 2015).

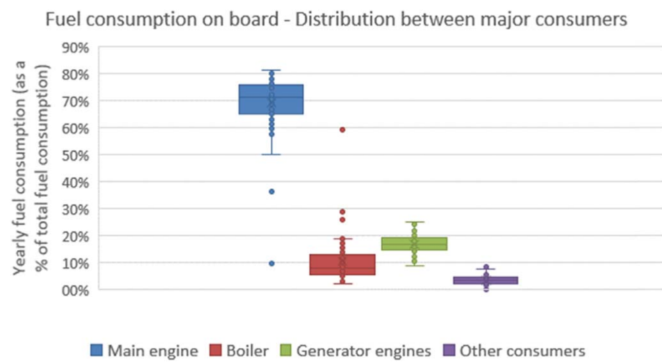

Fig. 1. Tanker fuel consumption distribution per major consumer.

2. Description of the proposed methodology

2.1. Energy efficiency

As discussed in Section 1, electricity production on board is influenced by multiple factors, and therefore consumption patterns need to be associated to the operational conditions of the vessel and analysed under comparable conditions. When looking at the typical operational profile of a vessel, operations such as loading of cargo or sailing are characterized by rather steady and predictable consumption patterns. In these cases the vessels are mostly idle and several systems such as the engine cooling or lubrication systems are either completely turned off or operating at a low capacity.

The central argument in this analysis is that the existence, frequency and consumption profile of those steady-state conditions are central to the assessment of energy efficiency on board. They are characterized by an operational environment where energy consumption is predictable, as it is dominated by steady-state consumption of various major consumers such as major pumps and big blowers. Especially when the vessel is idle, the crew on board has the opportunity to turn off - or at least operate at a low capacity- several systems such as the engine cooling and lubrication systems. The consumption of major consumers can be estimated and aggregated to estimate the expected fuel consumption. The expected fuel consumption allows comparison to the actual consumption of a particular vessel, and also across sister vessels that share the same design.

Other operations can be inherently difficult to assess and compare to each other, as they are often influenced by multiple factors that can be hard to predict. For example, when examining consumption patterns of the cargo systems during discharging, factors such as the cargo discharge rate and the backpressure from the storage tanks can vary a lot between terminals and result in large scatter in the data.

Lastly, there are certain patterns of operations that can indicate a lack of energy efficiency. One of those is the case where the vessels are standby at port. During standby the vessel is not turning off any equipment as it should be in a position to depart imminently. While it can be a request from terminals and port authorities to keep the vessel in standby as a safety precaution, when a vessel is systematically on standby it can indicate improper Finished-With-Engine (FWE) procedures either due to a lack of energy awareness from the crew or because