CO_2 emissions monitoring and fault-detection based on big navigation data

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LONG ABSTRACT

Global warming and climate change refer to an increase in average global temperatures that is primarily caused by the rise in greenhouse gases such as carbon dioxide (CO_2). Maritime transport has an impact on global climate and air quality, as a result of CO_2 and other harmful emissions. The International Maritime Organization (IMO) states that ships' energy consumption and CO_2 emissions could be reduced by up to 75% by implementing operational measures and existing technologies (IMO, 2009). As a consequence, the new regulation (EU 2015/757) of the European Council as well as the growth in competitiveness imposed by the shipping market urge shipping companies to adopt systems for monitoring, reporting and verification of CO_2 emissions based on fuel consumption. In this work, Partial Least-Squares (PLS) method is exploited to face classical multiple regression issues highlighted by the recent literature (Bocchetti D., et al., 2015) (Erto P., et al., 2015). The presented statistical approach is capable of dealing with big navigation data automatically acquired on-board in order to monitor ship fuel consumption and CO_2 emissions. Data are collected on board of four Ro-Ro PAX ships owned by Grimaldi Group that operate in the Mediterranean Sea. Summary statistics are provided by the data acquisition system at the end of each voyage and refer to the actual sailing time defined as the time interval between Finished with Engine and Stand by Engine (IMO, 2000) orders. The response variable object of this study is the fuel consumption per hour (i.e. the ratio between fuel consumed and actual sailing time in hours for each voyage). The following 20 physical variables have been used as predictors:

- Speed Over Ground (SOG);
- variance of SOG (σ^2_V);
- head wind component (W_H);
- side wind component (W_S);
- following wind component (W_F);
- displacement (Δ);
- shaft generator power (port) (SG_P);
- shaft generator power (starboard) (SG_S);
- power difference between port and starboard shaft generators (ΔSG);
- power difference between port and starboard propeller shafts (ΔP);
- Departure and Arrival draughts at fore, aft, midship section port and starboard (T_{FD}, T_{AD}, T_{PD}, T_{SD}, T_{FA}, T_{AA}, T_{PA}, T_{SA});

- Departure and Arrival trim ($Trim_D$, $Trim_A$).

One year's worth of data has been utilized as reference for model calibration in order to avoid seasonality effect.

Then, the response variable has been monitored at each new voyage via the following statistical tools: Hotelling T^2, SPE_x charts and contribution plots (Kourti T. & MacGregor J.F. , 1996). When a point falls outside the upper control limit of T^2 and/or the SPE_x charts, the management is urged to further investigate physical variables that have caused the out-of-control condition by exploiting the corresponding contribution plot.

As an example, in the presented case study the variable ΔSG shows the larger contribution to T^2 and in fact the Port Shaft Generator has been found out of order.

Without those statistical tools, the management cannot easily investigate and diagnose faults responsible of increase in fuel consumption (and CO_2 emissions). The proposed statistical approach is therefore able to support managerial decision making in setting up suitable actions to improve ship performance as well as to quantify consumption/emission savings after energy efficiency improvement operations (e.g., hull form optimization, hull cleaning and propeller polishing, ultra-smooth coating, engine maintenance operation, propulsion and power plant efficiency improvement). As is known, this is particularly profitable in order to claim for carbon credit.

REFERENCES

Bocchetti D., Lepore A., Palumbo B. & Vitiello L., 2015. A Statistical Approach to Ship Fuel Consumption Monitoring. *Journal of Ship Research,* 59(3), pp. 162-171.

Erto P., Lepore A., Palumbo B. & Vitiello L., 2015. A Procedure for Predicting and Controlling the Ship Fuel Consumption: Its Implementation and Test. *Quality and Reliability Engineering International,* 31(7), pp. 1177-1184.

IMO, 2000. Standard marine communication phrases (SMCP).

IMO, 2009. *Second IMO GHG study final.*

Kourti T. & MacGregor J.F. , 1996. Multivariate SPC Methods for Process and Product Monitoring. *Journal of Quality Technology,* 28(4), pp. 409-428.