PROPOSAL FOR A SEDIMENTATION STATISTICAL APPROACH FOR NAVIGABLE DEPTH PREDICTION ASSESSMENT IN THE ST. LAWRENCE WATERWAY

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The St. Lawrence Waterway is a major route for waterborne commerce in North America, acting as a gateway to opportunities for trade across the whole continent. Despite its importance, the St. Lawrence presents many challenges, such as shallow water sections, making navigation along its waterway very perilous. Therefore, ensuring a safe and optimal navigable depth along the St. Lawrence Waterway is a major concern for the Canadian Coast Guard. This is done by regularly monitoring the bathymetry of the waterway and performing dredging, when necessary.

To help ensure safe navigation and optimize traffic, the Canadian Coast Guard is implementing an e-navigation system along the St. Lawrence Waterway. This system allows dynamic management of under-keel clearance by providing real-time data, such as weather or bathymetry. In particular, bathymetric data and water depth may be among the most important information needed to optimize ship load and avoid groundings.

Owing to Quebec's cold climate, the St. Lawrence River is covered in ice during winter, making surveys impossible for several months each year. Consequently, real-time bathymetry is impossible to provide. This is problematic, since many reaches of the St. Lawrence have a dynamic bed with important sedimentation events and bed movements/transport. Indeed, to predict a ship's "real" under-keel clearance, the water depth needs to include navigable depth, which takes sedimentation and waterway bed movements into account. Therefore, it is important to be able to predict sedimentation occurring during winter for e-navigation systems to be efficient even during this period of the year.

A literature review of bed sedimentation prediction led to the conclusion that this topic has only scarcely been considered in literature. Few machine learning methods have been considered using few weather variables, such as wind speed. These studies all concern the Rotterdam harbour (Netherlands), which does not have the Nordic climate constraint of Quebec, meaning that they had the luxury of an important amount of frequent data. In addition, sedimentation in a harbour is not likely to be related to the same causes as in an inland waterway.

New statistical approaches can be proposed for assessing a bathymetric navigational depth used to calculate and monitor the under-keel clearance of merchant vessels transiting through the St. Lawrence Waterway. With these approaches, the navigational depth would be assessed using the most recent bathymetry. These approaches can include machine learning methods, as applied in the Rotterdam harbour, such as neural networks and regression trees, but also functional methods to take advantage of weather variables throughout winter, and panel data methods to include a spatial component in the prediction. In particular, panel data analysis methods are very promising for modelling and predicting winter sedimentation. They are now applied to data from the St. Lawrence Waterway. This application characterizes changes in winter sedimentation over the past 15 years in the waterway between Montréal and Trois-Rivières, which can be used for sedimentation rate forecasting.

The choice of a performant predictive method for sedimentation has to be driven by the knowledge about the sedimentation along the waterway. As stated above, this knowledge is scarce. As a first step, it is of interest to understand spatio-temporal variations of sedimentation along the waterway. Thus, a spatio temporal analysis of sedimentation in the St. Lawrence Waterway between Montréal and Trois-Rivières is presented here. This analysis includes the panel data analysis mentioned above, but also trend and clustering analyses.

The trend analysis considers trend tests such as Mann-Kendall and Sen's slope. Both agree on the lack of temporal trend; however, both identify a spatial heterogeneity in the sedimentation. Indeed, data suggest that there is an important amount of sedimentation around the Montréal harbour and little sedimentation on the Trois-Rivières side.

Cluster analysis is performed with K-means and density-based clustering. The latter is useful when the clusters are expected to overlap. These methods outline several regimes in sedimentation with especially high amounts of sedimentation near the Montréal harbour, and low amounts near Trois-Rivières and Lake Saint Pierre, one of the most critical sections of the waterway.

These results can be used to recommend relevant navigational depth predictive models to use for dynamic, optimal and safe management of the under-keel clearance of merchant vessels in e-navigation systems.