

AI- BASED DECISION-MAKING TOOLS FOR PORT MANAGEMENT: SHIP- INFRASTRUCTURE OPERABILITY AND OVERTOPPING

Andrés Figuero¹, [Enrique Peña](mailto:enrique.peña@udc.es)¹, José Sande¹, Raquel Costas¹, Humberto Carro¹, Alberto Alvarellos¹, Juan Rabuñal¹, Andrés Guerra², Juan Diego Pérez²

¹University of A Coruña, Spain, andres.figuero@udc.es, enrique.penag@udc.es, jose.sande@udc.es, raquel.costas@udc.es, humberto.fidalgo@udc.es, alberto.alvarellos@udc.es, juan.rabunal@udc.es

²Port Authority of A Coruña, Spain, aguerra@puertocoruna.com, jdperrez@puertocoruna.com

INTRODUCTION

The globalization of production and consumption has encouraged the competitiveness between ports. In this context, the availability of precise decision-making tools can be a differential element with competitors. In recent years, port operators have shown an increasing interest in developing innovative automatic learning techniques, to provide complete predictive packages for safety and efficiency systems, trained and calibrated with field database. Another relevant aspect in these kinds of projects is to determine the long wave influence. The port-ship resonance, due to the coincidence between the long wave periods and the ship horizontal motions, causes downtimes with consequent economic losses.

The Port Authority of A Coruña (Spain) started years ago to work towards the application of Artificial Intelligence, providing Machine Learning-based models in their facilities of its Outer Port of Punta Langosteira, together with the University of A Coruña. The main objective was to provide a system to predict operability and overtopping with the forecast of maritime climate information.

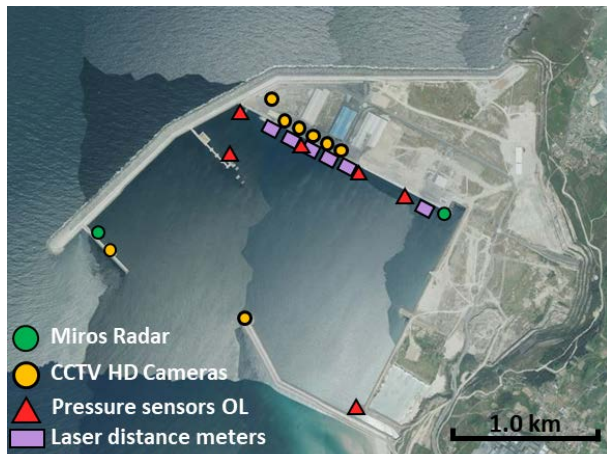


Figure 1 - Outer Port of Punta Langosteira, A Coruña, Spain. Monitoring equipment for moored vessel motions, overtopping, wave agitation and long waves.

DATABASE GENERATION

Models' development was based on the use of recorded data from met-ocean parameters, moored vessel movements, downtimes, and overtopping. With this approach, five field campaigns (years 2015-2021) were conducted to monitor both ship movements and overtopping events. For this purpose, inertial measurement equipment, laser distance meters and cameras were installed in different areas of the port and inside the vessels (Figure 1), following an already

validated methodology (Figuero et al., 2019). The data collected were related to the concomitant values of the met-ocean agents recorded by the port equipment (wave buoy outside the harbor, tide gauge and weather station with wind speed and direction), giving rise to the databases used to obtain the prediction tools: 3200 overtopping events and more than 3000 hours of movements monitoring of 112 representative vessels (mainly dry bulk and general cargo). Additionally, information concerning 27 incidents (mooring breakages and downtimes) from different vessels was registered. During the last field campaign, additional 6 pressure sensors were installed to analyze the long wave phenomenon and its influence on the operations of both the main dock and the future oil tanker jetty.

In previous works at the Outer Port of Punta Langosteira (Spain), the infragravity energy was identified in some resonant periods of the basin, greater than 100s due to its large dimensions. In addition to the relationship of both periods, basin and vessel, the amplification of motions depends on the long wave energy (Costas et al., 2022). To study in detail the moored ships behavior and the influence of long waves on them, the Wavelet Transform Analysis was applied, both to the movement's registers, and to the concomitant waves recorded by each pressure sensor installed in its corresponding berthing area. This tool gives the transformation of a signal into an energy spectrum, simultaneously providing the energy packages in the frequency and time domains (Figure 2).

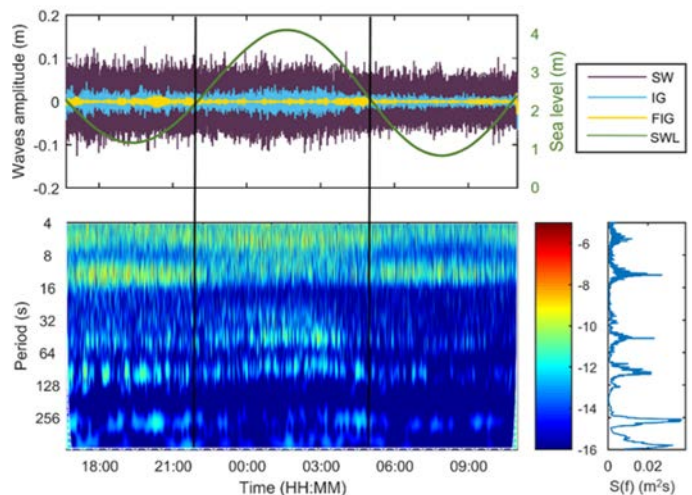


Figure 2 - Application of Wavelet Transform Analysis in the Inner Port of A Coruña. SW: short wave, IG: infragravity wave, FIG: far infragravity wave. SWL: still water level

The methodology identifies the coupling of the wave period and the vessel movements, especially low frequency ones, with situations involving resonant effects that arise in operational risk situations. This allows advancing in the development of critical operational thresholds and prediction tools with maritime climate forecast at the external buoy, including other parameters as tide range and influence of cargo loading and unloading evolution.



Figure 3 - Moored ship close to the 3.3km main breakwater.

PREDICTIVE MODEL BUILDING

With the data recorded, two alternative tools were developed using Machine Learning techniques:

- Predictive models based on ensemble learning techniques: Boosting and Random Forest.
- Predictive models based on Deep Learning techniques: Deep Neural Networks (DNN).

The application of these techniques capable of interpreting the complex relationships between the different forcing factors, the behaviour of the ship and overtopping, improved the results obtained so far, with previous transfer functions based on multiparametric adjustment, fitting best the problem requirements. The environment used to process the data and develop the models based on Deep Learning is Anaconda, <https://www.anaconda.com/>, a platform with data science and Machine Learning tools. Anaconda is chosen as a development environment and Python as a programming language, because of the advantages that both offer for scientific research, and their widespread use, even at the company's level.

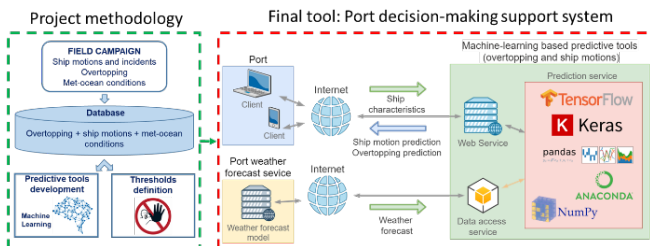


Figure 4 - Sketch of the decision-making system.

Both tools were created using the Keras framework (<https://keras.io/>) with Tensorflow as backend (<https://www.tensorflow.org/>). Since the models must work as a public operability management system, only the use of variables provided by the forecast system of the

Spanish Port Authority and Meteorological National Agency AEMET were considered. In this way, the tools-package allows obtaining the movements estimation and overtopping events prediction within 72 hours in advance for decision-making.

LONG WAVE INFLUENCE

Considering the relevance of the basin period in the port-ship resonance, significant long wave heights (H_{sLW}) were determined for different frequency ranges at each of the locations (pressure sensors and tide gauge). The studied low wave ranges (LW) were the following: low infragravity waves (LIG) (30-70s), up infragravity waves (UIG) (70-150s) and far infragravity waves (FIG) (150-300s). To obtain them, a window filter of the pressure sensors and tide gauge records was applied to calculate each wave height of those ranges, using the zero-crossing method. The generated database, adding the concomitant wave parameters outside the port [$H_{s,buoy}$, $T_{p,buoy}$], allowed to obtain the coefficients (a , b and c) for the long wave prediction, using $H_{sLW} = a \cdot H_{s,buoy}^b \cdot T_{p,buoy}^c$ (Thiebaut et al., 2013).

RESULTS

The most relevant result of the work is that both systems are currently in operational use by the Port Authority. Regarding the moored ship behavior prediction tools, they showed a promising performance in terms of RMSE and fit (R^2), in training and validation (Table 1).

Table 1 - Results of predictive models of ship motion.

Results	Roll	Pitch	Yaw	Heave	Surge	Sway
R^2	0.84	0.91	0.92	0.96	0.92	0.96
RMSE (t.)	0.26°	0.05°	0.19°	0.03m	0.11m	0.06m
RMSE (v.)	0.30°	0.06°	0.22°	0.04m	0.13m	0.16m

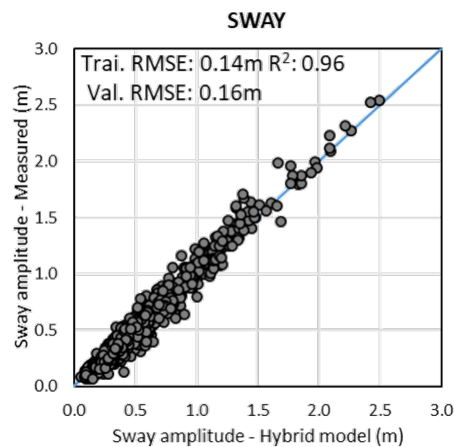


Figure 5 - Comparison of measured and hybrid modelling values for Sway amplitude

As an additional conclusion, the safe stay at berth criterion was proposed for vessels and is currently used as a decision criterion.

Regarding the overtopping model, it was decided to use one of the easiest Machine Learning techniques to implement, the Random Forest one, which generally

provides satisfactory results in classification problems (the model must determine whether an overtopping event could take place). The results expressed in the testing phase (a full winter), provided a significant improvement over the previous decision trees (Table 2).

Table 2 - Results of predictive model of overtopping. Confusion matrix of the testing phase (2021-2022 winter).

Prediction values	Actual values	
	Overtopping	No overtopping
Overtopping	26	42
No overtopping	1	2174

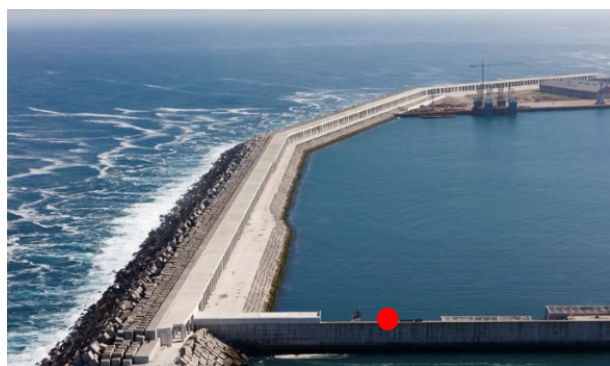


Figure 6 - Aerial view and service area (red circle: location of camera in Figures 7 and 8)

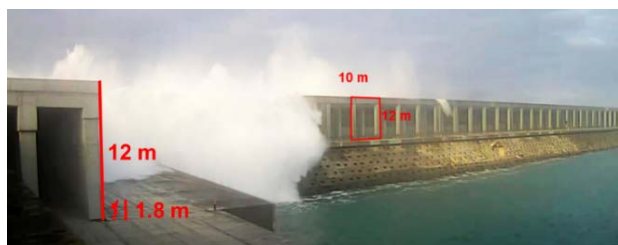


Figure 7 - Overtopping event (date: 17/01/2018)



Figure 8 - Overtopping event (date: 28/10/2020)

The thresholds actually in use regarding port access due to overtopping in the different service areas are available in <http://cma.puertocoruna.com>. These criteria were also established from the data analysis with relevant parameters in this phenomenon, not only met-ocean variables such as wave height, tide, wind speed and direction, but also the frequency and intensity of occurrence alongside the breakwater locations.

Regarding the infragravity waves and resonance analysis, a downtime criterion combining long wave height and wind speed and direction, for different vessel sizes, was determined. In addition, a jointly forecast analysis of the agitation records of long waves height inferred by short waves related to the outer maritime climate in that same instant, in different frequency ranges, was achieved (Figure 9). The whole approach allows identifying if the critical variables in operational downtimes are produced by short wave or long waves, tides, or wind.

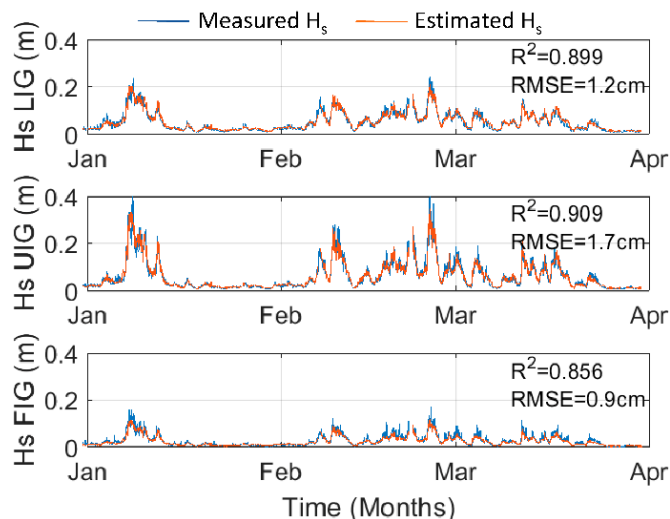


Figure 9 - Results of predictive models of long waves at Miro radar location (spur breakwater)

The high correlation obtained in the prediction based on short wave outside the port, indicates that the existing long wave is mainly a bound wave.

The main result of the whole study presented here, is the possibility of replication of methodology and thresholds, with appropriate adjustments depending on the port characteristics and environment.

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