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Toward Low-Emission Port Operations: A Multidisciplinary Approach to Tugboat Emission Optimization

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Maritime transport is the pillar of economic growth as it carries over 80 % of the world's trade in goods by volume (UNCTAD 2025). Among port-related vessels, tugboats play a critical operational role in ship manoeuvring but remain an under-studied emission source due to the lack of reliable methods for quantifying their highly variable in-port activities. Approaches integrating detailed operational data with emission modelling have been shown to significantly improve estimation accuracy compared with traditional bottom-up methods (Mahmud et al. 2023). The TUGEMI projec [1] introduces a comprehensive, multidisciplinary framework to characterize, quantify, and optimize tugboat emissions. The main objective is to provide insights into port operational strategies that can reduce or significantly mitigate local air pollutants from maritime activities and their harmful effects on the environment and human health. The methodology follows a structured sequence to characterize ship–tug manoeuvres in port areas by combining stakeholder interviews (Ribet et al. 2024), fuel-consumption field campaigns, emission monitoring campaigns, Automatic Identification System (AIS) data analysis (Niyazi et al. 2024), and full-mission bridge simulation. Based on the results, several operational mitigation strategies are identified: (1) optimization of free-sailing speeds through standardized speed ranges (see Figure 1); (2) improved tug allocation and port logistics planning to reduce waiting times and unnecessary transit distances (see Figure 2); (3) implementation of Engine Power Limitation (EPL) as a short-term measure, combined with the future adoption of lower-power engines while preserving safety through temporary power-boost systems; and (4) targeted training of tugboat skippers in efficient and sustainable navigation practices. This study provides a robust foundation for operational optimization, offering port authorities and tug operators evidence-based tools to reduce unnecessary engine loads, shorten waiting times, and mitigate air pollution. Improving tug manoeuvre efficiency emerges as a practical and scalable pathway toward more sustainable and lower-emission port operations.

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[1] (https://cremit.upc.edu/en/projectes/tugemi)

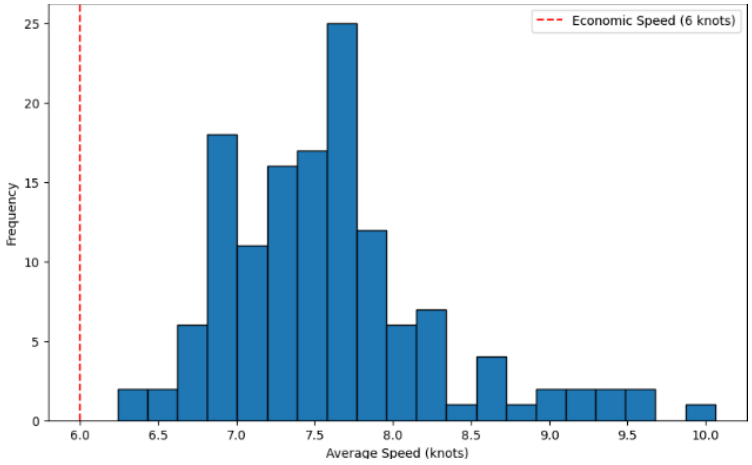

Figure 1. Average free-sailing speed distribution during tugboat shifts (year 2024)

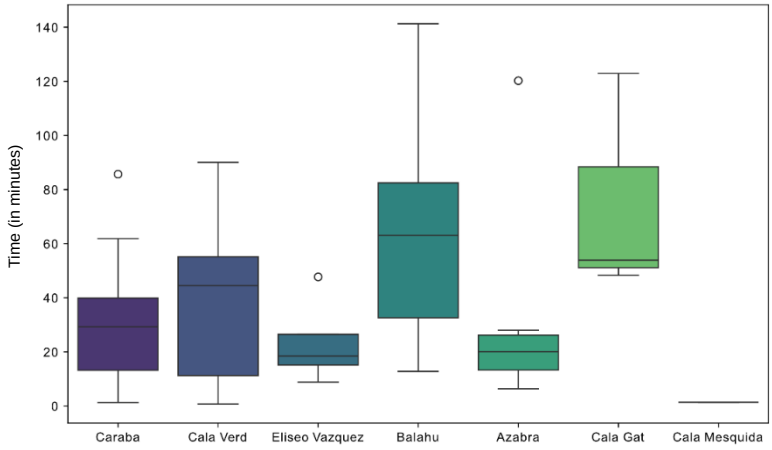

Figure 2. Waiting time (in minutes) of the tugs at the south entrance of the Port of Barcelona (data from 1/11/25-15/11/25)