

Deep Learning-Based Significant Wave Height Prediction and Harbour Entry Risk Index for Ferry Crossing Safety in the Sunda Strait

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The Sunda Strait ferry crossing between Merak and Bakauheni is Indonesia's busiest maritime route, carrying approximately six million passengers during the annual Eid exodus. Operational disruptions are not solely caused by high significant wave height (SWH); wave steepness and directional alignment relative to harbour orientation are equally critical, yet undetected by the single SWH threshold (≥ 2.5 m) in current regulations. This study compared five machine learning models: LSTM, GRU, BiLSTM, CNN-LSTM, and XGBoost for SWH prediction, and introduced the Harbour Entry Risk Index (HERI), a novel composite berthing risk index. ERA5 reanalysis data (2010–2024) with eight input variables were used across three prediction horizons (t+6h, t+12h, t+24h). NN-LSTM achieved the best performance at short-to-medium horizons, with RMSE = 0.058 m and $R^2 = 0.946$ at t+6h. BiLSTM outperformed at the 24-hour horizon (RMSE = 0.131 m, $R^2 = 0.724$), with all models consistently surpassing the persistence baseline. HERI combines normalised SWH, wave steepness, and a harbour-relative direction factor into an additive weighted index with weights assigned through expert judgement based on physical wave dynamics. Historical analysis showed 59.3% of hours during the 2022 Eid exodus were classified as Dangerous despite maximum SWH of only 1.2 m, demonstrating that monsoon transition conditions present risks invisible to single threshold systems. HERI offers a multi-parameter framework for real-time ferry safety early warning.

Keywords: *Significant Wave Height, Deep Learning, CNN-LSTM, Sunda Strait, Harbour Entry Risk Index, Ferry safety*