Quantifying the Effects of Mitigation Measures on North Sea Shipping Noise

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Abstract

A generic local shipping lane scenario is developed for a computationally effective study of the effects of mitigation measures to reduce the underwater noise from ship traffic. The scenario is designed using recorded AIS (Automatic Identification System) data for ships passing through a shipping lane north of the Dutch Wadden Islands in January 2020. Assuming that all ships sail at constant speed along a straight shipping lane in a uniform environment, the monthly statistics of the depth averaged sound pressure level (SPL) are calculated as a function of the distance to the shipping lane. The calculations are performed

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using the JOMOPANS-ECHO ship source level model and a parabolic equation sound propagation model. Results are presented for a baseline case (January 2020) and for scenarios in which mitigation measures are applied, such as the application of a maximum speed limit and a maximum ship radiated noise level. The results provide insight in the contribution of various ship types to underwater sound as well as the effectiveness of the studied noise reduction scenarios.

Keywords

Shipping noise · Speed reduction · RNL limit

Introduction

Concern about the impact on aquatic life drives various initiatives to reduce the underwater radiated noise (URN) from ship traffic. The international maritime organization (IMO) encourages various stakeholders to reduce URN via management planning (IMO 2023). Several class societies have published class notations to measure (IACS 2024) and characterize the underwater noise signature of ships and compare them with given limits. The European Commission has adopted recommendations on maximum acceptable levels for continuous underwater noise in European seas (EU Directorate-General for Environment 2022), which is in many locations dominated by shipping URN.

Modelled underwater sound maps have emerged as a tool for assessing the pressure on the environment and the impact on aquatic life. Shipping sound maps have been produced for many regions, such as Canada's Pacific Exclusive Economic Zone (Erbe et al. 2012), the Baltic Sea (Folegot et al. 2016), the North Sea (de Jong et al. 2021), UK waters (Farcas et al. 2020), and recently for all European seas (European Maritime Safety Agency 2025).

While such maps allow for the quantification of the effect of selected noise reduction measures on the mapped underwater sound levels, they compress so much temporal and spatial variation in one map that it is often hard to identify the relevant sound sources and propagation paths. Moreover, calculating sound maps for large-scale sea regions over a relevant time period such as a calendar month requires substantial computational power and time. Hence, it is often infeasible to study many different noise management scenarios.

The EU Interreg North Sea Region project DEMASK (Development and Evaluation of noise Management Strategies to Keep the North Sea healthy) aims to help maritime policymakers and other stakeholders to evaluate scenarios for managing the future North Sea soundscape. In DEMASK, the effect of noise reduction measures is first studied for a generic local scenario so that the most promising measures for reducing shipping noise can be selected before quantifying their effect in large-scale sound maps.

Generic Shipping Lane Scenario

A generic local shipping lane scenario is developed to study the effects of various noise reduction strategies. The generic scenario is designed using historic AIS (Automatic Identification System) data for the shipping lanes north of the Dutch Wadden Islands displayed in Fig. 1.

The AIS data used in this study are the same as the data used for the sound mapping conducted in the Jomopans project (de Jong et al. 2022). AIS data contain snapshots of the geographic location, speed over ground (SOG), type and length of all ships. In this case the data are interpolated to a regular time grid with a resolution of 10 min. From this data set, ship tracks were linearly interpolated to identify the passage time and speed of all ships that crossed a 24 km long reference line perpendicular to the shipping lane (the solid green line in Fig. 1), with the location and time of crossing and the speed over ground.

The selected data for the crossings were extrapolated, creating straight ship tracks of 200 km length crossing the reference line, assuming that all ships are sailing at a constant speed and course. The ships in the northern shipping lane sail towards the west and the ships in the southern shipping lane sail towards the east. Ships that do not cross the reference line were ignored. To facilitate computationally efficient scenario calculations the underwater environment is simplified to a homogeneous environment with a constant depth of 25 m and uniform acoustic properties of the water and sediment (coarse sand), representative for the North Sea environment.

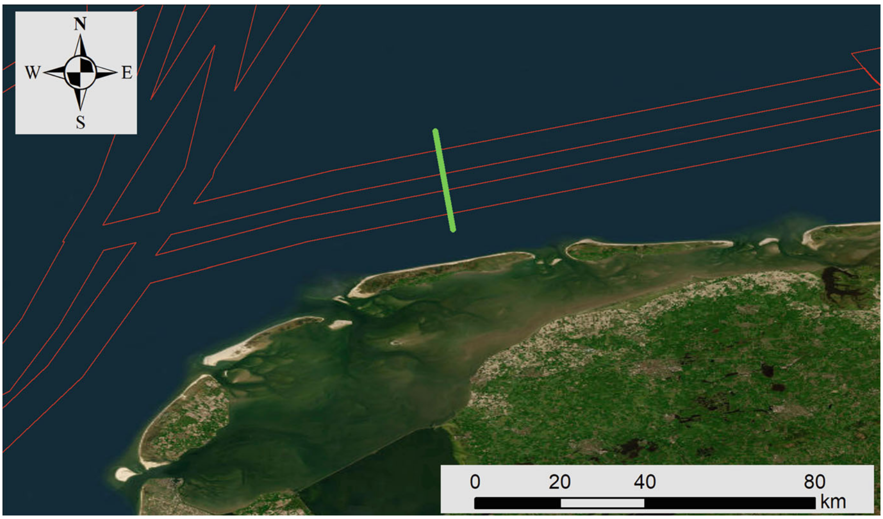

Fig. 1 Map showing the contours (red lines) of the shipping lanes north of the Dutch Wadden island Terschelling. The green solid line indicates a reference line that crosses two shipping lanes at which AIS vessel passages were recorded in January 2020

Ship Statistics

The generic shipping lane scenario was limited to tracks from ships from the main four commercial vessel classes: bulkers, tankers, container ships, and vehicle carriers, for 1 month (January 2020). The vast majority of the tracks was from these commercial vessel classes, for which the monthly traffic did not change significantly in 2020. For the analysis of noise reduction scenarios additional data, not recorded in AIS, were included from the Lloyd's Register database (de Jong et al. 2022). Ships for which no design speed was available were removed from the reference scenario (design speed is required for one of the scenarios, see §3). Table 1 provides an overview of the properties of the 1570 ship tracks that were kept for the reference scenario (67% of all recorded ship tracks). Because it is based on recorded AIS data, this is considered a representative and pragmatic reference scenario for studying the effects of noise reduction measures.

Ship Source Level

The reference ship source levels are calculated using the Jomopans-ECHO source level model (MacGillivray and de Jong 2021). This predicts decidecade band spectra (from the 16 Hz to the 20 kHz band) of the ship source levels as function of ship class, length, and speed, for a fixed source depth of 6 m for all ships. The calculated broadband SL per ship class is summarized in Table 1.

Propagation Loss

Propagation loss (PL) is calculated using the RAM parabolic equation model (Collins 1993). PL in the 16 Hz–20 kHz decidecade bands is estimated from calculations at the band center frequencies, taking the arithmetic mean over range intervals corresponding to the decidecade frequency bands (Harrison and Harrison 1995). Because the environment is uniform (range independent), a lookup table could be generated of PL versus range for horizontal distances between 0.01 and 290 km, in 10 m steps, and averaged over depths between 0 and 25 m, in 1 m steps, see Fig. 2. For water and sediment properties the same frequency-dependent values as used for the Jomopans mapping were selected, see (de Jong et al. 2021).

Table 1 Overview of the selected ship track properties (mean value and standard deviation)

Vessel class	Nr. of tracks (total 1570)	Length/m		Speed/kn		SL / dB	
		mean	st.dev.	mean	st.dev.	mean	st.dev.
Bulkers	834	104	31	10	3	157	11
Tankers	237	107	18	11	2	154	10
Container ships	377	218	89	14	3	155	11
Vehicle carriers	122	159	41	14	2	156	12

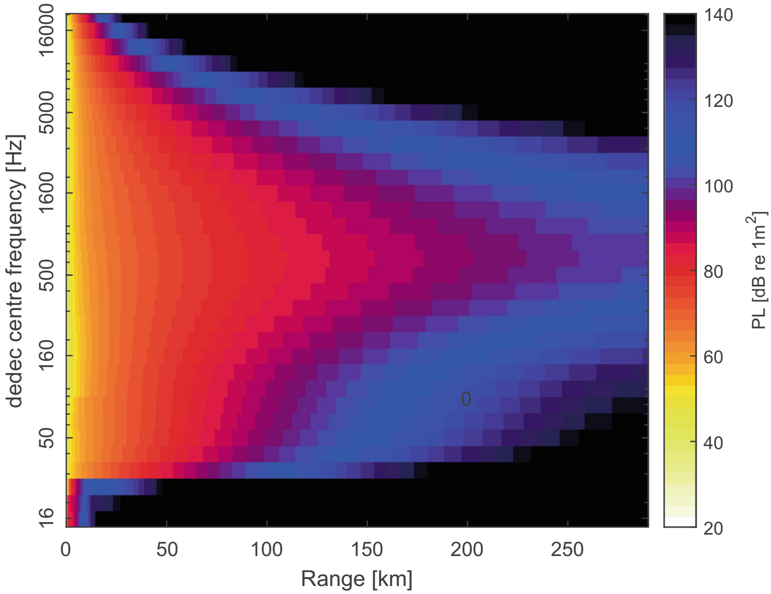

Fig. 2 Depth-averaged propagation loss as function of horizontal range and decidecade band frequency

Calculated Sound Pressure Levels

For each time step, the depth-averaged SPL is calculated at locations along a 50 km-long receiver line at the middle of the generic ship tracks and perpendicular to the tracks, summing the contributions (source level minus propagation loss) from all ships in the shipping lanes, per vessel class, and in total. The calculated SPL time series is then summarized in terms of temporal statistics over the specified period (January 2020): arithmetic mean and 10%, 50% (median), and 90% exceedance levels (i.e., 90th, 50th, and 10th percentiles).

The statistics of the broadband SPL along the long receiver line are shown in Fig. 3. Inside the shipping lanes the mean SPL is higher than the 10% exceedance level, indicating that a few vessel passages, during less than 10% of the time, dominate the monthly mean SPL. Sensitivity tests in which the length of the shipping lanes was decreased stepwise from 400 km to 10 km indicated that the modelled shipping lanes should be at least 100 km long to avoid underestimation of the total SPL at the largest distance (50 km) by more than 2 dB.

Underwater Noise Reduction Scenarios

The generic shipping lane scenario and selected source and propagation model were applied to study the effect of different underwater noise reduction strategies.

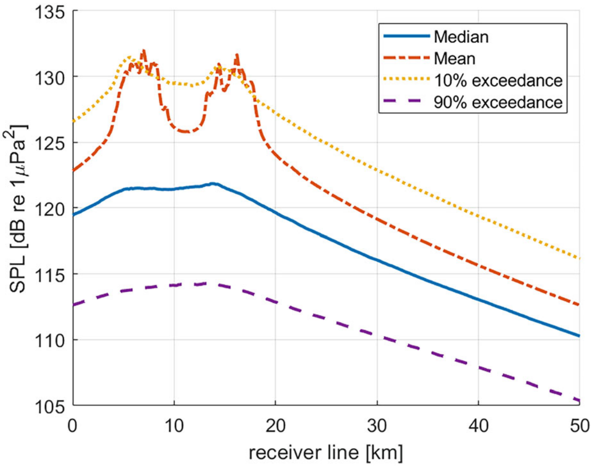

Fig. 3 Broadband SPL (16 Hz–20 kHz) statistics along a receiver line perpendicular to the center of the shipping lane for the reference scenario (generic shipping lanes with bulkers, tankers, container ships, and vehicle carriers)

Speed Limit ("Slow Steaming") Scenarios

Slowing down is an effective method for reducing the source levels of commercial vessels (MacGillivray et al. 2019; Findlay et al. 2023). However, reduction of the SPL statistics around shipping lanes is generally smaller (Joy et al. 2019). It depends on the ship traffic and number of participating vessels. The generic shipping lane scenario allows for efficient calculations to study the effectiveness of various noise reduction measures, e.g., speed limits or a maximum radiated noise level.

The generic shipping lane scenario is adapted to represent the implementation of a speed limit. To implement speed limits in the generic shipping lanes, the speed of all ships exceeding the speed limit is reduced to the selected speed limit, keeping the time and location where they cross the reference line and updating their track locations to match the reduced speed. The adaptation does not include interaction between the ships. Close encounters and possible ship collisions are ignored. Furthermore, the number of ships is not increased to compensate for a reduced traffic volume rate due to the speed limit. To assess the maximum achievable effect, it was assumed that all ships adhere to the limits. The Jomopans-ECHO SL model (MacGillivray and de Jong 2021) predicts a reduction of the ship SL with 60 times the logarithm of the ship speed. This model applies as long as the speed is not reduced to speeds where propeller cavitation is no longer the dominant sound source.

Speed limit scenario 1 is based on the CE Delf study report (Nelissen et al. 2022) that discusses the possibilities for implementing "Blue Speeds," defined as "ship speed levels that protect the marine environment from the negative impact of URN and that are associated with co-benefits for marine life and humans by reducing the hazard of ship strikes to whales, GHG emissions and air pollution." Following their suggestion, a maximum speed limit was set at 75% of the design speed of all ships in the shipping lane scenario. This speed reduction affects about 25% of the vehicle

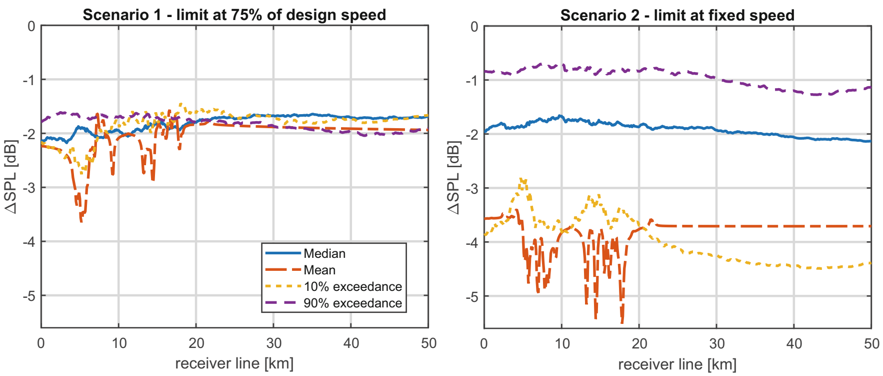

Fig. 4 Effect of slow steam scenarios on modelled SPL on receiver line. The SPL difference between calculation using original speed and reduced speed due to slow steam scenarios is shown. (left) Scenario 1 where speed limit based on 75% of the design speed is applied and (right) Scenario 2 where fixed speed limit is applied

carriers and container ships and around 55–60% of the bulkers and tankers respectively.

Speed limit scenario 2 is inspired by the voluntary vessel slowdown from the ECHO program of the Port of Vancouver. The maximum speed of vehicle carriers and container ships was limited to 14.5 knots and the speed of bulkers and tankers to 11.5 knots. This speed reduction affects about 35% of the vehicle carriers and container ships and around 20–30% of the bulkers and tankers respectively.

In speed limit scenario 1 the reduction is about 2 dB in all statistics of SPL, except for some local short-term reductions up to 3.5 dB in the shipping lane (Fig. 4). In speed limit scenario 2, the reduction in the median is about 2 dB as well, but it varies more. In the 90% exceedance level it is limited to 1 dB, but the reduction in 10% exceedance level and the mean is about 4 dB, with local short-term reductions up to 5.5 dB in the shipping lane (Fig. 4).

Radiated Noise Level Limit Scenarios

This scenario considers the effectiveness of applying radiated noise level (RNL) limits to the vessels. RNL-limits were proposed by several classification societies. As an example, the DNV GL SILENT-E class limits (DNV GL 2018) for “transit” and “quiet cruise” conditions were implemented, ignoring that the measurement procedure specified by DNV GL deviates from the ISO-procedure (ISO 17208-1 2016). It was assumed that the specified maximum allowable levels in one-third octave bands represent an RNL-spectrum in decidecade bands that can be converted to a SL-spectrum via the correction proposed in (ISO 17208-2 2019).

The RNL limit was applied at the ship design speed, as proxy for 80% of maximum continuous power available at the propeller shaft(s). DNV GL requires that the quiet cruise condition is applied at a speed of 11 knots for vessels longer than 50 m and a speed of 8 knots for vessels shorter than 50 m, but this has been ignored in this study. The SL of each vessel in the shipping lane is computed at its reported design speed and compared with the limit. If the limit is exceeded for a certain decidecade center frequency, the SL at that frequency is then reduced to the SL corresponding to the limit. Next, the updated SL-spectrum was scaled to the vessel speed in the shipping lane scenario, using the speed dependence from the JOMOPANS-ECHO model. Ship tracks and speeds were kept equal to the reference scenario.

Application of the "transit" limit results in about 4 dB reduction of the median SPL inside and outside the shipping lane, the "quiet cruise" limit results in a reduction of about 8 dB. The reduction of the mean SPL and 10% exceedance level is 2–4 dB higher than the reduction of the median SPL in both scenarios. See Fig. 5, showing all mitigation measures. As observed in the speed limit scenarios, a few vessel passages appear to dominate the mean and 10% exceedance level, so that the applied measures resulting some local short-term reductions, particularly inside the shipping lanes.

Combined RNL and Speed Limit Scenarios

A speed limit can be applied in addition to RNL-limits. If the DNV GL Environmental limits are combined with speed limit scenario 1, and if all ships stay below the limits, the reduction in the median SPL is about 6 dB for the transit limit and almost 12 dB for the quiet cruise limit (Fig. 5). The reduction due to adding the limit at 75% of the design speed on top of the RNL limit is approximately equal to the sum of the reductions of the individual measures.

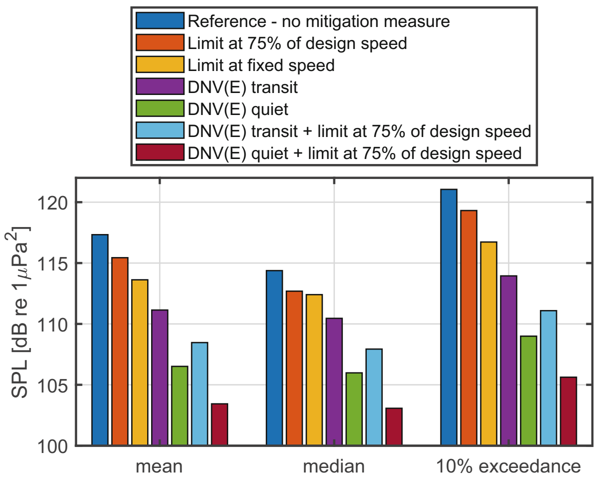

Fig. 5 Modelled SPL statistics outside the shipping lane (averaged over 25–50 km range on the receiver line) for the reference scenario and the different noise reduction scenarios from this study

Conclusions

- A generic local shipping lane scenario has been constructed that enables computationally effective studies of the effects of various shipping URN reduction measures.
- The scenario is limited to merchant ships (bulker, tanker, container ship, and vehicle carrier classes) for which the design speed is available and to a simplified range independent shallow water environment.
- Two considered speed-limit scenarios (limit at 75% of design speed and a fixed speed limit of 14.5 knots for container ships and vehicle carriers and 11.5 knots for bulkers and tankers) both lead to a reduction of the monthly median SPL by about 2 dB inside and outside the shipping lane. The reduction inside the shipping lane is higher during shorter periods.
- Application of the DNV GL Environmental "transit" RNL limit to all ships results in a median SPL reduction of about 4 dB inside and outside the shipping lane. The studied implementation of the "quiet cruising" limit results in a median SPL reduction of about 8 dB. The reduction due to adding a speed limit at 75% of the design speed on top of the RNL limit is approximately equal to the sum of the reductions of the individual measures.
- Hence, the studied RNL-limit scenarios appear to be more effective (leading to a greater underwater noise reduction) than the studied speed limit scenarios. However, it is easier to monitor vessel speed than vessel RNL (Ainslie et al. 2022), so implementation of an RNL-limit will be more complex than implementation of a speed limit.
- In the North Sea there are many shipping lanes and many vessels that do not follow these lanes. To quantify the effect of speed and RNL limits for ships on the North Sea sound scape large scale mapping is needed. This will be the next step in the DEMASK project, benefiting from the insights obtained from this study.

Competing Interest Declaration The author(s) has no competing interests to declare that are relevant to the content of this manuscript.

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