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Analyzing the interaction between maintenance dredging and seagoing vessels: a case study in the Port of Rotterdam

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Abstract

Purpose Maintenance dredging can often hinder port operations resulting in waiting times for seagoing vessels. The purpose of this paper is to investigate the dynamics between maintenance dredging activities and seagoing vessels, specifically focusing on how waiting times can be reduced. Then, the role of selecting different maintenance dredging strategies in reducing these waiting times is outlined.

Methods The study analyzes historical automatic identification system (AIS) data to identify the interaction between maintenance dredging and seagoing vessels and quantify the hindrance periods for the Mississippihaven case study in the Port of Rotterdam, the Netherlands. The trajectories of the vessels are analyzed in a simple case to show how the vessels interact and how the waiting times are quantified. The interactions are checked with the Port of Rotterdam for different port calls to ensure that maintenance dredging was the reason for these delays.

Results By analyzing the AIS data analysis of vessels in a given time window, the dredgers for maintenance work can be identified and their activities within or near the terminal can be determined. In addition, the waiting time of the seagoing vessel caused by the maintenance dredging is quantified at the terminal entrance.

Conclusion The study discusses how the maintenance dredging operations could be improved by adjusting the loading and sailing phases of maintenance dredging and provides some theoretical and managerial insights. Alternative port maintenance strategies to minimize the waiting time caused by the hindrance are also discussed.

Keywords Dredging · Port accessibility · Berth hindrance · AIS data

1 Introduction

Sedimentation in port terminals and navigation channels has a direct impact on accessibility for shipping and the efficiency of port processes (Zikra et al. 2021). To ensure the accessibility of ports, maintenance dredging is often carried out to remove accumulated sediments in channels and terminals. This measure not only counteracts the adverse effects of sedimentation but also improves the efficiency of port processes by keeping berths and fairways accessible and avoiding waiting times during berthing, unloading, and maneuvering (Xu et al. 2018).

Maintenance dredging is unavoidable in ports and waterways due to the high rates of siltation in some areas and the increasing size of seagoing vessels. Therefore, berths and navigation channels should be kept accessible during port calls of deep-draft vessels (Moon and Woo 2014). Maintenance is implemented through a variety of strategies to keep the nautical-guaranteed depth at a level that is navigable for deep draft vessels which refers to large ships with 15–25 m of draught that require significant water depth to float without grounding. These vessels have a considerable vertical distance between the waterline and the bottom of the hull,

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making them suitable for deep-water navigation and capable of carrying substantial loads. These strategies can mainly be divided into sediment relocation or remobilization. Sediment relocation involves mechanically collecting the sediments and depositing the dredged material at specific locations, while remobilization involves agitation of the bed and transporting them to a more favorable location with the help of tidal currents. As maintenance dredging focuses on cohesive sediments, hydraulic dredging methods are more commonly used for maintenance in ports (Bianchini et al. 2019).

A Trailing Suction Hopper Dredger (TSHD) is the most commonly used equipment for relocation, as it picks up the sediments while trailing, and transports the dredged material in the onboard hoppers to the discharging area. Sandy material that has accumulated at berths can be conveniently dredged with TSHDs, while berth pockets and areas close to the quay walls are less accessible due to the size of the equipment. The discharging area is usually an offshore site that has the least environmental impact on flora and fauna (Ban and Bebić 2023; de Boer et al. 2023). The maintenance dredging performed by a TSHD follows a dredging cycle consisting of loading sediments from the dredging area, sailing full to the discharging area, unloading sediments in the discharging area, and sailing empty to the dredging area. This cycle continues until the expected total volume of sediment is dredged from the port area (Laboyrie et al. 2018) to ensure nautical accessibility (See Fig. 1).

The TSHD vessels require a relatively large area for maneuvering and trailing when collecting the sediments. These vessels trail in circular patterns to cover the entire area and dredge all spots. Therefore, the entire terminal may need to be closed occasionally to allow the TSHD vessels enough space to load the sediments. This closure could disrupt port operations and lead to long waiting times for seagoing vessels (Bai et al. 2022). Therefore, the cargo-handling process is delayed for a while and the seagoing vessels have to wait in the anchorage area or near the terminal entrance.

Among the various challenges arising from maintenance dredging is the precise planning of dredging operations in high-traffic areas which refers to sections of the port characterized by a significant volume of vessels (80–90 deep draught vessels per day). These areas which include navigation channels, berths, and terminal facilities frequented by large container vessels, tankers, and bulk carriers experience notably dense maritime traffic, often measured by metrics such as the number of vessel movements per day or annum. Therefore, optimizing berth allocation is critical when selecting maintenance dredging strategies. In addition, other factors such as cost efficiency and the environmental impact of each strategy should be considered and a trade-off between different performance criteria should be quantified. The environmental impact of maintenance dredging strategies mainly includes assessing sediment quality to prevent contaminant spread, minimizing habitat disturbance, managing noise and vibrations, and monitoring greenhouse gas emissions. By addressing these factors, maintenance dredging strategies can be developed to minimize negative environmental impacts while maintaining the functionality and safety of port processes.

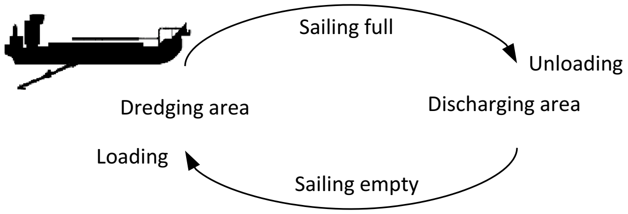


Fig. 1 Dredging cycle of a Trailing Suction Hopper Dredger (TSHD)

The optimization of berth occupancy schedule is addressed in a study by Tang et al. (2016), who investigated the potential of developing a just-in-time scheme for arrivals and departures to minimize the total duration of a vessel's stay in the port area (i.e. turnaround time). In another study by Jahn and Scheidweiler (2018), a forecasting model based on the historical AIS data of vessels is presented to estimate the arrival time of vessels. Optimizing berth allocation may also have other incentives, such as minimizing potential emissions across the port system (Merkel et al. 2022). In this context, Poulsen and Sampson (2020) conducted a study using empirical data from port calls and analyzed the impact of the idling time of ships on total emissions. To quantify these interactions, Xu et al. (2018) discussed how the lack of nautical accessibility affects berth planning. They proposed a mixed-integer linear programming model to formulate the berth planning problem, and then analyzed three cases assuming that the berth is built based on one-way traffic, bidirectional traffic, and temporary closure due to lack of nautical accessibility. In another study by Souf-Aljen et al. (2016), the interference between dredging and port operations is discussed by analyzing the waiting time of seagoing vessels caused by a grab dredger when it performs dredging operations near the quay walls. In this study, two cases were compared, namely the normal navigation of vessels and the navigation of vessels interfering with dredging operations, and it was proved that the number of ships served at berth is relatively higher when the areas next to the quay wall need to be dredged.

In a research work proposed by Cheng et al. (2019), AIS data is used to track the movements of dredgers and detect anomalies in their navigation. The collected dataset is used in an online platform that estimates anomalies and predicts possible interactions with other vessels in a given region. This analysis is done by developing probabilistic models based on historical dredging trajectories. Another study on dredge trajectories is proposed by Bokuniewicz and Jang

(2018) by visualizing heat maps showing the highest intensity of dredger presence in specific areas. They then use these heat maps to present a scheme for the sustainability of sand reserves in the port. Other data-driven methods are used in dredging operations by using simulators for crew training, developing morphological models using machine learning, using big data for strategic planning of dredging operations, and automatically controlling equipment (Bashir 2022). Yen et al. (2023) investigated the interactive relationship between port authorities and contractors through the sharing of real-time data, focusing on interference between maritime and dredging operations. The study highlights the importance of data-driven methods for improving communication and collaboration between the various parties involved in port maintenance.

Conventional methods have mainly focused on the design phase of bed levels, overlooking the crucial interaction between nautical accessibility, maintenance dredging strategies, and port process performance. This study aims to fill this knowledge gap by systematically investigating the interactions between dredging operations and seagoing vessels. To this end, the Mississippihaven harbor in the Port of Rotterdam, the Netherlands, is selected as a case study and the Automatic Identification System (AIS) data of this port is analyzed in a specific period. This analysis is repeated for similar periods to determine the delays experienced by vessels due to their interference with maintenance dredging operations. The results of the analysis of the AIS data trajectories are then presented and theoretical and managerial implications are drawn.

The research methodology used in this study is a combination of big data analysis and strategic management, which aims to track the interference between maintenance dredging and seagoing vessels and determine the total waiting time experienced by seagoing vessels when the berth area is dredged. Substantial historical data on vessel movements is analyzed to cover the traffic density in Mississippihaven during 2019. This data is coupled with operational data from port operations, including vessel schedules, berth occupancies, and navigation channels' utilization. The final dataset includes the movement of dry bulk vessels operated in the terminal and the dredging cycles of TSHDs conducting maintenance dredging. In total, 250 files of vessel data (real-time location of movements) are obtained for the initial analysis after filtering the datasets based on vessel types and vessels operating in the terminal. To simplify the problem and focus on the representation of these interferences, this study analyzes a limited time window and a certain amount of AIS data to illustrate the waiting times. After identifying the waiting times, theoretical and managerial implications of this analysis are proposed and solutions to the emerging challenges are recommended. Future research directions are also discussed when addressing these challenges from both port authority and dredging contractor perspectives.

The remainder of this paper is structured as follows. Section 2 discusses the research methodology, focusing on the simulation between dredgers and seagoing vessels. Section 3 presents the results of analyzing the Mississippihaven AIS data and discusses the interference between a single TSHD and a single seagoing vessel due to simplicity. Section 4 interprets the results, suggests theoretical and managerial implications, and identifies possible future research directions. Finally, the research is concluded in Section 5.

2 Methodology

The Port of Rotterdam, the Netherlands, is responsible for the maintenance of the port basins. The research uses data from the Automatic Identification System (AIS) to analyze vessel movements in the Mississippihaven harbor. The AIS data is accessed through the Port of Rotterdam's API and the dataset is analyzed on the Microsoft Planetary Computer platform. This platform provides a robust environment for processing large-scale geospatial data and enables efficient analysis of vessel movements and interactions.

The available AIS data provides insight into the presence of vessels in the Port of Rotterdam in 2019, and capturing snapshots of a vessel's locations shows its movement and interaction with other elements of the system. Due to the high traffic of different vessels in Mississippihaven, this terminal was selected as a case study to analyze how seagoing and dredging vessels interact. Maintenance dredging at this terminal is mainly conducted by TSHDs. These vessels load sediments from the berth area and unload them in the designated discharging area at Loswal. During maintenance dredging, the berth is occasionally closed, or access to the berth is restricted as the large TSHDs have to use the entire area for dredging.

To identify maintenance dredging in Mississippihaven, the vessel type is limited to dredging vessels. Then, it is determined if the vessel was present at both the terminal and discharging location. This filtering ensures that the dredging vessel is a TSHD performing maintenance dredging, while other capital dredging operations such as deepening or reclamation could be performed by a TSHD where the vessel is not discharging sediments at the discharging area. Monitoring the dredging vessel's movements and examining its interaction with seagoing vessels (dry bulks in the case of the Mississippihaven) provides insight into the length of time seagoing vessels spend waiting before entering the terminal. Moreover, the length overall (LOA) which is the maximum length of the vessel from its foremost point to its aftermost point is considered in the analysis of port processes as a crucial measurement in assessing the size and capacity of dry bulk vessels. The maximum draft which denotes the deepest point of the vessel's hull submerged below the waterline is also another attribute of the analyzed AIS data which shows the navigational capabilities and cargo handling capacities of dry bulk vessels.

The flowchart for processing the AIS data is shown in Fig. 2. It provides a visual representation of the steps used to extract the target dataset and determine the interaction between seagoing and dredging processes. This flowchart guides the study through the key stages, including selecting the geographic region of interest, delineating specific timestamps within the selected time window, and identifying the intersections between seagoing and dredging vessels. Together, these steps help to capture the dynamics of vessel interactions in the designated port area. By tracking ship movements based on potential interaction periods, the waiting time of bulk carriers can be measured.

The area of interest is selected based on the highest number of vessel movements and possible interferences observed between vessels during one year. Amazonehaven and Mississippihaven were the two candidates for the case study and due to the low number of TSHDs working in Amazonehaven for maintenance dredging, Mississippihaven was chosen as the case study which is a crucial dry bulk terminal for large draft vessels. The temporal limitation allows for a targeted study of vessel movements during a certain time, which enables a differentiated analysis of the dynamics in the terminal. The nautical guaranteed depth (NGD) which is the water depth required to ensure the safe navigation of vessels is 23 m for Mississippihaven which shows the large draft of dry bulk vessels being served in this terminal. After filtering the vessel types and required timeslots for vessels' navigation, the movement of vessels and their interferences are shown in separate Gantt charts.

3 Results

By analyzing the AIS data in the Mississippihaven terminal, a total of 11420 trips were identified (see Fig. 3a). The trips were accurately filtered to determine the interaction of TSHDs with dry bulk carriers. To ensure the accuracy of the analysis, separate polygons are used for both the terminal and the discharging areas, excluding data consisting of vessels passing through both regions and in particular TSHDs carrying out dredging operations. Five TSHDs are identified by filtering the dredgers that are in the terminal and discharging area. The trajectory on which these vessels travel back and forth is shown in Fig. 3b.

Since some of the seagoing vessels used the Mississippihaven to access other terminals, a narrower area is filtered to represent the areas closer to the berths for unloading bulk cargoes. Two cases are then examined: case 1 shows no interference between maintenance dredging and seagoing processes and in case 2 the seagoing vessel experiences a waiting time due to a dredger.

Fig. 2 Automatic identification system (AIS) data analysis flow

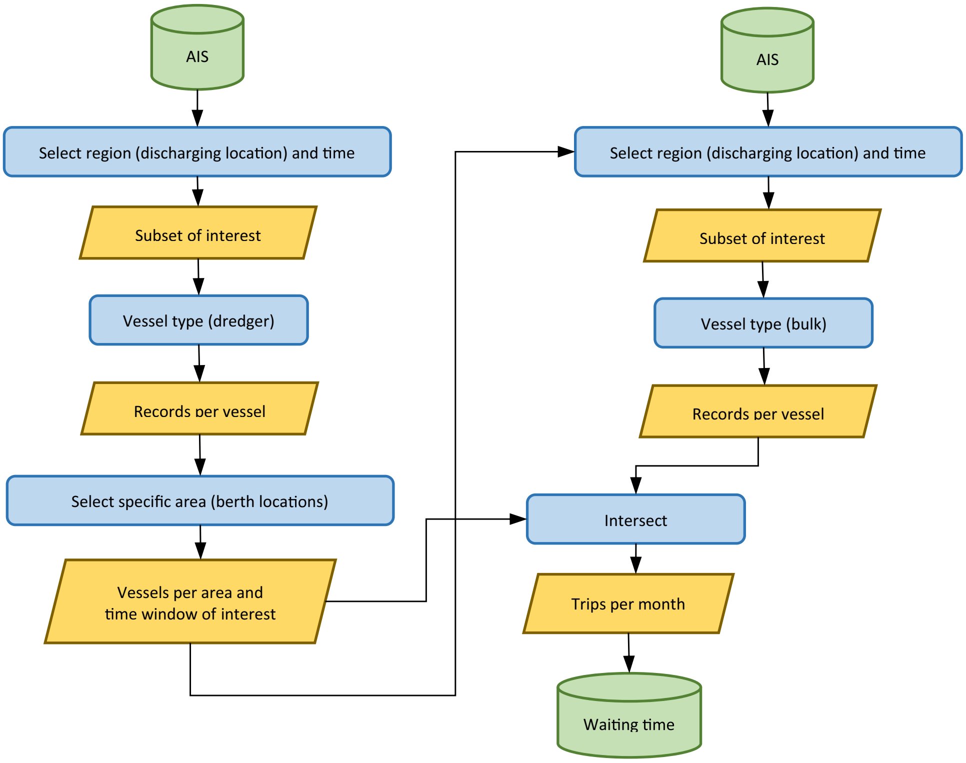


Fig. 3 Traffic intensity of **a** all vessels and **b** Trailing Suction Hopper Dredgers (TSHDs) movements between Mississippihaven and the Loswal (discharging area)

3.1 Case 1. No interference between dredging and seagoing vessels

Five TSHDs are identified, and the interaction between these vessels and bulk carriers served at the terminal is analyzed during the periods when the TSHDs were operating at the terminal. In this case, the movement of a TSHD with a dry bulk carrier is analyzed when the maintenance dredging does not cause a delay for the dry bulk carrier before it is served in the terminal. The interaction of two dry bulk carriers with a TSHD on the 29th and 30th of July 2019 is analyzed to determine a possible waiting time for one of these vessels. Figure 4 shows the exact timestamp of the dredging and seagoing processes on these two days to give a visual representation of the problem. These vessels are used as examples of interference while other seagoing vessels were operating in the area at the same time.

In the early hours of the 29th of July 2019, TSHD 1 initiates its first loading cycle, removing sediment from the port. After TSHD 1 has completed its dredging cycle, the dry bulk carrier 1 arrives at the berth and heads directly to the quay wall to unload the cargo. During the unloading process, TSHD 2 carries out another cycle in the central area of the terminal, as there is sufficient space there for the dredger to load sediment. Dry bulk carrier 1 and TSHD 1 then leave the area at the same time without waiting. The next day, dry bulk carrier 2 arrives at the terminal to unload the cargo, and during the transshipment, TSHD 1 conducts another cycle of maintenance dredging. In this case, TSHD 1 leaves the area more than an hour earlier than dry bulk carrier 2. In total, TSHD 1 performs three different cycles of maintenance dredging without affecting the waiting time for the seagoing vessels. This is mainly due to the fact that the vessels are planned precisely before they are served at the terminal and the bulk carriers have sufficient nautical depth when they depart from the quay wall.

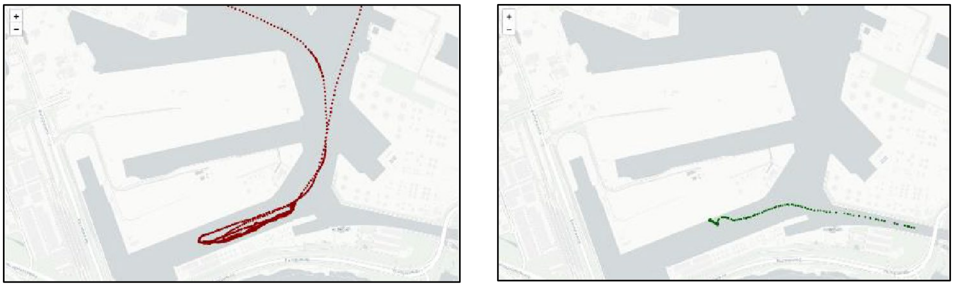
3.2 Case 2. Interference between dredging and seagoing vessels

Refining the dataset to focus exclusively on vessels handling cargo at the dry bulk berth on the north side of the terminal reveals interesting patterns. The analysis shows that 57 trips were made by 10 different seagoing vessels along the quay wall. In particular, consecutive cycles of the identified TSHDs were identified in the period from the 17th of July 2019 to the 19th of July 2019. Consequently, the interference between TSHD 2 and seagoing vessels during this period will be studied in detail, including some days of extension at the beginning and at the end. The processes of dredging and dry bulk carrier are summarized in Fig. 5, where the maintenance dredging performed by the TSHD 2 is shown in red on the right panels, and the seagoing processes are shown in green on the left panels.

In the early hours of the 17th of July 2019, the TSHD 2 initiates its first loading cycle, during which sediments are removed from the port. At the same time, a dry bulk carrier 3 arrives at the port entrance. As the TSHD 2 loads sediments, the dry bulk carrier waits at the port entrance, following precise maritime protocols. This wait continues until midday on the 18th of July 2019, when the dry bulk carrier 3 finally receives clearance to approach the quay area for cargo handling operations. While the dry bulk carrier3 completes its operations, TSHD 2 carries out further loading cycles on the 17th and 18th of July, each carefully planned to ensure the navigability of the port. The vessels lie side by side in this area. On the morning of the 19th of July 2019, as dry bulk carrier 3 leaves the berth area, TSHD 2 begins its fourth loading cycle. This sequential analysis of timestamps enables a differentiated understanding of the interaction between maintenance dredging and seagoing vessels.

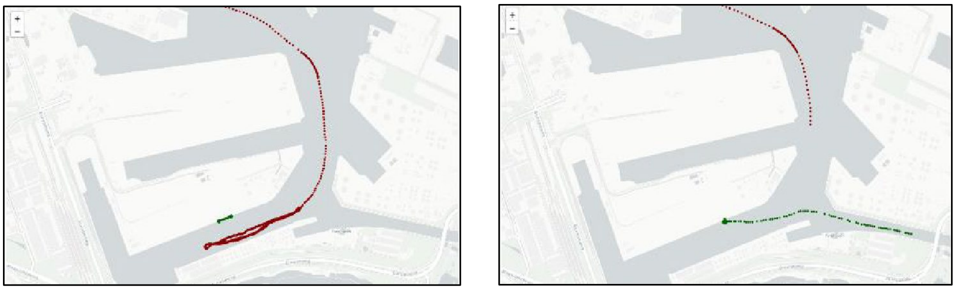
The interference between maintenance dredging and seagoing vessels, analyzed using AIS data, shows that several factors such as berth capacity, nautical depth, sailing speed, and hopper capacity are important. A holistic consideration of these factors provides both contractors and port authorities with a comprehensive perspective and facilitates the identification of solutions to minimize waiting times. The different processes of dredgers and dry bulk carriers in both cases are summarized in Fig. 6.

Fig. 4 Results obtained from automatic identification system (AIS) trajectories to visualize the interference between seagoing (green trajectory for dry bulk carrier 1 and blue trajectory for dry bulk carrier 2) and dredging processes (red trajectory)



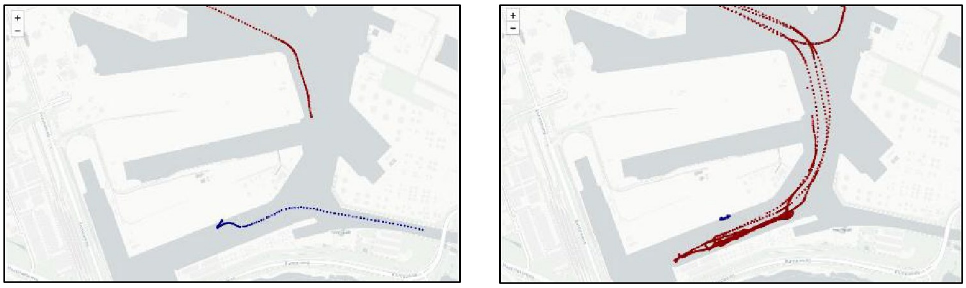
TSHD 1 loading cycle 1
(29/07/2019 05:48:55 - 29/07/2019 08:38:07)

Dry bulk carrier 1 arriving
(29/07/2019 10:19:27 - 29/07/2019 11:00:00)



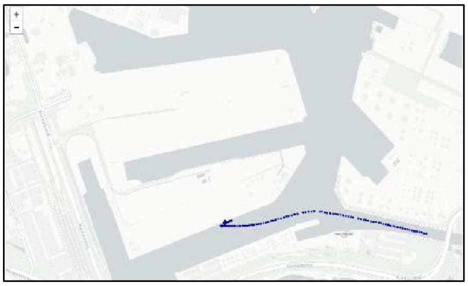
TSHD 1 loading cycle 2
(29/07/2019 11:00:00 - 29/07/2019 18:00:00)
Dry bulk carrier 1 unloading
(29/07/2019 11:00:00 - 29/07/2019 18:00:00)

Dry bulk carrier 1 departing
(29/07/2019 18:00:00 - 29/07/2019 18:49:57)



Dry bulk carrier 2 arriving
(30/07/2019 5:58:13 - 30/07/2019 06:20:00)

TSHD1 loading cycle 3
(30/07/2019 06:20:00 - 30/07/2019 16:37:39)
Dry bulk carrier 2 unloading
(30/07/2019 06:20:00 - 30/07/2019 18:00:00)

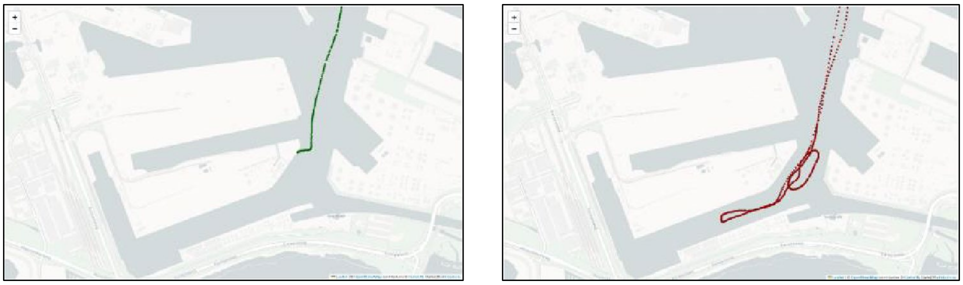


Dry bulk carrier 2 departing
(30/07/2019 18:00:00 - 30/07/2019 20:00:00)

In the first case, the vessels operated without waiting. In addition, three cycles of maintenance dredging are carried out by the TSHD1, which ensures sufficient nautical accessibility for dry bulk carriers passing through the terminal area. The potential interference between TSHD 1 and two dry bulk carriers over two days is analyzed to ensure that the dredging operations do not cause any interference (see Fig. 6a).

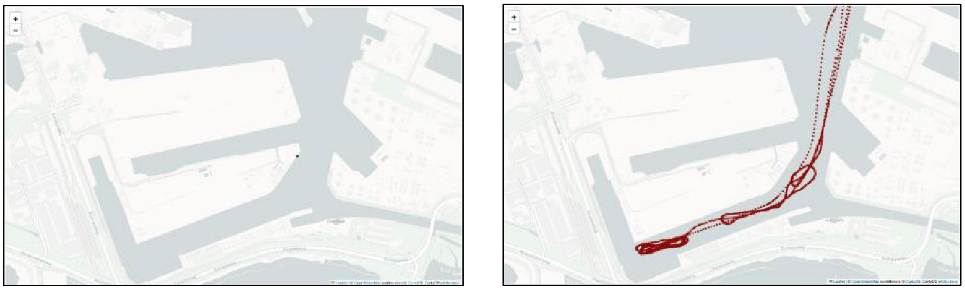
The waiting time for dry bulk carriers at the port entrance is too long (21 h) in the second case (shown in red color), which shows the lack of nautical accessibility before the dredging works and the lack of unloading infrastructure in the terminal (see Fig. 6b). The observed disruption underlines the central role of careful planning of the dredging operations to significantly reduce delays.

Fig. 5 Results obtained from automatic identification system (AIS) trajectories to visualize the interference between seagoing (green trajectory) and dredging (red trajectory) processes



Dry bulk carrier 3 arriving at the berth entrance
(17/07/2019 11:11:12 - 17/07/2019 15:00:00)

TSHD 2 loading cycle 1
(17/07/2019 05:24:04 - 17/07/2019 14:15:39)



Dry bulk carrier 3 waiting in the berth entrance
(17/07/2019 15:00:00 - 18/07/2019 12:00:00)

TSHD 2 loading cycle 2
(17/07/2019 16:33:16 - 18/07/2019 03:44:17)

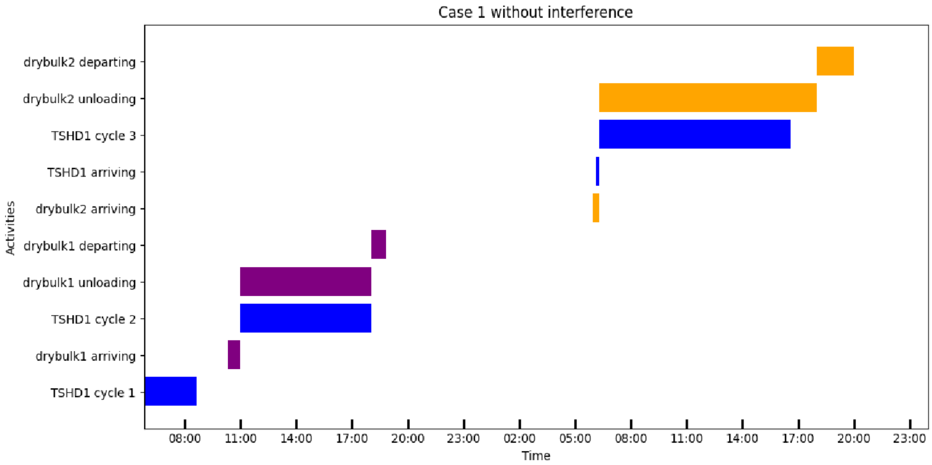
Dry bulk carrier 3 moving to the quay area
(18/07/2019 12:00:00 - 18/07/2019 21:00:00)

TSHD 2 loading cycle 3
(18/07/2019 17:46:36 - 19/07/2019 04:01:08)

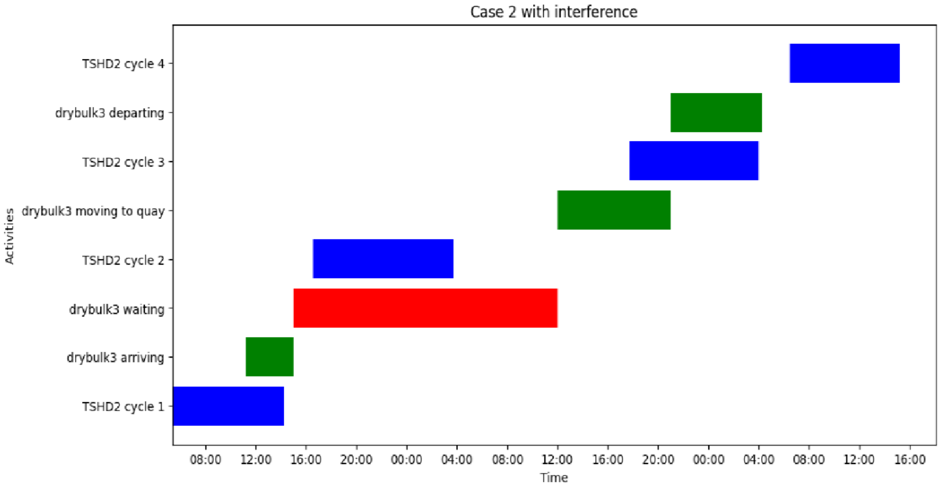
Dry bulk carrier 3 leaving the berth area
(18/07/2019 21:00:00 - 19/07/2019 04:15:49)

TSHD 2 loading cycle 4
(19/07/2019 06:28:08 - 19/07/2019 15:12:56)

Fig. 6 Case 2: interference between seagoing and dredging vessels



(a) Case 1: no interference between seagoing and dredging vessels



(b) Case 2 with interference

4 Discussion

Based on the obtained, the following implications are proposed. In addition, research limitations and possible directions for future research are discussed.

4.1 Implications for port maintenance implications

The study of the interactions between maintenance dredging and seagoing processes has significant implications for port maintenance strategies. The maintenance work carried out mainly by the TSHD often leads to temporary berth closures due to providing the maneuvering space needed for a TSHD which can vary depending on several factors such as the vessel's size, draft, propulsion system, and navigational safety. Generally, TSHDs require a sufficient turning radius and clearance pace to navigate safely within harbors, channels, and berth areas while conducting dredging. Port authorities, harbor masters, and dredging contractors often assess and plan maneuvering space requirements for TSHDs based on the mentioned considerations to ensure safe and efficient dredging operations. This limitation prompts consideration of alternative equipment such as WID vessels (PIANC 2013; Kirichek et al. 2021) and bed levelers (Laboyrie et al. 2018), which are smaller and more maneuverable and can reach areas close to the quay walls that would be difficult for TSHDs to access. In addition, stationary equipment such as backhoes and grab dredgers offer themselves as less disruptive alternatives (van Koningsveld et al. 2021), especially when used in conjunction with barges to redistribute sediments.

Different stakeholders might have opposing views on this issue. Port authorities aim to minimize waiting times for seagoing vessels, as any idle time might cause penalty costs for ports and reduce the efficiency of cargo handling processes. Also, they aim to maintain nautical accessibility to ensure the safe navigation of deep-draft vessels. On the other hand, dredging companies focus on increasing the efficiency of their processes by shortening the length of dredging cycles and minimizing the idle time of vessels. This contradictory approach can be extended in terms of implementing different strategies for maintenance dredging and quantifying various key performance indicators such as emissions, energy consumption, operational costs, etc.

4.2 Research limitations

Data availability is limited to four months of 2019, which limits the number of maintenance dredging cycles conducted in the Mississipihaven. The analysis conducted in this study showed that only one TSHD maintenance was performed in July 2019 and interactions with seagoing vessels were detected on two days. The identification of these interactions also requires a detailed analysis of vessel movements in short periods to visualize the movements of these vessels.

The general purpose of the analysis performed is to quantify the trade-offs between different criteria, such as the time needed to complete maintenance dredging, the operational costs of the dredging vessels, the environmental impact of dredging activities, and the use of alternative equipment and strategies for port maintenance. However, the AIS data only provides us with limited anonymous information on vessel characteristics and any further data must be requested separately from the port authorities. To quantify the trade-offs, more information on dredging equipment also needs to be obtained from the dredging contractors.

The analysis of AIS data in this study has helped to identify the interactions between the maintenance dredging and seagoing operations, however, these interactions are generally not apparent. This is because many delays are due to other reasons, such as lack of berth availability, high terminal congestion, and lack of available port operators (tugboats, pilots, etc.). Even if more information is obtained about the vessel types and the trajectories of each type of vessel observed, the interactions are best quantified by asking port authorities that have an integrated system of vessel logs.

The increasing availability of AIS data can provide more detailed information on trade statistics for each port infrastructure and determine the trade flows in each port area. Navigation performance can also be measured using AIS data, as vessels must follow a specific route before being handled at terminals. Any deviation can have cascading effects on other port processes. The use of AIS data extends its impact from seagoing navigation to inland shipping, which is a new approach for both the public and private sectors to facilitate the transportation of products between the cities.

4.3 Future research directions

Simultaneous simulation of dredging operations and port processes is a promising avenue for research. Such simulations allow port authorities and contractors to forecast and proactively reschedule dredging operations to respond to fluctuations in port traffic. Optimizing the operational parameters of dredging vessels, including adjusting speed and loading rate, is one possible strategy to minimize waiting times for seagoing vessels.

Extending the scope of AIS data application from seagoing to inland navigation is an interesting area for future research. The increasing availability of AIS data can be used to provide detailed trade statistics, assess navigation performance, and determine trade flows in specific port areas. In addition, the application of AIS data on mitigating environmental impacts and improving the overall sustainability of port operations needs to be further investigated. As the integration of AIS data continues to grow, its potential to revolutionize the strategic planning of dredging operations and improve overall navigational efficiency remains an exciting prospect for future research.

The simulation of dredging and port processes allows both port authorities and contractors to predict upcoming port traffic and schedule dredging operations more efficiently. Simulating port processes and dredging operations simultaneously can help port authorities determine the total waiting time for seagoing vessels in anchorage areas or near terminal entrances. The waiting time, which is associated with penalty costs for port authorities, can be minimized by carrying out maintenance dredging on time. Changing the operational parameters of dredging vessels (speed, loading rate, etc.) can also regulate activities in such a way as to reduce waiting times for seagoing vessels.

5 Conclusion

In this study, the interaction between dredging and seagoing vessels in the Mississippihaven (the Port of Rotterdam) is investigated. These interactions are quantified as waiting times experienced by the vessels due to a lack of sufficient nautical depth at berth. For this purpose, the time frame is limited and vessel movements are monitored within this time frame. After identifying the waiting times, the port authorities confirmed that these were due to the ongoing maintenance dredging work.

A new data-driven approach was developed to analyze the interaction between dredging and seagoing vessels. The AIS data collected from the port authority was analyzed to identify the TSHDs that were conducting maintenance dredging in the terminal and to monitor their impact on the navigation of other vessels. To narrow the analysis, the timeframe was limited to a single month of available data in 2019 and the interaction of vessels was examined for a single berth. It was found that a dry bulk carrier had to wait at the terminal entrance before being served at the berth because a TSHD was dredging the entire terminal. Subsequently, this interaction was analyzed in a Gantt chart and solutions were proposed to minimize the waiting time. Finally, the implications and limitations of this study were discussed and future research directions were recommended.

Industry practitioners can use the analysis proposed in this study to consider the interaction of dredging and seagoing processes in the tendering phase before the project is implemented. During the tendering process, a precise prediction of the number of delays helps both port authorities and contractors to compromise on the selection of different strategies. Moreover, minimizing the waiting times due to lack of nautical accessibility helps port authorities to facilitate the port processes and contractors to select dredging strategies. It will also be useful for the selection of alternative dredging equipment for maintenance dredging projects to reduce disruption and minimize the time and cost required for the project.

In addition, other aspects of maintenance dredging projects such as sustainability (environmental impact on the marine ecosystem, emission reduction, etc.) and circular economy (beneficial reuse of dredged sediments) can be defined, quantified, and applied based on the aforementioned interactions. According to the significance of each aspect for each stakeholder, the selected strategy varies in comparison to the case that selecting the strategy is only based on the lower cost of dredging.

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Data availability The data used in this study are derived from confidential historical Automatic Identification System (AIS) records of the Port of Rotterdam. Due to the sensitive nature of this data and restrictions imposed by the data provider, these data cannot be shared publicly.

Declarations

Competing interests The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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