Simulating the interference of seagoing and maintenance dredging processes

Sepehri, Arash; Kirichek, Alex ; van den Heuvel, Marcel; van Koningsveld, Mark

Publication date
2024

Document Version
Final published version

Published in
Proceedings of the 35th PIANC World Congres 2024

Citation (APA)
Sepehri, A., Kirichek, A., van den Heuvel, M., & van Koningsveld, M. (2024). Simulating the interference of seagoing and maintenance dredging processes. In J. S. Schoonees (Ed.), *Proceedings of the 35th PIANC World Congres 2024* (pp. 245-251). PIANC.

35th PIANC World Congress, 29 April – 23 May 2024, Cape Town, South Africa
Paper Title: Simulating the interference of seagoing and maintenance dredging processes
Authors Names: A. Sepehri, A. Kirichek, M. van den Heuvel, M. van Koningsveld

Simulating the interference of seagoing and maintenance dredging processes

Arash Sepehri [1, *], Alex Kirichek [1], Marcel van den Heuvel [2], Mark van Koningsveld [1,2]
[1] Section of Ports and Waterways, Department of Hydraulic Engineering, Faculty of Civil Engineering and Geosciences, Delft University of Technology, Delft, Netherlands
[2] Van Oord Dredging and Marine Contractors, Rotterdam, Netherlands
* Corresponding author: a.sepehri@tudelft.nl

Abstract: Efficient port operations require minimizing turnaround time which is the total duration of a vessel's stay in the port and encompasses waiting, maneuvering, berthing, and de-berthing times. The turnaround time can be reduced by optimizing arrivals and departures, maximizing berth availability, facilitating cargo handling, and maintaining water depth. Maintenance dredging, the primary method for maintaining water depth, is used as a continuous activity to ensure the available water depth is sufficient for the navigation of commercial (seagoing, inland, barges, etc.) vessels. The continuity of maintenance dredging interferes with commercial vessels that aim to be served in terminals. Despite the cost imposed on port authorities due to these interferences, addressing this challenge in a structured way is overlooked. To fill this gap, an open-source discrete-event model is presented in this study that employs agent-based simulation to model the interaction between seagoing and maintenance dredging processes. A simple case is proposed to provide an example of how this interaction is simulated. Then, the implications and limitations of this study are discussed and the directions for future research are recommended.

Keywords: maintenance dredging, port accessibility, agent-based simulation

Introduction

Optimizing shipping operations is imperative, considering that over 80% of global trade passes through ports. Efficient navigation through ports prevents idle times and enhances maritime operations [1]. Arrivals and departures can be optimized, berth availability maximized, and vessel movements streamlined to reduce turnaround time. This also necessitates maintaining nautical accessibility and ensuring adequate bed levels keep the ports and waterways navigable for large-draught vessels [2].

Maintenance dredging, the primary method for maintaining nautical accessibility, can be implemented using various dredging vessels such as Trailing Suction Hopper Dredgers (TSHDs) and Water Injection Dredgers (WIDs) [3]. The dredging equipment reallocates collected sediments to designated placement locations or remobilizes sediments in the same area and leads them out of the system [4]. Despite a considerable number of studies on the physical properties of the equipment, their efficiency, and their environmental impacts, the interaction between dredging and seagoing operations has remained a challenge addressed barely in the literature [5].

The aim of addressing this challenge is to determine how these interferences can be quantified, what methods exist to address them, and how the whole process can be optimized. To have an integrated overview of the raised challenge, the following research questions are proposed.

- What seagoing and dredging processes apply to a specific harbor?
- What is the interaction between dredging and seagoing operations, and which variables can be controlled to minimize waiting times?
- How can this interaction be optimized to reduce waiting times and smoothen port processes?

To answer the abovementioned questions, this study aims to identify and quantify the interactions between seagoing and dredging processes. Then, an agent-based simulation approach is suggested to quantify these interactions for a simplified case study. Moreover, some insights into how these interactions can be minimized are proposed and directions for further research in this field are recommended.

Literature review

Nautical accessibility, a critical factor for safe navigation in ports and waterways, depends on various factors, including vessels' draught, waves, currents, and environmental conditions. Bakker and van Koningsveld's model [6] quantifies port accessibility based on hydrodynamic conditions and tidal amplitude, incorporating a safety margin called under keel clearance (UKC) [7] to ensure safe passage for vessels. De Jong's study [8] assesses the impact of nautical accessibility on the vertical design of navigation channels in the Port of Rotterdam, focusing on the water depth required for vessels with the largest draughts.

Selecting the optimal strategy for maintenance dredging is the next step that should be done by quantifying the trade-offs between costs, emissions, the time needed to finish the project, and the required nautical accessibility [9]. The model developed by Ahadi et al. [10] is a quantitative decision-making model that aims to optimize budgeting for maintenance dredging projects by considering various factors, including the potential disruptions caused by different strategies. This model helps port authorities make informed decisions about dredging schedules and budgets to minimize disruptions and ensure efficient operation. Another study proposed by Bian et al. [11] is a cost-benefit analysis model that focuses on the economic outcomes of maintenance dredging projects. This model assesses the trade-offs between dredging costs and the benefits of improved navigability to determine the optimal dredging strategy under a fixed budget. It helps port authorities make decisions that balance financial considerations with the need to maintain safe and efficient navigation.

The nautical accessibility measures and maintenance dredging strategy selection align with the port processes' performance. Optimizing port calls helps improve traffic efficiency and minimize turnaround time. Cho et al. [13] proposed a decentralized scheduling approach for port call efficiency, reducing congestion in bulk terminals. Štepec et al.'s machine learning approach [13] predicts turnaround time based on standardized port call information, facilitating port optimization. Kolley et al.'s data-driven optimization model [14] utilizes machine learning to optimize berth scheduling, preventing conflicts during terminal quay assignments. Nikghadam's study [15] analyzed factors influencing port call performance, highlighting the importance of shared information among pilots, tugboats, and boatmen in enhancing port call efficiency.

Despite the availability of models and studies on individual components of port operations, such as nautical accessibility and maintenance dredging, there is a lack of research on their combined impact. This is a critical gap because the interactions between these components can have significant consequences for port efficiency and environmental sustainability. For example, poorly planned maintenance dredging can disrupt port operations, leading to longer turnaround times for vessels and increased emissions.

An integrated approach to port operations is needed to address these challenges. This approach would bring together models and data from different areas of port operations, such as nautical accessibility, maintenance dredging, and cargo handling, to provide a more comprehensive understanding of the system and identify opportunities for improvement. Such an integrated approach would allow port authorities to make more informed decisions about scheduling dredging operations, optimizing berth allocation, and managing vessel traffic. This could lead to significant improvements in port efficiency, reduced environmental impacts, and improved safety for vessels and port workers.

Methods

Maintenance dredging is implemented based on providing safe navigation for seagoing vessels from the seabed perspective. Sedimentation in each terminal is surveyed regularly to ensure that the water level is higher than the maintained bed level. A safety margin is defined by port authorities as a threshold to determine when the maintenance dredging job should be initiated. This safety margin is called Nautical Guaranteed Depth (NGD) in Dutch maritime terminology and helps the practitioners monitor the bathymetry and request for dredging when the NGD is no longer achieved [7].

After initiating the dredging, different processes of the job should be identified. For instance, when a TSHD is maintaining the port, the phases of loading sediments, sailing full/empty, and placement of sediments are determined and a rough estimation of the job properties is proposed. These properties can be related to the dredging vessel (sailing (and trailing) speed, hopper capacity, fuel consumption, emissions), bed level (sediment properties), and dredging site (terminal traffic, NGD, dimensions, and tidal windows).

Considering all of these aspects is a complicated process that requires real-time monitoring of problem parameters. Simulation is an effective approach that can be used to show how the processes are done and how different aspects of the problem affect the efficiency of these processes. Simpy is a process-based discrete-event simulation framework based on standard Python. Processes are defined by generator functions that can be used to model active components like seagoing vessels, cranes, and dredging equipment. The concept of containers can be used to share (continuous or discrete) matter between processes. The concept of shared resources allows SimPy to model limited capacity congestion (like berths). A SimPy simulation resolves how different processes interact, which indicates how well a modeled system performs [9].

Both dredging and seagoing processes can be simulated in SimPy considering the impactful factors on their efficiency. An open-source Python package called OpenCLSim (Open Source Complex Logistics Simulation) is developed by TU Delft, Van Oord, and Deltares [5] based on SimPy concepts that can be used to facilitate the definition of sites, vessels, and activities In general, OpenCLSim defines key processes of logistics systems (e.g. material handling, moving, and waiting) considering the influence of different factors on these processes (e.g. sailing speed, loading rate, etc.). Thereafter, the processes are registered following a first-in-first-out (FIFO) scheme when consuming the required resources.

Different Python modules are developed and integrated into OpenCLSim as assets that can be used for simulating the logistics processes. These modules follow SimPy concepts and either stimulate a process or assign a property to objects. Table 1 summarizes these modules which are classified as mixins (object properties), activities (performing processes), and plugins (define process conditions).

Table 1 OpenCLSim modules

Module	Parameter(s)
Processor (mixin)	• loading and unloading function
HasResource (mixin)	• number of resources
Locatable (mixin)	• location
HasContainer (mixin)	• capacity • level
Movable (mixin)	• locations • speed
BasicActivity (activity)	• start time • duration
MoveActivity (activity)	• locations • mover object
ShiftAmountActivity (activity)	• locations • processor • container • duration
SequentialActivity (activity)	• subprocesses
WhileActivity (activity)	• subprocesses
RepeatActivity (activity)	• subprocesses
ParallelActivity (activity)	• subprocesses
Weather (plugin)	• met ocean criteria • met ocean data frame
Delay (plugin)	• delay percentage

Based on these modules, a simple case study is proposed to simulate the interaction between dredging and seagoing operations in the Port of Rotterdam.

Results

To quantify the interactions, the activities of each of the seagoing and maintenance dredging operations should be specified. A seagoing vessel normally enters the terminal berth for berthing and does the de-berthing during its departure. Before berthing, they may spend some time waiting in the anchorage area and they do some maneuvering when navigating through narrow channels or during berthing and deberthing. Multiple operators in port (tugboats, pilots, etc.) assist the vessels during their journey. A TSHD may also have similar processes, except for extra loading and unloading phases during a dredging cycle. A simplified hierarchy of the problem processes is shown in Figure 1.

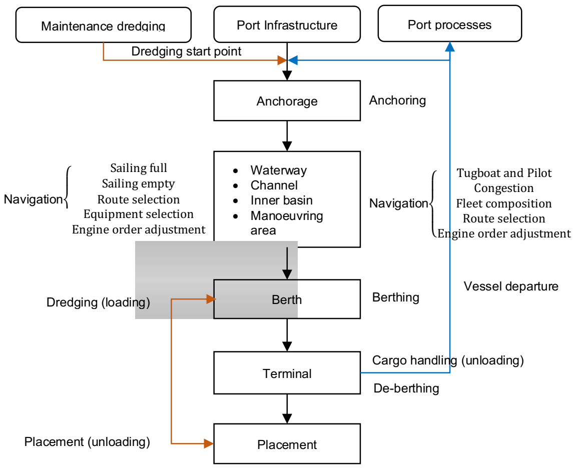

Figure 1 Specifying the interaction between port processes and maintenance dredging operations

Before initializing the simulation of these processes and finding the interactions, three basic elements need to be defined as follows.

- Site: The locations that are used in the simulation (e.g. dredging, placement, berthing, and anchorage locations).
- Vessels: The vessels (seagoing or dredging) that are classified based on the operations they perform and the material they carry.
- Activities: The activities that are defined to simulate the processes executed by each type of vessel in different locations.
- The Vessels should claim the Sites as resources so that capacity-related congestion is generated for the simulation.

A simple case study of the Europahaven terminal in the Port of Rotterdam is performed to elaborate on how many vessels are being served in this harbor and how maintenance dredging processes interact with their navigation. Europahaven, a harbor located in the Maasvlakte II area, is one of the largest container terminals in the world that

experiences high traffic of container vessels during the year. Due to the high penalty costs of delays for the port authorities, seagoing processes are always before maintenance dredging operations.
The container vessels can be served immediately if the berth location is available. To show the interactions, it is considered that the berth can serve only one vessel at the same time and other vessels must wait (container vessels in the offshore area and dredging vessels in the placement location). Besides, container vessels always have priority. A simple picture of the port location and the site objects is shown in Figure 2. The seagoing process is done between offshore and berth sites, while TSHD sails between berth and placement sites.

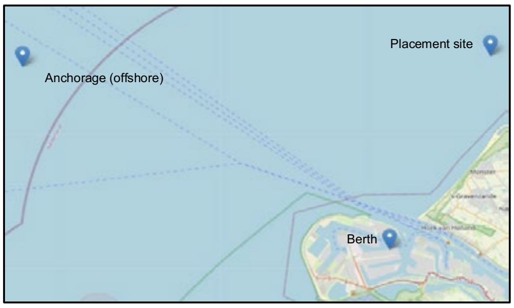

Figure 2 Site locations of the case study

To provide a simple indication of the problem, it is assumed that three container vessels aim to enter the berth when the TSHD should dredge the area as a regular maintenance plan. Therefore, the TSHD should wait for the three vessels to finish their job in the berth before starting the dredging. A Gantt chart is displayed in Figure 3 to address the interactions between three seagoing vessels and the one TSHD that is trying to work in the berthing site.

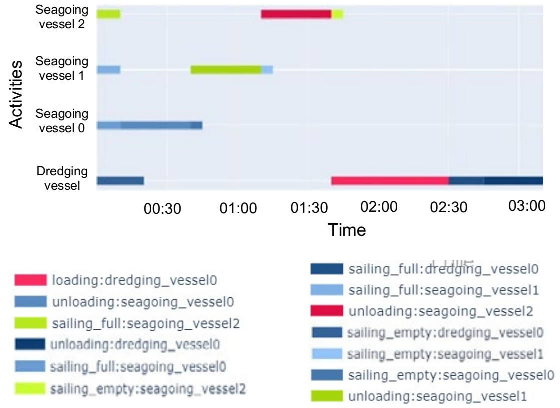

Figure 3 Gantt chart of vessel logs for both dredging and seagoing operations

It is observed that all of the three seagoing vessels finish with the unloading processes and then the dredging vessel can start loading the soil in the berth and finish its dredging cycle.

The handled material by seagoing and dredging vessels are also different, while container vessels unload containers and the TSHD loads soil in the berth location. The changes in the level of these two materials are shown in Figure 4.

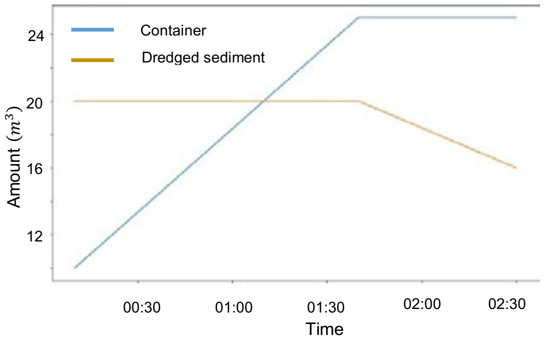

Figure 4 Step chart of the changes in the number of containers and amount of soil at berth

The interaction is mainly the waiting time each vessel experiences before working in the berthing site. This waiting time is not only affected by the berth capacity and the number of resources available to conduct cargo handling but also, the sailing speed of vessels to perform the consecutive job. As shown in Figure 3, the waiting time for the TSHD is relatively higher as it should be waiting for the three container vessels to finish their cargo unloading job. Berth traffic and capacity are two major factors that can affect the waiting time of the dredging vessel. By doing a sensitivity analysis of these factors, the changes in the waiting time are addressed in Figure 5.

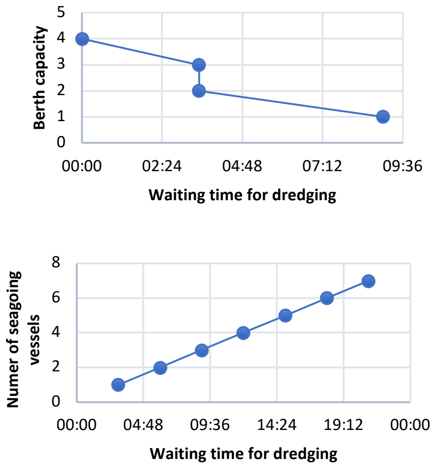

Figure 5 Sensitivity analysis on the problem condition

Discussion

Based on the agent-based simulation concepts, sites, and vessels are considered agents, and the events are defined as activities. The total waiting time for each seagoing and dredging operation can be controlled by implementing different solutions.

The berth capacity plays a pivotal role in handling the vessel agents in the simulation and real-time projects as a result. This capacity which is simply the number of vessels that can be present in the berth location at the same time can be optimized in two main ways.

To better align dredging and container unloading, partial disclosure of a quay can be helpful to provide some space for both types of vessels to operate in the same berth. For example, a container vessel can unload cargo at half of the terminal, while the other half is assigned to the dredging vessel. Increasing the capacity of the existing infrastructure in terminals (such as cranes, trucks, etc.) helps facilitate container unloading in designated locations.

Real-time tracking of a vessel’s movements can be also helpful in providing insights into monitoring the seagoing-dredging interaction. This job can be done by analyzing the automatic identification system (AIS) data that all vessels broadcast within a short period. Analyzing the AIS data helps anticipate the expected vessels' trajectories and ensure the safety of vessels without any accidents. Then, simulation is used to reproduce the obtained results and propose solutions that optimize the effectiveness of vessels’ navigation. Therefore, shorter waiting times have resulted in the anchorage area, and fewer penalty costs are imposed on port authorities.

Data-driven methods such as machine learning and artificial intelligence (AI) can be adapted to optimize the interaction between seagoing and dredging vessels by improving the planning phase of each operation. These methods require analyzing a considerable amount of historical data in real-time and anticipating the patterns that exist between them. Along with this, a continuous collaboration between port authorities and contractors is needed.

Along with optimizing the seagoing processes, dredging activities can be more efficient by selecting the best equipment. The majority of maintenance dredging jobs are done by TSHD in the Port of Rotterdam, while the economic and environmental impacts of other equipment are overlooked in some cases. Water injection dredger (WID), backhoe dredger (BHD), and grab dredger (GD) are three other dredging equipment that can be used for maintenance dredging as well. WIDs are small vessels that fluidize sediments and pull them up in the water column before being remobilized out of the system. They can easily dredge berth pockets and corners which are not accessible by TSHDs because of their large size. BHDs and GDs are stationary equipment that can be employed to dredge specific areas near quay walls and transport the collected sediments with separate barges. The strategies are selected based on quantifying the trade-offs between the equipment cost, required nautical accessibility, overall port performance, environmental impacts, etc.

Mitigation measures are occasionally employed for port maintenance to mitigate the dredging effort needed. Maintaining nautical accessibility can be achieved by implementing sediment traps in the terminal basins to collect the sediments in an over-dredged area and dredging them with a TSHD to the designated placement location. However, it is not applicable for all port areas as it attracts more sediments and requires extra work for dredging and over-deep locations. Current deflecting walls are constructed at the entrance of terminals and estuaries to distract the sediments to the open sea. An air bubble screen is another measure that can be used as a hindrance wall of bubbles to restrict sediment intrusion in the port area. However, implementing all of these measures needs a precise estimation of costs and environmental impacts.

Understanding the interactions between seagoing and dredging processes is sometimes a very experimental operation that should be confirmed by the port authorities. It is because the waiting times can occur because of a lot of reasons such as lack of berth space, lack of port operators, etc. To have a better understanding of how these complex processes align with a practical case, simulation can be a good tool; however, the efficiency of simulation is based on how fast and accurately the data can be shared between stakeholders. Efficient data handling process limits the possibility of any potential disruptions.

Time and cost are two factors that have been studied in a lot of research works; however, other aspects of maintenance dredging such as sustainability and circularity are rarely discussed. Sustainable maintenance dredging can refer to utilizing methods that generate less turbidity and less emissions. It can be helpful to protect the marine environment and reduce the impact of dredging work on climate change. Controlling the overflows of TSHDs and applying turbidity tracking systems along with the transition towards applying greener fuels are some instances of addressing sustainability. Circularity which refers to re-using the collected sediments in a beneficial way (agricultural use, reclamation, etc.) can be another factor to be considered. The equipment that needs to be used for the circular maintenance dredging and the infrastructure that needs to be installed for this purpose is also something that should be taken into account before the execution phase of each project.

Conclusion

Ensuring the nautical accessibility of a port plays an important role in facilitating port operations and results in maintaining the competitiveness of ports. Maintaining the nautical accessibility is done through maintenance dredging by different strategies. Moreover, seagoing processes and dredging operations interfere in some cases and cause extensive delays.

This study discussed the interaction between seagoing and dredging operations by focusing on a case study of the Port of Rotterdam. Quantifying these interactions results in developing solution approaches to achieve a better economic optimum.

An agent-based simulation approach called OpenCLSim is presented in this study which uses SimPy concepts to simulate activities of vessels in an integrated logistics system. These activities are defined as loading, unloading, sailing full, and sailing empty which can be defined for each type of vessel separately. Then, the results provide a piece of information about the time needed to finish each activity and the whole process of a vessel.

The effectiveness of simulating these processes depends on how many real-world conditions are addressed and how the physical properties of agents are defined. For instance, the water-related (tidal windows, maintained bed level, etc.) and bottom-related (sediment properties, bathymetry, etc.) properties of site locations need to be considered simultaneously to clarify what are the characteristics of a maintenance dredging project.

Developing smart techniques such as optimizing the planning with a simulation-driven approach can result in increasing profitability. The final results can be used to assess not only cost and time-related factors, but also other aspects of doing the maintenance dredging job such as sustainability and circularity. Besides, implementing different dredging equipment and mitigation measures can be beneficial in quantifying the trade-offs between these factors before selecting the best strategies.

References

[1] van Koningsveld, M., Verheij, H. J., Taneja, P., and de Vriend, H. J. (2021). Ports and waterways: navigating the changing world, TU Delft Open.

[2] Jahn, C., and Scheidweiler, T. (2018). Port call optimization by estimating ships' time of arrival. In Dynamics in Logistics: Proceedings of the 6th International Conference LDIC 2018, Bremen, Germany, 172-177, Springer International Publishing.

[3] Bianchini, A., Cento, F., Guzzini, A., Pellegrini, M., and Saccani, C. (2019). Sediment management in coastal infrastructures: Techno-economic and environmental impact assessment of alternative technologies to dredging, Journal of environmental management, 248, 109332.

[4] Laboyrie, P., Van Koningsveld, M., Aarninkhof, S., Van Parys, M., Lee, M., Jensen, A., Csiti, A., and Kolman, R. (2018). Dredging for sustainable infrastructure, The Hague, The Netherlands: CEDA/IADC.

[5] de Boer, G., van Halem, J. P., van Koningsveld, M., Baart, F., de Niet, A., Moth, L., Schaarsberg, K., and Sepehri, A. (2023). Simulating for sustainability: Alternative operating strategies for energy efficiency, Terra et Aqua, 170.

[6] Bakker, F. P., and van Koningsveld, M. (2022). Optimizing bed levels in ports based on port accessibility, Coastal Engineering Proceedings, (37), 62-62.

[7] PIANC, Harbour approach channels design guidelines. (2014): PIANC.

[8] de Jong, A. K. W. (2020). Assessing maintained bed levels in ports, TU Delft Repository.

[9] Sepehri, A., Kirichek, A., and van Koningsveld, M. (2023). Sustainable port maintenance strategies: trade-offs between dredging cost and port call efficiency, 13th International SedNet Conference 2023.

[10] Ahadi, K., Sullivan, K. M., and Mitchell, K. N. (2018). Budgeting maintenance dredging projects under uncertainty to improve the inland waterway network performance. Transportation Research Part E: Logistics and Transportation Review, 119, 63-87.

[11] Bian, Z., Bai, Y., Douglas, W. S., Maher, A., and Liu, X. (2022). Multi-year planning for optimal navigation channel dredging and dredged material management. Transportation Research Part E: Logistics and Transportation Review, 159, 102618.

[12] Cho, J., Craig, B., Hur, M., and Lim, G. J. (2022). A novel port call optimization framework: A case study of chemical tanker operations, Applied Mathematical Modelling, 102, 101-114.

[13] Štepec, D., Martinčič, T., Klein, F., Vladušič, D., and Costa, J. P. (2020). Machine learning based system for vessel turnaround time prediction, In 2020 21st IEEE International Conference on Mobile Data Management (MDM) (pp. 258-263), IEEE.

[14] Kolley, L., Rückert, N., Kastner, M., Jahn, C., and Fischer, K. (2023). Robust berth scheduling using machine learning for vessel arrival time prediction, Flexible Services and Manufacturing Journal, 35(1), 29-69.

[15] Nikghadam, S. (2023). Cooperation between Vessel Service Providers for Port Call Performance Improvement.