

## Methodology of creating a work schedule for dredging a port area

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### Abstract

Since there is a tendency that new build vessels are increasing in size, dredging has become an important part of the development and maintenance strategy for ports serving the largest ships. The increase in the technical depth of vessels drives additional development of the entire port. However, the effectiveness of this type of project depends heavily on unrestricted traffic and uninterrupted operation of the terminal. This paper presents a modelling of various type of dredging activities in ports based on an existing work schedule. A tool used to queue work activities with a vacation was used in this effort. The methodology of creating a dredging time schedule in the port area depended mainly on disentangling interference caused by the ship traffic and dredgers trying to work at the same time.

### Introduction

Investments related to the deepening of port areas with heavy traffic, such as channel depth, docks, fairways, and anchorages so they can accommodate larger commercial vessels, requires a detailed implementation plan as well as a documentation plan addressing organization and navigation safety. Dredging is a bespoke order, which is essential to an investment project intended to increase a port's accessibility to larger vessels.

Generally it is true that larger vessels draw deeper water. Hence, port fairways should increase in depth to the same proportion as the increase in width. One implication of such an increase is the need for a degree of cooperation from both the dredging company and the owners whose vessels must move through the construction zones, as well as with port and terminal authorities. Such projects as a significant deepening of a channel, or a simple, periodic canal cleaning, generate impediments that temporarily reduce a port's operational efficiency and throughput.

### Dredging works and their impact on port operation

Maintenance dredging to sustain the technical depth of port canals and approach channels is an important part of the proper operation of ports. These activities ensure the removal of bottom deposits that reduce technical depth, as well as eliminating bottom pockets exceeding the allowable depth in the vicinity of hydraulically engineered constructions. Periodic canal cleaning and levelling focuses on the maintenance of the technical depth necessary to accommodate ships of a certain draft.

Technical depth (Mazurkiewicz, 2008) is determined at the design stage of engineering. It represents the sum of the largest planned draughts of the ship, according to the freeboard lines and the depth reserve under the keel, providing buoyancy under the worst possible hydrological conditions.

Another important parameter for maintaining proper bottom depth is the depth limit. Currently, there is a tendency to build increasingly large vessels, which necessitates the dredging and

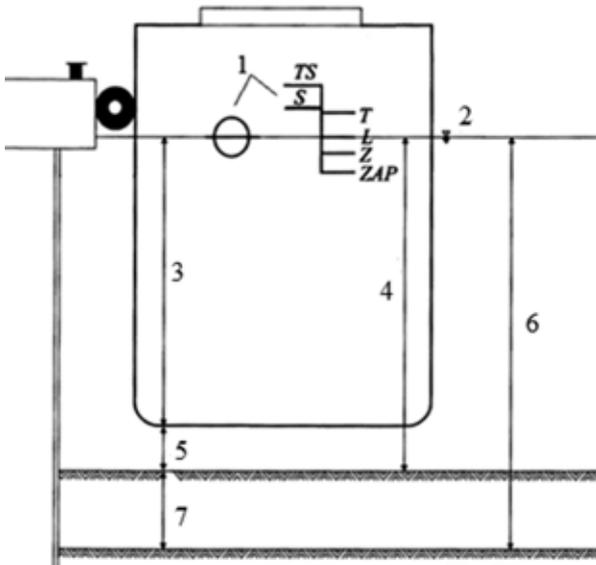


Figure 1. Characteristic wharf depth parameters (Mazurkiewicz, 2008); 1 – load line mark (Plimsoll mark), 2 – water level, 3 – ship’s draught, 4 – wharf technical depth, 5 – under keel clearance, 6 – depth limits, 7 – dredging tolerance level

deepening of ports. However, to avoid destabilizing wharves following such excavation, the excavation in the vicinity of hydrotechnical structures must be constrained by depth limits. The permissible depth is the sum of technical depth and dredging reserve. It is regarded as a safe limiting depth in the vicinity of a given hydrotechnical structure like a wharf.

**The principles of scheduling dredging work**

Dredging activities must be conducted in accordance with the schedule of the project, which has

to take into consideration numerous factors in order to optimize the combination of maximal maritime traffic in the area, the priority of the works, timeliness of project completion, minimal impediments to the functioning of individual terminals, and a minimum of noise and other environmental issues.

A very important issue is maritime traffic in the area of the works (Gucma, 2005). The efficiency of a dredging project depends on the frequency and duration of project-related interruptions to the vessel traffic stream (entry/exit of ships to/from the port) over a given period of time. The main objective in organizing a dredging project is to develop a dredging work schedule that allows for maximizing the productivity of dredgers with the least possible disruption of maritime traffic (Jagniszczak, 2001).

A contrast to this more typical situation is one in which the dredging fluctuates between one of two extremes, either being given total priority over shipping or being totally subservient to it. In the former case, dredgers always have priority; no other vessels can pass through the work area until the project has been completed. Projects of this type are infrequent, usually being associated with the construction of an extremely shallow port canal, a new fairway, or a rescue operation related to an accidental stranding on a fairway. Simulations could be used to estimate the losses caused by such a scenario. An example of a simulation of this scenario is given in Figure 2.

At the other extreme is a system by which vessels declaring entry/exit to/from the port always have priority, and the dredger is obliged to let them pass

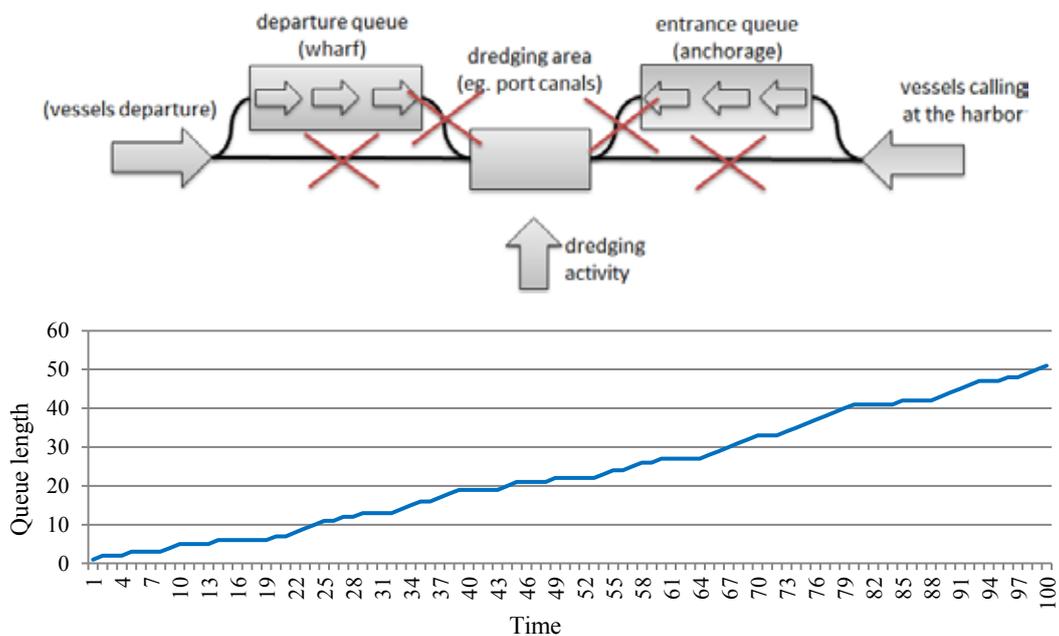


Figure 2. The model scheme and exemplary growth graph of queue length under a traffic ban scenario

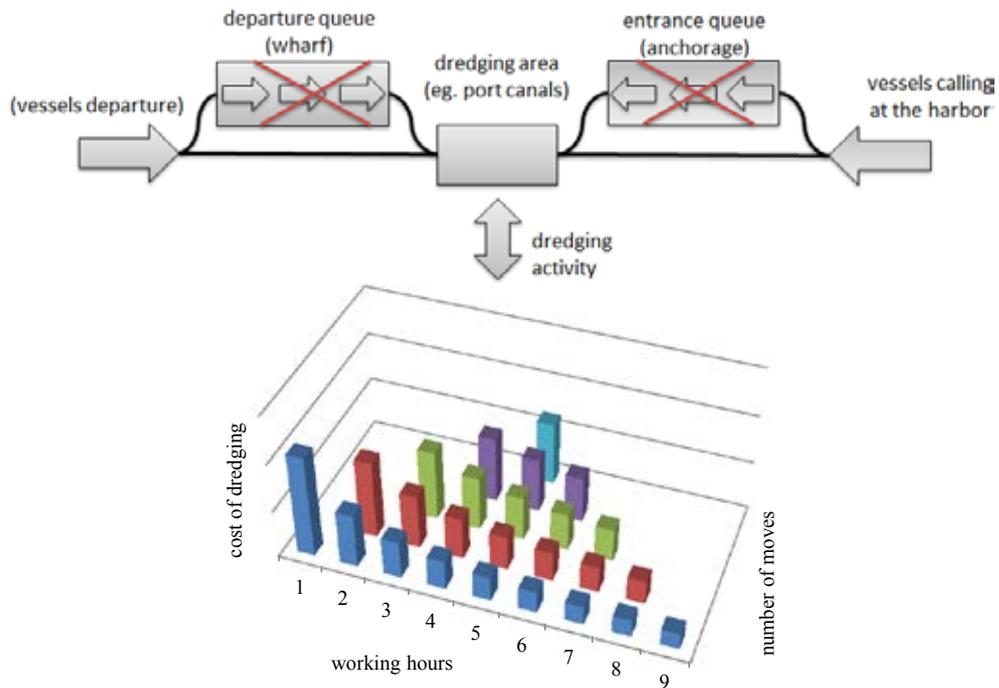


Figure 3. Model scheme and illustrative graph of the cost of dredging as function of working hours and moves

(Figure 3). This type of situation occurs during periodical cleaning of ports or in ports with low traffic.

An intermediate situation between the two extremes, which has yet to be modelled, is a system in which dredging must be conducted with the least disruption of maritime traffic (Figure 4). For this purpose, mathematical modelling of a type called the “system of holiday queues” may be used. In this kind of modelling, the authors propose that during dredging operations, the terminals and port activities have a “vacation” (see details in section four).

### A sample schedule of dredging for the Port of Gdynia in the area of the port canal

A dredging schedule in a port area is heavily dependent on maritime traffic. A large number of vessels passing through the work area reduces the period of continuous operation of dredgers and thus reduces the efficiency of dredging.

The Port of Gdynia has the highest cargo handling rate in its western part, where container terminals are located (Figure 5).

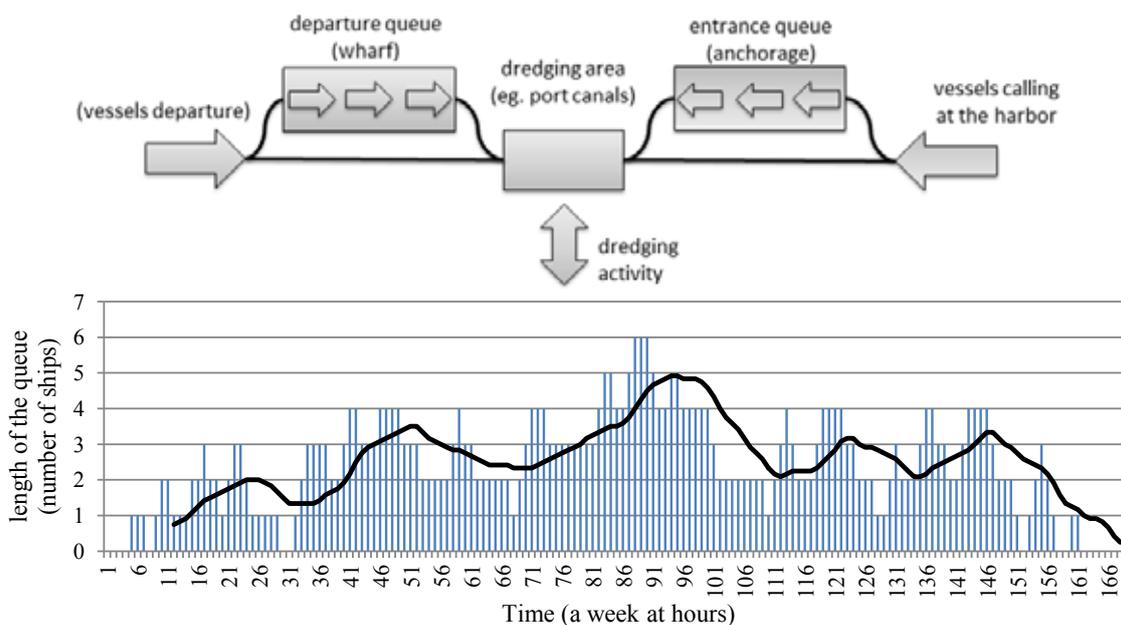


Figure 4. A graph illustrating weekly queue dynamics caused by a specific, around-the-clock dredging schedule

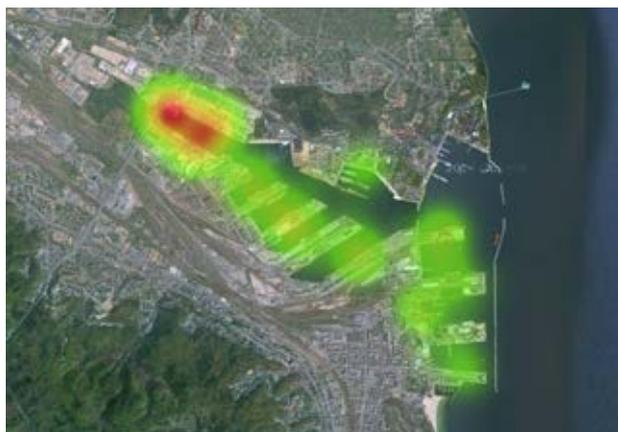


Figure 5. The vessel traffic heat map in the Port of Gdynia

However, in order to improve the depth parameters of container terminals, the port canal has to be deepened along its entire length. An additional difficulty of dredging in these areas is the ferry service provided by Stena Line, as well as vessel traffic from ships calling at neighbouring wharves and shipyards. The proposed dredging schedule for the port canal should therefore allow for the estimated entry or exit time for these vessels. In the case of regular ferry and shipping services, this is a relatively simple task. The remaining calls at the port may be simulated by estimating the average time from a series of observations of typical traffic.

Smolarek and Kaizer (2015) analysed maritime traffic in the port, finding that the average time for a vessel to pass through the port canal is approximately 3 hours. Therefore, assuming 1 hour is required for dredgers to allow other vessels to pass, the schedule for dredgers on the canal may be modelled as follows: 3 hours of operation and one hour for letting other vessels through, taking care to avoid blocking the canal for vessels on fixed schedules. On the basis of the schedule based on the patterns seen here, dredging equipment can be expected to be in operation 105 hours a week. Therefore, with an excavation rate of  $300 \text{ m}^3/\text{h}$  (for the dredger Eng. St. Łęgowski), a total of  $31,500 \text{ m}^3$  of material can be excavated per week. The schedule also anticipates a total of 63 hours of downtime to allow for passage of other vessels, which amounts to foregoing the opportunity to excavate an additional  $18,900 \text{ m}^3$  of material.

### Mathematical modelling of dredging works at port areas: the queuing vacation model

Queues with vacations have wide applications in computer and communication systems (Doshi,

1986, 1990; Teghem, 1986; and Takagi's 1991 monograph). The queuing vacation model has various types. In the single vacation variant, the server goes for only a single "vacation" when the queue becomes empty; in a multiple vacation model, the server, on returning from a vacation, goes for another vacation if it finds the system is still empty. Other variations involve the server resuming service only when it finds a list of  $M$  jobs waiting when it returns from a vacation.

In this paper we present two queuing vacation models with sliding variations. In the first model we take  $M/G/1$  queues in which the server is busy so long as there are units in the main system. The stream of arrivals is a homogeneous Poisson process. The service times are independent random variables with the same probability distribution and a finite mean. Whenever the server (port, terminal, or wharf) becomes idle, the server leaves for a "vacation".

In the first scenario, the server returns to the main system and starts service immediately after finishing its "vacation". The occupation period is the total time that elapses from the moment the server returns from a vacation until it leaves for another one, and the sequence of busy periods is in an  $M/G/1$  queue.

In the second scenario, if the server finds the system empty at the end of a vacation, it immediately takes another vacation, and so on. The vacation time is a random variable with a known distribution function.

The model has two random variables, a single vacation time and a defined vacation time period. A vacation time period is the geometric sum of a random number of independent vacation times. Others variables are the same as in the first scenario. Using the known result (Levy & Yechiali, 1975), we can obtain the stationary characteristics of the system. In the second model we consider  $GI/M/c$  queues, with either a "port vacation" mechanism, or a "terminal" or "wharf" vacation. In the first type, all the port terminals take vacations simultaneously whenever the system becomes empty, and they also return to the system at the same time; that is to say, station vacation is a group vacation for all terminals. This occurs in practice when the dredging is occurring at port channels, basins, anchorages, and entrance channels. For the second type of vacation, each terminal takes its own vacation whenever it completes a service and finds no ships waiting in the queue.

During a port vacation, the system is unavailable for further arrivals, and this is equivalent to taking a terminal vacation. The second type is encountered more often in practice. In this case, each terminal

is an independent working unit, and it can take its own vacation upon serving a customer and finding no customers waiting (Chao & Zhao, 1998).

We can derive steady state probabilities that have matrix geometric form, and develop computational algorithms to obtain numerical solutions (Chao & Zhao, 1998). I have done so with the single server system and for two coincident vacation mechanisms. This case has also been considered by Tian, Zhang & Cao (Tian, Zhang & Cao, 1989).

## Conclusions

Modern seaports often face the problem of a lack of adequate depth and constant silting. Periodic dredging and investment projects are therefore very important to the proper operation of ports. Due to the fact that such maintenance activities take a considerable amount of time, the correct timing and organization of labor is an important issue.

It can be argued that the stream of vessels entering and exiting the port can be presented as a superposition of two deterministic streams (a deterministic random stream, and a steadily disordered fuzzy stream) responsible for the planned (systematic) movement of vessels as well as purely random movements associated with occasional calls or significant random factors disrupting travel time (e.g., storms, breakdowns.) Dredging schedules based on a precise modelling of ship traffic estimate the time required for dredging more accurately than less precisely modelled schedules. Therefore, proper analysis and prior model study of planned activities helps reduce the impact of dredging on vessel movement, thus reducing the negative impact of dredging on transshipment performance.

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