

Article

The Model of Support for the Decision-Making Process, While Organizing Dredging Works in the Ports

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Abstract: The aim of the research was to create a decision-making model, which would be able to support planning, organizing and conducting the dredging works in the port area. The proposed solution is a multiple element system which enables to verify, in a comprehensive way, the majority of the aspects determining the quality and the time of dredging enterprise realization. The paper presents an original approach to the decision-making process during the organization of dredging works, using the computer program. In order to achieve the main goal of the study, the conditions of dredging works were considered. Furthermore, the factors that have an influence on the schedule of the project were evaluated and algorithms, as well as process organization schemes, were developed. If it is not enough, the decision models corresponding to the discussed issue were analysed and the computer program was created. And last but not the least, the proposed project and equipment were verified using a simulation model. While creating this model, the method of multiple criteria AHP (Analytic Hierarchy Process) decision support was used. Moreover, the mass service model with the priority queue regulations, the expert study, and statistical analysis of the traffic flow, were provided. The model was developed in reliance to multiple criteria studies, based on the opinions of multinational experts. These enabled to adjust each element of the system in accordance with various locations. As a result of the research, the following thesis has been proven, that detailed analysis of the conditions of dredging works and taking into account the received conclusions enables to reduce the costs and shorten the time of dredging projects realizations.

Keywords: dredging; port; decision making; computer support systems



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1. Introduction

The constant increase in the technical parameters of seagoing vessels causes difficulties in servicing the largest ships in the ports where the dimensions of the ports areas and technical depths are insufficient. Therefore, dredging works are nowadays an area of interest of port authorities as a necessary investment for further development [1,2]. Port dredging is a long-term and burdensome process throughout the regular operation of navigation and the normal functioning of port terminals [3–6].

The aim of the study was to create a decision model, in the form of a computer application, which would be able to support planning, organizing and conducting the dredging works in the port area [7]. The proposed solution is a multi-element system which enables to conduct a comprehensive verification of most of the aspects determining a quality and a time of dredging [8].

Scientific research concerning dredging work is widely described in the literature published most often in the Netherlands, Belgium, England, China, and also the USA [9,10]. However, in such publications, many items refer to the construction and operation of dredging equipment, but rarely to the technology of conducting dredging work. Furthermore, scientific publications and numerous post-conference materials broadly describe the aspects of ecology associated with this type of work [11–13]. When reviewing the commercial literature, it can be noticed that reports are published for particular investments with local conditions [14–17].

According to the expert analyses, dredging work, as a capital-intensive investment, should be previously verified and assessed in terms of both the realization time and the cost estimate, as well as in terms of risk analysis, which is confirmed in publications [18–21].

In addition, the publications of associations of academics and experts from the dredging industry also make a significant contribution to the branch of science dealing with global dredging projects. The most popular organizations of this type are as follows: IADC (International Association of Dredging Companies), CEDA (Central Dredging Association), WEDA (Western Dredging Association), and PIANC (World Association for Waterborne Transport Infrastructure). Additionally, a significant cognitive value is also provided by scientific journals, as well as by trade magazines, i.e., “Journal of Waterway, Port, Coastal and Ocean Engineering”, “Dock and Harbour Authority”, “Ports and Dredging”, “Terra et Aqua”, and “World Dredging, Mining and Constructions”.

While reviewing the literature, the authors found various types of computer applications, which could be used in the operation of dredgers. However, the solutions proposed in the article, such as a computer program supporting managers’ decisions, constitute a new approach and a tool, which has not been implemented yet in such form. Therefore, in accordance with personal experience and literature reviews, the authors perceive a significant potential of the possibility of using decision-making processes as a part of planning the organization of dredging works in seaports [22–24].

Within the research aim, the following particular (partial) goals were defined:

- Analysis of dredging work conditions;
- Assessment of factors influencing the work schedule;
- Development of algorithms and schemes for the rules of dredging process organization;
- Creation of models supporting the decision-making process associated with planning and conduction of dredging works;
- Verification and implementation of the introduced components of the model;
- Invention of tools, including a computer program, supporting the decision-making process related to planning and conducting dredging works;
- Operational analysis of the proposed solutions based on the simulation model.

The article presents a model of organization of the dredging works that is a new approach of a multi-element system, which allows to verify planning and implementation of dredging in ports in a comprehensive manner.

The model uses research methods from the field of decision support systems, mathematical queue theory, statistical analysis, and expert study [25–28]. These methods were integrated into the computer program generating the results of the study. Moreover, the model enables to simulate the scenario of the selection of suitable dredging equipment along with the prediction of dredging time and cost [29–31].

The research problem contained in the article was also defined in the form of a few questions, as follows:

- What main and subsidiary factors determine the selection of dredging equipment?
- Do obstacles to navigation during dredging works in seaports disturb the proper functioning of transshipment terminals?
- To what extent can the developed model be applied to projects implemented in many ports with different locations and parameters?
- Does the expert assessment method in the organization of dredging work affect the decision-making process?
- How is the recommended model implemented and authorised to verify the usefulness of the tool in a real system?

Also, the hypothesis of the work was formulated as follows: dredging port areas are difficult to undertake both technologically and organizationally, therefore in order to obtain a higher efficiency at reduced costs, it is necessary to create and use tools such

as a simulation model and a computer program to support the decision-making process associated with the organization of the work.

The most important outcomes of the study, established on the created model, have proven that a detailed analysis of the conditions while examining several scenarios of dredging works [32] allows to implement the project in an optimal way in terms of selected criteria, which enables to reduce the costs and time of conducting dredging projects.

This paper is organized as follows. Section 2 explains the function of the various research methods used in the entire model. The process of verification of the interactions between the ships and dredger traffic is described here. Also, the suitability of the dredger to the soil type has been taken into consideration. A method for selection of the dredging technology and a method for verification of the costs of the planned project have been proposed. Section 3 is designated to describing the effects of the work in the form of a computer program, which operates on the basis of the above methods and generates results pointing to the verifiable scenarios for planned dredging works. The final chapters contain discussions and conclusions about the functioning and the usefulness of the program along with the specification of limitations.

2. The Structure of the Model and the Methods Used in IT

The proposed model takes advantage of several research methods (modules) which have been functioning together and therefore enable to conduct a multi-criteria analysis of the issue [33–38]. The operation of the modules has been implemented and integrated in the form of a computer application.

The methods that were applied while creating the components of the model, which were adopted and finally integrated into the computer program, include the following:

- The mass service model with the priority queue regulations—the M/G/1 system—as a tool for verifying the ship traffic and the operation of the dredger in the port area;
- The statistical analysis of the traffic flow in the assumed period, as a study of the extent of dredger-ships interactions during the conduct of the dredging works in the port waters;
- The original algorithms and decision trees with particular criteria for selecting the appropriate dredging equipment, i.e., modules for soil-type verification, work technology, project location, form of transport and storage of dredging spoil;
- The method of multiple criteria decision support AHP, as an analysis of the final, specific choice of dredging equipment available on the market among the previously selected dredgers;
- The cost and time analysis verifying the effectiveness of works of the particular dredging scenarios.

The proposed M/G/1 model analyses the temporal correlation of ship traffic and dredging works in the port area during the conduct of dredging projects with the statutory scheduling priority. However, there are also dynamic changes in priority when priority is given to the ship or to the dredger, depending on the condition of the queue. If the basic time parameters are known, it is possible to calculate the average number of notifications from a vessel/a dredger towards a given priority in the system, and the median quantity of notifications in the queue.

The layout of all steps of the procedure is displayed below in Table 1.

Table 1. The layout of all steps of the methodology and given results from inputs to outputs.

	Analysis of the Conditions of Dredging Work	Assessment of Factors Influencing the Work Schedule	Verification of the Type of Dredger	Verification of Dredging Costs and Efficiency
Inputs	Location/dimensions of the work area The volume of the excavated material Type of soil	Schedule verification	Dredge type/dredge technology	Dredging performance Auxiliary equipment Mobilization/demobilization
Methods	Algorithm for the selection of the dredging equipment according to the type and location of dredging work	The M/G/1 mass handling system Statistical analysis of vessel traffic Algorithm of vessel traffic taking place in the area of dredging works	Algorithm of vessel traffic taking place in the area of dredging works AHP method	Cost analysis based on the schedule Cost analysis by used added support equipment Cost of mobilization Cost of demobilization
Software application		Simulation/Scenarios		
Outputs/Results		The total duration of the planned project, working time of the dredging equipment in the work area, estimation of the number of ships' notifications (random or according to a fixed schedule), the daily cost of the operation of the dredging fleet, daily dredging efficiency		

2.1. Module for Ship Traffic and Dredger Operation in the Port Area Verification

Ship traffic in the port areas is characterized by its own specificity resulting from the COLREGS regulations and the harbour master's guidelines. Research verifications of the vessel traffic in ports indicate that there are different forms of the observed traffic flow [39–41]. The basic situation is a flow where the ships' readiness notifications are typically random and completely independent of each other [42]. However, at the same time, there are also vessels that arrive at the port within a fixed schedule, e.g., ferries according to daily timetables and service vessels with a fixed weekly schedules [43].

The ship traffic module and the operation of dredgers in the port area have been simulated in the model by using the M/G/1 mass handling system with relative priority (Figure 1) [44].

This module verifies the ship traffic criterion by analysing the time correlation between the ship traffic and dredging works in the port area during the conduct of dredging projects with the statutory scheduling priority. However, there are also dynamic changes in priority when priority is given to the ship or to the dredger depending on the condition of the queue [45]. In this module, it has been assumed that three independent sources N_1 , N_2 , N_3 generate Poisson streams of notifications.

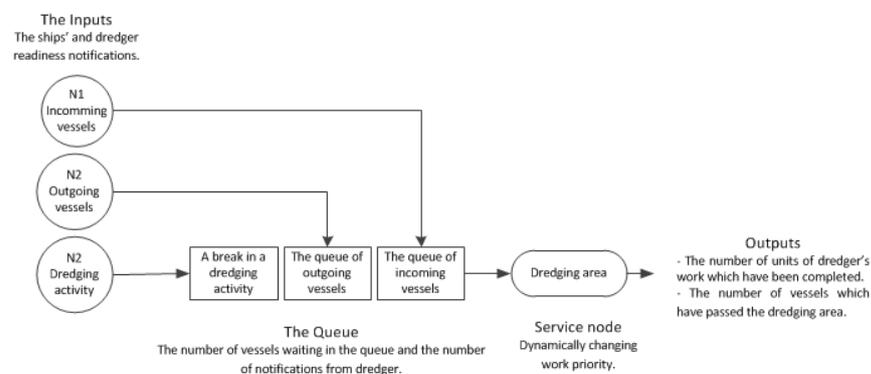


Figure 1. Service system module with relative priority during the conduct of dredging works in the port area. Source based on [46].

In the considered queue module, the work area represents the service station, where both dredgers and passing ships operate (one service station). The dredger aims to max-

imize the working time in the water area, while the ships pass when the dredger lets them do so, in sequence one by one taking into consideration the order and the directions. Moreover, due to the specificity of the port operations, it has been assumed that a ship which comes in the dredging area has to continue and finish its navigation outside the work area.

Subsequently, the notifications generated in the queue system are successively verified with the proposed algorithm of vessel traffic (Figure 2), which creates a timetable schedule for the operation of ships or dredgers.

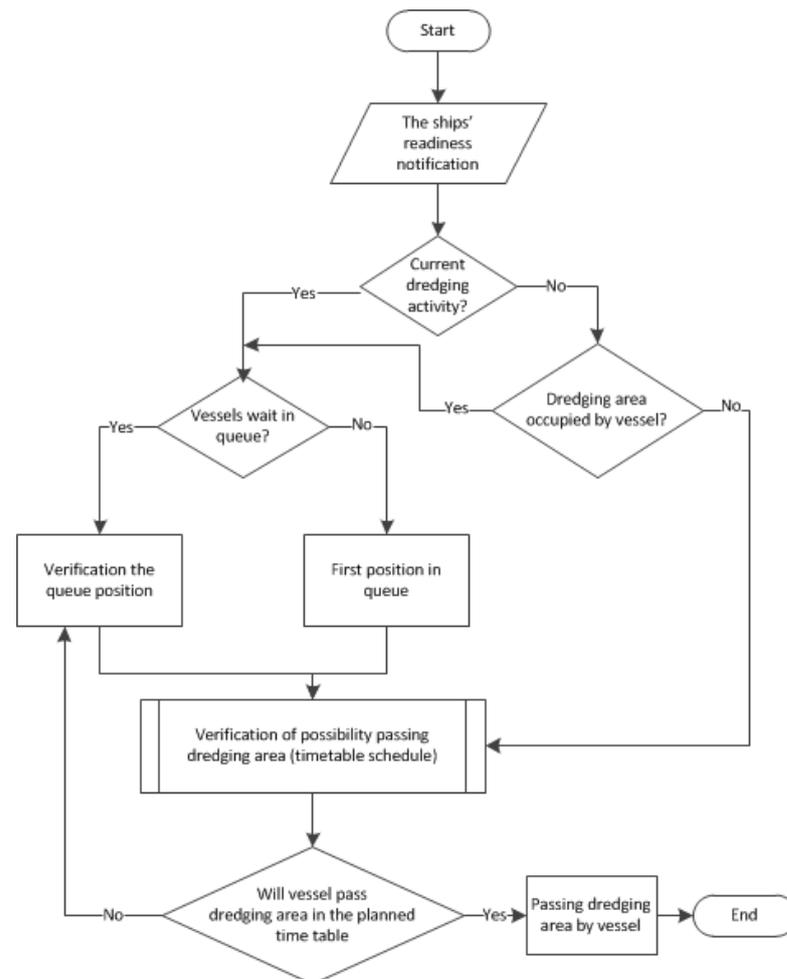


Figure 2. Algorithm of vessel traffic taking place in the area of dredging works.

2.2. Module for Soil Type Verification

The next module in the model analyses the choice of dredging equipment by suiting the dredger to the soil type.

The physical and mechanical parameters of bottom soils, such as soil texture, grain size, cohesion, plasticity, and shear strength are basic elements determining the choice of dredging technology. These features affect the workability of soil and enable to determine the possibility of using a particular dredger [47,48].

After analysing the available literature, as well as taking into considerations the opinions and experience of experts, it is not feasible to define the scheme for selecting the dredger for the type of soil clearly. Therefore, the authors propose to choose the suitable dredger according to the workability of the soil at the planned digging depth, which was classified in the computer program as hard, medium and easily workable soils (Figure 3).

The type of dredging area	
<input checked="" type="radio"/>	Any
<input type="radio"/>	The fairway
<input type="radio"/>	The harbour's channel (the area enables a self-propelled dredger to turn)
<input type="radio"/>	The harbour's channel (the area does not enable a self-propelled dredger to turn)
<input type="radio"/>	The awanport, the turning basins
<input type="radio"/>	The harbour basins
<input type="radio"/>	The mooring places
The type of soil	
<input checked="" type="radio"/>	Any
<input type="radio"/>	Hard to dredge soil
<input type="radio"/>	Medium to dredge soil
<input type="radio"/>	Easy to dredge soil
Possibility that a self-propelled dredger could conduct turn back manoeuvre?	
<input checked="" type="radio"/>	Yes
<input type="radio"/>	No

Figure 3. Types of dredging area and soil.

2.3. Module for Technology and Work Location Verification along with Transport of the Dredging Spoil Verification

The verification of the dredging technology is a module of the model which analyses the validity of using the proposed equipment, relying on the dredger selection algorithm (Figure 4). Such research, taking advantage of the proposed algorithm, analyses the manoeuvrability of the dredgers, the characteristics and the parameters of the work location, and the possibility of using an appropriate technology for breaking up and transporting the dredging spoil.

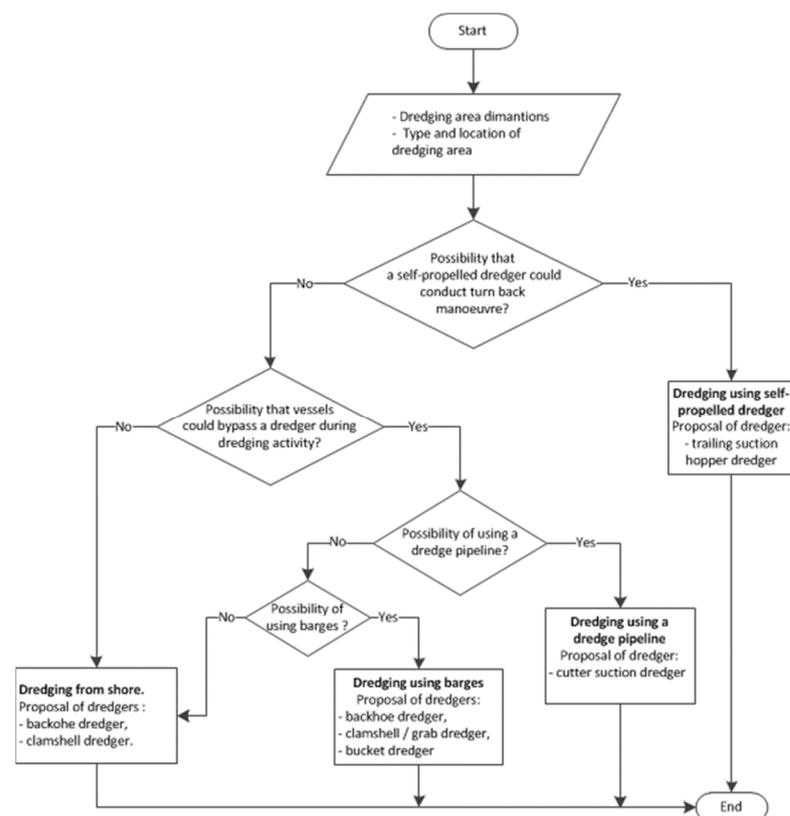


Figure 4. Algorithm for the selection of the dredging equipment according to the type and location of dredging work.

The range of work, in respect of the amount of dredging spoil to be broken up and transported, is an important factor influencing the selection of equipment with appropriate dredging capacity [49].

Matching the dredge parameters to the length and width of the working area is an especially important factor for TSHD dredgers (Trailing Suction Hopper Dredger).

Operation with this type of equipment in short, narrow channels and fairways will be ineffective due to the frequent lifting of the suction pipe and the frequent turn-back manoeuvre. When working in finite ports' areas, the equipment with better manoeuvring parameters should be chosen. This is because despite the lower digging efficiency, it is characterized by a high accuracy of processing in the working area.

Another factor that influences the selection of the equipment is the location and type of the place where the dredging spoil is put (dump-site or dumping area). If the dumping area is at a great distance, or if it is not possible to use the pipeline directly, self-propelled dredgers equipped with holds or dredgers cooperating with barges are proposed. The removal of the dredging spoil to the dump-sites, which are usually located in an open sea, is possible only with the use of self-propelled vessels. The greater the distance to the dumping area is, the more reasonable this form of dredging spoil transport becomes [50].

Therefore, the aspects of the type and location of dredging works have been analysed, and the algorithm for the selection of the dredging equipment has been created (Figure 4). The effect of this algorithm has been implemented into the computer program (Figure 5).

Scale	Degree of importance
1	Equally important
2	Equally to moderately important
3	Moderately important
4	Moderately to strongly important
5	Strongly important
6	Strongly to very strongly important
7	Very strongly important
8	Very strongly to extremely important

Figure 5. Dredger selection.

2.4. Module for the Analytic Hierarchy Process (AHP) as a Method of Support for the Decision-Making Process within the Collection of Dredgers

While AHP can be used in many decision-making troubles, AHP is conventionally used in collection, ranking, along with predicting. AHP supposes that the decision-makers recognise or will come up with independently or jointly, indirectly otherwise unambiguously, the conditions or purposes as well as the substitutions related with the assessment. AHP is also especially valuable for states in which we have together noticeable and indefinable conditions to reflect in the conclusion.

The use of the AHP method in the model is the final specification for selecting a particular dredger among several dredgers currently available on the market with the required technical parameters.

While the AHP is amongst the most progressive approaches available in managing knowledge and processes exploration, the complexity concerned in using this instrument formulates it as problematic to operate. Appreciatively implemented software devices have been constructed, making the calculations easier. The operator has to go along an easy procedure of information compilation, which is then fed into the device to get the outcomes.

1. Phase 1: Describe Choices The AHP procedure activates by describing the choices that need to be evaluated. These choices might be the various conditions that explanations should be evaluated against. At the end of phase 1, a wide-ranging catalogue of all the offered selections should be prepared. The decision matrix for dredger selection is presented in Table 2.
2. Phase 2: Describe the Question and Conditions The second phase is to demonstrate the predicament. Corresponding to the AHP procedure, a challenge is linked to a group of associate troubles. The AHP technique therefore trusts on interrupting the trouble in an order of slighter troubles. In the procedure of interrupting the

sub-problem, conditions to calculate the results appear. Nevertheless, in the same way as the origin initiate investigation, anyone may take to greater ranks inside the trouble. The moment to stop dividing the trouble into slighter sub-problems is individual decision.

3. Phase 3: Create Importance between Conditions Operating Pairwise Relationship The AHP technique purposes a pairwise relationship to generate a base.
4. Phase 4: Verify Stability This phase is inherent in the implemented software tool, that assistance resolves AHP troubles.
5. Phase 5: Get the Qualified Emphases The implemented software instrument will compete the measured scheming founded on the facts and allocate comparative emphases to the conditions. When the calculation is complete with prejudiced standards, one can calculate the substitutes to get the superlative resolution that accords their requirements.

When conducting the AHP method for the selection of an appropriate dredger for the planned dredging project, the comparative analysis of the criteria related to various aspects could be proposed. These criteria could be such as follows: the technical specification of the dredgers, the type and the characteristic of the port area planned for dredging, the type of soil, the cubic capacity of dredging spoil, the work technology, and the obstacles for ship traffic caused by the operation. According to the authors' opinion, the verification of the technical specifications of dredgers is the most reliable in the study. The choice of technical specification is also facilitated because of the data provided by dredging companies.

Table 2. Decision matrix for dredger selection.

Manufacturer and Type of Dredger	Total Length (m)	Width (m)	Maximum Dredging Depth (m)	Hold Capacity (m ³)	Maximum (knots)	Total Power Installed (kW)
Boskalis						
Seaway	171.90	22.00	10.55	13,255	14.0	12,819
Gateway	143.53	28.00	10.00	12,000	15.4	13,870
Barent Zanen	133.58	23.13	8.81	8116	13.5	12,658
Eke Mobius	121.32	21.00	6.80	7350	11.5	7121
Jan De Nul						
Gerardus Mercator	152.90	29.00	11.85	18,000	15.2	21,990
Juan Sebastián de Elcano	157.50	27.80	11.10	16,500	15.7	17,880
Pedro Álvares Cabral	147.80	30.00	11.20	14,000	15.7	15,960
James Cook	144.00	25.50	9.70	11,750	15.3	14,180
DEME						
Pearl River	182.22	28.00	10.60	24,130	15.0	19,061
Nile River	144.00	28.00	10.56	17,000	14.0	19,559
Lange Wapper	129.80	26.82	9.81	13,700	14.2	13,860
Uilenspiegel	142.80	26.80	9.80	13,700	15.7	13,960
Van Oord						
Volvox Terranova	164.10	29.03	11.20	20,046	17.3	29,563
Utrecht	154.60	28.00	10.37	18,292	14.8	23,807
Ham 310	138.50	23.04	10.07	13,392	15.1	13,522
Volvox Asia	133.93	26.04	9.47	10,834	15.0	21,453

Source: own study.

While conducting such a study, the relative analysis of the conditions associated to the technical specification of dredgers is proposed (Figure 6). This includes the determination of the criteria of choice in accordance to, e.g., general dimensions, hopper capacity, maximum dredging depth, speed loaded, maximum cutter power, total power installed and bucket capacity.

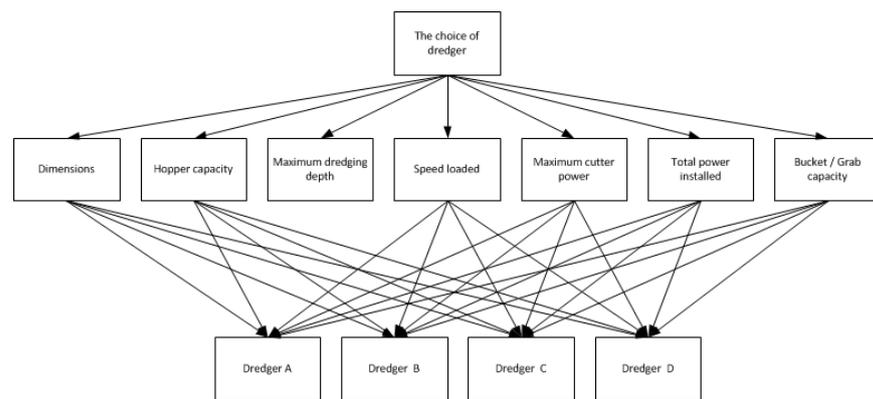


Figure 6. Chart of the hierarchy of the dredger selection using the AHP method.

An inquiry questionnaire was enlarged based on the recognised conditions and qualities for choosing the dredgers. The survey opinion poll was managed to advisors, academics, and captains of ships. A total of 30 expert panels were selected to determine the criteria and options.

The computer program has been loaded with a database with examples of popular dredgers available on the market from popular dredging companies, i.e., Van Oord, Jan De Nul, Deme, and Boskalis. The list is an example of equipment that can be selected in the decision-making procedure using the AHP method. The database of available equipment could be edited by adding new dredgers or removing vessels that have expired (Figure 7).

ID	Dredger Type	Company	Model	Value 1	Value 2	Value 3	Value 4	Value 5	Value 6
50	TSHD dredger	Van Oord	Ham 310	138.5	23.04	10.07	13392	15.1	13522
51	TSHD dredger	Van Oord	Volvo Olympia	96.57	19.93	7.19	4883	12.5	6542
52	TSHD dredger	Van Oord	Volvo Maxima	203.4	31.06	14.5	31387	17.2	31309
53	TSHD dredger	Van Oord	Volvo Asia	133.93	26.04	9.47	10834	15	21453
54	CSD dredger	Boskalis	Helios	152	28	6	7000	35	22886
55	CSD dredger	Boskalis	TAURUS II	112.6	24	4.85	4000	30	24610
56	CSD dredger	Boskalis	Proton	132.2	19.7	18	1000	15	3000
57	CSD dredger	Boskalis	Cynus II	107	19	4.85	2650	25	12904

Figure 7. Dredger selection with AHP analysis.

Please note that the multi-criteria method may have limitations. Experience shows that potential restrictions on the use of AHP are as follows:

- The relationship procedure can be extensive if the conclusion is multifaceted;
- The relationship assessment can be unpredictable when the contributors are not completely involved within the procedure;

- The decision-making clearness can be counter-productive aimed at supervisors who will be concerned around deploying the outcomes;
- Collection decision-making can construct incomprehensible to hold reliability troubles [51].

2.5. Module for Cost and Time Analysis

Dredging investments are characterized by significant capital intensity, which requires multidimensional economic analyses [52].

The basic cost of work in the port area is the efficiency of dredging and transporting the dredging spoil over a period of time [8]. Due to the high hourly capital intensity, every downtime and each obstacle constitute a considerable cost to the project.

Moreover, an important financial aspect related to conducting dredging work is the cost of mobilization, demobilization and transport of dredging equipment to the work area. The mobilization of equipment and transport of dredging fleet is a significant issue because it is often a great cost that can affect the final financial profitability of the entire project [53].

Furthermore, the use of auxiliary equipment also plays a significant role in the costs of dredging projects. The appropriate configuration of auxiliary stock, such as tugs, dump barges, discharges, hydrographic vessels, as well as long pipelines and pumps, which are additional equipment, greatly influences the cost of dredging.

However, in accordance to the functioning of the port, especially with high ship traffic, the dredging works themselves constitute an obstacle, which also generates costs for shipowners and terminals.

Therefore, when estimating the total cost of dredging works in port areas, the correlation between the costs generated for both the dredging company and the other users of the port areas should be taken into consideration [54]. In the program, the authors proposed a method of calculating the project costs on the basis of the unit cost of dredging converted to the dredging efficiency. Additionally, there is a possibility to add costs connected with particular stages of the organization of dredging work (mobilization, demobilization) and resulting from the usage of additional equipment (see Figure 8).

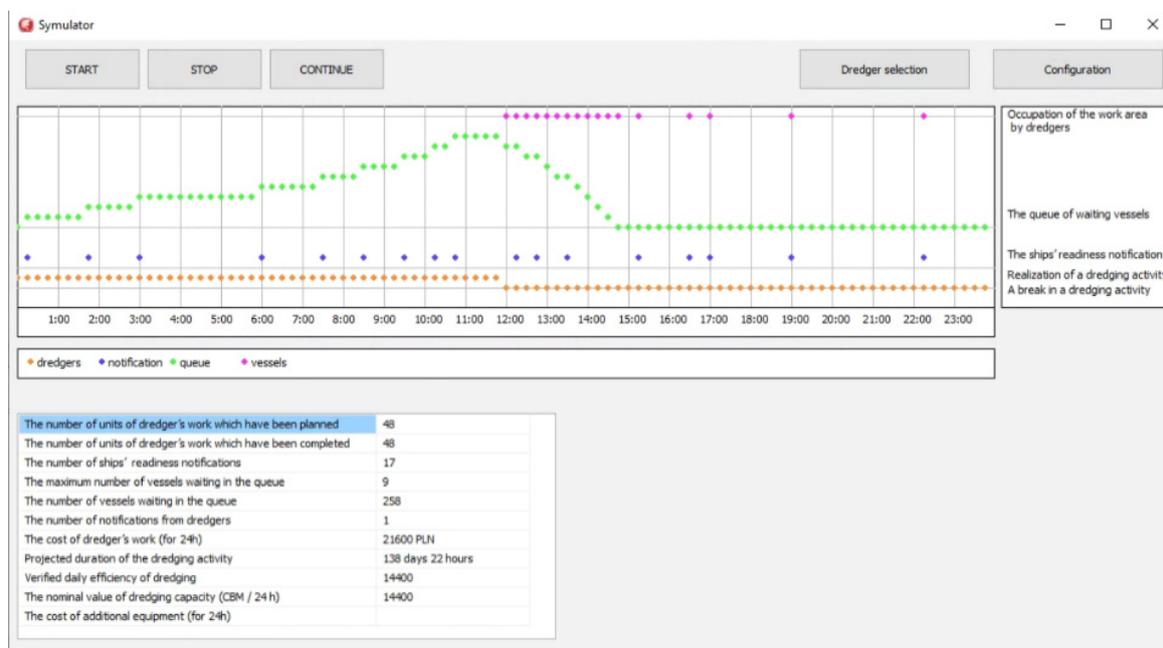


Figure 8. Figure from the computer program concerning costs.

2.6. Description of the Simulations Performed by the Program

The computer program integrally functions on the basis of the modules described above. The experience initiating the operation of the program is the occurrence of a notification (from a ship or from a dredger), followed by a verification of the possibility of commencing work of a dredger or of a ship in a particular unit of time. In the program, if dredging works are conducted in the port area, it is impossible for the ship to pass and therefore the queue of the ships is generated. The exact mechanism of creating the process of the ship's queue is described by the algorithm of vessel traffic taking place in the area of the dredging works functioning together with the M/G/1 queue system (in accordance with Section 2.1).

The notification in the model is understood as an occupation of the port area by a dredger or by a vessel. This area represents the service station.

The scenarios simulated by the program have been created in the form of zero-one systems of basic parameters, i.e., ship's notification, occupation of the port area by a ship, occupation of the port area by a dredger, and notification from a dredger.

These parameters are verified in the zero-one system, where 1 means execution (event occurrence) and 0 means lack of realization (no activity).

Moreover, the scenarios in the program are verified as acceptable (Table 3) or unacceptable (Table 4) due to their suitability to actual conditions.

Table 3. Acceptable scenarios simulated in the program.

Set	Description
(0,0,0,0)	The set of four zeros represents the situation that there are not any notifications as well as any activities in the analysed port area
(1,0,0,0)	The program noted a ship notification when there were no dredging works ongoing and no notification about intention to conduct dredging
(0,0,0,1)	There is a notification from a dredger as a readiness to conduct dredging when the work area is unoccupied and there are not any ships' notifications
(0,1,0,0)	In this set, there is a lack of notifications, neither from the ships nor from the dredgers; however, it could be observed that the ship is currently crossing the work area because the dredger is not operating
(1,1,0,1)	The port area is being crossed by the ship, and at the same time the notifications from the ship and from the dredger are given simultaneously
(1,0,0,1)	The ship's notification coincides with the dredger's notification when the work area is unoccupied
(0,0,1,0)	No notifications, the dredger is realizing the dredging works in the area of work
(0,1,0,1)	The ship is crossing the work area and the dredger notifies the readiness to start realization
(1,1,0,0)	At the present moment, the ship is crossing the port area, and another ship notifies its readiness to pass the verified area

Source: own study.

Table 4. Unacceptable (unrealistic) scenarios simulated in the program.

Set	Description
(0,0,1,1)	The discriminatory element of the proposed scenario is the simultaneous occurrence of a dredging notification when the dredger is currently working. In the proposed model, the dredger gives a notification as a readiness to conduct dredging. That configuration will be applied if there is a possibility of using more than one dredger simultaneously.
(1,0,1,1)	
(0,1,1,0)	The proposed scenarios are eliminated from the system because if they are real both the dredger and the ship will occupy the work area at the same time. This is unacceptable in the proposed simplified model.
(1,1,1,0)	
(0,1,1,1)	
(1,1,1,1)	

Source: own study.

3. Results

The result of the study is a new multi-element model. Its operation has been presented in the form of a computer program, which enables to verify the criteria affecting the administration of dredging occupations in the ports. The program was created using the Delphi development environment.

The main task of the program is to optimize the process of organization. The essential activity of the program is to give the possibility to examine the planned dredging activities in respect of minimal disruption to vessel traffic. The most convenient solution is to adjust the working time of the dredgers and the passage of the ships to economic and technological criteria.

The program generates simulated results by analysing the coherence between the work of the dredger and the ship traffic in the port area, with relation to various scenarios and priorities. The available results from the simulations are as follows: the total duration of the planned project, working time of the dredging equipment in the work area, estimation of the number of ships' notifications (random or according to fix schedule), daily cost of the operation of the dredging fleet, daily dredging efficiency analysed in reference to dredger downtime when it is bypassed by the ships, and time that ships will spend in the queue in case of dredger's priority.

Furthermore, the program analyses the schedule of the ships' notifications, both in a random and permanent form, and it is also possible to combine a random schedule with a fixed schedule of ships' readiness notifications, e.g., for ferries.

In the program, the system operation time is considered in regard to the assumed time unit, i.e., 15 min.

4. Discussion

The organization of a dredging project and the selection of an optimal dredger is a complex process. This conduct involves analysing many factors and criteria that affect the effectiveness and cost of the entire project. Previous studies and expert opinions indicate that soil conditions, transportation selections, dredging position, water depths and location, and finances have the greatest impact on the choice of the dredging equipment. It is worth mentioning that some dredgers are self-propelled and are equipped with holds, and thus they work effectively in open water, while the others could operate only at quays using pipelines or barges. Therefore, suiting the dredger to the particular water area is also an important decision.

In the model, a detailed analysis of the dredger parameters using the AHP method is possible with the determination of an appropriate criteria of selection. The advantage of this method is the possibility of making a selection by hierarchizing alternatives depending on the requirements of the decision maker. However, a shortcoming of the AHP method is the necessity to provide a generally accessible base of available dredgers.

The model also takes into account the intensity of ship traffic, which has a limiting effect on the possibility of realization of dredging activity in the same area. In order to model the correlation between the work of dredgers and ships, a mass service model with the priority queue regulations has been used—the M/G/1 system with a relative priority, which enables to analyse the waiting times in queues and prioritize the work. The use of such a system has enabled to simulate the work priorities of both ships and dredgers while searching for a more convenient work schedule. The limitation of the queue system is the fact that there is only one service station (one area of dredging works).

Another shortcoming of the proposed model is the validation of the system, which is possible only after using the simulated results in real conditions, where the project would be planned and implemented in accordance with the proposed model methods.

Furthermore, relying on the knowledge and experience of the authors, the algorithms and decision trees constitute a theoretical solution to the considered problem.

The proposed model considers only the case with one ship and one dredger in the port area. Further work concerning the program will aim to develop opportunities for better cooperation between more ships and a number of dredgers operating in the investigated port area.

The works on the model planned in the future will include the use of navigation and manoeuvring simulators to determine the details of selected dredgers for specific locations, i.e., manoeuvrability, possibility that vessels could bypass a dredger in finite ports' areas,

the determination of time that dredgers and barges spend to get to the dumping area (in different meteorological conditions), analysis of the use of pipelines that are floating or submerged in the port.

The proposed research solution was subjected to expert discussion. According to the opinions and experts' assessments, the most significant attributes that affect the collection of dredging equipment are the type of soil (83% of respondents), quantity of dredging spoil (69% of respondents), and also the place and geography of the harbour (62% of respondents). These results indicate that through the association of dredging efforts, it is a necessity to regulate the operational equipment to the port's basin. Furthermore, around the assessment was signalized, which it is also significant to reflect the vessel passage concentration while selecting the dredger (59% of respondents). This aspect has an impact on the organization of the operate timetable, and therefore it determines the efficiency of the development. It is also worth mentioning that experts have concluded that the hydrometeorological aspects and environmental performance have a medium or low influence on the choice of a dredger.

5. Conclusions and Future Works

The main aim of the study was to create a multi-criteria model of support for the decision-making process while organizing dredging works in the ports. The task was carried out by conducting an analysis of the issue and taking advantage of research methods and original solutions for particular elements, which make up a comprehensive decision-making model in the form of the computer program. The hypothesis defined in the introductory part was confirmed by the conducted research.

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