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Modeling and simulating processes in optimizing port activities – literature review

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Abstract. The international economic and social context, due to the COVID-19 crisis, has highlighted the resilience of international maritime trade and global supply chains. For these reasons, port activities have constantly adapted to the new challenges. The specialized literature in this field argues for the importance of modeling and simulation in the process of optimizing port activities. This direction of research facilitates the adaptation of port activity to the requirements of the maritime market, to competition in the field and last but not least to technological progress. Modeling and simulation in the field of port activity has become the tool through which new investment projects can be analyzed, such as a specialized terminal. Modeling and simulation can also contribute to the identification of technical or procedural optimal solutions both from the perspective of implementation costs and depending on the actual situation in the hinterland area.
As part of a larger research, the paper is a literature review article. This paper proposes an assessment of the state of research in the field of modeling and simulation of processes in specialized port terminals in order to identify research directions that would increase the efficiency of the activities carried out.

Keywords: simulation modeling, port terminals, optimizing port activities, literature review.

1. Introduction

This paper represents an extensive analysis of the specialized literature regarding the application of modeling and simulation techniques in the research activity, analyzing general aspects useful to novice researchers in the field, but also to terminal managers who want to improve a certain process or the overall activity in the a specialized terminal, focusing on modeling and simulation techniques used in terminals in the maritime industry. This concept of modeling and simulation is analyzed to understand

very well where, when and how it can be applied and what exactly needs to be followed for the research results to be validated and valuable. The advantages and disadvantages of implementing modeling and simulation software are weighed, to understand that the decision to apply these techniques is not always the best solution, as a conventional, much simpler method may be more suitable.

Through the study of the specialized literature in the field, the modeling and simulation software/techniques most used in the maritime industry are highlighted, for all types of terminals, and the most researched fields in the maritime industry are identified with their help.

Modeling and simulation techniques have been used for over 50 years, but recently they have become important research methods for investigating operational and organizational systems, in addition to their success in designing, manufacturing, analyzing and improving physical systems. [1, 2]. Since 1980, with the development of computer technology, simulation technology is applied to all aspects of production and people's life, and then simulation software has been developed. The advances in simulation hardware and software over the past decade have been dramatic. Computers now offer unprecedented processing power even compared to just a few years ago. Improved user interfaces and product design have made software programs much easier to use, reducing the expertise required to use simulation effectively. Revolutions in object-oriented technology continue to improve the flexibility of modeling and enable the accurate modeling of highly complex systems. Publicly available hardware, software, and symbols make it possible for even beginners to produce simulations with compelling 3D animation to support communication between people in all environments. These innovations work together to propel simulation into a new position as a critical technology. [3,4]

2. Literature review

Simulation is a modeling approach with a much wider applicability. [5]

These simulations can be applied to a wide variety of fields. The following are just a few examples of areas where simulation has been used to understand and improve system efficiency: airports, hospitals, ports, mining, amusement parks, call centers, supply chains, manufacturing, military, telecommunications, justice system , emergency response system, public sector, customer service. [6]

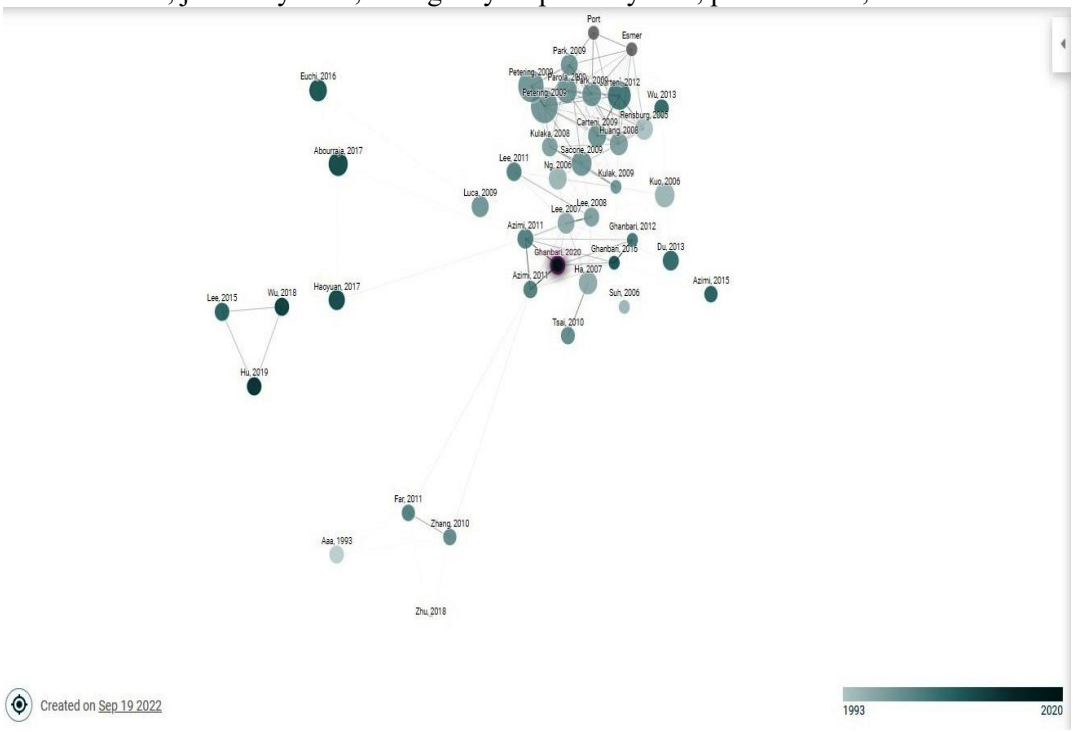


Figure 1. The graph of the most important papers regarding the use of the concept of modeling and simulation in port activities [7]

Far from being a tool for manufacturing only, the domains and applications of simulation are vast and virtually limitless.

Modeling and simulation are valuable tools that engineers and managers should consider when making decisions about the execution of various processes in the maritime industry.

Modeling and simulation involves a process of designing a model of a real-world system or an anticipated system, such as a design concept, and then conducting experiments, for specified periods, with the model to understand the performance of the system in different operating conditions and the evaluation of alternative management strategies and decision-making processes [8].

Theoretically speaking, the concepts of model and simulation are different because a model is a tool, while a simulation is the act of using that tool. However, these notions are connected and in practice are often used interchangeably.

A model of a system is an experiential representation [9] – figure 2.

Modeling is the process of producing a model; a good model is a judicious compromise between realism and simplicity. Simulation practitioners recommend increasing the complexity of a model iteratively. An important issue in modeling is model validity. Model validation techniques include simulating the model under known input conditions and comparing the model output to the system output [10, 11, 12, 13].

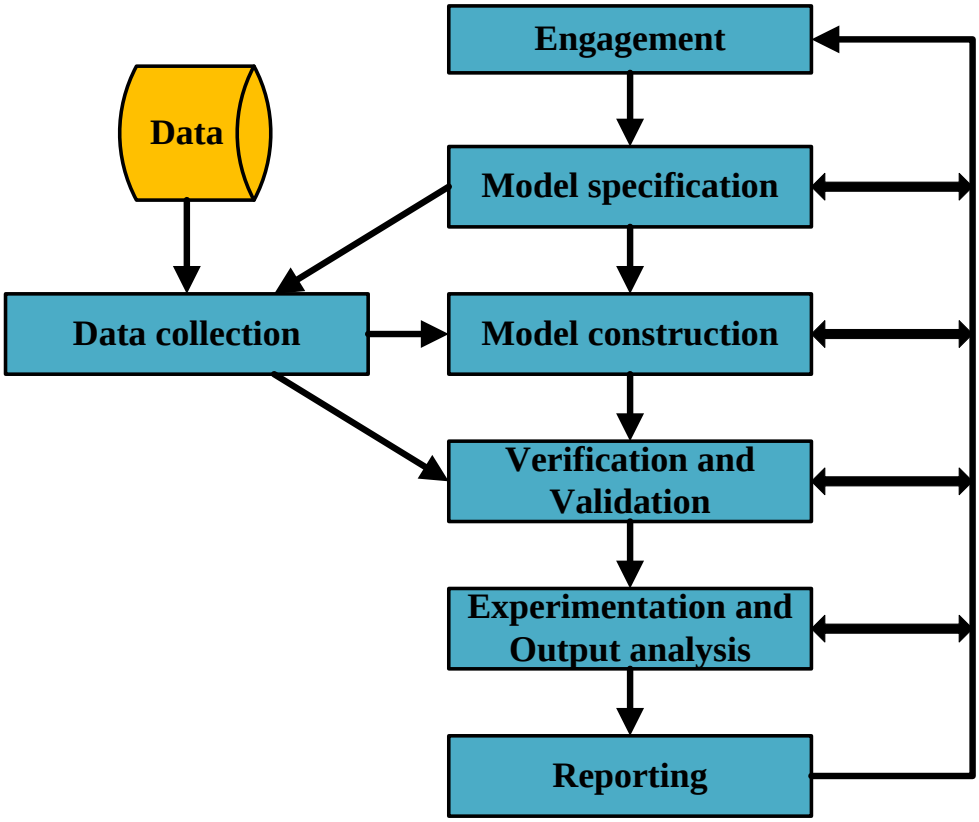


Figure 2. The modeling process of a system [11]

Modeling and simulation are used to study the systems. [14]. A simulation is the act of performing a test on a model [9].

A simulation of a system is the operation of a model of the system. The model can be reconfigured and experimented with; usually, this is impossible, too expensive or impractical to do in the system it represents. The operation of the model can be studied and hence properties relating to the behavior of the actual system or its subsystem can be inferred. In its broadest sense, simulation is a tool for

evaluating the performance of an existing or proposed system in various configurations of interest and over long periods of real time [10].

Analyzing the simulation process as a schematic study we can divide this process into two: in the real world and the simulation study. Of course, we will start from a study system that we subject to the first phase of model creation, after which we proceed to the simulation phase of this model through the simulation experiment. Next, the simulation is analyzed and conclusions are drawn, which are the final part that fines the system under simulation. In a simulation study, human decision-making is required at all the stages outlined above, the only stage where human intervention is not required is when running the simulations, as most simulation packages work efficiently [16].

Modeling and simulation methods have also been applied in interdisciplinary research areas such as decision-making mechanisms for designing systems [15], the management of integrated product teams [17], new product development processes, and organizational management. The application of modeling and simulation methods to understand the performance of complex socio-technical systems is becoming a promising research area [18].

Since World War II, simulation has become an indispensable tool in system-related activities [15].

The development of computers has greatly expanded the applicability of simulation modeling [19].

The simulation technique is widely used in [20]: manufacturing processes such as processing, assembly, material transfer, storage; production systems;inventory systems;service systems; air, maritime, rail and bus transport; ports and terminals; logistics and distribution systems; construction systems; communication networks and IT systems; business process reengineering (BPR) [21]; military activities.

It is very well known that most of the university institutions around the world want to implement the concept of simulation learning/entry for students considering the advantages offered, but also for building skills in using modeling and simulation software. With the help of simulation modeling method, a model of a real system is generated using computer software and the system can be analyzed easily. In the maritime industry, in addition to the use of simulators for training purposes, simulation applications are performed on various aspects such as container terminal operations, maritime traffic risk assessments, port/terminal capacity analysis, marine pollution risk assessments, resource optimization in the technical field for nautical services. [22, 23, 24, 25]

3. Research methodology

This paper aims to provide a systematic literature review in the field of process modeling and simulation for process improvement in seaports. First of all, the questions that this study must answer were formulated, and they were two in number:

RQ1: What is the current state of research through modeling and simulation of maritime processes?

RQ2: What are the procedural steps to follow and what software are used to model and simulate a process in a marine terminal?

Next, the most relevant bibliographic sources were identified in order to obtain as much information as possible in the treated area and to emphasize the information that can answer the research questions of this paper.

Following the analysis of the relationships between various works in the field and following the research evolution, the 4 most significant aspects were treated in order to answer the two questions proposed in this research methodology.

3.1. Procedures used in modeling and simulation

The specific procedures used to simulate real-world problems can vary for a number of reasons, such as differences in problem formulation, the purpose of the simulation experiments, the preferences of the experimenters, and the limitations of the simulation technologies that are used. [26]

Figure 3., presents a simulation procedure designed following the literature review, to guide research activities and modeling-simulation experiments in a way that is as easy to understand as possible. The modeling and simulation procedure exemplified in the figure below is described in 13

steps, considering both R. E. Shannon's 11-step procedure and A. F. Seila's 13-step modeling and simulation procedure [8].

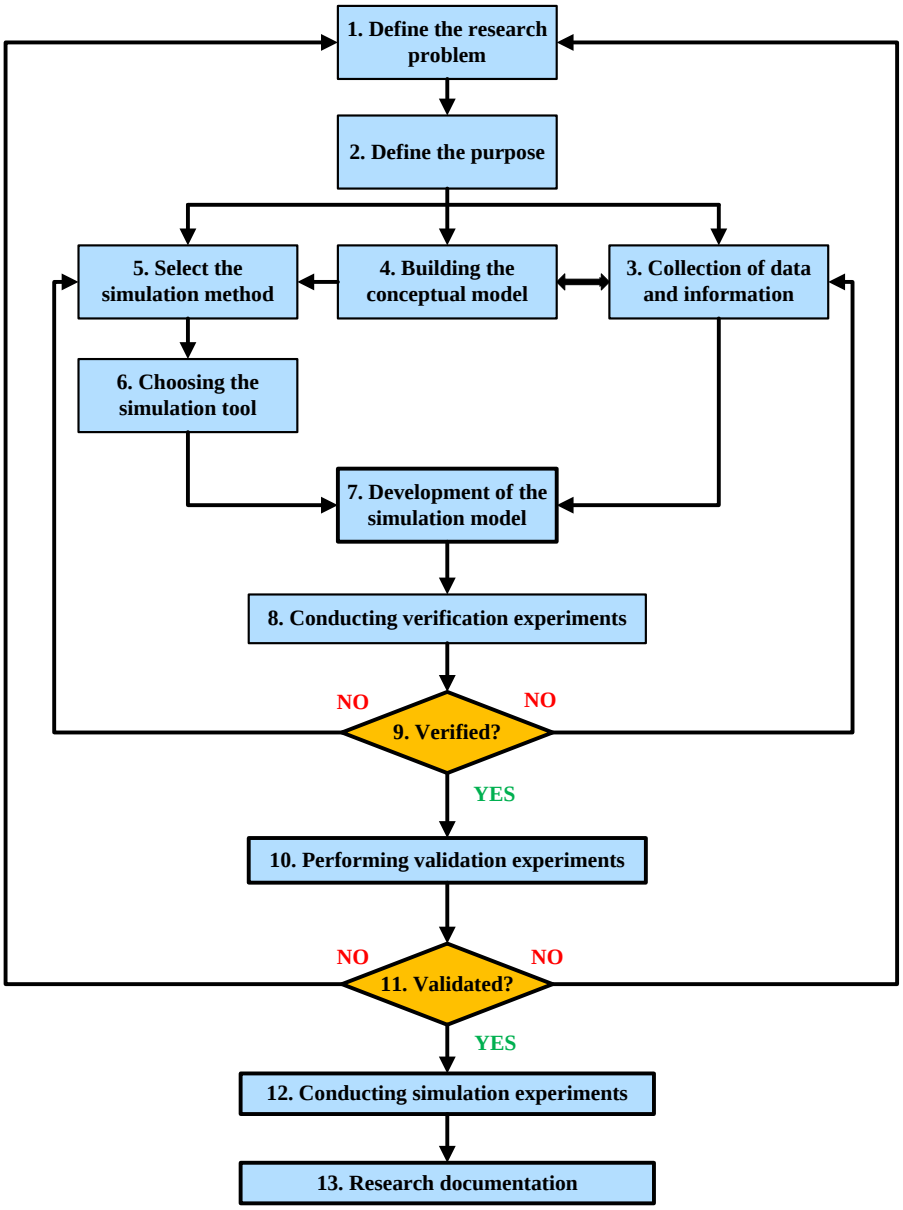


Figure 3. Modeling and simulation procedure [8, 27]

3.2. Model validation and optimization

The purpose of model verification and validation is to make the simulation model meaningful in a real-world context. For this reason, the modeling and simulation procedure includes model verification and validation in addition to model design and development. Figure 4 provides an example of a complete view of a model verification and validation architecture. Model verification and validation activities include validating the simulation model against the real-world situation and the conceptual model. [8]

Model checking refers to the identification and elimination of errors in the simulation model by comparing the simulation results from the model with analytical solutions from the real situation. In

this way, the model checking process deals with the mathematical relationships and simulation specifications associated with the model. Model checking ensures that the model is as complete and accurate as necessary to provide a sufficiently accurate representation of the real-world situation. In this way, model validation ensures that the simulation model is useful for solving real-world problems. Model validation processes are concerned with quantifying model accuracy by comparing simulation results with real-world experimental or operational results [8].

Figure 4, illustrates a model verification and validation architecture for implementing the activities exemplified in figure 3.

The representations in figure 4 represent results from three primary steps in figure 3: the definition of the research problem (step 1), the conceptual model (from step 4) and the computerized model (from step 7).

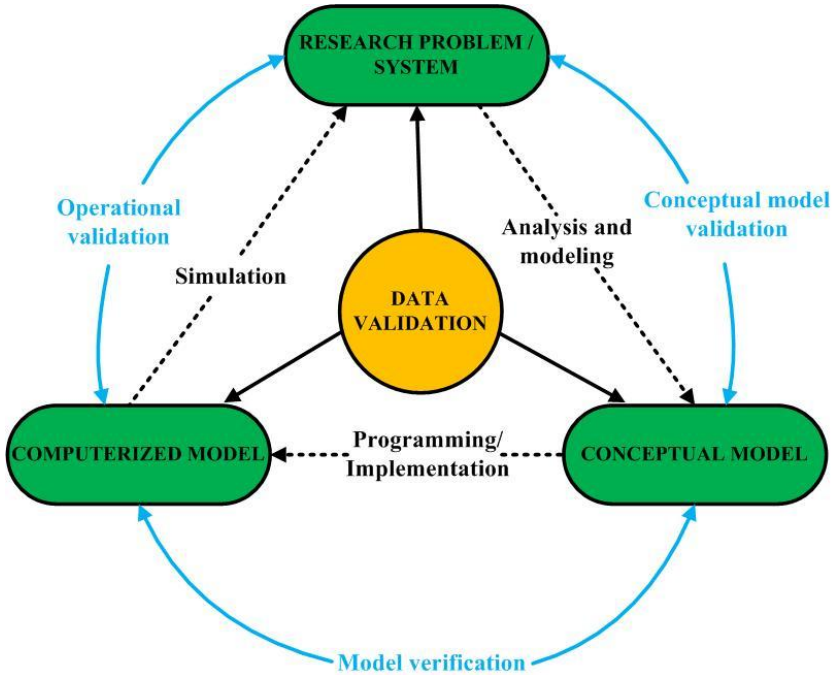


Figure 4. Model verification and validation architecture [8]

As shown in figure 4, three model verification and validation activities are required. First, conceptual model checking ensures that the conceptual model is an accurate representation of the research problem in the real situation. Second, simulation model verification ensures that the computer-based simulation model is a sufficiently accurate implementation of the conceptual model. Third, simulation model validation performs a series of simulation experiments that focus on verifying the model's efficiency and accuracy against the specific research goal. Additionally, in the center of the diagram in figure 4, all data used in the three aspects of model design and development, and model verification and validation must be validated.

There are four main strategies used to verify and validate the simulation models [28]:

1. Self-validation;
2. Covalidation;
3. Independent validation;
4. Validation by scoring.

Each strategy has distinct characteristics, meaning that different strategies are suitable for different real-world situations and simulation purposes.

The model validation methods developed for specific simulation situations, they are exemplified in the figure below:

Figure 5. Model validation methods

3.3. Advantages and disadvantages of using modeling and simulation techniques

Modeling and simulation, like any other research tool, offer us a wide range of advantages and disadvantages. The technique of modeling and simulation is frequently used and related to the specific fields of application, it represents the most effective way of applying, testing and evaluating different activities.

Advantages of using modeling and simulation techniques [8, 10, 14, 16, 29]:

Table 1. Advantages of using modeling and simulation techniques

1. It allows testing every aspect of a proposed change or addition without committing resources to purchase them, so it provides the possibility of a correct choice;
2. It allows to speed up or slow down some phenomena, so that we can analyze them better, thus increasing or decreasing the time required for analysis and testing;
3. The assumptions about the system can be tested for feasibility;
4. It can reconstruct (play) certain sequences during the simulations, thus managing to understand or find answers to different questions, such as: why?, how?, etc.;
5. Different possibilities, procedures and methods are explored without experiments using real systems;
6. It allows to view a plan which can help us to understand some design flaws;
7. Changes can be made to certain models in a system, if following simulations we want to answer questions such as: "What would happen if?";
8. May experiment with new or unfamiliar situations about which poor/little information is available;
9. Blockages in the flow of entities (materials, people or information, etc.) can be identified;
10. Simulation costs are low, generally 1% of the total amount that would be allocated to implement an entire test plan;
11. It is a good opportunity to train the team interested in developing a project by analyzing the input and output data in the simulation.

Simultaneously, in the activity of modeling and simulation there are a number of disadvantages that represent traps in which we can fall very easily, such as [8, 10, 14, 16, 29, 30]:

Table 2. Disadvantages of using modeling and simulation techniques

1. Simulation can be used ineffectively, when the analytical method can more easily solve the problem;
2. The simulation model is too complex or too simple;
3. Undocumented assumptions. This is extremely important to be analyzed at each stage of the simulation model, and by analyzing the simulation we ensure that the assumptions are thoroughly documented;
4. Simulation results can be misinterpreted (often simulation results are random variables and it is difficult to determine whether an observation is a system result or a random value);
5. Simulation of built models and subsequent analysis can be time-consuming and expensive. Skimping on modeling and analysis resources can lead to insufficient simulation to achieve the intended goals and thus consume time, effort and money without achieving the intended objective;
6. Running a single simulation for a configuration;
7. Allocating a time resource after a poorly thought out schedule and bad budget planning;
8. Poor communication among staff involved in the simulation study.

Weighing the advantages, disadvantages and pitfalls of modeling and simulation, we can finally appreciate that this activity represents an effective way to test and evaluate different activities/systems, of course the analysis is done for each individual case.

3.4. Analysis of research activities through modeling and simulation of maritime industry processes

Modeling and simulation tools have been used in the study of ports, port terminals and the maritime industry in general since the mid-20th century. Nowadays, they represent an indispensable tool in the planning and design stages of terminals as well as in their daily management. However, the new technological revolution that started a decade ago, industry 4.0, is on the upswing in the implementation of "frontier technologies" such as artificial intelligence (AI), robotics, biotechnology and nanotechnology. This, of course, brings a series of advantages and disadvantages for each industry, but also for the safety of global economies. Making a brief parenthesis on these advantages and disadvantages of industry 4.0, this industry has left its mark with enormous benefits - highlighted dramatically in 2020 by the accelerated development of vaccines against the coronavirus, but at the same time a number of disadvantages such as the existence of fears about job cuts, the inability of developing countries to keep up with this industry and the fact that industry 4.0 is in full swing, these countries are being overwhelmed or simply left behind. [31, 32]

Starting from this context, the maritime industry is also facing problems due to these technological developments also known as the Internet of Things (IoT) where the digital and physical worlds converge and which have defined a new generation of smart ports or ports 4.0. This process naturally generated new challenges and opportunities for port managers, port users, port service providers and other components of port processes. Modeling and simulation as means to optimize these processes from different points of view as well as the interconnectivity of systems should play a relevant role in this new era and it is imperative that modeling and simulation tools join this wave and evolve accordingly. [2, 4, 9, 33]

Modeling and simulation activity in the maritime industry began taking shape in the early 2000s, with the development of information technology, through the use of modeling and simulation software such as: ProModel, Simple++, Visual SLAM, Taylor II, Witness, the languages of programming: C++, ProModel, Delphi, Pascal, etc. and to this day, this side being constantly improved.

4. Results

In order to have an approach that is as easy to understand as possible for a manager/engineer responsible for the improvement/optimization of processes within a port terminal, a beginner in the field of modeling and simulation, following the study of the specialized literature and the novelties appearing in the specialized software market, this paper answers the initiation questions in this field and shows him which are the most used software for modeling and simulating some processes in the maritime industry. In table no. 3, a presentation of these modeling and simulation software solutions used in the maritime industry by researchers in this field is concretized, as follows:

Table 3. The main software used in the research activity through modeling and simulation of processes in the maritime industry

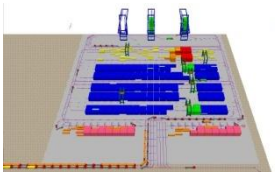
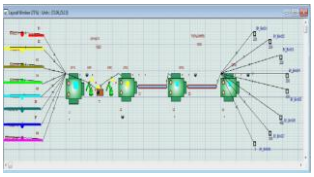
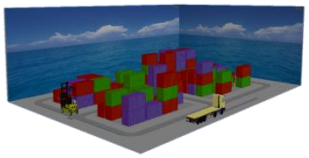
Simulation tool		Characteristics
AnyLogic [34, 35, 36, 37,38, 39]		✓ Graphical interface: 2D + 3D ✓ The programming language used: Java
Arena [19, 40, 41, 42, 43,44]		✓ Graphical interface: 2D + 3D ✓ The programming language used: Visual Basic ✓ Data exchange with Microsoft Excel
ProModel [45, 46, 47, 48]		✓ Graphical interface: 2D + 3D ✓ The programming language used: ProModel
Automod [49, 50]		✓ Graphical interface: 2D + 3D ✓ The programming language used: Automod
Witness [51, 52]		✓ Graphical interface: 2D + 3D ✓ The programming language used: Witness, C++
Plant simulation [53, 54, 55]		✓ Graphical interface: 2D + 3D ✓ The programming language used: Simtalk
ExtendSim [56, 57, 58]		✓ Graphical interface: 2D + 3D ✓ The programming language used: Modl

Table 3. The main software used in the research activity through modeling and simulation of processes in the maritime industry

Simulation tool		Characteristics
Flexsim /FlexTerm [59, 60, 61, 62]		✓ Graphical interface: 2D + 3D ✓ The programming language used: C++
Chesscon [63, 64, 65]		✓ Graphical interface: 2D + 3D ✓ The programming language used: Java

Following the analysis of 59 studies from the specialized literature, which used modeling and simulation software of naval industry processes as research methods, exemplified in table no. 3, the results obtained in the representation from figure no. 7.

As can be seen in figure no. 7, the modeling and simulation activity of various process problems in the maritime industry is mainly focused on the research of the following 6 areas: container terminal; bulk terminal; the Ro-Ro terminal; technical-nautical services; naval traffic; as well as other areas such as: passenger ship services, canal and strait transit, barge fleet management, port operations in crisis conditions, etc.

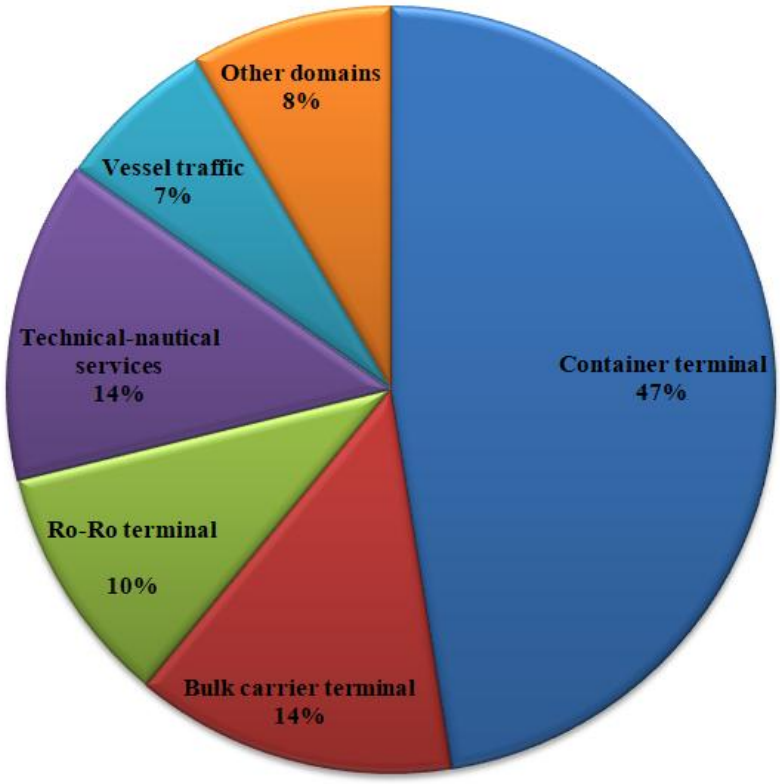


Figure 7. Proportionality of areas in the naval industry researched using modeling and simulation tools

As can be seen, the research activity through modeling and simulation has left its mark the most on the problems in the container terminal, and in 2nd place is the bulk terminal. One of the main reasons why the container terminal is at the top of research with the help of modeling and simulation tools is the fact that it has a much more complex structure than other terminals and also recently, in the context of the Covid-19 pandemic, which had implications on the education and development of online commerce, containerized traffic has increased quite a lot, many container terminals facing the problem of space and management of these terminals, even reaching blockages of shipping goods with container ships.

The software most used in the study of the processes in the activity in the container terminals were: AnyLogic, FlexTerm and Chesscon.

5. Conclusions and future research directions

This paper answers the questions formulated in the research methodology by highlighting the information and results regarding how to carry out research in good conditions in the field of modeling and simulation of processes in the maritime industry, accessing a vast specialized literature in the field, most of which are open sources. Regarding the sources of information about modeling and simulation software, this paper represents a very easy way to access the most important sources in the field where information can be found regarding the scope of application of each modeling and simulation software, the experience and knowledge needed to be able to carry out a research in the field, examples of results obtained with the help of these softwares and so on. It should also be noted that most software can also provide consultancy for researchers/managers/users in the activity of modeling and simulating a process or several processes for an optimization analysis of the overall specialized terminal.

As future research directions, given a global port with different development strategies, it is possible to analyze the processes of all types of terminals and improve/optimize certain processes using the software proposed in this study, thus benefiting from the advantages of modeling and simulation in such cases to find the best solutions to implement within the specialized terminal/company. It is proposed to study all the aspects related to the good practices encountered in the terminal chosen for the study, the analysis of the problems associated with the storage of goods in the terminal, the optimization of the processes of docking and departure of ships from the quay – analysis of the problem of berth allocation (BAP), unloading and loading of goods from/to the ship, management of stacking of containers, waiting times for the transport of goods in multimodal system, etc.

The next step in the development of research within a specialized terminal is the proposal to choose a process, from those listed above or another one identified in the field research, which will be studied with the help of a modeling and simulation software presented in this paper with the aim of to be improved. If the results of the software, following the proposed measures, will be positive and of course following the validation of the results in the chosen terminal, they will be able to be implemented as solutions to improve the general activity, with the approval of the general manager of the terminal/company.

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