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An Integrated Quay Crane Assignment and Scheduling Model in a Maritime General Cargo Terminals Considering Stochastic Weather Condition & Learning Effect

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Article

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Abstract

As the maritime industry grows rapidly in size, more attention is being paid to to a wide range of aspects of problems faced at ports with respect to the efficient allocation of resources. A very important seaside planning problem that has received large attention in literature lately is the quay crane scheduling problem (QCSP). The problem involves the creation of a work schedule for the available quay cranes at the port to vessel or given set of vessels. These optimization problems can be very complex and since they involve a large number of variables and constraints, the use of a commercial solver is impractical. In this paper, we reformulate a problem that can be solved by column generation. Finally, the proposed model was coded and solved by the exact solver GAMS 25.0 and evaluated by some evident examples. Also in view of theoretical challenges, and industrial implicating a genetic algorithm is proposed to solve the problem. The performance of proposed algorithm is evaluated by a number of numerical example. Finally, computational results show that the proposed algorithm significantly outperforms.

1. Introduction

The increasing development of world trade has increased cargo transportation on a large scale. There are three ways of land, sky and sea to transport cargo between different parts of the world. Ground transportation is mainly carried out by heavy vehicles and rail lines, which makes land transportation less attractive than sea transportation due to the high cost of road transportation such as trucks and the limitations of building railway lines in long distances (inter-country) [1]. Also, air transportation has a very high cost and in most cases it is effective for transporting precious, essential and small goods. Considering that 65% of the earth is made up of water and many countries have water borders and the cost of this type of transportation is much lower compared to other types, it has made countries highly interested in the development and increasing use of maritime transportation [2].

The high traffic rate of commercial ships in ports and the high volume of goods unloaded from ships or loaded onto ships require detailed planning and comprehensive coordination so that operations can be carried out correctly and with high precision, with the least amount of time on the ships, as well as the waiting time in their queues [3]. This issue becomes more difficult when all kinds of bulk and container cargoes are imported into a port terminal, some of which are sensitive to certain weather conditions and it is not possible to load and unload them in adverse weather conditions [4]. In this research, we are looking for a solution for better planning of this type of coastal ports. In the rest of this chapter, we will explain the problem in full.

1.2 Define the problem

Global trade, particularly influenced by the shipping industry, plays a fundamental role in the global economy. Maritime transport covers about 90% of the world's commercial transport, which is increasing day by day [5]. This ever-increasing growth has made smaller ports and cargo ports to be of great importance in addition to ports and container terminals. An efficient and effective terminal enables faster loading and unloading to serve more ships [6].

Port operations include a hierarchy of activities that require accurate planning and implementation of programs to achieve the maximum amount of unloading and loading. In general, port operations are divided into two parts: coastal operations and warehouse operations [7]. Coastal operations are such that, according to the time of the ship's arrival at the port, a berth is assigned to it, where unloading and loading operations will be carried out. Then the cranes should be assigned to that ship to carry out unloading or loading operations, the unloading and loading operations will also be carried out by shore cranes based on a schedule, and the unloaded cargo will be transferred to the intended environment or warehouses to perform administrative and customs formalities [8].

Considering the nature of the cargo entering the cargo terminals, such as paper and grain, and the sensitivity of these types of items to rain, the parameter of the weather condition should be considered in these types of issues, considering that in the real world, the weather condition cannot be considered definitively. taken, it is assumed that this parameter is possible [9].

Also, due to the difference in the size and type of cargo entering the cargo and container terminals and the involvement of manpower in unloading and loading, the time required for each unloading/loading cannot be considered fixed. Repetition of similar tasks by the human force will increase their skill in using the equipment and doing the assigned tasks, which will reduce the activity time [10].

Crane allocation issues are generally from the same category as allocation issues, taking into account some additional parameters, such as: agreements made between the port terminal operator and the shipping line operator, the minimum and maximum number of available cranes to be allocated to a ship, the number of usable and operational cranes available [11]. It is in the port terminal and etc.

In the following, we will explain the operation of the terminals to get more familiar with the problem space.

1.3 Research purposes

Reducing the service time for ships, in other words, reducing the time between the arrival and departure of a ship and increasing the efficiency and productivity of resources and equipment are known as the main goals of ports. Given that the cost of building docks and purchasing and using equipment such as cranes is very high, as a result, focusing on optimization Coastal operations are very important.

In this matter, according to the limit of the number of cranes and the expected conditions, it is determined how many cranes should be allocated to each ship and the optimal sequence of activities to achieve the shortest operation time on the ship.

1.4 Assumptions of the problem

In order to design a mathematical model according to the problem under investigation, appropriate assumptions have been presented in accordance with the real conditions governing public terminals, which include the following:

- Cranes are considered similar and their number is also limited, which in reality is usually the same and only changes to load and unload cargo with a different type of extension.
- Each berth has capacity for cranes and ships.
- Weather forecast for different times.

- The possibility of loading and unloading any type of cargo is determined according to the weather at any time.
- There is a specific number of operators required for each type of cargo and one crane. It is considered to be different.
- According to its dimensions, each ship has the capacity of the number of cranes that can operate on it at the same time.
- Carrying out operations on each ship with each type of cargo is different according to the number of assigned cranes.
- The cargo of each ship and the arrival time of each ship are known.
- Each operator can be assigned to a specific crane, dock and ship only when it is his working time and he is present at the shore.
- Operations on all ships must be carried out.

2. Theoretical literature and research background

2.1. Introduction

Today, global trade in the container transport sector has grown and progressed tremendously. The existence of cargo terminals in port cities of the world always affects the lives of many people. Since these ports are equipped with coastal cranes, these cranes need to be planned. Allocation and planning of cranes is directly related to the results of operations and the speed of work of forces, this category becomes particularly important [12]. Weather conditions are also an important variable that should be considered in planning. Man always seeks to optimize and plan his resources, which requires extensive studies in the field under investigation. For this purpose, all the important and effective factors in this matter should be examined in order to be able to provide a workable and useful solution [13].

In this chapter, with the aim of getting familiar with the important issues and challenges in the subject of this research, we will review the literature on the topic of planning and allocation of coastal cranes and the background of the research in two parts of influential researches in this field. For this purpose, concepts such as scheduling and sequence of operations, cargo terminals and genetic algorithm are examined in detail [14]. Then we will state some of the researches that are close to the present topic.

2.2 Theoretical concepts

In order to get more familiar with the concepts examined in this research, these concepts are explained in this section.

2.2.1. Timing and sequence of operations

Timing is a common word in everyday conversation. But the lack of a clear definition of timing in people's minds makes them unable to implement it properly. What is in people's minds is the schedule, such as the schedule for the arrival of the bus, the start of the class, etc., if all the activities are carried out on time and according to the schedule. In the definition of the schedule, it can be said that a tangible and specific plan that is going to be implemented. One of the most important characteristics of a proper schedule is its flexibility. The following are usually caused by changes in programs for various reasons. Operation sequence and scheduling is a kind of decision-making process that has a fundamental role in improving productivity in manufacturing and service industries. In today's competitive world, for organizations, having the best sequence of operations and proper timing of activities is a basic requirement for survival. In today's real world, there is practically no order without a delivery date. The operation sequence and timing can be defined as follows [15].

- Sequence of operations: Determine the order in which operations are processed
- Scheduling: determining the start and end time of operations on resources

In fact, to determine the timing of operations, the sequence of their execution must be determined first. Organizations' need for proper planning in using their limited and valuable resources in order to maximize productivity can be named as the main reason for planning and scheduling the sequence of operations. Scheduling means allocating limited resources to activities that require those resources. In fact, scheduling is a kind of decision-making activity that is done with the aim of optimizing one or more goals [16]. Defined resources and activities can be graphed in several ways as follows:

Sources: machines in a workshop, pilots and flight attendants of an airplane in a flight, flight of an airplane in an airline, processor units in a computing environment, available professors for students applying for a thesis, etc.

Activities: activities needed to prepare a product, take off and land airplanes at airports, different stages of a construction project, run a computer program, guide a lesson project, etc.

Any process may require a prerequisite activity, the earliest possible start time, and a delivery date. In scheduling problems, the goal of finding the sequence of activities may be different. Some of the common goals are:

- Minimization of total completion time (makespan)
- Minimization of the number of tasks completed after due date
- Minimization of total flow time

Scheduling is a decision-making process that has a very important role in production systems and information processors. Scheduling process has many applications in transportation, distribution and other similar service industries.

2.2.2. History of scheduling theory

The history of scheduling dates back to 1950 when Johnson's algorithm was presented to solve the optimization problem of maximum completion time for n jobs and two machines. In 1955 and 1956, for the first time, the basic rules of the earliest delivery date and the shortest process time for the optimal solution of problems for n machines were presented. This method was the basis of many subsequent methods. Gradually, the use of methods such as integer programming, branch and limit, and dynamic programming was noticed, while innovative solution methods were used to solve a number of problems. The discussion of the complexity of scheduling issues has been noticed by a number of researchers. It has been shown that a number of scheduling problems are in the NP-hard category [17].

In recent years, innovative and meta-heuristic methods for solving scheduling problems have been noticed, and studies have been directed towards a more realistic and practical plan. The flow shop scheduling problem is one of the most famous and difficult combinatorial optimization problems. This issue is important from two aspects of management research and combined optimization. Since 1960, it has been proposed as a criterion to evaluate the quality of new optimization techniques, of which the bottleneck transfer method can be mentioned as the most successful. At the same time, an efficient algorithm that can solve this problem in an acceptable time has not been found. Johnson in 1956 and Ballas in 1969 and Jarlton in 1970 and Florin in 1971 worked on the development of state counting methods and their research showed that the speed of progress in this method was very slow, Fisher and Tubson in 1963 problem 10 And they proposed 10 cars. This problem was solved in 1989 by Carlieri. In 1995, Gupta and his colleagues presented a method for minimum and maximum completion time [18].

2.2.3. Definition of timing

Scheduling means allocating resources to activities in such a way as to ensure the completion of these activities at an acceptable time. One of the most famous scheduling models is job shop scheduling, where sets of jobs must be processed on sets of machines. Each task consists of several operations, each of which must be processed at a specific time on one of the machines. The goal is to find the sequence of performing different operations of each task on a set of machines in such a way as to optimize the desired goal in scheduling. Various criteria can be considered for a workshop scheduling problem, including minimizing the maximum completion time and minimizing the maximum discrepancy between delivery date and completion time. Scheduling is a practical problem of allocating resources over time to execute a set of tasks in different situations, but in most cases, the task of scheduling tasks is considered after solving some issues related to the main planning [19].

2.2.4. Scheduling theory

Scheduling theory mainly deals with mathematical models, and establishes a relationship between scheduling work and the development of scheduling models, and continuously tests them with theoretical and practical scheduling issues. The theoretical perspective is predominantly a quantitative approach and its attempt is to achieve the structure of the problem in the form of a mathematical compact form, especially since this quantitative approach starts with the interpretation of decision-making objectives in the form of an explicit objective function and the expression of decision-making obstacles in the form of explicit constraints. The objective function should include all system costs for implementing the scheduling decision. However, when implementing it in practice, it is difficult to measure or even fully specify such costs. In fact, the major operational costs are determined by the planning work [20]. While it is difficult to separate short-term costs. However, there are three types of scheduling decision-making objectives:

A) Efficient use of resources

b) Fast response to demand

c) Exact compliance of delivery times, set delivery dates.

Often, an important cost criterion related to measuring system performance (such as machine idle time, waiting time for late work) can be used as a proxy for total system cost, and few approaches to problems related to these criteria can be found in the existing literature on scheduling. Two types of feasibility constraints usually appear in scheduling problems: First, there are constraints on resource availability. Secondly, there are technological limitations in the order of doing things. Answering any scheduling problem is finding a feasible solution to these two types of constraints, so that "solving" any scheduling problem is equivalent to answering these two questions:

1- Which resource will be allocated to perform each task?

2- When will each task be done?

2.2.5. Sequence of operations

One of the basic and important tasks of management is to establish coordination and control between complex activities and optimal allocation of resources to these activities. In situations where both the allocation of resources and the sequence of performing activities are important, the issue is raised under the title of sequence of operations. In recent years, various quantitative methods have been proposed to deal with such problems. Public workshop scheduling is one of these methods. In this method, the goal is to find the optimal sequence of performing a set of tasks or activities on one or more machines. In workshop scheduling, the main goal is to find that sequence of doing work on machines that optimize some of the evaluation goals. Workshop scheduling problems are classified according to four factors.

A) Work entry pattern: n works arrive at the workshop at the same time and all of them are ready to perform operations immediately.

b) The number of machines that must be operated on, this number is denoted by m.

c) Circulation of the work process through the machine: if all the work have the same circulation through the machines, then the problem is called a flow workshop.

In other words, in the flow workshop scheduling, the number of m machines is arranged in series, each job must be processed on each of these machines. In this environment, all jobs must follow the same path.

d) system evaluation criteria to choose the best sequence of operations.

One of the most commonly used evaluation criteria is the maximum completion time. This criterion indicates the total time required to perform operations on all tasks, or in other words, the maximum time to complete tasks. There are other criteria as well. For example, if d_j indicates the period of time when the completion of the jth task is planned and C_j is the time period when the jth task is actually completed, then L_j=c_j-d_j will be a standard for measuring the amount of delay in the completion of the jth task. . Now, by using this evaluation criterion, the goal can be to determine the sequence of operations that minimizes the average effects in the works [6].

2.2.6. Container transport

In the late 1950s, the first ocean-going container ships were introduced, and container shipping became a serious mode of maritime transportation. Before containerization, most sea freight was placed on pallets and loaded and unloaded by cranes on ships and docks. This method was very time-consuming and the products were moved with high vulnerability. With containers, easy, fast and safe relocation became possible. Containers are metal boxes of standard sizes, with 5 standard lengths being common. 20, 40, 45, 48 and 53 feet. 48 and 53-foot containers are not used in international transport and are instead used for domestic transport. To name the containers, they use the TEU unit, which is equivalent to a container with a length of 20 feet, a width of 8 feet and a height of 6 feet. Also, TEU is an approximate unit. For example, a 45-foot container is called a TEU2 container [21].

At the end of the 20th century, container transportation has seen a noticeable growth, and for this purpose, ships with higher capacities were built, and today the capacity of these ships reaches 15,000 TEU.

2.2.7. An overview of container terminal activities

Generally, container terminals are considered as open systems of material flow with two external ducts. These two canals include the offshore side, which is for unloading and loading ships, and the shore side, which is for loading and unloading trucks and trailers. The container terminal connects these two channels and provides space for storing containers. Containers are either stacked and stored on the chassis of trailers. Under the storage on the trailer chassis, each container is available separately and the transfer in the beach area is done faster. But under bulk storage, containers are stored in several piles and stacks with the height of several containers, and each container is no longer directly accessible. Yard cranes are used to retrieve and move containers in piles [22].

When a ship arrives at the terminal, it first anchors to carry out unloading or loading operations. For this purpose, there are a number of berths in each terminal. Berths have a very high construction cost and therefore their number and length is one of the most important strategic decisions in the terminal that must be addressed at high management levels. A berth decision initiates the movement of containers into or out of storage areas. Clearly, the productivity of the berths directly affects the productivity of the entire terminal, so the decisions of operational levels related to the allocation of berth space for ships are critical [23]. In the next step, when a ship is in the anchorage, unloading and loading operations are carried out. Deck cranes are standard equipment designed for this purpose. Deck cranes are a type of gantry crane with a large iron frame that is placed along the deck and where ships are anchored. This equipment's are usually divided based on the lifting capacity and the size of the containers that can be loaded and unloaded. Today's modern cranes are capable of lifting two 20-foot containers at a time and have a minimum lifting capacity of 40 tons. The speed of moving cranes is also important. Today's cranes have a speed of 60 to 80 meters per minute when carrying cargo. According to the given parameters, it takes about 90 seconds for a professional operator to move a 40-foot container crane [24]. After moorings, deck cranes are the second most expensive equipment in terminals. Another key parameter in these terminals is the number of available cranes. By improving the cranes, the terminals can reduce the stopping time of the ships and increase the efficiency and productivity of the terminal [25].

2.2.8 Terminal transportation optimization methods

The need for optimization using research methods in operations in the container terminal has become an important issue in recent years. It is a fact that transportation, especially in large container terminals, has now reached a level of complexity that requires scientific methods to progress. The effect of simultaneous transportation and optimization methods cannot be evaluated by operation experts for a long time.

Targeted methods are necessary to support decision making. Different concepts of transportation decision rules and optimization algorithms are evaluated by simulation before they are implemented in the real system [26].

Container terminal operation characters require real-time and online optimization and decision-making because most of the processes running in terminals cannot be predicted for a long time. In general, the optimization planning horizon is very short. Some examples prove the fact that although the container data arriving at the terminal by truck may be predetermined by electronic data exchange, the exact time when the container arrives at the terminal is not known. Containers should not be checked for damage at the time of arrival as the predetermined data may be incorrect. Both types of data affect the location of shipments. As the trucks have to move from place to place to the transport points, where the containers are lifted by cranes, the sequence of trucks at the entrance and at the transport points does not need to be the same. Therefore, only those container jobs can have a sequence that are currently free for the transportation of domestic equipment, as the trucks arrive permanently, renewal is required. This can be a similar argument for the train [27, 28]. Although the container data and other positions inside the ship are known exactly ahead of the planning process and allow the sequence of work to be calculated, they often have to be changed due to operational disturbances. Just as the ship is not stationary and its movement is permanent (due to the weather), the containers that are in the wake are not seen by the movement of the crane. The crane driver makes his decision and may load or Change your discharge [29].

The optimization area consists of the opposite and general effective factors, which include: ship planning, storage of supplies and transportation. According to the classification above, this section describes important processes in container terminals that can be optimized by operations research methods.

2.3 Literature Review

Padamitriou et al introduced both dynamic and static deck allocation models. They developed an innovative method based on Lagrangian discounting. They also extended the static model they proposed under the influence of a series of environmental constraints such as water depth and deck length [30]. Kim et al. considered the discrete allocation model and used refrigeration simulation to solve the model [31]. In another research, Petrkovsky and Daganzo proposed a branch-and-bound algorithm to solve the coastal crane scheduling problem. In both of these researches, it was assumed that each ship involved only one activity and the relationships between coastal cranes were not considered [32].

Terminal operation planning has a multi-objective, non-deterministic and complex nature. Most research is focused on optimizing a specific part of the system. There is a very small body of research that has applied planning problems to different equipment and sectors and integrated them together [33]. Berish developed models and algorithms to integrate multiple parts together. This problem includes: 1. Determining the storage location of each container 2. Sending trailers or trucks for incoming containers 3. Scheduling unloading and loading for each crane so that the maximum time spent by the ships is minimized [34].

Terminal programming problem includes different variables and constraints. Therefore, to overcome the complexities of the problem, uncertainty and possible factors should be considered. Therefore, recently, simulation has been widely used in such problems [35]. Discrete event simulation models have advantages over optimization mathematical models, including: covering the limitations of mathematical models, supporting the computerization of policies and strategies and making them comprehensible, and helping the decision maker in making daily decisions using the "what-if" approach. Shabaik and Yang developed a simulation model by witness software for the Wai Chong terminal. Their simulation model was developed with an object-oriented approach and SIMPLE++ software was used [36].

In 2012, Yang et al. considered the interaction between the allocation of cranes to berths and ships to berths. designed a mathematical model aimed at minimizing the service time of ships arriving at the shore and solved it with an evolutionary algorithm with inner loops [37]. In 2013, Ansal et al. modeled the constraints that exist in real-life onshore terminals using constraint programming. Margins of safety, travel time and relationships of precedence and delay are among these limitations. They also considered different time windows in this planning. The performance of this model has been evaluated compared to the models presented in previous studies, which shows that it produces more favorable and stronger results than them [38].

In 2016, Turkoghleri et al. examined berth allocation, berth crane allocation and crane planning in an integrated manner. presented a mixed integer linear programming considering the loading time of the ships along with their crane scheduling during their stay at the shore. The purpose of this model is to minimize all the costs of loading and unloading ships. Then, in order to solve the model, they used the brush plates method [39]. In 2017, Agra and Oliveira presented a mathematical model using the formulation of relative position in order to solve the problem of scheduling and allocation of cranes in an integrated manner. This model is designed in the presence of heterogeneous cranes. Then another mathematical model is presented to complete the planning process. Then they solved this model using the innovative method of rolling horizon optimization [40].

3. Methodology

3.1. Introduction

Considering the importance of the topic that has been discussed before and many researches have been investigated in this field. In this chapter of the research, taking into account the actual conditions of the coasts and wharves to which all kinds of bulk and container cargoes are sent, we have expressed the problem and assumptions. Then, according to these assumptions, a single-objective mathematical programming model is presented. It has been tried to include all the determining and important parameters and variables in this model, the output of which is the optimal planning of coastal ports according to the weather, types of cargo, cranes and human resources.

3.2. Proposed model

In this section, the proposed mathematical model for the investigated problem is presented. Before presenting the model, the characteristics used in the model, input parameters, decision variables, limitations and its objective function are discussed:

Table 1 Characteristics used in the proposed model

i	**Index related to the number of cranes.**
j	Index of the dock.
t,h,ţ	Time period index.
v	Ship index.
s	Index related to the type of cargo.
o	Operator index.

Table 2 Input parameters

d_{iv}	Time required to load or unload ship v with i number of cranes.
A_v	Ship arrival time v.
w_s^t	1 if the weather is suitable for cargo type s in time period t and 0 otherwise.
g_s	The number of manpower required per crane for the type of cargo s
q_o^t	If in the time period t the working time of operator o is 1 and otherwise 0.
U_{vs}	1 if the cargo of ship v is of type s and zero otherwise.
l_v	The maximum number of cranes that can operate on the ship v at one time.
c_j	The capacity of the number of cranes in the wharf j.
b_j	The capacity of the number of ships in the wharf j.
N	Total number of available cranes.
T	The entire planning period.
M	big number.

Table 3 Decision variables

X_{ijvs}^{t}	If the unloading or loading operation of vessel v with cargo s starts with i number of cranes at berth j at time t 1 otherwise zero.
Y_{ijvs}^{t}	If the unloading or loading operation of vessel v with cargo s with i number of cranes is in progress at berth j at time t 1 otherwise zero.
F_{ojvs}^{t}	1 if operator o is used to load ship v with cargo s at berth j at time t otherwise zero.
P_{vs}	1 if the loading operation of ship v for product s is finished, otherwise zero.

Mathematical model

$$Min\ Z = \sum_{v=1}^{V}\left(\sum_{s=1}^{S}|t|\,P_{vs} - A_v + 1\right) \qquad (1)$$

$S.t$

$$\sum_{s=1}^{S}\sum_{i=1}^{I}\sum_{j=1}^{J} X_{ijvs}^{t} = 0 \qquad \forall v, t = 1, \dots, A_v - 1 \qquad (2)$$

$$\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{t=A_v}^{T} X_{ijvs}^{t} = U_{vs} \qquad \forall v, s \qquad (3)$$

$$\sum_{o=1}^{O} F_{ojvs}^{t} \leq M * \sum_{i=1}^{I} Y_{ijvs}^{t} \qquad \forall t, j, v, s \qquad (4)$$

$$Y_{ijvs}^{t} \leq \sum_{h=1}^{t} X_{ijvs}^{h} \qquad \forall i, j, v, s, t \qquad (5)$$

$$\sum_{t=1}^{T} Y_{ijvs}^{t} = d_{iv} * \sum_{t=1}^{T} X_{ijvs}^{t} \qquad \forall i, j, v, s \qquad (6)$$

$$\sum_{i=1}^{I}\sum_{v=1}^{V}\sum_{s=1}^{S} |i| Y_{ijvs}^{t} \leq c_j \qquad \forall t, j \qquad (7)$$

$$\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{v=1}^{V}\sum_{s=1}^{S} |i| Y_{ijvs}^{t} \leq N \qquad \forall t \qquad (8)$$

$$\sum_{i=1}^{I}\sum_{j=1}^{J} Y_{ijvs}^{t} \leq w_s^{t} \qquad \forall t, s, v \qquad (9)$$

$$\sum_{o=1}^{O} F_{ojvs}^{t} \geq \sum_{i=1}^{I} |i| g_s Y_{ijvs}^{t} \qquad \forall t, j, v, s, t \qquad (10)$$

$$\sum_{j=1}^{J}\sum_{v=1}^{V}\sum_{s=1}^{S} F_{ojvs}^{t} \leq q_o^{t} \qquad \forall t, o \qquad (11)$$

$$\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{s=1}^{S} |i| Y_{ijvs}^{t} \leq l_v \qquad \forall t, v \qquad (12)$$

$$\sum_{i=1}^{I}\sum_{v=1}^{V}\sum_{s=1}^{S} Y_{ijvs}^{t} \leq b_j \qquad \forall t,j \qquad (13)$$

$$d_{iv} * \sum_{h=1}^{t} X_{ijvs}^{h} - \sum_{h=1}^{t} Y_{ijvs}^{h} \leq M * (1 - w_s^{t+1}) + M * Y_{ijvs}^{t+1} \qquad \forall t,i,j,v,s \qquad (14)$$

$$M * \left(Y_{ijvs}^{t+1} - 1\right) \leq d_{iv} * \sum_{h=1}^{t} X_{ijvs}^{h} - \sum_{h=1}^{t} Y_{ijvs}^{h} - 1 \qquad \forall t,i,j,v,s \qquad (15)$$

$$|t| * Y_{ijvs}^{t} \leq P_{vs} \qquad \forall t,i,j,v,s \qquad (16)$$

$$X_{ijvs}^{t}, Y_{ijvs}^{t}, F_{ojvs}^{t} \in [0,1]\ , P_{vs}\ is\ Integer \qquad \forall t,i,j,v,s,o \qquad (17)$$

3.3. Model description:

Function (1) is the objective function of the model. This function seeks to minimize the time interval between the arrival of the ship and the end of the loading and unloading operations. The first term of this function means ∑_(t=1)^T▒ 〖|t|.P_vt 〗 calculates the time spent until the end of the operation on each ship and A_v is the time when the ship reaches the shore of the operation. Therefore, their arrival time A_vs should be subtracted from the time of the end of the operation, and since the time period of the ship's arrival is also calculated apart from the time of its presence on the beach, one has been added, thus the time between arrival and departure is obtained. Limitation (2) is for the purpose of not starting operations on any ship before its arrival. Constraint (3) requires that unloading or loading operations be carried out for all ships entering the shore according to the type of cargo. Constraint (4) ensures that an operator is assigned to the ship only if the operation is active on the ship in each period, and no operator is assigned to it otherwise. Constraint (5) means that if the activity is being performed on the crane in a period, the operation must have started before that. Constraint (6) guarantees that the number of activity periods on each ship is equal to the time required to load or unload it. Constraint (7) ensures that the number of active cranes in each berth does not exceed the capacity of that berth. Constraint (8) ensures that the number of active cranes in each period does not exceed the total number of cranes on the beach. Limitation (9) requires that the operation on the cargo should be carried out according to the weather conditions and if the weather is not suitable for the operation on a cargo, the operation on that particular cargo should not be carried out during that period. Limitation (10) of the model requires that the number of operators assigned to one ship at any time according to the number of cranes assigned to it is not less than the required number. Constraint (11) means that in each period only operators can be assigned to activities that are available during their working time. Limitation (12) is to comply with the limit of the number of cranes that can operate on a ship at the same time. Constraint (13) requires that the number of vessels operating on each berth does not exceed the capacity of the berth. Constraints (14) and (15) create the conditions that if after the start of the operation on a cargo, the weather becomes unsuitable for that type of cargo during that period, the operation is stopped and then after the weather becomes suitable for the period The operation is initiated to completion. Constraint (16) is also used to determine the final period of operation on each ship. In constraint (17), the type of variables of the problem is determined.

4. Proposed meta-heuristic algorithm and calculation results

In this section, the way to display the answers is examined. In the assumed model, the solution of the problem is represented by a two-dimensional matrix. This matrix has 3 rows and has columns for the number of shipments. The first row shows the crane assigned to each ship to unload its cargo inside the berth. The second line shows the berth assigned to the cargo of each ship to discharge its cargo. And the numbers inside this line are the berth numbers. The third line shows the start time of the unloading operation, and the numbers in this line are the start time of the activity. In the following, how to display the answer and algorithm operators and how to generate the initial population for the problem with the specifications of 4 cargoes, 5 crane centers and 3 docks and 5 time periods are presented. The way to display the matrix of this problem is shown as an example in table (4).

Table 4 showing the answer for 4 cargoes, 5 crane centers and 3 docks and 5 time periods

	Cargo1	**Cargo2**	**Cargo3**	**Cargo4**
Crane No	**2**	**3**	**2**	**1**
Berth No	**2**	**1**	**2**	**3**
Evacuation start time	**3**	**1**	**1**	**2**

As mentioned above, the Chromosome shows the planning of the discharge of the products of the ships. The first line shows the assigned crane, the second line shows the assigned berth, and the third line shows the unloading start time. For example, the first cargo starts to be unloaded by crane No. 2 at berth No. 2 in the third period.

4.1. How to generate the initial population?

First, a random sequence of shipments is generated. Then, based on the limitations, the problem and the time limit required for loading or unloading the ship, the limitation related to human power, the capacity of the number of cranes in the wharf and the capacity of the number of ships in the wharf and other side restrictions for each crane cargo, wharf and start time are randomly determined. At the end, the objective function is calculated.

4.2. Mutation and intersection operator and stopping condition of genetic algorithm

In genetic algorithms, there is mixing by nature. Mixing is done by exchanging genes between two chromosomes, and each of the chromosomes transmits its own characteristics to the children. It is obvious that the chromosomes that have more fitness have a higher chance of mixing. The most important operator in the genetic algorithm is the intersection (combination) operator. Crossover is a process in which the old generation of chromosomes are combined with each other to create a new generation of chromosomes. The pairs that were considered as parents in the selection part exchange their genes and create new members. Intersection in the genetic algorithm causes the loss of dispersion or genetic diversity of the population. Because it allows good genes to find each other. This type of crossover operator always makes the produced children to be legal (that is, it is never possible to produce chromosomes that do not correspond to any member of the solution space). Common methods are single-point displacement, two-point displacement, multi-point displacement, and uniform displacement. The simplest mode of moving is single-point moving. In single-point translocation, first the parent chromosome pair (binary strand) is cut at a suitable point along the length of the strand, and then the parts from the cut point are exchanged. In this way, two new chromosomes are obtained, each point of which inherits genes from the parent chromosomes. For the genetic algorithm for the chromosome of the problem, the single-point intersection operator is used for combination:

$$ch_1 = round\,(Paret_1(1:Alpha) + Paret_2(1+Alpha:N\ ))$$
$$ch_2 = round\,(Paret_2(1:Alpha) + Paret_1(1+Alpha:N\ ))$$

which $Paret_1\ t \quad er_2$ is the selected parent and alpha is a cut point between the number 1 and $ch_1 h \quad _2$ the number of columns of the matrix and are the resulting children. This operation is schematically presented below: (the $Alpha$ value is equal to 3).

Table 5 Intersection Operator

$Paret_1$					**First child**			
1	**2**	**3**	**2**		**1**	**2**	**1**	**4**
3	**2**	**1**	**2**	→	**3**	**2**	**2**	**3**
2	**1**	**1**	**3**		**2**	**1**	**3**	**4**
$Paret_2$					**Second child**			
2	**3**	**1**	**4**		**2**	**3**	**3**	**2**
2	**1**	**2**	**3**	→	**2**	**1**	**1**	**2**
1	**2**	**3**	**4**		**1**	**2**	**1**	**3**

The Swap operator is also used for the mutation operator. That is, the two cargoes are selected and the dock, crane and their assigned unloading start time are moved.

Table 6 Mutation operator

$Paret_1$					**Child**			
1	**2**	**3**	**2**		**3**	**2**	**1**	**2**
3	**2**	**1**	**2**	→	**1**	**2**	**3**	**2**
2	**1**	**1**	**3**		**1**	**1**	**2**	**3**

For example, in the example above, the specifications of shipment number 1 and assignment number 3 have been moved. The stop condition in the presented algorithm is equal to the maximum number of repetitions of the algorithm. Also, the selection process is in the roulette cycle algorithm. At the end, after performing the jump operation and combining the limitations related to the time required to load or unload the ship, the limitation related to human power, the capacity of the number of cranes in the wharf and the capacity of the number of ships in the wharf and other side restrictions are checked and if any of the restrictions If the chromosome is violated, it will be corrected. And the chromosome is restored to its normal state.

4.3. Parameter setting and specification of sample problems

Since the proposed model is new, according to the researches, there is no standard sample problem for the proposed problem, the randomly generated sample problems are used to solve the proposed algorithms. In this research, 15 problems according to table (7) were used to generate the answers. Also, the parameters related to the problem were randomly generated in order to evaluate the performance of the proposed algorithms, and the uniform distribution function was used to generate numbers. Also, the scope of generating parameters according to the available articles in this field for the considered proposed algorithms is presented in Table (8). Also, the probability of occurrence of each scenario is selected so that the sum of the probability of occurrence of scenarios is equal to 1.

Table 7 Details of solved problems

No	Pier	Crane	Ship	Cargo	Operator	Period
1	3	4	4	2	2	5
2	3	4	5	3	4	5
3	3	5	8	5	6	6
4	3	6	10	5	8	6
5	3	6	12	5	8	8
6	4	8	15	8	10	8
7	5	10	18	8	10	10
8	7	15	20	10	12	10
9	8	15	25	10	12	12
10	10	18	28	12	15	12
11	12	20	30	12	18	15
12	15	25	35	15	20	15
13	18	25	40	15	22	18
14	20	30	45	18	25	20
15	20	35	50	20	30	22

Table 8 Probability distribution functions for generating parameters

Criteria	$U(a, b)$
d_{iv}	Uniform (1, 0.75*T)
A_v	Uniform (1, T-d_{iv})
w_s^t	Integer Uniform (0, 1)
g_s	Uniform (1, 3)
q_o^t	Integer Uniform (0, 1)
$\sum_s U_{vs} = 1$	Integer Uniform (0, 1)
l_v	Integer Uniform (2, 4)
c_j	Integer Uniform (0.25*N, 0.5*N)
b_j	Integer Uniform (0.3*v, 0.7*v)

In this section, the parameters used in the proposed genetics, which include the initial population, mutation rate, combination rate, and the number of repetitions in each of the execution times of the model, are adjusted. To adjust the parameters of the proposed algorithms, Taguchi experiments design method has been used. Four factors of initial population number, maximum number, mutation coefficient and displacement coefficient are considered for the genetic algorithm method. Also, the criterion of the value of the objective function is considered as the response criterion. Also, three levels are considered for each factor as follows.

Initial population: 50, 40, 60

Maximum number of repetitions: 50, 150, 200

Displacement coefficient: 0.7, 0.8, 0.9

Mutation coefficient: 0.3, 0.2, 0.1

In the Taguchi method, the S/N criterion is used. This measure shows the amount of changes occurred in the response variable. For each factor, the optimal level value is the one whose S/N criterion value is higher, so according to table (9) for all four factors of the primary population, the maximum number of repetitions, intersections, and mutations in the order of the second level (50) , second level (150), second level (0.8) and second level (0.2) are the best values.

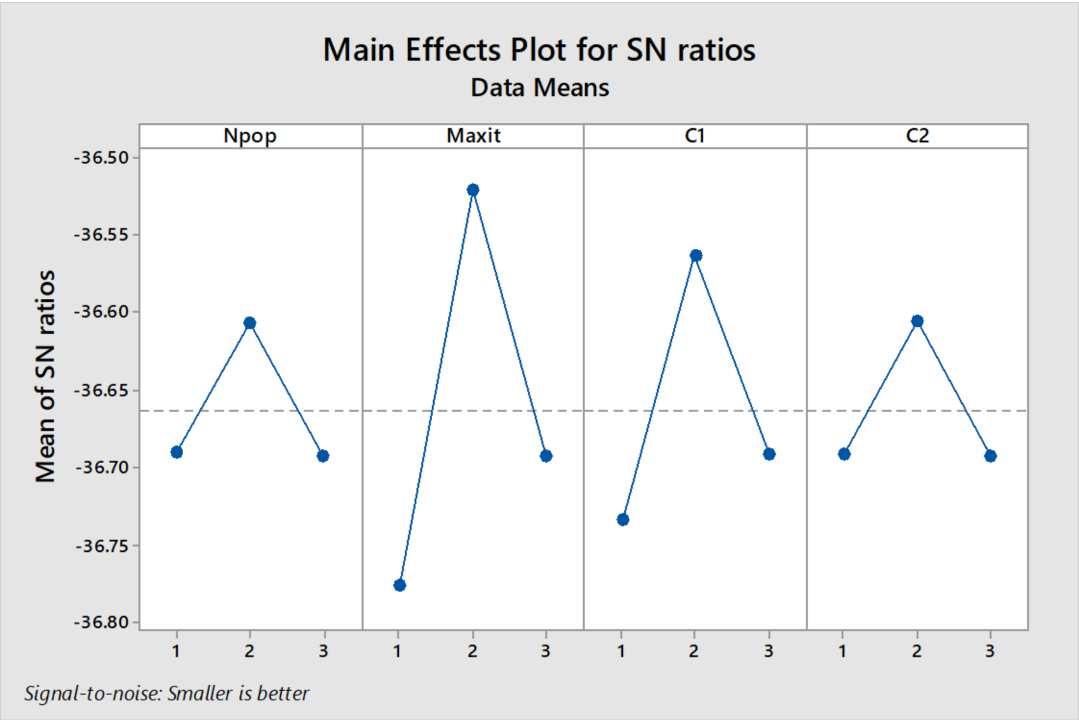

Figure 1 S/N rate for genetic algorithm coefficients

Table 9 The results of setting the parameters of the genetic algorithm

The number of iterations of the algorithm	Primary population	Composition rate	Mutation rate
150	50	0/2	0/8

4.4. Computational results of the proposed algorithm

In this part, the calculation results of the examples solved with the proposed algorithm are presented in table (7). This algorithm is programmed in MATLAB version 2013b. In these tables, the first column of the problem number is based on table (4). In the second and third columns, the optimal value of the objective function and the problem solving time obtained from the Gems software, and in the fourth and fifth columns, the optimal value of the objective function and the time per 10 executions for the genetic algorithm are presented. Also, considering that the solving time of the games software increases exponentially with the increase in the size of the problem. The maximum solution time considered for GEMS software was considered to be 9000 seconds, so this time is the best solution reported by GEMS software. After calculating the objective functions, the sample problems are solved by Gems software and genetic algorithm. In the following, the value of the relative difference resulting from the problem for the objective function of the algorithm is calculated for each sample problem in the last column of the table (10). The value of RPD is calculated based on the formula ((metaheuristic - best answer))/(best answer).

Table 10 The results of the proposed algorithms

	Gamez		**Genetic algorithm**		**RPD**
problem	**The objective function**	**Running time (seconds)**	**The objective function**	**Running time (seconds)**	**The objective function**
1	8	3	8	6	0
2	16	7	16	10.2	0
3	31	15	16	17	0
4	22	26	31	21.7	0.045
5	63	47	66	36.6	0.048

6	78	194	81	41.3	0.038
7	104	853	111	60.1	0.067
8	114	1203	123	79.9	0.079
9	150	3395	160	126.8	0.067
10	161	4381	176	239.9	0.093
11	144	8627	154	332.3	0.069
12	231	9000	251	590	0.087
13	266	9000	287	656.4	0.079
14	378	9000	416	1018.6	0.101
15	517	9000	581	1250.6	0.124
Average	152.2	3650.1	165.6	299.2	0.06

4.5. Variance analysis of algorithms evaluation

In order to better evaluate the algorithms, it is necessary to compare the algorithms with the help of statistical analysis. As mentioned, we have used hypothesis testing technique in this area. In this research, we have used the test of the equality of the mean of three two-way societies (Tukey's test). So that we considered the null hypothesis to be equal to the averages of the evaluation criteria in the algorithm with a confidence level of 95%. If the obtained P-Value is smaller than 0.05 (1-0.95), the null hypothesis is rejected and we conclude that there is a significant difference between the performance evaluation criteria of the three algorithms and vice versa. In this research, two evaluation criteria have been investigated. The first criterion of the value of the objective function and the second criterion of the solution time of the algorithm are compared.

Table 11 Statistical characteristics related to the seven investigated criteria for both algorithms in small size

	SECTION	N	Mean	Std. Deviation	Std. Error Mean
CPU Time	Gams	15	152.2000	144.32216	37.26382
	GA	15	165.2000	161.48985	41.69650
Objective Fu.	Gams	15	3650.0667	4066.54589	1049.97763
	GA	15	299.1600	399.64729	103.18849

In table 12, the third column (Sig. (2-tailed)) shows the p-value. On the other hand, two p-values have been calculated for each criterion. The first one is used when the desired standard deviation is equal for both communities, otherwise, the second p-value should be used. As it is known, the p-value for the objective functions is equal to 0.812 and this value is more than 0.05. As a result, there is no significant difference in the 5% error and the performance of the two algorithms in this error value is almost the same, that is, the results of the resulting objective function There is no significant difference from the genetic algorithm with the performance of GEMS, although the results obtained from GEMS are better than the genetic algorithm, but this difference is not significant. The p-value for computing time is equal to 0.004 and this value is less than 0.05. As a result, there is a significant difference in the 5% error and the computing time of genetics is significantly lower than Gems. That is, the results of the objective function obtained from the genetic algorithm do not have a significant difference with the performance of Gomes, although the calculation time obtained from Gomes is significantly more than that of the genetic algorithm, which means that the genetic algorithm obtains a solution close to the optimal solution with much less delay.

Table 12 The test of the assumption of equality of means for seven criteria

		t-test for Equality of Means						
		t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference: Lower	Upper
CPU Time	Equal variances assumed	-0.240	28	0.812	-13.400	5592.129	-127.94957	101.1495
	Equal variances not assumed	-0.240	27.6	0.812	-13.400	5592.129	-128.01425	101.2142
Objective Fu.	Equal variances assumed	3.176	28	0.004	3350.90	1055.035	1189.7634	5512.049
	Equal variances not assumed	3.176	14.2	0.007	3350.90	1055.035	1092.0956	5609.717

Table 13 P-value calculated for criteria for issues

	(P-value)
CPU Time	0.004
Objective Fu.	0.812

5. Conclusion

Today, with the development of global trade and the exchange of goods around the world, ships are one of the most important vehicles for transporting goods between countries and sometimes even between different cities. Since air and rail transportation have high costs for transporting goods, sea transportation is a priority for countries that have good water borders. Therefore, we can understand the importance of the location of shipping ports and their high capacity. Also, the delay of a ship to load and unload its cargo in the port can involve a lot of costs. These factors make the planning of shipping ports an important challenge that researchers have also solved these challenges in their studies. The special climatic conditions of the ports, which are very variable, and the existence of different types of goods and materials that are transported by ship and must be loaded and unloaded in these ports are an important challenge. In this research, focusing on this issue, we have sought to provide a model to solve this challenge. Some goods cannot be loaded and unloaded in some weather conditions. Therefore, some prerequisites should be made, such as an accurate forecast of the weather in the ports, in order to determine at what time of day the weather is rainy, sunny, or even snowy.

In this research, using this information, we have presented a model that can provide proper planning for a commercial port where ships with different volume and type of cargo come to it, so that the loading and unloading of ships is done as soon as possible and with the least delay. Also, the cargoes should not be loaded and unloaded in bad weather so that the ships suffer the least loss due to delay time and cargo loss. Also, this model is designed in such a way that if the weather becomes unsuitable for that cargo during the operation at one hour, the operation can be left half-finished and the operation can be carried out on other ships, and then the half-finished operation can be completed after the weather conditions are suitable. delivered Until this research, this issue has been raised in the literature review as a challenge that has not yet been addressed in a study.

In the initial parts of the research, the research gap was determined by examining previous theories and researches and recognizing the important aspects of the problem. In the following, by presenting the exact assumptions that represent the conditions of the problem in the real world, a mathematical model was presented in order to optimally plan the loading and unloading of ships in the port.

Due to the size of the problem, the presented mathematical model is an NP-hard model. After solving the model, an innovative genetic algorithm according to the mathematical model of the research was presented. This algorithm was implemented for 15 problems in small, medium and large dimensions, which shows the significant difference in the solution time of the proposed algorithm compared to the method. As it was stated in the third chapter, the solution time in the large dimensions of the problem in the proposed algorithm has been greatly reduced, and despite this, the optimal value does not show a significant difference with the exact solution of GMAS, which is an indication of the efficiency of the genetic solution algorithm in this problem.

Referencess

1. Rodrigue, J.-P., *The geography of transport systems*. 2020: Routledge.
2. Wensveen, J.G., *Air transportation: A management perspective*. 2018: Routledge.
3. Toscano, D. and F. Murena, *Atmospheric ship emissions in ports: A review. Correlation with data of ship traffic.* Atmospheric Environment: X, 2019. **4**: p. 100050.
4. Castelein, B., H. Geerlings, and R. Van Duin, *The reefer container market and academic research: A review study.* Journal of Cleaner Production, 2020. **256**: p. 120654.
5. Jugović, A., N. Komadina, and A. Perić Hadžić, *Factors influencing the formation of freight rates on maritime shipping markets.* Pomorstvo, 2015. **29**(1): p. 23-29.
6. Acciaro, M. and A. McKinnon, *Efficient hinterland transport infrastructure and services for large container ports.* 2015.
7. Le Tixerant, M., et al., *How can Automatic Identification System (AIS) data be used for maritime spatial planning?* Ocean & Coastal Management, 2018. **166**: p. 18-30.
8. Levander, O., *Autonomous ships on the high seas.* IEEE spectrum, 2017. **54**(2): p. 26-31.
9. Vermesan, O. and P. Friess, *Internet of things applications-from research and innovation to market deployment.* 2022: CRC Press.
10. O'Brien, K., et al., *RNA delivery by extracellular vesicles in mammalian cells and its applications.* Nature reviews Molecular cell biology, 2020. **21**(10): p. 585-606.
11. Jiang, X.J. and J.G. Jin, *A branch-and-price method for integrated yard crane deployment and container allocation in transshipment yards.* Transportation research Part B: methodological, 2017. **98**: p. 62-75.
12. Abdullah, A.-Q., *MSc Port Management 2018.*
13. Sharma, U., T. Loreman, and C. Forlin, *Measuring teacher efficacy to implement inclusive practices.* Journal of research in special educational needs, 2012. **12**(1): p. 12-21.
14. Bierwirth, C. and F. Meisel, *A follow-up survey of berth allocation and quay crane scheduling problems in container terminals.* European Journal of Operational Research, 2015. **244**(3): p. 675-689.
15. Schuler, R. and S.E. Jackson, *Human resource management and organizational effectiveness: yesterday and today.* Journal of Organizational Effectiveness: People and Performance, 2014. **1**(1): p. 35-55.
16. Cohen, S. and J. Roussel, *Strategic supply chain management: the five disciplines for top performance*. 2013: McGraw-Hill Education.
17. Chauhan, C., R. Gupta, and K. Pathak, *Survey of methods of solving tsp along with its implementation using dynamic programming approach.* International journal of computer applications, 2012. **52**(4).
18. Kowsari, K., et al., *Text classification algorithms: A survey.* Information, 2019. **10**(4): p. 150.
19. Lin, W., et al., *Bandwidth-aware divisible task scheduling for cloud computing.* Software: Practice and Experience, 2014. **44**(2): p. 163-174.
20. Makaremi, Y., A. Haghighi, and H.R. Ghafouri, *Optimization of pump scheduling program in water supply systems using a self-adaptive NSGA-II; a review of theory to real application.* Water Resources Management, 2017. **31**: p. 1283-1304.
21. Cruz-Reyes, L., et al., *Constructive algorithm for a benchmark in ship stowage planning.* Recent advances on hybrid intelligent systems, 2013: p. 393-408.
22. Gharehgozli, A.H., et al., *Scheduling twin yard cranes in a container block.* Transportation Science, 2015. **49**(3): p. 686-705.
23. Ursavas, E., *Priority control of berth allocation problem in container terminals.* Annals of Operations Research, 2015: p. 1-20.

24. Babicz, J., *Encyclopedia of ship technology.* Second. Publisher: Wärtsilä Corporation, 2015. **2**: p. 2019.
25. Luo, J. and Y. Wu, *Modelling of dual-cycle strategy for container storage and vehicle scheduling problems at automated container terminals.* Transportation Research Part E: Logistics and Transportation Review, 2015. **79**: p. 49-64.
26. Cascetta, E., et al., *A new look at planning and designing transportation systems: A decision-making model based on cognitive rationality, stakeholder engagement and quantitative methods.* Transport policy, 2015. **38**: p. 27-39.
27. Barua, L., B. Zou, and Y. Zhou, *Machine learning for international freight transportation management: a comprehensive review.* Research in Transportation Business & Management, 2020. **34**: p. 100453.
28. Cieślewska, A., *From shuttle trader to businesswomen: the informal bazaar economy in Kyrgyzstan*, in *The Informal Post-Socialist Economy*. 2013, Routledge. p. 121-134.
29. Kim, K.H. and H. Lee, *Container terminal operation: current trends and future challenges.* Handbook of Ocean Container Transport Logistics: Making Global Supply chains Effective, 2014: p. 43-73.
30. Papadimitriou, E., S. Lassarre, and G. Yannis, *Introducing human factors in pedestrian crossing behaviour models.* Transportation research part F: traffic psychology and behaviour, 2016. **36**: p. 69-82.
31. Kim, D., et al., *Implementation of a Long Short-Term Memory Transfer Learning (LSTM-TL)-Based Data-Driven Model for Building Energy Demand Forecasting.* Sustainability, 2023. **15**(3): p. 2340.
32. Peterkofsky, R.I. and C.F. Daganzo, *A branch and bound solution method for the crane scheduling problem.* Transportation Research Part B: Methodological, 1990. **24**(3): p. 159-172.
33. Keirstead, J., M. Jennings, and A. Sivakumar, *A review of urban energy system models: Approaches, challenges and opportunities.* Renewable and Sustainable Energy Reviews, 2012. **16**(6): p. 3847-3866.
34. Berisha, V., et al., *Digital medicine and the curse of dimensionality.* NPJ digital medicine, 2021. **4**(1): p. 153.
35. Drgoňa, J., et al., *All you need to know about model predictive control for buildings.* Annual Reviews in Control, 2020. **50**: p. 190-232.
36. Ren, T., et al., *Small-molecule BH3 mimetic and pan-Bcl-2 inhibitor AT-101 enhances the antitumor efficacy of cisplatin through inhibition of APE1 repair and redox activity in non-small-cell lung cancer.* Drug design, development and therapy, 2015. **9**: p. 2887.
37. Victor, C.R. and K. Yang, *The prevalence of loneliness among adults: a case study of the United Kingdom.* The Journal of psychology, 2012. **146**(1-2): p. 85-104.
38. Remya, V., et al., *Single-phase DVR with semi-Z-source inverter for power distribution network.* Arabian Journal for Science and Engineering, 2018. **43**: p. 3135-3149.
39. Angloher, G., et al., *Results on light dark matter particles with a low-threshold CRESST-II detector.* The European Physical Journal C, 2016. **76**: p. 1-8.
40. Agra, A. and M. Oliveira, *MIP approaches for the integrated berth allocation and quay crane assignment and scheduling problem.* European Journal of Operational Research, 2018. **264**(1): p. 138-148.