Controlling Sea Tugs for Container Ships in a Tandem Sea Port

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ABSTRACT

Background: The paper solves the problem of managing tugs for container ships in seaports. A tandem seaport consists of a roadstead, quays, container warehouses, port canals, port basins, a dispatch point and a tugboat base. Ships transport goods in containers from/to other ports. A standard, a weekly of ship service is given. Ships, between the roadstead and the quays, are transported by tugs. The tugs are assigned to shift-cycle transport tasks by the dispatcher. The ship can be unloaded/loaded at many quays. However, this requires tugs for ship transport between them. Containers are unloaded from ships to warehouses at the quays from where they are picked up by trains or TIRs. Similarly, containers are loaded onto ships from warehouses at the quays where they are delivered by trains or TIRs. The management system tugs should ensure the achievement of optimal economic results.

Methods: The presented problem was solved with the artificial intelligence method with the help of a computer program. The optimization criterion was the minimization of the ship service time in the port takes into account the limitations.

Results: A logistics system for the management of tugboats introducing container ships into the port has been developed. The system takes into account random disturbances: weather conditions, ship transport times, container unloading/loading times and the state of warehouses.

Conclusions: Managing multiple tugs in a port is a multi-agent system. The problem of controlling tugs is of the NP class. Each tugboat leaves/returns to the base for crew replacement, i.e. its route is <0,..., *m*,..., 0> where: 0 - the base and *m* - the quay/roadstead. Random handling times ξ_n become deterministic data t_n because the dispatcher only respects the execution of the task for the *n*th ship.

Keywords: tugboat, logistics, wharf, optimization, seaport, container ship.

INTRODUCTION

The management of tugboats of container ships in a seaport was presented in the publication [Frąckiewicz and Marecki 2020]. The problem presented in this paper concerned the port $P_i, i = 1, \ldots, I$ (e.g. in Gdynia) which was not a tandem of two ports (e.g. Świnoujście-Szczecin). In such a port there was only one dispatcher managing the tugs between the roadstead and the quays. In general, the P_i port is a tandem of two ports:

a) outer R_i (with the sea road);
b) inner S_i (inland).

The immersion depth of a vessel with containers in the channel connecting the tandem ports is important. For this reason, usually a ship unloads some of the containers in the port of R_i. Additionally, tandem ports have separate dispatchers.

Timetables (e.g. for airplanes, buses, passenger trains) are commonly used but transport times are randomly disrupted. An example is the controlled intersection of streets where "everything" depends on fate. This article presents the agent-based AI method which is to solve the logistics problem of tugboat management in the port. This method is based on the elimination of randomness by introducing the date of completion of the operation, not only the transport operation [Bordini et al. 2005].

The considered logistics problem consists in the management of tugboats with containers by the dispatcher. The weekly schedule for servicing these ships in the port is given, however, its implementation requires tugs the crew of which is changed during the shift cycle. This disproportion causes computational complications. In addition, transport times (by ships) and the location of containers (in port warehouses) are randomly disrupted (similarly to trains and planes).

The aim is to optimally solve the problem of delivering containers with goods, however, only one-criteria optimization is possible. Multi-criteria optimization consists in determining:

a) weighting factors of various criteria (e.g. time, capacity);
b) the order and tolerance of various criteria;
c) constraints (varying over time) of various criteria.

Thus, the method of multi-criteria optimization belongs to artificial intelligence. Simply put, it consists in reducing the problem to one criterion.

The computational problem of single-criteria optimization can be formulated as follows:

1) Check whether there is an acceptable solution?
2) If "YES", then the optimal solution should be found.

In technology and in other fields, the acceptable solution is important because there are many limitations while in mathematics, the optimal solution is important because there should be no limitations.

The problem, in fact, is the choice of the optimization criterion [Hossenfelder 2019].. Contemporary physical models are considered from the aesthetic point of view because nature is assumed to be perfect. For this reason, the models of modern physics draw from mathematics and philosophy at the same time (some models have been awarded the Nobel Prize despite the fact that they are contradictory!). In the past (over 300 years ago), theory was presented verbally, but since the invention of differential equations (Newton / Leibnitz), the theory has been the system of equations.

In computer science, parallel programming is used, because each processor has to solve $(M-1)!$ NP tasks [Papadimitriou 2002, [Marecki and Marecki 2007]. For example, if an optimal route through M cities needs to be determined (the travelling salesman problem), then M processors can solve this problem faster than one processor. It is enough that at the beginning each travelling salesman goes to a different city m, $m = 1, \ldots, M$, that he has to check $(M-1)!$ routes. So, there are few decision variables in technology while in mathematics – as many as you want.

STATEMENT OF THE PROBLEM

Let us consider the problem of steering tugs in the tandem type port P_i, $i = 1, \ldots, I$ assuming the following designations:

a) external port - R_i;
b) internal port - S_i.

The ship transports goods in containers:

a) exported from the port of P_i;
b) imported to the port of P_i.

The essential route of the ship from the first to the last port is important as the ship performs the transport service. Determining this route is an NP problem (i.e. the problem of the travelling salesman) with a relatively small number of ports. However, the goods exported in containers are unknown as there is the limitation in the form of the draft of the ship. Goods from the port of P_i to the port of P_j, $i < j$ can be shipped at the last minute as priority / express (i.e. the data is random). The tugboats are driven by the dispatcher and assisted by the software. The dispatcher assigns the tasks to be performed to the tugboats in the seaport.

The seaport usually consists of a tandem:

a) an outer port (with a roadstead at sea);
b) an inland port (inland).

An example of such a port is the Świnoujście-Szczecin tandem. The ports of the tandem are connected by a channel that is long, narrow and relatively shallow. For this reason, container ships are transported by tugs along the channel between the outer and inner ports. However, tugs are not always available, creating "deterministic chaos" [Papadimitriou 2002, Marecki and Marecki 2007].

The article assumes that a container ship transports goods between ports P_i, $i = 1, \ldots, I$ which are a tandem of R_i (outer) and S_i (inner) ports.

Therefore, the problem of "the travelling salesman" should be solved in order to determine the optimal route between the ports of P_i. Moreover, due to the limited draft in the channel connecting the ports of R_i and S_i, such a ship leaves some containers in the port of R_i. These containers are designated by solving the "knapsack" problem. Similarly, the problem of "backpack" needs to be solved for loaded containers containing exported goods. The schedule of vessel service in the port of P_i including transport and unloading of imported goods and loading of containers with exported goods requires solving the NP problem [Papadimitriou 2002, Marecki and Marecki 2007, Frąckiewicz and Marecki 2018].

A characteristic feature of these NP problems are:

a) a relatively small number of decision variables;
b) forecasted transit times for ships due to weather;
c) forecast container reloading times due to their location in warehouses on the quays;
d) the tugs remain on site if the work shift is completed, little time left (i.e. ΔT);
e) the tugs return to the base if there is little time left before the end of the work shift (i.e. $< \Delta T$)

Therefore, it is assumed that:

a) the dispatcher designates a "free" tug and the time limit for the completion of the task that he allocates to it;
b) the tug boat reports to the dispatcher about the completion of the ship transport task;
c) the ship reports to the dispatcher that it is ready for transport in the port (e.g. after unloading or loading containers).

In this way, the random times of transport, unloading and loading a ship are replaced in the model by deterministic terms. Based on these "facts" the dispatcher directs the tugs.

Let us consider a multi-agent steering system by a dispatcher of *N* tug boats operated by

N crews, so:

a) the dispatcher has no full information on the time of the operations;

b) tugs / agents are informed about random disruptions to the operations.

In practice, multi-agent systems function in external R and internal S ports on the same principles, therefore, only the external R port is presented.

It is assumed that:

a) R and S ports have a parallel structure of quays m, $m = 1,\ldots, M$;

b) each ship k, $k = 1,\ldots,K$ is transported from the roadstead to the port quay: R or S by one tug;

c) there is a port berth warehouse: R and S are able to accommodate the containers being unloaded and loaded;

d) the immersion depth in the channel between the ports of the tandem is given.

Tugboats replace the crew at base 0 which is visible by the dispatcher in a shift cycle (every 8 hours). Thus, the route of each tug starts and ends at the base (i.e. $< 0,\ldots,0 >$ that is the travelling salesman problem). Meanwhile, it is assumed that tugs are available in the scheduling of ships between the roadstead and the quays, which causes "deterministic chaos" [Hossenfelder 2019, Frąckiewicz and Marecki 2018, Frąckiewicz and Marecki 2020].

THE METHOD OF CONTROLLING TUGBOATS

The tugboats are managed by two dispatchers, separately in the port R_i and S_i, provided that:

1) R_i port dispatcher designates tugs:
   a) from the road to unload containers at the berths of the R_i port;
   b) after loading the containers at the berths of the port R_i on the roadstead.
2) S_i port dispatcher designates tugs:
   a) from the road to unload containers at the quays of the port of S_i;
   b) after loading containers at the S_i quay onto the roadstead or for loading containers at the quay of the R_i port;
3) There can be only authorized vessels in the port tandem channel.

The multi-agent tug steering method belongs to artificial intelligence. Intelligence is classified into natural (domain knowledge associated with a human) and artificial (IT / bit) - associated with a computer. Information intelligence uses a mathematical binary system, i.e. digits 0 or 1, although they interpret two states of different physical processes (e.g. electric, magnetic, optical, wave, quantum). It should be emphasized that man uses the decimal system and the computer uses the binary system. For this reason, encoders (taking time / money) are used at the "input" to the computer and at the "output" from the computer.

The immersion depth g of the ship in the tandem channel of the ports is of primary importance in the problem of controlling merchant ships as the permissible depth G is greater than g and it results from the displacement W of the ship). For this reason, the weight of the containers C transported by ship to the port is limited. As the ship loads and unloads various containers in the port, this problem is an important computational task. Function F which is used as a constraint in the NP problem can be formulated for the i-th port:

$$g_i = F(W, C_j, j) \tag{1}$$

where: C_j – the weight of containers transported through the port tandem channel.

Thus, some containers ($i \neq j$) must be unloaded in port R_i (outer tandem) to respect the immersion depth g_i in the tandem channel ($R \Leftrightarrow S$) of the ports.

In the case of port S_i, it is assumed that:

1) Ships from road to berths R_i ports are transported by one tug. The tugboat reports delivering the ship to the m-th R_i port quays to the dispatcher after completing the task.
2) The ship reports to the R_i port dispatcher after unloading the containers that it is ready for further transport to the S_i port.
3) Ships assigned by the R_i or S_i port dispatcher (i.e. only authorized tugs) can carry out the transport process in the tandem channel of $R_i \Leftrightarrow S_i$ ports (the allocation is determined by the shorter access time of the tug).
4) A ship in the port of S_i loads containers with exported goods in such a way as to respect the current draft depth g_i in the port tandem channel.
5) The ship reports to the S_i port dispatcher that it is ready for further transport to the roadstead or to the R_i port quay.
6) The S_i port dispatcher decides in other cases.

In the case of a bigger number of required tugs (more than one), it is assumed that the ship transport operation begins upon the arrival of the last tug. In addition, it is usually assumed that one of the dispatchers has the priority.

In the general case at the port P_i, $i = 1, \dots, I$ the problem NP is solved with a relatively small number of decision variables (i.e. the problem can be solved with the aid of the dedicated software), [Papadimitriou 2002, Marecki and Marecki 2007, Bucki, et al. 2010, Bucki et al.

2012 Bucki, et al. 2013, Frąckiewicz and Marecki 2018, Frąckiewicz and Marecki 2020] so the following problems are solved:

1) the ship's route through ports P_i, $i = 1, \dots, I$ (the travelling salesman problem);

2) schedules (i.e. a subset of ships with different priorities) on a weekly basis (the travelling salesman problems);

3) unloading ships in the port of R_i (the "knapsack" problem);

4) loading ships in the port of S_i (the "knapsack" problem).

The problem of steering tugs (the travelling salesman problem) is solved by the multi-agent method because the tug crews are changed during the working shift cycle (i.e. randomly).

The problem of targeting tugs in the external port R_i (tandem) requires cyclical decisions of the dispatcher after each time δt:

$$t^{k} = t^{k-1} + \delta t, k = 1, \dots, K \tag{2}$$

in the following cases:

1) at the moment $t^{k} = t^{k-1} + \delta t$ there is no:
   a) ship at the roadstead;
   b) ship at the *m*-th quay of the external port R_i as it did not report "readiness" to the dispatcher for transport to the internal port;
   c) free tug.

2) at the moment $t^{k} = t^{k-1} + \delta t$ there is only one free tug:
   a) there is a ship in the roadstead;
   b) there is a ship at the *m*-th berth of the outer port R_i which has reported the dispatcher "readiness" for transport to the inland port.

3) at the moment $t^{k} = t^{k-1} + \delta t$ there are many free tugs but only one event from the following:
   a) there is a ship in the roadstead;
   b) there is a vessel at the *m*-th berth of the outer port R_i which has reported the dispatcher its "readiness" for transport to the inland port.

4) at the moment $t^{k} = t^{k-1} + \delta t$ there are many free tugs and many events of the type:
   a) there are ships in the roadstead;
   b) there are ships at the *m*-th quay of the outer port which have reported the dispatcher their "readiness" for transport to the inland port.

The dispatcher in the port R_i makes the following decisions:

In the first case, the dispatcher "waits" for the time δt.

In the second case, the dispatcher allocates the only tug following:

a) the time of transport of the tug;
b) the tug's permissions;
c) other reasons.

In the third case, the dispatcher selects a tug following:

a) the time of transport of the tug;
b) the tug's permissions;
c) other reasons.

In the fourth case, the softwarer solves the allocation problem for the dispatcher. It should be noted that when there are more tugs than incidents the problem may not be solved due to the tugboats' permissions. A similar problem occurs with many tugs transporting ships in the $R \Leftrightarrow S$ channel.

CONCLUSIVE REMARKS

The paper describes the problem of controlling ships in a container port by means of tugs. It includes:

a) ship steering or "timetable";
b) container warehouse management;
c) steering the tugs in port.

The problem of managing tugboats in the port was solved by the multi-agent method.

Due to random disruptions (weather etc.), ship transport times are random.

Also, the times of unloading / loading containers are random due to the condition / arrangement of containers in warehouses. The parameters of these randomness changes over time, therefore the classic identification / optimization methods are not used instead the artificial intelligence multi-agent method [Bordini et al. 2005, Frąckiewicz, and Marecki 2018, Frąckiewicz and Marecki 2020] when it is implemented:

1) Managing multiple tugs in the port as a multi-agent system;

2) The problem of driving tugs as NP class (the travelling salesman problem) because every tug boat leaves / returns to the base for crew replacement i.e. its route is $< 0, \dots, m, \dots, 0 >$ where: 0 is the base while m is the quay / roadstead.

3) Random service times ξ_n become deterministic data t_n as the dispatcher only respects the execution of the task for the n-th ship.

The dispatcher may only take into account the dates of the ship's arrival at the roadstead.

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