Software System for Container Vessel Stowage Planning using Genetic Algorithm

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ABSTRACT

This paper presents a genetic algorithm (GA) software system for solving the container vessel stowage problem. The problem is a NP-hard problem with multiple and complex restrictions. The approach is based on a two-phase procedure, one for master planning and the other for allocation of the containers into slots. In this paper GA parameters are analyzed to achieve practical and best results. The system offers stowage allocation solutions for both phases, thus offering flexibility for a wide variety of vessels and route combinations.

Categories and Subject Descriptors

G.1.6 Optimization- Constrained optimization
I.2.8 ARTIFICIAL INTELLIGENCE - Problem Solving, Control Methods, and Search
I.6.3 SIMULATION AND MODELING: Applications

General Terms

Algorithms

Keywords

Container vessel stowage planning; Constraint optimization; Genetic algorithms.

1. INTRODUCTION

Since the world's economy changed to a global economy, linear shipping companies have faced the increasing shipping demand by building larger ships that can carry up to 22,000 containers. The vessel stowage loading plans of containers must be optimized so that costs can be reduced. Moreover, load and discharge operations at container terminals are costly. Hence, reducing the number of moves and the total time in port is essential to achieve cost reductions [1,3]. Container stowage planning is also known as the Master Bay Plan Problem (MBPP). This problem can be defined as follows [1]: given a set C of n containers of different types to load on a ship and a set S of m available locations within the ship, we need to determine the assignment of the containers to the ship locations in order to satisfy the given structural and operational constraints related to both the ship and the containers and to minimize the total loading time.

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The space on a vessel is divided into bays. Each bay consists of container stacks placed along the length of the ship. All bays are divided into an over deck and an under deck area, separated by structures called hatches [2]. On the under deck, the parts of a bay are divided into stacks/slots that are one container wide, and are composed of two Twenty-foot Equivalent Unit (TEU) stacks and a single Forty-foot Equivalent Unit (FEU) stack [5]. Some slots that have power plugs are known as reefer slots. A standard ISO container is usually 20 or 40 feet long, Each container has a weight, height, length and port where it has to be unloaded (discharge port), and may need to be provided with electric power (reefer container). IMO containers carry dangerous goods and must be placed according to a complex set of separation rules. A container in a stack is considered to be over-stowing another container in the same stack if it is stowed above it and discharged at a later port.In the process of solving the MBPP problem, the following restrictions apply: Over-stowage: In sea transportation, container vessels visit several ports according to their planned routes. The vessel loads and unloads additional containers in each port on the ship's route. The arrangement of the cargo on the vessel and the loading and unloading order are determined before the vessel arrives at each port. A stowage plan specifies the position of each container on the vessel [2]. Ship stability: A container ship becomes unstable if the vessel's weight distribution is unbalanced [5]. Container restrictions: Containers and the cargo they carry are constrained by many restrictions that must be considered when making a stowage plan. Line of sight: When containers are stacked on deck, the line of sight must be visible. Wind force: When a container vessel sails at sea, the wind affects its performance and the safety of the cargo it carries. Our work is an extension of the basic model described in [2] in that we attempt to solve the planning not only for the bays below but for the entire vessel. We take into consideration the following [3]: Both 20' and 40' containers are modeled, reefer containers are stowed in cells with power plugs, container stacking rules are considered, trim and draft are within the limit, and wind and line of sight are taken into consideration.

2. CONTAINER STOWAGE PLANNING GENETIC ALGORITHM

To solve the stowage problem we divide the problem into two sub-phases. The first sub-phase is the master bay planning phase, which allocates the containers that will be stowed at each bay. The second sub-phase is the slot planning phase, which allocates a specific slot for each container within each bay.

Master bay planning

For master bay planning encoding, tree encoding is used. The root of the tree represents the entire ship, and each leaf represents a bay. The root also contains the total ship weight. Each leaf (bay) contains the total weight of the bay, the total number of ports it needs to deploy, the number of reefer slots it contains and an array of containers For each bay, the target port with the maximum number of containers is defined as the main target for that bay - B_i^p. Each container that is targeted to a different port is assigned a penalty of $T_F = 20$ points. Since we want to able to stow more containers in further ports, the system maintains as many empty bays as possible. Thus, for example, each bay we use, we assign a penalty of $B_F = 10$ points. The weight limit is B_i^{WL}. Every ton exceeding that limit is assigned a penalty of $B_F^W = 100$ points. The basic definitions are based on the IP model [3]. We added the following parameters: B – all the bays in the vessel. B_i – containers in bay i. C_j^D – destination of container j. B_i^C –bay i is being used. B_i^R – number of reefer slots in bay i. C_j^R – container j is reefer. B_i^X – bay i exceeded its weight limit. C_j^W – container j's weight, the evaluation function for this stage is as follows:

$$f(x) = \sum_{i \in B} \sum_{j \in B_i \wedge C_j^D \neq B_i^P} T_P + B_P \cdot \sum_{i \in B} B_i^c + R_p \cdot \sum_{i \in B} \left| B_i^R - \sum_{j \in B_i} C_j^R \right|$$
$$+ B_P^W \sum_{i \in B} B_i^X \cdot \left(\sum_{j \in B_i} C_j^W - B_i^{WL} \right) (1)$$

$$Evaluation(x) = \frac{1}{f(x)} \ (2)$$

This is a minimization problem, where all of the values are greater than one. Therefore: $Fitness(x) = \frac{Evaluation(x)}{\sum_{i \in B} Evaluation(i)}$ (3)

Slot planning

In this stage, the allocation of a specific slot for each container is solved. The restrictions we need to take into consideration for this problem include some of the restrictions from the master bay problem, such as stability, reefer slots and over-stowage. Moreover, new restrictions must be considered, such as container size, line of sight and wind forces [5] The evaluation function is used to evaluate how well a specific bay is stowed. A summation of all bays follows. For each restriction a penalty value is assigned. For example, over-stows container B, is assigned a penalty of $O_P = 100$. When a container above the deck "over-stows" a container below the deck, we add a penalty of $0_P^{AB} = 5$ for all the containers stowed above. For every reefer container that is not stowed at the reefer slot or the opposite slot, we assign a penalty of $R_P = 100$. The evaluation function for this stage is defined by:

$$f(i) = O_P \cdot \sum_{j \in B_i^S} \sum_{c_1 \in S_j} \sum_{c_2 \in S_j - \{c_1\}} O_{C_1,C_2} + R_P$$
$$\cdot \left(\sum_{j \in B_i} R_j \cdot C_j^{NR} + \sum_{j \in B_i^{slot}} SL_j^R \cdot SL_j^{NRC} \right)$$
$$+ W_P \cdot \sum_{j \in B_i^S}^{B_i^S - 1} H_{j,j+1} + S_P^W \cdot \sum_{j \in B_i^S} S_{j_{B_i}}^{X} \cdot \left(\sum_{l \in S_j} C_l^W - S_{j_{B_i}}^{WL} \right) + 0_\mathrm{P}^\mathrm{AB}$$
$$\cdot \sum_{c_1 \in Below, c_2 \in Above} O_{C_1,C_2} \cdot \#Containr\ Above$$
$$+ S_P \cdot \sum_{j \in B_i^S} \left(\sum_{l \epsilon j_A} \sum_{k \epsilon j_A - \{l\}} A_{l,m} \cdot C_{m,l}^S + \sum_{l \epsilon j_B} \sum_{k \epsilon j_B - \{l\}} A_{l,m} \cdot C_{m,l}^S \right) + NS_P$$
$$\cdot \sum_{j \in B_i^S} S_{j_{B_i}}^{C} \ (4)$$

$S_{j_{B_i}}^{WL}$ - weight limit of stack j in bay I, $SWL_j^{B_i}$ - weight limit of bay I, $S_{j_{B_i}}^{x} \in \{0,1\}$ – stack j in bay i exceeds weight , $B_i^{slot} \in \{slot_1, \dots, slot_n\}$ – group of all slots in bay I, $SL_j^{RC} \in \{0,1\}$ – container j is reefer , $O_{x,y} \in \{0,1\}$ – container x is over stowage y, $H_{S1,S2} \in \{0,1\}$ – stack S_1 over one container higher than S_2, $B_i^S \in \{stack_1, \dots, stack_n\}$ – group of stacks in Bay I, $SL_j^R \in \{0,1\}$ – slot j is a reefer , $SL_j^{NRC} \in \{0,1\}$ - slot j is a non- reefer, $S_j \in \{container_1, c_2 \dots, c_m\}$ – set of containers in stack j, $C_j^{NR} \in \{0,1\}$ – container j is not stowed in a reefer slot, $A_{l,m} \in \{0,1\}$ – container l is higher than m, $C_{m,l}^S \in \{0,1\}$ – container m is larger than container l, j_A – set of on deck containers in stack j, j_B - set of below deck containers in stack j. The fitness function is as follows:

$$Evaluation(x) = \frac{1}{\sum_{i \in B} f(i)} \ (5)$$

$$Fitness(x) = \frac{Evaluation(x)}{\sum_{i \in G} Evaluation(i)} \ (6)$$

3. RESULTS

Figure 1 depicts an example of a result for 49 containers. Of these, 35 were destined to Cuba (yellow), 12 to the USA (green) and two to the Netherlands (red). The route of the ship is Israel -> Netherlands -> USA -> Cuba. The result of the algorithm avoided unnecessary movement of containers and unnecessary opening of hatch covers by placing all containers that are destined to a single destination in the inner part of the ship, which is not over-stowed.

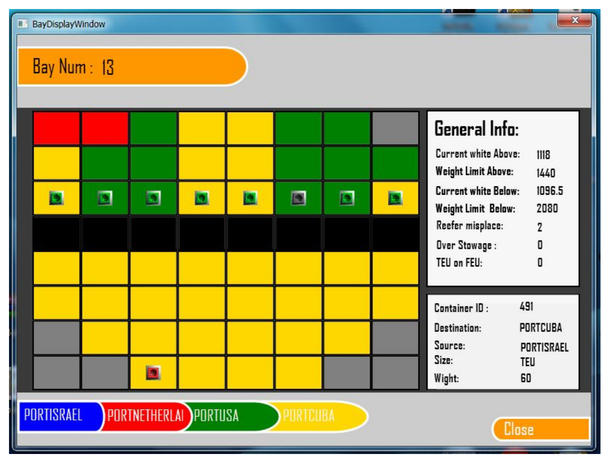

Figure 1. Example for bay deployment.

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