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A Proposed Genetic Algorithm Method for Integrated Quay Crane Scheduling Problem

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ABSTRACT: The optimization of container terminal operations is a very crucial field of study. Some of the common problems include berth allocation, quay crane assignment and quay crane scheduling. Here we are considering an integrated model of both quay crane assignment and scheduling problem. An initial mathematical model is considered which is used to minimize the make span. Based on the mathematical model and making certain assumptions, a proposed genetic algorithm is studied. In the last part, a modified method of genetic algorithm is specified.

INTRODUCTION

An increase in the number of transshipped container goods has been marked over the recent decades, due to globalization. Container terminals are called to meet the challenge of accommodating very large vessels, which are capable of carrying 10,000–12,000 twenty-foot equivalent container units (TEUs). A systematic approach to container terminal optimization therefore becomes necessary in order to overcome this challenge.

As far as container terminal operations are concerned, they can be divided into quayside and yard side operations. On the one hand, quayside operations involve allocating berths to arriving ships, known as the Berth Allocation Problem (BAP), the assignment of cranes to ships, known as the Quay Crane Assignment Problem (QCAP) as well as the sequencing of quay crane operations, known as the Quay Crane Scheduling Problem (QCSP). On the other hand, yard side operations include the allocation of containers to certain storage locations, the scheduling of container transporting vehicles and the scheduling of yard cranes for optimal container storage sequence.

Because Quay Cranes (QCs) are the most expensive equipment utilized at container terminals, their performance largely affects the container throughput and handling efficiency. QCs move on a single rail track alongside the quay of the port. As soon as a ship is positioned at the berth, QCs are responsible for the unloading and loading of containers from and to the vessel. The planning of QC operations is part of the quayside operations of a container terminal and consists of the QCAP and QCSP. These problems are frequently integrated, as they are interrelated.

The QCAP is basically an assignment problem which considers additional parameters, such as service agreements contracted with vessel operators, dictating a minimum or maximum number of cranes that can be assigned to a vessel, the available QCs at the port, the number of vessels berthed within a given planning horizon, the container workload on each vessel, and whether or not cranes are allowed to perform handling operations on more than one ship within a planning horizon.

The QCSP is a scheduling problem, more complicated than the QCAP, as it decides upon the sequencing of the QCs' handling tasks and the points in time at which these are performed. An important aspect of the QCSP is the fact that positioning conditions must be enforced at all times. More specifically, since cranes travel on a single rail, they are not allowed to cross one another. These are known as the non-crossing constraints. Furthermore, assuming that cranes are indexed based on their position, middle-indexed cranes cannot serve end bays, because again this would violate the non-crossing conditions. In several models clearance conditions are also accounted for, in order to prevent adjacent cranes from being positioned too close to one another. Yard congestion constraints are also considered in certain cases, where it is important to ensure that there will not be traffic at the yard storage areas at any point in time.

In this paper, we consider an integrated model for the QCAP and the QCSP, namely the Quay Crane Assignment and Scheduling Problem (QCASP). The purpose of the model is to assign cranes to ships that are berthed within a given planning horizon. Furthermore, the model specifically decides which crane is allocated to which bays and it aims to minimize the time required for the completion of the handling of the latest ship, i.e. the ship carrying the largest number of containers, which is expected to take the most time at the berth. This article presents the implementation of a Genetic Algorithm (GA) for solving the QCASP.

LITERATURE REVIEW

Several models are proposed in the literature for the QCSP and a very useful classification of these models can be found in the work of Bierwirth and Meisel (2010). As far as the problem formulation is concerned, the prevalent objective is the minimization of the makespan required to complete tasks.

In the work of Kim and Park (2004) the authors minimize the weighted sum of the makespan and the total completion time, but the drawback of their formulation in terms of constraints is that they do not consider crane clearance conditions, i.e. constraints that ensure that cranes will be positioned at least certain bays apart, and they only consider the single-ship case. Clearance conditions were added to the model of Kim and Park (2004) by Moccia et al. (2005), rendering the formulation more robust. Both formulations have since been used in numerous works.

In terms of solution methodologies, heuristics are widely employed due to the large number of variables and high complexity of the discussed problems. Exact techniques have also been implemented in addition to heuristics. Such is the case in the work of Kim and Park (2004). The authors propose a Branch-and-Bound (B&B) method to obtain the optimal solution of the MIP for the QCSP, as well as a heuristic search algorithm, the Greedy Randomized Adaptive Search Procedure (GRASP), in order to overcome the difficulty of the B&B method. Daganzo (1989) also proposes both an exact and an approximate solution method for crane scheduling.Tavakkoli-Moghaddam et al. (2009) integrate the quay crane scheduling and allocation problem (QCSAP) in their work. They develop a MIP formulation whose objective is to minimize the total cost of the proposed model

Lee et al. (2008) develop a GA to reach near-optimal solutions due to the large size of the problem. Based on the 43 computational experiments, the authors conclude that the performance of the GA is satisfactory in solving large size instances. Tavakkoli- Moghaddam et al. (2009) also employ a GA, due to the complexity of their model and in order to solve real-size instances of the problem. The obtained results showed a reasonable gap between the optimal solutions found by a commercial solver and the GA (between 1.9% and 3.5%), while the GA reaches the near-optimal solution in reasonable time.

The major problems associated with the existing studies are that the integration of both problems is not effectively modeled before. Cranes are assigned to ships rather than bays.In real cases, cranes are assigned to multiple bays. Also most problems considered are single ship cases.

MATHEMATICAL MODEL

For a given number of ships I berthed within a certain planning horizon and given a number of available quay cranes K, the aim of the QCASP is to allocate cranes to the bays j of every ship i, carrying a certain number of containers, with an objective of minimizing the handling time of the latest ship. By reducing the makespan for the cranes to perform all operations, it is possible to ensure an early completion time for all ships and an efficient distribution of container workload amongst port resources.

Certain assumptions have been considered for the specific problem. Firstly, all quay cranes are assumed identical, and they are indexed sequentially according to increasing positions alongside the quay. The bays are also indexed sequentially and cranes begin handling the lowest-indexed bay out of the total bays they are assigned to. This implies that cranes travel in a single direction, identical for all, in order to enforce positioning constraints and avoid crane interference. Furthermore, by adopting a unidirectional movement for cranes, clearance conditions are enforced (cranes will always be positioned certain bays away from other cranes). Since cranes move on a single rail they are not allowed to cross each other, which leads to the need for non-crossing constraints. Furthermore, it is possible for one quay crane to be assigned to more than one ship, which means that cranes can move between ships. Only unloading operations are considered and all containers are assumed identical. Container handling rates for cranes are identical, measured in containers per crane-hour, while travel times for cranes between bays are not considered. Finally, the ships that will be handled within the planning horizon are already berthed and only after their tasks have been completed can a new profile of ships be assigned to the quay.

The aim of the model is to minimize the maximum makespan of all unloading operations. Here the decision variables used are $x_{jk}$and T. Parameters used are containers on bay j, crane handling rate, first and last bays of all ships. Using these values the following mathematical model is solved in any optimization software.

Here the problem being considered is a mixed integer program formulation. We have to specify the objective function and other constraints like non negativity constraints, non crossing constraints etc.

The MIP formulation of the QCASP can be stated as follows:

Objective Function:

$$\min \ T \qquad (1)$$

Minimize handling makespan of ship that requires greatest time

Constraints :

$$\sum_{k=1}^{K} x_{jk} = 1, j = 1......B \qquad (2)$$

Every bay will be assigned to exactly one quay crane

$$\sum_{j=1}^{k-1} x_{jk} \leq 0, k = 2......K \qquad (3)$$

$$\sum_{j=(B+1)-(K-k)}^{B} x_{jk} \leq 0, k = 1......(K-1) \quad (4)$$

Middle indexed cranes will not be placed at end bays

$$x_{jk} \leq \sum_{l=j+1}^{B} x_{l.k+1}, j = 1......(B-1); k = 1......(K-1) \quad (5)$$

Lower indexed crane won't be positioned to right of higher indexed crane

$$x_{jk} \leq \sum_{l=1}^{j-1} x_{l.k-1}, j = 2......B; k = 2......K \qquad (6)$$

Higher indexed crane won't be positioned to left of lower indexed crane

$$T \geq \sum_{k=1}^{K} \sum_{j=j_i}^{B_i} c_j x_{jk}, i = 1......I \qquad (7)$$

Makespan will be equal to latest completion time

$$\mathrm{x}_{\mathrm{jk}} = (0,1), \mathrm{j} = 1......\mathrm{B}; \mathrm{k} = 1......\mathrm{K} \qquad (8)$$

Integrity constraint

$$\mathrm{T} \geq 0 \qquad (9)$$

Non negativity constraint

GENETIC ALGORITHM

Genetic Algorithms (GAs) have been extensively employed in combinatorial optimization problems, including sequencing and scheduling problems (Tavakkoli-Moghaddam et al., 2009). The GA is a meta-heuristic approach that is based on the concept of natural biological evolution of living organisms. It operates on a population of potential solutions and applies structured, yet randomized information exchange in order to robustly explore and exploit the solution space.

At each generation, a new set of approximations is created by the process of selecting individuals according to their level of fitness in the problem domain and breeding them together using operators borrowed from natural genetics, such as crossover and mutation. This process leads to the evolution of populations of individuals that are fitter with reference to their environment than the individuals that they were created from, as occurs in natural adaptation

The individuals of the population are encoded as strings, namely chromosomes, which are created based on a certain alphabet, in a way that the genotypes or genes (chromosome values) correspond to a unique position on the decision variable domain. The representation of chromosomes is the initial and most important step of the GA

By examining the current model, an initial representation of the chromosome can be derived by assigning each of the binary decision variables, i.e. the crane to bay assignment variables, to a gene. The integer variable, i.e. the makespan, can be directly calculated in the objective function in order to provide a fitness value to the corresponding chromosome. This would mean that the length of each chromosome is equal to the number of bays, multiplied by the number of cranes, i.e. K* B and it would be a binary representation.The chromosome representation can be further simplified by defining the value of each gene as the number of bays that each crane is assigned to. This implies that the length of the chromo- some (the number of genes) is equal to the number of available cranes K.

An advantage of this final chromosome representation, aside from the fact that it is shorter in length, is that it always generates feasible solutions, and therefore the need for a feasibility restoration technique in the initial pool of individuals is not required. The only requirement for feasibility with this new representation is that the sum of the values of genes is exactly equal to the total number of bays.

As far as population initialization is concerned, the choice is to generate a population of feasible chromosomes. This population is randomly generated but ensures that the sum of genes will be equal to the total number of bays. This guarantees that every bay will be assigned exactly one crane, thus ensuring feasibility.

The operators of crossover and mutation in the present paper have been designed to ensure that feasibility will be maintained throughout the evolution process, in order to prevent the need for a computationally complex repair procedure. The parents to be paired, number of genes to be exchanged and the indices of the corresponding genes are chosen randomly. The corresponding genes are then exchanged. Then the offspring's are checked for feasibility. If they are not feasible, necessary adjustments are made.To make the solutions feasible we add slack number of bays to the crane with lowest number. Otherwise subtract surplus number of bays from the crane with largest number of bays.

In terms of the operation of mutation, care is required in order to not result in non-feasible chromosomes. For this reason, swap mutation will be employed for this problem. This basically means the shuffling of genes within the chromosome. Because the primary concern for feasibility is maintaining the sum of genes equal to the number of bays, shuffling the genes, i.e. changing their positions in the chromosome, will not lead to infeasibility. Furthermore, it can achieve what mutation is intended to achieve, that is the constant diversification of the population. Swap mutation is performed between two genes in the specific problem; however, it could even be applied to more genes, as this would still maintain feasibility.

The parent selection strategy plays a significant role in regulating the bias in the reproduction process, because it determines the number of times a particular individual from the population is chosen for reproduction and, thus, the number of offspring that an individual will produce.

Several selection techniques implement a 'roulette wheel' mechanism to probabilistically select individuals based on a certain measure of their performance. Assuming that the fitness value is the chosen measure of performance, individuals are mapped into contiguous intervals in the range between 0 and the sum of their fitness values. The select an individual, a random number is generated within this range and the individual whose segment includes the random number is selected. The process is repeated, until the desired number of individuals has been selected. This technique is generally employed when it is preferred that better solutions have a greater chance of being chosen for creating offspring. This method is being followed in the current paper as well.

PROPOSED CHANGES

An extension is being proposed to the existing study. Here we are changing certain assumptions of the model and we are proposing a new GA model. The modified assumptions and the genetic operators are being mentioned in this paper.

In this model the inter–vessel movements are allowed. Bi directional quay crane movement is also possible. Another assumption that we are considering is that different vessels have different priority. Also the travelling times are negligible between two ships.

The objective is again to minimize the makespan of the system. Since the time factor comes into play in this model, the loading profile is considered in terms of units of QC hours, i.e., time to unload a quay crane for each bay.

A 2D matrix is considered as the chromosome in this case. Quay cranes are represented along the rows and time units are represented along the columns. Each element of the matrix will then represent the bays. The crossover operator needs to be suited for the 2 dimensional chromosome. Hence we make use of a patching matrix with same dimension as that of our original chromosome. Using the patching matrix we will go for the patching crossover procedure.

In the case of mutation we can go for swap mutation. But the procedure is different from that of one dimensional case. Here we will swap within a particular row alone rather than going for inter row swap.

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