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Particle swarm optimization algorithm for the berth allocation problem

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ABSTRACT

The berth allocation is one of the major container port optimization problems. In both port operator's and ocean carriers' perspective, the minimization of the time a ship at the berth may be considered as an objective with respect to port operations. This paper focuses on the discrete and dynamic berth allocation problem (BAP), which assigns ships to discrete berth positions and minimizes the total waiting times and handling times for all ships. We formulate a mixed integer programming (MIP) model for the BAP. Since BAP is a NP-hard problem, exact solution approaches cannot solve the instances of realistic size optimally within reasonable time. We propose a particle swarm optimization (PSO) approach to solve the BAP. The proposed PSO is tested with two sets of benchmark instances in different sizes from the literature. Experimental results show that the PSO algorithm is better than the other compared algorithms in terms of solution quality and computation time.

1. Introduction

Since the introduction of the container in the 1950s, containerships gradually become an important role in the global freight transportation. The world seaborne trade grew by an estimated 7%, taking the total of goods loaded to 8.4 billion tons. World container port throughput increased by an estimated 13.3% to 531 million 20-foot equivalent units (TEUs) in 2010 (UNCTAD, 2011). Thus, the terminal operation is an important part of the international trade of ocean shipping.

Operations in a container terminal can be broken down into three functional systems: seaside operations, yard operations, and land-side operations (Theofanis, Boile, & Golias, 2009). The first issue of seaside operations planning is the berth assignment to a set of vessels that have to be served within the planning horizon. One of the important objectives shared by the port operators and the ocean carriers is for the ships to leave the port as soon as possible. Thus, the container port authorities are forced to provide efficient and cost-effective services by utilizing the scarce berthing resources efficiently due to the fierce competition between ports.

The berth allocation problem (BAP) is to allocate berths to a set of vessels scheduled to arrive at the port within the planning horizon in order to minimize their time spent at the port (the sum of their waiting and handling times). Bierwirth and Meisel (2010) classified the BAP according to the following spatial and temporal variations: (1) discrete versus continuous berthing space, (2) static versus dynamic vessel arrivals, (3) deterministic versus stochastic vessel handling time. The quay is divided into a set of berths, and each berth can be used by only one vessel at a time in the discrete case. In the continuous case, a vessel can occupy any arbitrary position along the quay as long as the safety restriction between vessels is considered. Static BAP assumes that all vessels already arrived at the port for the service, while vessels can arrive at any time during the planning horizon with known future arrival information in a dynamic BAP. The main focus of this research is the discrete berth allocation problem with dynamic vessel arrivals.

The discrete BAP is NP hard (Cordeau, Laporte, Legato, & Moccia, 2005). Exact solution approach cannot solve large scale realistic environments, heuristics algorithms are proposed in the literature to solve the BAP. In this paper, we investigated the use of particle swarm optimization (PSO) algorithm for the BAP. PSO is a population-based random search algorithm inspired by the social behavior of bird flocks and has been applied to solve many combinatorial optimization problems. We did not find any other work in the related literature using PSO to tackle the BAP. Thus, it is worthwhile to evaluate the PSO for this task. The proposed PSO was tested with two sets of benchmark instances and compared with promising methods found in the literature to verify its efficiency.

The remainders of the paper are organized as follows. In the next section we review the related literature. Section 3 presents our problem with a mixed integer programming model. The proposed particle swarm optimization algorithm to tackle the discrete and dynamic berth allocation problems is presented in Section 4. In Section 5 computational experiments are performed and the results are presented. Finally, conclusions are summarized in Section 6.

2. Literature review

Berth allocation problem has attracted considerable practical and academic attention in recent years due to the needs of growing

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global supply chain. Different berth allocation models have been proposed in the literature. Steenken, Voß, and Stahlbock (2004), Vacca et al. (2008), Stahlbock and Voß (2008), and Bierwirth and Meisel (2010) provided a detailed review. We refer interested readers to the paper and references therein. In the following, we focus on the discrete and dynamic berth allocation problem. Other variants and possible extensions of the BAP will be briefly reviewed.

Thurman (1989) proposed an optimization model for ship berthing plans at the US Naval Station Norfolk. Later, Brown, Lawphongpanich, and Thurman (1994) and Brown, Cormican, Lawphongpanich, and Widdis (1997) considered berth allocation models in naval ports and allowed two or more submarines to occupy a single berth position. Imai, Nagaiwa, and Chan (1997) formulated a static BAP as a nonlinear integer programming model to minimize the weighted sum of two conflicting objectives, berth performance and vessel dissatisfaction. Imai, Nishimura, and Papadimitriou (2001) introduced the dynamic BAP and solved the problem with a Lagrangian relaxation based heuristic. Nishimura, Imai, and Papadimitriou (2001) considered a dynamic BAP with multi-water depth configuration in a public berth system and berth dependent vessel handling time. Later, Imai, Nishimura, and Papadimitriou (2003) considered a dynamic BAP in which different vessels have different service priorities. Genetic algorithms were developed to solve the problem in Imai et al. (2001) and Nishimura et al. (2001).

Cordeau et al. (2005) addressed a dynamic BAP with time windows in both discrete and continuous cases based upon data from a terminal in the Port of Gioia Tauro (Italy). The problem was formulated as a multiple depot vehicle routing problem with time windows (MDVRPTW), and solved by a tabu search heuristic. Monaco and Sammarra (2007) presented a compact formulation as a dynamic scheduling problem on unrelated parallel machines. The problem was solved by a Lagrangian relaxation heuristic. Imai, Nishimura, Hattori, and Papadimitriou (2007) considered a BAP in which up to two vessels can be served by the same berth simultaneously. They formulated the problem with an integer linear programming model and solved it by genetic algorithms. Imai, Zhang, Nishimura, and Papadimitriou (2007) analyzed a two-objective berth allocation problem which minimizes service time and delay time. They used the Lagrangian relaxation with subgradient optimization technique and a genetic algorithm to identify the non-inferior solutions in the bi-objective model.

Cheong and Tan (2008) developed a multiple ant colony algorithm for Nishimura et al.'s (2001) model and evaluated their algorithm by simulation experiments. Hansen, Oğuz, and Mladenovic (2008) presented a minimum cost BAP based on an extension of Imai et al.'s (2003) model, and developed a variable neighborhood search (VNS) heuristic for solving it. Imai, Nishimura, and Papadimitriou (2008) studied a variant of the dynamic BAP in which an external terminal is available when there is a lack of berth capacity at the operator's own terminal.

Mauri, Oliveira, and Lorena (2008) proposed a hybrid approach called PTA/LP, which used the population training algorithm with a linear programming model using the column generation technique. Barros, Costa, Oliveira, and Lorena (2011) developed and analyzed a berth allocation model with tidal time windows, where ships can only be served during those time windows. Buhrkal, Zuglian, Ropke, Larsen, and Lusby (2011) studied several mathematical programming models of the dynamic BAP and formulated the problem as a generalized set partition problem (GSPP). They solved the problem with CPLEX and obtained the optimal solutions on those instances from Cordeau et al. (2005). To the best of our knowledge, their mathematical model provides the best results on benchmark instances from the literature.

de Oliveira, Mauri, and Lorena (2012b) presented an algorithm based on the clustering search method using the simulated annealing algorithm to generate solutions for the discrete BAP. Lalla-Ruiz, Melián-Batista, and Marcos Moreno-Vega (2012) developed a hybrid algorithm that combined tabu search with path relinking (T^2S^*+PR) to solve the BAP. They tested the instances from Cordeau et al. (2005) and newly generated data sets by themselves. The results showed that the hybrid algorithm was competitive with the GSPP in small size instances. Xu, Li, and Leung (2012) considered the static and dynamic BAP that berths are limited by water depth and tidal condition. The problem was formulated as a parallel machine scheduling problem and solved with a heuristic.

Another line of berth allocation research assumes that berths along a quayside can be shared by different vessels. Lim (1998) was the first to study the continuous berth allocation problem. The continuous BAP was formulated as a restricted form of the two-dimensional packing problem and solved with constant handling times. Li, Cai, and Lee (1998) and Guan, Xiao, Cheung, and Li (2002) modeled berth allocation as machine scheduling problems with multiprocessor tasks, while Guan and Cheung (2004) developed efficient heuristics using a discrete berthing section model for batch arriving vessels. Tong, Lau, and Lim (1999) proposed an ant colony optimization (ACO) approach for the BAP addressed by Lim (1998). Park and Kim (2002) presented a mixed integer programming (MIP) model to minimize the penalty cost associated with service delays and placing a ship at a non-preferred location. A Lagrangian relaxation model with subgradient optimization technique was proposed to solve the problem.

Park and Kim (2003) integrated the berth scheduling into the quay crane assignment. The BAP was solved with an adaptation of the method from Park and Kim (2002) and the crane assignment was solved by dynamic programming. Kim and Moon (2003) formulated the continuous BAP as a MIP model and solved the problem with a simulated annealing algorithm. Imai, Sun, Nishimura, and Papadimitriou (2005) presented a heuristic for the continuous BAP. Moorthy and Teo (2006) proposed a framework addressing the berth template design problem at the terminal on a weekly basis and solved the problem with a sequence-pair-based SA algorithm. Wang and Lim (2007) proposed a stochastic beam search algorithm to solve the BAP in a multiple stage decision-making procedure. The improved beam search scheme and a stochastic node selection criterion were proposed.

Lee and Chen (2009) developed a candidate-based approach to handle BAP by allowing vessel shifting and considering the clearance distance between vessels which depends on the ship lengths and the order of berthed vessels. A three-stage neighborhood search based heuristic was proposed to solve the BAP. Tang, Li, and Liu (2009) proposed two mathematical models to minimize the total weighted service time. The authors developed an improved Lagrangian relaxation algorithm to solve the BAP at the raw material docks in an iron and steel complex. Cheong, Tan, Liu, and Lin (2010) considered a multiple objective BAP which includes makespan, waiting time, and degree of deviation from a predetermined priority schedule. They proposed a multi-objective evolutionary algorithm that incorporates the Pareto optimality to solve the problem. Lee, Chen, and Cao (2010) developed two versions of greedy randomized adaptive search procedure (GRASP) to solve the continuous BAP. The numerical results were compared with CPLEX and stochastic beam search of Wang and Lim (2007). Raa, Dullaert, and Van Schaeren (2011) presented a MIP model for the integrated BAP and quay crane assignment taking into account vessel priorities, preferred berthing locations and handling time. de Oliveira, Mauri, and Lorena (2012a) presented a clustering search (CS) method with simulated annealing heuristic to solve the continuous BAP. The computational results of the I3 instances from Cordeau et al. (2005) were compared with the tabu search by Cordeau et al. (2005) and memetic algorithms by Mauri, De Andrade, and Lorena (2011).