Computers & Industrial Engineering 119 (2018) 289–300

Contents lists available at ScienceDirect

Computers & Industrial Engineering

journal homepage: www.elsevier.com/locate/caie

Planning the transport of loads to oil platforms considering the arrangement of the loads on the ship's deck

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ARTICLE INFO

Keywords:
Oil and gas logistics
Capacitated vehicle routing problem
Two-dimensional loading constraints
Simulated annealing
Keel balance

ABSTRACT

Oil exploration in Brazil is done mainly by offshore oil platforms located far from the coast and ships transport all supplies for them. This paper proposes a method based on a Hybrid Simulated Annealing with Ship's Balance (HSA-SB) metaheuristic to plan the transport of loads to offshore platforms considering the arrangement of the loads on the ship's deck and the ship's balance about its keel. The main objective of HSA-SB is to minimize the ships affreightment costs by reducing the number of ships used and the distance sailed. It also arranges the loads on the deck, aiming to reduce ship's imbalance. HSA-SB was tested on real instances from a major Brazilian oil company and the results showed possible financial benefits.

1. Introduction

Oil is currently the main energy source for the world and it is important in several economic sectors, namely the transport and petrochemical sectors. The exploration of this resource in Brazil is done by offshore platforms, located at about 300 km from the Brazilian coast (Petrobras, 2016).

These platforms require several supplies to work properly. Specialized ships called Platform Supply Vessel (PSV) are used to transport these supplies from the coast to the platforms. To transport break bulk loads using a PSV, the focus of this paper, loads must be placed on the deck and cannot be stacked. The company's planners manually plan the ship's routes to meet all the demand. Their main objective is to minimize the transport costs by reducing the number of ships used and the distance sailed. After the route is established, he plans the arrangement of the loads on each ship's deck, aiming to reduce ship's imbalance to avoid losing time with ballast maneuvers to balance the ship. He also plans the load arrangement in a compact way, closer to the bowl, because if the loads were spread out on the deck, it would become very hard to tie them.

Thus, this paper proposes a method based on a metaheuristic called Hybrid Simulated Annealing with Ship's Balance (HSA-SB) to plan routes to supply offshore platforms considering the arrangement of the loads on the ship's deck. HSA-SB defines how many ships is necessary to meet the demand for all platforms and determines each route considering the arrangement of the transported loads on the deck. Its main objective is the minimization of the transport costs, which is calculated as the number of ships used multiplied by the affreightment cost plus the total distance sailed multiplied by the cost per kilometer sailed. After that, it plans the arrangement of the loads on the ship's deck, aiming to reduce ship's imbalance to a value near zero and to put the loads as close as possible to the ship's bowl. We proposed a mathematical model to describe mathematically the problem and to serve as a benchmark for HSA-SB in small instances.

Establishing a ship's route without considering the arrangement of the loads may lead to an infeasible solution. This may happen the sum of the load's area can be equal to, or smaller than, the ship's deck area, but it might not be possible to fit them on the ship's deck because of their dimensions. Thus, it becomes clear that is necessary to implement methods that integrate both problems. In the literature, the Vehicle Routing Problem with Two-dimensional Loading Constraints (2L-CVRP) was proposed, which deals with the routing problem integrated with the two-dimensional load arrangement. In the HSA-SB, we propose a strategy to call the arrangement part fewer times because it takes more time to be processed. To the best of our knowledge, no published metaheuristic has considered routing ships with their load arrangement considering the ship's balance about its keel. We tested HSA-SB with data from the major Brazilian oil company and the results showed possible financial benefits.

The paper is organized as follows. Section 2 reviews relevant studies about the 2L-CVRP. Section 3 describes our proposed mathematical model. Section 4 shows and explains the Hybrid Simulated Annealing

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https://doi.org/10.1016/j.cie.2018.03.013
Received 29 June 2016; Received in revised form 5 March 2018; Accepted 6 March 2018
Available online 19 March 2018
0360-8352/

with Ship's Balance (HSA-SB). Section 5 describes the computational experiments and the case study. Section 6 shows the results and analysis. Section 7 contains the conclusions.

2. Vehicle routing problem with two-dimensional loading constraints

The 2L-CVRP is a combination of the Capacitated Vehicle Routing Problem (CVRP) and the Two-Dimensional Bin Packing Problem (2-BPP). In the 2L-CVRP, customers request delivery of a set of rectangular loads to be transported by vehicles with a given weight capacity and two-dimensional loading surface. These loads have defined dimensions and weights and cannot be stacked. All loads from a given customer must be assigned to a single vehicle. All vehicles must start and end their route at the depot and the transported loads must be arranged respecting the vehicle's loading surface dimensions. The main objective of the problem is to reduce the number of vehicles used and the total distance traveled (Iori, Salazar-González, & Vigo, 2007; Leung, Zheng, Zhang, & Zhou, 2010).

The 2L-CVRP can be classified as sequential loading and unrestricted loading. In sequential loading, the arrangement of the loads on the vehicle's loading surface shall obey the inverse unloading order (Last In - First Out) (Gendreau, Iori, Laporte, & Martello, 2008). In unrestricted loading, the arrangement of the loads does not include the sequencing constraint, and in general, this case corresponds to vehicles, which can be unloaded vertically with a crane (Khebbache-Hadji, Prins, Yalaoui, & Reghioui, 2013). Regarding the arrangement, 2L-CVRP can be classified as oriented and non-oriented. In the oriented problem, the loads have a fixed orientation and cannot be rotated. In non-oriented, the loads can be orthogonally rotated (Fuellerer, Doerner, Hartl, & Iori, 2009).

Iori et al. (2007) introduced the 2L-CVRP, proposing an Integer Linear Programming (ILP) model, a Branch-and-Cut (B&C) and a Branch-and-Bound (B&B) heuristics. To solve 2L-CVRP several metaheuristics were proposed. Gendreau et al. (2008) proposed a Tabu Search (TS), Fuellerer et al. (2009) used Ant Colony Optimization (ACO) for the 2L-CVRP with non-oriented loading, Zachariadis, Tarantilis, and Kiranoudis (2009) proposed the Guided Tabu Search (GTS), Azevedo, Hokama, Miyazawa, and Xavier (2009) used B&C, Leung et al. (2010) presented a Simulated Annealing (SA), Leung, Zhou, Zhang, and Zheng (2011) proposed the Extended Guided Tabu Search (EGTS),

Duhamel, Lacomme, Quilliot, and Toussaint (2011) proposed the Greedy Randomized Adaptive Search Procedure (GRASP) combined with the Evolutionary Local Search (ELS), Zachariadis, Tarantilis, and Kiranoudis (2013) proposed a Promise Routing-Memory Packing (PRMP) and Dominguez, Juan, and Faulin (2014) presented a Multistart Biased-Randomized Algorithm (MS-BR).

Some variants of the 2L-CVRP were prosed. Malapert, Guéret, Jussien, Langevin, and Rousseau (2008) presented the 2L-CVRP with pickup and delivery (2L-PDP). Limone Muñoz (2011) presented a 2L-CVRP with handling costs (2L-CVRP-H), whose objective function minimizes the routing costs and the costs of handling the loads at the demand location. Leung, Zhang, Zhang, Hua, and Lim (2013) approached the 2L-CVRP with heterogeneous fleet (2L-HFVRP) using the metaheuristic SA with heuristic local search (SA_HLS). Khebbache-Hadji et al. (2013) proposed the 2L-CVRP with time windows (2L-CVRPTW) using a Memetic Algorithm (MA). Martínez and Amaya (2013) presented the 2L-CVRP with multi-trips, time windows and two-dimensional circular loading constraints (VRPM-TW-CL) and used TS to solve it. Dominguez, Juan, Barrios, Faulin, and Agustin (2016) solved the 2L-HFVRP with rotation of the loads for the unrestricted versions of the problem, using MS-BR. Rivero, Pérez, de la Nuez Pestana, and Ouelhadj (2016) proposed a mathematical model and an ILS-biased randomization heuristic for the 2L-HFVRP, sequential loading, and load rotation.

Arpini and Rosa (2015) proposed a mathematical model for the 2L-CVRP considering the ship's imbalance. Loads are placed on the deck and cannot be stacked. A single ship can visit each platform once. Their problem was classified as an oriented and unrestricted 2L-CVRP, as the loads cannot be rotated and are removed from the ships by cranes, with no need for sequencing constraints.

3. Proposed mathematical model

The proposed mathematical model aims to plan ship's routes and for each route, it plans the arrangement of the loads on the ship's deck. The arrangement of the loads considers that each load can be orthogonally rotated, but cannot be stacked. Each platform can be visited once by a single ship, which has a maximum sail time limit. Loads are removed from the ships by cranes, with no need for sequencing constraints.

There are two main differences between our proposed model and Arpini and Rosa (2015) model. First, in our model, loads can be orthogonally rotated, while they didn't consider rotation of the loads. Second, we consider the load's coordinates as continuous variables, while they considered the ship's deck with discretized length and width, i.e., one meter, so, load's coordinates are discretized.

Considering np as the number of platforms, nk as the number of ships and nl as the number of loads, we can define the sets of the model. Set $Nc = \{0,1,...,np,np+1\}$ represents all nodes, where node 0 corresponds to the portt of origin and $np+1$ corresponds to the virtual port, i.e., the end of the route at the port. There are also the following auxiliary sets: $Cc = \{1,...,np\}$ is the set of platforms, $C0c = \{0,1...,np\}$ is the set of platforms considering the port and $C1c = \{1...,np,np+1\}$ is the set of platforms considering the virtual port. $Kc = \{1,...,nk\}$ is the set of ships in the fleet and C is the set of loads requested by all platforms.

In our model, the bottom left corner of the diagram corresponds to the $(0,0)$ coordinates. Rectangular loads must be arranged on a two-dimensional plane. Fig. 1 shows a diagram of a ship's deck containing a load $i \in C$, with its dimensions and position. The load's balance must be calculated in relation to the ship's keel, which is located at half of the ship's width, $L_j/2$.

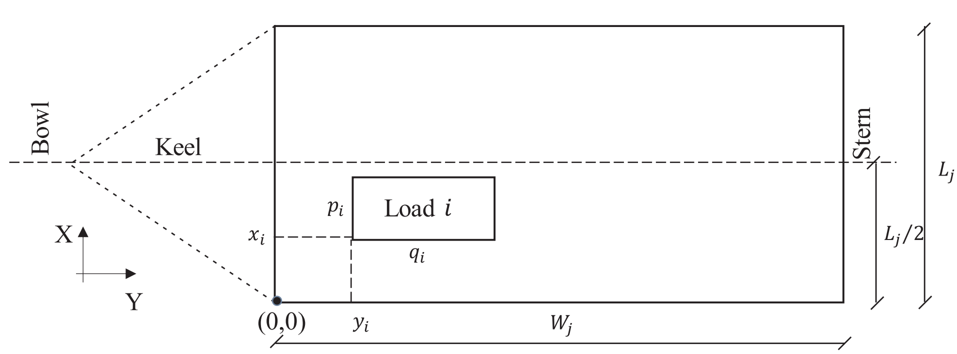

Fig. 1. Schematic representation the main parameters and decision variables.