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Optimizing lift operations and vessel transport schedules for disassembly of multiple offshore platforms using BIM and GIS

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ABSTRACT

As the coming decades will witness a big trend in the decommissioning of offshore platforms, simultaneously disassembling topsides of multiple offshore platforms is getting increasingly common. Considering high risk and cost of offshore operations, module lift planning among multiple offshore platforms with transport vessels is required to be carefully conducted. The lift planning usually contains two main parts: module layout on vessels planning and vessel transport schedules arrangement. In contrast to the current experience-driven module lift planning, this paper formulates the lift planning optimization problem and develops a web system integrating building information modeling (BIM) and geographical information system (GIS) to efficiently disassemble topsides for multiple offshore platforms. BIM provides detailed information required for planning module layout on vessels and GIS contains the management and analysis of geospatial information for the vessel transport schedule arrangement. As for module layout optimization, three heuristic algorithms, namely genetic algorithm (GA), particle swarm optimization (PSO), and firefly algorithm (FA) are implemented and compared to obtain the module layout with the minimum total lift time. While for vessel transport schedule, graph search technique is integrated with a developed schedule clash detection function to obtain the transport schedule with the minimum sailing time. The proposed optimization algorithms and techniques are integrated into a developed BIM/GIS-based web system. An example of three offshore platforms with eighteen modules in total is used to illustrate the developed system. Results show that the developed system can significantly improve the efficiency of lift planning in multiple topsides disassembly. The developed BIM/GIS-based web system is also effective and practical in the resource allocation and task assignment among multiple locations, such as construction sites, buildings, and even cities.

1. Introduction

Offshore platforms are large structures with functional modules to drill and process oil and natural gas from the seabed. An offshore platform generally has a lifetime of 30 to 40 years. The decommissioning of offshore platforms is the most important concern of the stakeholders when platforms are reaching their end of service lives. The big markets of offshore platform decommissioning for the coming decades around the world, such as the North Sea [1], coastal of Southern California [2], and Asian Pacific areas [3], were presented in [4]. There are different types of offshore platforms, while fixed platforms are one of the commonly used offshore platform types in the world. Topsides disassembly is an important task during the decommissioning of fixed platforms considering the cost, time, and risk. The main work of topsides disassembly is to lift the functional modules from the deck of platforms to transport vessel. Since functional modules are usually big and heavy, the module layout on a vessel can impact the total module lift time and stability of the transport vessel. Especially, the unstable offshore environment is a critical concern during the disassembling phase [5]. Therefore, planning and optimizing module layout on transport vessels is necessary.

The study of functional module layout on transport vessel is still limited. Although Tan et al. [6] studied the module layout problem, the study only optimized module layout in a “one platform one vessel” scenario. However, a stakeholder usually owns several offshore platforms, which are located in clusters. It is meaningful and necessary to share vessel resources among multiple offshore platforms. Therefore, decommissioning multiple offshore platforms is getting common. In the North Sea, increasing number of stakeholders tend to decommission multiple offshore platforms simultaneously to share decommissioning

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knowledge and take full advantages of available equipment, such as huge heavy lift vessel. For example, ConocoPhillips (U.K.) Limited plans to decommission three offshore platforms in Lincolnshire Offshore Gathering System [7]. Centrica North Sea Limited has started to decommission four offshore platforms [8,9] in Audrey filed simultaneously. Considering the size and weight of the functional modules, multiple transport vessels are required and shared by the platforms. The module assignment, meaning which module should be assigned to which predetermined locations on which transport vessel, is similar to quadratic assignment problem (QAP). Since there is no known algorithm for solving QAP in polynomial time, and even some cases require long computational time, this problem is usually treated as non-deterministic polynomial-time hardness problem (NP-hard problem). QAP has already been studied in the manufacturing industry and the building construction industry for decades. Heuristic algorithms such as genetic algorithm (GA), particle swarm optimization (PSO), and the recently developed firefly algorithm (FA) have been commonly applied to solve QAP with promising performance and advantages over computational time. However, the study of formulating module lift problem as QAP to optimize the module layout on transport vessel with different heuristic algorithms is still limited.

In addition to the module lift operations, module transport is another important part of the topsides disassembly of multiple offshore platforms. After obtaining optimal module layout on all transport vessels, the platforms to be visited for each vessel are determined. Since offshore platforms are usually far away from each other and the weight of loaded modules has an impact on the sailing speed of transport vessels, the transport schedule of each vessel to offshore platforms requires being carefully planned considering the potential unexpected environment such as hurricanes and storms. The optimization problem of vessel transport schedule can be treated as a graph search problem especially when the number of offshore platforms to be decommissioned increases. However, unlike traditional graph search problem [10,11], where each edge usually contains no more than two weights that represent the travel cost or distance between two nodes, the number of weights (sailing time between two platforms) on each edge varies according to the number of platforms to be visited by each vessel. Although the study of developing efficient search algorithms on graph has been conducted for decades [12] and applied to various fields [13] such as supply chain management and path planning, graph search is still lacking in the vessel transport schedule problem studied in this paper.

To optimize lift operations, including module layout on vessels and vessel transport schedule for topsides disassembly of multiple offshore platforms, information such as module locations on different offshore platforms, module weight, predetermined locations on each vessel, size of all offshore platforms and vessels, distances among platforms, and distances between each platform and onshore factory site is required. Building information modeling (BIM) has been increasingly used to provide detailed geometric and semantic information for elements in civil engineering projects for the past decade. Geographic information system (GIS) has advantages over geospatial data management and spatial analysis for the objects with multiple spatial scales, from nationwide and citywide issues to a construction site or a building. Increasing number of researchers try to take advantage of the benefits of BIM and GIS by integrating them. Therefore, this study integrated BIM and GIS on web technology to provide enough information for the optimization objectives. Heuristic algorithms will be implemented to optimize the lift operations, and graph search technique will be applied to plan the vessel transport schedule.

The rest of this paper is outlined as follows. Section 2 reviews related work on lift planning optimization that has been previously conducted. A BIM/GIS-based web system for optimizing module lift operations and vessel transport schedule is proposed in Section 3. To illustrate the proposed system, an example is used in Section 4. Section 5 discusses the study and concludes the study with limitations and future work.

2. Related work

2.1. Facility layout problem: quadratic assignment problem

Determining facility placement in production systems, plant areas, construction sites, and other spaces is defined as the facility layout problem (FLP) [14–16]. Minimizing the materials handling cost based on distances and material flows among facilities is the most common objective used when formulating the mathematical models. FLP can be categorized into different models according to the way of layout problem formulation. Quadratic assignment problem (QAP) model, mixed integer programming (MIP) problem model, and graph theory model are three of the most commonly studied models for FLP [14,15]. QAP is considered as a challenging combinatorial optimization problem [17], which assigns facilities to locations in a way that each facility is assigned to one location [18]. One process to be studied in this paper is lifting modules from the offshore platform to the predetermined locations on heavy lift vessel. Therefore, the module lifting process can be formulated as QAP without considering material flow between any two modules on the vessel.

QAP, as a classical NP-hard combinational optimization problem, has been studied since 1957 by many researchers using developed exact and heuristic approaches [19]. Among the heuristic approaches, genetic algorithm (GA) and particle swarm optimization (PSO) were commonly used to solve QAP models. For the GA-based QAP studies, Tate and Smith [20] implemented GA to solve QAP problem and it performed well compared with the previously studied heuristic algorithms. Li and Love [21] used GA to plan facilities on construction sites and the efficiency of GA in solving the construction site-level facility layout was demonstrated. Other GA-based QAP studies not only used GA to solve the assignment problem, but also tried to improve GA performance by incorporating greedy principles [22], developing effective operators [23], and designing a parallel GA with multiple processors in a GPU [24].

As for PSO-based QAP studies, Lv et al. [25] used PSO to solve quadratic assignment problem and proposed a new particle representation for the problem. Gong and Tuson [26] generalized PSO operator in a formal manner using forma analysis and the obtained results are comparable to a GA. In addition, PSO was also integrated with other methods to well solve quadratic assignment problem. For example, Liu et al. [27] designed a fuzzy scheme to extend traditional position and velocity of the particles to fuzzy matrices. Zhao et al. [28] introduced fuzzy PSO to handle multi-objective QAP.

In addition to GA and PSO, another heuristic algorithm named firefly algorithm (FA) [29,30], which was first proposed in late 2007 and 2008 [31,32] and was based on the flashing patterns and behavior of fireflies, can also be used for QAP. For example, Durkota [33] proposed a way to adjust FA to solve discrete problems such as QAP with permutation solutions. Fister Jr. et al. [34] applied FA, hybridized with local search heuristic, to optimize the combinational problem called graph 3-coloring problem. The results of using FA were promising and showed that FA can also be applied to other combinational optimization problems.

Previous efforts of applying heuristic approaches to solving quadratic assignment problem are based on total handling cost or time among all the assigned facilities. However, in this study, no material flow exits among the lifted modules on the vessel. Total lift time of all modules is the objective function to be minimized, which means this study focuses on the process of heavy lifts between platforms and vessels. Although Tan et al. [6] studied lift planning and module layout arrangement for one platform and one heavy lift vessel, the study of QAP-based module lift among multiple offshore platforms and vessels is still lacking.