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# TEACHING OPERATIONS RESEARCH METHODS IN LINER SHIPPING

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## ABSTRACT

Liner shipping has been a hot topic in higher education for students with logistics and transportation backgrounds. Various Operations Research (OR) methods have been applied to solve problems arising in these operations, both by industrial practitioners and academic researchers. For students majoring in logistics and transportation, learning how to use OR techniques to solve practical problems in liner shipping facilitates them to better adapt themselves to future work. This paper introduces the philosophy and practice we applied in a subject that teaches college students how to use OR techniques to solve problems arising in liner shipping. We found that learning how to use OR methods to solve problems arising in liner shipping helps students acquire a systematical understanding of the operations in liner shipping. It also leads students to analyze and solve problems in a logical and rigorous way.

Keywords: Liner Shipping; Teaching Strategy; Operations Research.

Subject area: (Please put an "X" as appropriate, you may choose more than one)

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| | a) | Connected and Autonomous Vehicles |
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Liner shipping has been a hot topic in higher education for students with logistics and transportation backgrounds. Various Operations Research (OR) methods have been applied to solve problems arising in these operations, both by industrial practitioners and academic researchers. For students majoring in logistics and transportation, learning how to use OR techniques to solve practical problems in liner shipping facilitates them to better adapt themselves to future work. This paper introduces the philosophy and practice we applied in a subject that teaches college students how to use OR techniques to solve problems arising in liner shipping. We found that learning how to use OR methods to solve problems arising in liner shipping helps students to acquire a systematical understanding of the operations in liner shipping. It also leads students to analyze and solve problems in a logical and rigorous way.

Keywords: Liner Shipping; Teaching Strategy; Operations Research.

## 1. INTRODUCTION

Container transportation is an integral part of the global supply chain, and liner shipping forms the backbone of container transportation. According to the estimation of UNCTAD (2018), the global trade volume of liner shipping reached 148 million TEUs in 2017. Considering its critical role in the global trade, liner shipping is treated as a vital part in subject LGT3003 "Intermodalism" which is taught to undergraduate students in the Department of Logistics and Maritime Studies at The Hong Kong Polytechnic University.

In liner shipping, a liner company operates in one or multiple shipping lines and controls a fleet of containerships. A shipping line is composed of a set of container ports, and containerships visit the ports in a given sequence and at a fixed frequency. Operations in liner shipping have given rise to many problems, including the berth allocation problem, the quay crane assignment problem, the ship slot allocation problem, and the containership deployment problem. Various operations research (OR) methods have utilized to solve these problems in liner shipping. The techniques include the greedy algorithm, the bisection search, linear programming, and integer programming. In addition, queueing theory and data envelope analysis are also frequently used to measure the performances of container ports. Despite the prevalence and importance of OR applications in liner shipping, we found that they are not taught in most subjects related to liner shipping.

This paper introduces the philosophy and practice we applied in LGT3003 that teaches college students how to use OR techniques to solve problems arising in liner shipping. In particular, we give examples to show how the teaching materials are prepared. We also discuss the findings and problems based on our experience. The remainder of the paper is organized as follows. Section 2 reviews the related literature. We demonstrate how the teaching materials are designed in Section 3. Section 4 discusses the findings from the teaching practices, followed by some concluding remarks in Section 5.

## 2. LITERATURE REVIEW

For solving the berth allocation problem (BAP), many heuristic methods have been developed, e.g., genetic algorithms (Nishimura et al., 2001), simulated annealing (Kim and Moon, 2003), tabu search

(Cordeau et al., 2005), ant colony optimization (Cheong and Tan, 2008), and variable neighborhood search (Hansen et al., 2008). In recent BAP literature, using diagrams for solving BAP is one of the most efficient and interesting ones. Lee et al. (2010) proposed the Time-space diagram by two versions of Greedy Randomized Adaptive Search Procedure (GRASP), to identify the possible locations for the next vessel and find the near-optimal solution. In subject LGT3003 "Intermodalism", we also introduce the time-berth diagram to students, which helps them to understand the underlying idea of the heuristic.

For the quay crane assignment problem (QCAP), see the comprehensive review works given by Bierwirth and Meisel (2010, 2015). Imai et al. (2008) introduced a formulation for the simultaneous berth and crane allocation problem and employed a genetic algorithm to find an approximate solution of the problem. In the literature, the QCAP and the BAP are always discussed together as an integrated problem (Chang et al., 2010; Yang et al., 2012; Vacca et al., 2013; Türkoğulları et al., 2014; Iris et al., 2015). The QCAP may also be simultaneously considered with the quay crane scheduling problem (Tavakkoli-Moghaddam et al., 2009; Meisel, 2011; Diabat and Theodorou, 2014; Fu and Diabat, 2015; Theodorou and Diabat, 2015). Recently, Agra and Oliveira (2018) proposed an integrated berth allocation, quay crane assignment and scheduling problem that is solved by a branch and cut algorithm.

At the tactical planning level, we discuss the containership deployment problem (SDP) and the slot allocation problem (SAP) with students in subject LGT3003. For managing ship deployment with container flow, Liu et al. (2011) formulated a sequential model and a joint optimization model. Wang and Meng (2012) proposed a liner ship fleet deployment (LSFD) problem with container transshipment operations, then Meng and Wang (2012) addressed the LSFD problem with week-dependent container shipment demand and transit time constraint. Song and Dong (2013) proposed a single liner long-haul service route design problem, in which ship deployment is considered with the route structure design and empty container repositioning. Referring to SAP, Ting and Tzeng (2004) formulated a slot allocation model to maximize freight contribution and conducted a case study of Taiwan liner shipping company. Ting and Tzeng (2016) proposed a containership slot allocation model concerning uncertainties of cargo transportation demand and weight, to deal with two conflicting objectives, i.e., carrier's freight contribution and agents' degree of satisfaction.

Since a large variety of factors complicate the port performance analyses, Roll and Hayuth (1993) presented the data envelopment analysis (DEA) to measure the port efficiency. Recently, Nguyen et al. (2016) measured port efficiency using bootstrapped DEA, to overcome limitations of standard DEA, i.e., exhibit statistical inconsistency, biased results, and an arguable inference process. To study the queueing behavior at the port, Jagerman and Altiok (2003) introduced the SHIP/G/1 queue by considering the vessel arrival process in ports handling either cargo containers or minerals. Kang et al. (2008) applied a cyclic queue model to study the steady-state port throughput and obtained the optimum fleet size for long-term operations.

## 3. DESIGNING TEACHING MATERIALS

The subject comprises both lectures and tutorials. To help students understand these methods and problems, we introduce the principles of the methods and the backgrounds of the problems through lectures, and numerical examples and practices are given in tutorials. We also give assignments to the students to help them reinforce the skills of solving problems. In this section, we selected the most typical examples of the teaching materials we used to teach OR methods applied in liner shipping operations. These methods are used to solve problems including the berth allocation problem, the quay crane assignment problem, the ship slot allocation problem, and the container ship deployment problem. Students are also taught to use the queuing theory and the data envelop analysis to analyze the performance of the gate system of a port and compare the efficiencies of different ports.

### 3.1 The Berth Allocation Problem

When a containership calls at a container terminal, it should be moored in a designated berth position in order to get handled. The berth allocation problem (BAP) is considered by the terminal operators. It determines the berthing positions and berthing time for visiting ships. The BAP has been well studied in the literature, and many state-of-the-art exact and heuristic algorithms have been developed to solve the problem. In LGT3003, we taught the students how to solve a BAP using the greedy algorithm (GA), which is a simple heuristic algorithm. To do so, we let the students work on the simplest version of the BAP in which the terminal is empty (with no ships) at the beginning of the planning horizon, the quay is uniformly divided into several berths and the ships can only take integral numbers of berths on the quay. The GA solves the BAP in a first-come-first-served manner. In particular, a ship will moor only when (1) all ships that arrived earlier have moored and (2) there are available berths. Besides, when there are more than one feasible berthing positions for a ship, we allocate the left-most berths to the ship.

Although the underlying idea of the GA is straightforward, the difficulty for students to implement the algorithm came from the coordination of two resources for serving ships i.e., time and berths. In order to demonstrate the procedures of the GA to the students, we introduced the time-berth diagram (see Figure 1). In the diagram, the x-axis records the time and the y-axis records the berths. We then used rectangles to represent ships in the diagram such that the length and height of a rectangle equaled the handling time and the number of berths required by a corresponding ship. Then, the GA was equivalent to a method that (1) places each rectangle into the two-dimensional coordinate system such that there are no overlaps among the rectangles, (2) the rectangles are placed into the coordinate system one by one in a given sequence, (3) each rectangle is placed at the left-most feasible location in the system, and (4) if possible, place each rectangle as close to x-axis as possible.

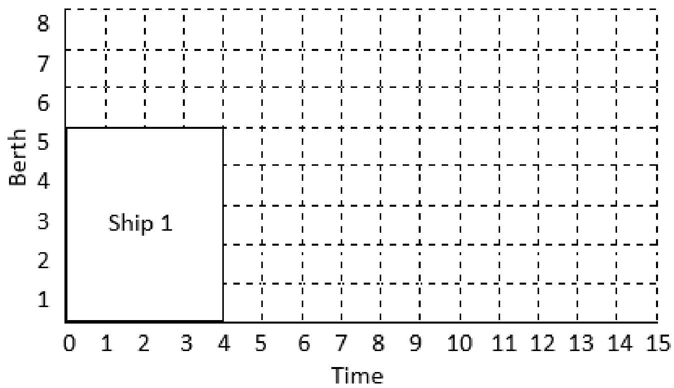

Figure 1. The time-berth diagram for solving the BAP

To further improve students' implementation of GA, we also required them to solve BAPs that slightly deviated from the simplest version. For example, the problems can be the BAP with a non-empty initial terminal or the BAP in which some berths have draft limitations.

### 3.2 The Quay Crane Assignment Problem

After a containership moors in the berths of a terminal, quay cranes are required to load and unload containers onto or from the ship. Therefore, another key problem faced by a terminal operator is the quay crane assignment problem (QCAP). The QCAP determines the assignment plan of handling (loading or unloading) tasks in a ship to a group of quay cranes such that the no-crossing constraints among quay cranes are respected. The objective is to minimize the makespan (the total handling time). Like the BAP, QCAP has also solicited many studies from the OR society. We taught the students to solve the problem using the bisection search (BS). The BS solves the QCAP in a branch-and-bound framework. It updates the lower upper bounds of the makespan of a QCAP in each iteration and terminates when the gap between the lower and upper bounds is less than a given threshold.

When teaching the BS method to the students, we found that it was difficult to make the students understand and implement the whole algorithm all at once. In the assignments, the students were required to solve a QCAP using the BS. However, instead of asking them to solve the whole problem all by themselves, the framework of the solution was given in advance. In particular, in the assignment, the first two iterations of the BS to solve the BS were given to the students. Besides, in the following iterations of the algorithm, we also gave guiding information to students to help them understand the details of the algorithm. Figure 2 gives an illustration of the guidance given in the assignment. After they became familiar with the procedures, students were then required to solve the QCAPs using the BS without the guiding information.

**Initialization:**

(i) $b_1 = \sum_{i=1}^{N} t_i = 36$. $a_1 = \frac{b_1}{M} = 12$.

(ii) Completion time $a_1$ is infeasible, because the three cranes are assigned with containers {1}, {2}, and {3,4}, respectively (not all containers can be assigned). Define the iteration number $k = 1$ and go to iteration 1.

**Iteration 1:**

(ii) Define $c_1 = \frac{a_1+b_1}{2} = \frac{12+36}{2} = 24$. Completion time $c_1$ is feasible, because the three cranes are assigned with containers {1,2,3}, {4,5,6,7,8}, and Ø, respectively. Set $a_2 = a_1$ and $b_2 = c_1$. Set $k = 2$ and go to iteration 2.

**Iteration 2:**

(ii) Define $c_2 = \frac{a_2+b_2}{2} =$ _________. Completion time $c_2$ is feasible, because the three cranes are assigned with containers {1,2}, {_______}, and {_____}, respectively. Set $a_3 = a_2$ and $b_3 = c_2$. Set $k = 3$ and go to iteration 3.

**Iteration 3:**

(ii) Define $c_3 =$ __________. Completion time $c_3$ is feasible, because the three cranes are assigned with containers {_____}, {_______}, and {_______}, respectively. Set $a_4 =$ __ and $b_4 =$ ___. Set $k = 4$ and go to iteration 4.

Figure 2. An illustration of the guidance in the assignment

### 3.3 Containership Deployment Problem and Slot Allocation Problem

On top of the problems that are faced by container terminal operators, we also showed the students how to solve problems faced by liner companies using OR techniques. These problems include the containership deployment problem (SDP), and the slot allocation problem (SAP). The SDP is a tactical problem for a liner company, and it decides how to deploy the containerships owned by the company to the shipping lines operated by it. Meanwhile, the SAP is an operational problem which determines how to allocate slots on the containerships to transport containers among different ports in a given shipping line.

We taught the students to solve these problems using integer programming models and linear programming models. In particular, we illustrated to them what a mathematical programming model is and how to formulate a programming model for a problem. Besides, we also demonstrated how to solve linear and integer programming models using EXCEL. To enhance students' abilities to use mathematical programming models to solve different problems, we slightly changed the SDP and the SAP in the assignments for the students. For instance, for the SDP, we forbad the re-deployment of containerships from a certain route to another one. For the SAP, we required that the demand from long-term contracts must be satisfied. The students were also required to solve other problems using programming models, including the yard crane dispatch problem, the empty container repositioning problem, and the maximum flow problem.

### 3.4 Port Performance Analyses

In addition to applying OR methods to solve problems arising in liner shipping, we also taught the students how to evaluate and compare the performances of ports using OR techniques. To this end, the students are taught to use the queueing theory to evaluate the performance of the gate system in a container port and to use the data envelopment analysis (DEA) to compare efficiencies of variable container terminals.

For the queueing theory, the difficulty came from the understanding of the terminologies in the theory and how to relate each element in the formulas of the queueing theory with the data in a real gate system. To handle this difficulty, we introduced several queueing systems that can be found in daily life and explained in detail how these systems can be analyzed using the queueing theory. Students were also required to give examples of different queueing systems in their daily life. Meanwhile, for the DEA, to better educate the students of its applications in real situations, we used the real data from several container terminals.

## 4. FINDINGS AND PROBLEMS

In this section, we summarize and discuss the findings from our teaching practices. In particular, we first highlight the benefits of teaching OR techniques in liner shipping. Then, we present several common problems we met in classes and the measures to solve these problems.

Comparing our method with the teaching methods that are based on qualitative analyses, we have found the following benefits. To begin with, by letting students solve problems that arise in real operations in liner shipping, students obtain more comprehensive and detailed understandings of various operations in liner shipping. Instead of only having general images of liner shipping operations, applying OR techniques in liner shipping requires the students to exactly capture the considerations (e.g., objectives and constraints) of different entities (e.g., liner companies and terminal operators) in different operations. We have also found that teaching OR techniques and showing how to use them for solving real problems can better raise the interests of the students and stimulates them to probe into various problems. Finally, we believe that teaching OR methods to students also lead the students to learn how to consider problems in a systematic and rigorous way.

We have also found some problems from the students in our teaching practice. First, students in the class have different backgrounds. This matters especially when some preliminary knowledge is required to understand a certain OR method. To solve this problem, before introducing a method, we first introduced the most important preliminary knowledge required for understanding the method. Besides, we also allowed the students to discuss with us and with each other when working on in-class assignments. Second, students in the class also have diverse quantitative abilities. To solve this problem, we included problems with different levels of difficulties in the teaching material, in-class assignments, and homework. In addition, we started with easier problems and gradually introduced harder problems in teaching and practices. By doing these, we try to make sure that all students understand the most basic knowledge and also gradually raise their interests of probing into more complicated questions. Third, learning methods alone is tedious. To make the class more interesting, we used problems to lead the study processes, and methods are introduced when we need to solve these problems. Besides, before introducing the method to solve a problem, we presented to the students the background of the problems and why it is important. We also have designed different questions in the assignments to help the students practice what they learned in classes.

## 5. CONCLUSION

This paper presents our practices in a subject which teaches the applications of OR techniques in liner shipping. We gave several examples of how to teach students to use various OR methods for solving problems arising in liner shipping. Based on our practices, we highlighted the merits of this teaching method. Problems from students and the ways to solve them were also discussed.

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