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An analysis on convergence of data-driven approach to ship lock scheduling

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Abstract

In this paper, a ship lock scheduling problem is investigated. Ships arrive randomly over time, and the instantaneous arrival rates are allowed to vary both temporally and stochastically in an arbitrary manner. A data-driven approach is applied to a single ship lock scheduling, which is a typical optimizing and decision-making problem. The objective is to minimize the operation costs and other costs(e.g. water cost, electricity cost, and staff welfare cost) by selecting an appropriate slot number during a planned period. The convergence of data-driven approach is discussed from three aspects: the convergence of ant colony optimization algorithm, the convergence of the proposed algorithm, and the error between the historical ship data and the current arrival ship data. The research findings are beneficial for the convergence analysis of data-driven theory and the management of waterway transportation.

Keywords: Convergence; Data-driven; Ship lock scheduling; Ant colonyoptimization

1. Introduction

Since the development of ship lock scheduling approach is closely related to the national economy development, research of ship lock scheduling is becoming a heat topic that everyone of us should pay great attention to. There are many rivers in China, such as Yangtze River and Beijing-Hangzhou Grand canal, along which many ship locks are constructed. These ship locks enhance the power-generating capacity as well as the irrigation capacity of rivers. However, they throw up an obstacle to waterway transportation. For example, the Three Gorges-Gezhouba dam system, the largest hydroelectric station in China, consists of the Three Gorges dam and Gezhouba dam. The Three Gorges navigation facilities are composed of double-line five-grade ship locks and a ship lift. When the ships navigate on the Yangtze river, such as from Chongqing to Wuhan, they have to wait for a long time to pass through the Three Gorges ship locks and Gezhouba Dam ship locks. In this circumstance, the operating efficiency of the ship locks has significant impact on the overall navigation time. Generally, in order to pass through the Three Gorges ship locks, the ships have to wait for at least two hours, much worse, even several days are required to pass through the ship locks,

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which happens when the weather is bad [15]. Therefore, the operating efficiency of these ship locks becomes more and more important.

There is few literature on the ship lock scheduling problems. Du and Yu [3] studied the scheduling problem arising from Gezhouba dam, where three parallel ship locks were considered and a sliding window method was used for scheduling. Liu et al. [4,6] suggested a heuristic algorithm, the depth-first search algorithm, for the scheduling problems of the Three Gorges permanent ship locks. A ship lock scheduling problem is composed of two subproblems. One is time scheduling, the other is bin packing. Both problems had been extensively studied separately [2,5,7], but the interaction of the problems, which can not be ignored in practical applications, has not been studied yet.

Data-driven approach is to those problems which can not be constructed theoretical models, but have abundant available data [1]. In data-driven approach, the computational resources come from historical data, on-line data, off-line data and simulation data. During the last ten years, a number of applications to many different NP-hard problems, such as scheduling problems, control problems, fault diagnosis, decision making, etc, have empirically shown the effectiveness of data-driven approach. Still, very little theory is available to explain the reasons underlying data-driven approach's success.

Convergence is very important to an algorithm, there has been no literature attempting to analyze the convergence of data-driven approach. However, many researchers have studied the convergence or stability of all kinds algorithms with various methods [8,10–12,16–21], which are helpful to analyze the convergence of data-driven approach.

This paper takes several aspects into consideration which have not been included in the existing literatures before. Firstly, different from the traditional objective functions where maximize the area utilization ratio and minimize the waiting time [13,14], the objective function of this paper is minimizing the operation cost in a planned period; Secondly, a data-driven approach is proposed in this paper because the previous transportation data always affects the present state. As far as the research group know, it is the first time that the data-driven approach is applied to the ship lock scheduling. Finally, the convergence of data-driven approach will be analyzed from three aspects.

The main contribution of this paper is in proposing the data-driven approach and analyzing its convergence. Data-driven approach is applied to the ship lock scheduling problem. The study described in this paper includes several aspects that are not seen in previous literatures. Firstly, in our problem the objective function is the total cost of ship lock consisted of operation cost and penalty cost, while the objective functions of previous literatures are the utilization ratio per area and waiting time. Secondly, a detailed data-driven approach on ship lock scheduling is proposed, which have not been seen in previous literatures. Thirdly, the convergence of data-driven approach is analyzed, which has not been seen in previous literatures.

This paper consists of five sections. Section 2 explains this ship lock scheduling problem and its model. The data-driven approach is described in Section 3. Section 4 presents the convergence analysis of the data-driven approach, which is followed by conclusions and a brief discussion of possible future research in the final section.

2. The problem and its model

In this paper, the ship navigation for a single ship lock along one direction is investigated, which means that there are two ship locks on the river, one for downstream and the other for upstream, the Three Gorges ship lock facilities are of this case. Ships arrive randomly over time according to a stochastic poisson process with instantaneous arrival rates given by $\Lambda_i(t)$, which is nonnegative and has continuous ample paths, such that $\mathbb{E}\int_0^T \Lambda_i(s)ds$ exists, where i denotes the ship types and is enumerated by {passenger ship, cargo ship, official ship, hazardous cargo ship }.

As the performance capability of the ship lock is limited, some ships can not pass through the ship lock in the specified time, thus have to be placed in an infinite-capacity buffer. Except hazardous cargo ships, other ships can be scheduled into a slot of the ship lock as long as their times and sizes are suitable. Since the loadings of the hazardous cargo ships are very dangerous because they usually load explosive gas and toxic materials etc, these hazardous cargo ships must be scheduled into a single slot of the ship lock.

Considering an interval [0, T], we define the ships' number up to time t: $F_i(t) = \int_0^t \Lambda_i(s)ds$, for $i = 1, 2, 3, 4$ and $0 < t < T$.

All ships concerned in our model are assumed rectangular, whose length, width, and area are denoted by l, w, s, respectively. We get $s = l * w$. The ship lock is also considered as rectangular, whose length and width are denoted by L, W, respectively, and the area is denoted by A, $A = L * W$. As the sizes of ships are various in China, thus the sizes