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Green transportation scheduling with pickup time and transport mode selections using a novel multi-objective memetic optimization approach

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ABSTRACT

This paper addresses a green transportation scheduling problem with realistic constraints widely existing in make-to-order manufacturing supply chains, such as pickup time and transport mode selections. The mathematical model of this problem is presented, which is formulated as a bi-objective mixed integer nonlinear program. The problem is simplified first by converting this program to a bi-objective integer nonlinear program. A novel evolution-strategy-based memetic Pareto optimization (ESMPO) approach is then developed to handle this new program, in which a multi-objective local search process is proposed to seek promising neighboring individuals and the faster nondominated sorting procedure is introduced into the memetic algorithm to perform multi-objective sorting. The performance of the proposed ESMPO approach is evaluated by numerical experiments based on industrial data and industrial-sized problems. Experimental results demonstrate that the proposed approach can effectively solve the investigated problem by generating much better solutions than 3 other metaheuristic-based Pareto optimization approaches and the industrial method do.

Introduction

Transportation is one of the most important parts of logistics, which is an essential fundamental infrastructure for economic growth. The performance of transportation scheduling has great effects on the performance of logistics and supply chain operations as well as the competitiveness of enterprises. According to ECOFYS (2010), around 15% of 2010 global greenhouse gas emissions resulted from transportation. Transportation has significantly negative impacts on the environment and it is important to reduce the carbon emission in transportation. This paper addresses a bi-objective green transportation scheduling problem, which is motivated by real-world transportation scheduling operations in some global make-to-order (MTO) manufacturing companies.

Previous studies on scheduling problems in transportation

The research on transportation scheduling problems can be traced back to the 1960s (Curry and Schuerma, 1968). Since then, a large variety of transportation scheduling problems have been investigated, such as block transportation scheduling

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(Joo and Kim, 2014; Lee et al., 2009; Roh and Cha, 2011), maritime and trans-shipment transportation scheduling (Huang and Karimi, 2006; Scott, 1995) and truck and train transportation scheduling (Grunow and Stefansdottir, 2012; Nozick et al., 1997; Solomon and Desrosiers, 1988; Yan et al., 2014; Zhang et al., 2010). Hu (2011) addressed a container multimodal transportation scheduling problem, which aims to schedule the multimodal transportation flow of the container supply chain. Grunow and Stefánsdóttir (2012) investigated a transportation planning and vehicle scheduling problem for short-term planning of transportation processes, which aimed to determine transportation routes and schedule vehicle resources. Wang and Yun (2013) addressed an inland container transportation scheduling problem, which considered truck and train transportation as well as time windows constraints. Meng et al. (2013) made a comprehensive review on previous studies that used operations research methods to tackle containership routing and scheduling problems at strategic, tactical, and operational planning levels.

In recent years, transportation scheduling problems with the consideration of environment issues, green transportation scheduling, have attracted researchers' increasing attention. Bauer et al. (2010) aimed to minimize greenhouse gas emissions in intermodal freight transport. Li et al. (2013) addressed a green train scheduling problem with the objectives of minimizing both the energy and carbon emission cost and the total passenger time. Kontovas (2014) has conceptualized the formulation of the green ship routing and scheduling problem based on existing formulations and highlighted the important parameters of the problem. Recently, Siddiqui and Verma (2015) investigated a bi-objective optimization problem for routing and scheduling of crude oil tankers from the cost and risk perspective. However, multi-objective green transportation scheduling problems with pickup time features have not been investigated so far.

Some researchers investigated different transportation scheduling problems with pickup features. Hachemi et al. (2013) addressed a synchronized log-truck scheduling problem arising in the forest industry, which combines routing and scheduling of trucks with specific problem features such as pickup and delivery, multiple products, inventory stock, multiple supply points and multiple demand points. Nishi and Izuno (2014) investigated a heterogeneous ship routing and scheduling problem with multi-item split pickup and split delivery finite capacity and loading constraints. Hennig et al. (2015) addressed a crude oil tanker routing and scheduling problem with split pickup and split delivery. However, the transportation scheduling problem with pickup time and transport mode selections has not been investigated so far.

This research aims to investigate a bi-objective green transportation scheduling problem with pickup time and transport mode selections. The two objectives are to minimize both the total transportation cost and the total carbon emission. This problem is motivated by a practical transportation scheduling problem widely existing in some manufacturing supply chains such as apparel and footwear. In such supply chains, the finished products in a delivery order need to be transported from the production plant to the distribution center. There are multiple transport modes available for transportation, each of which represents a type of vehicles (transporter) with a certain transport time and a certain carrying capacity. The manufacturer needs to determine when to pick up the finished products and which transport mode is selected for each delivery order. The features of pickup time and transport mode selections and the carbon emission objective are the most distinct features that differentiates our problem from transportation scheduling problems in the literature.

Techniques for transportation scheduling and optimization

A large variety of techniques have been developed to handle transportation scheduling and optimization problems, such as exact and heuristic techniques (Forbes et al., 1994; Franceschetti et al., 2013; Hachemi et al., 2013; Xie, 2014) as well as metaheuristics (Eskandarpour et al., 2014; Shafia et al., 2012; Xu and Gang, 2013; Zegordi and Nia, 2009). Some transportation scheduling problems are NP-hard combinatorial optimization problems because they are extensions of some classical NP-hard problems such as the multiple traveling salesman problem with time windows (Zhang et al., 2010), which are very hard-to-tackle. With the increase of problem size and complexity of transportation scheduling, it is hard for exact and heuristic techniques to handle these problems.

Metaheuristics have the potential to provide optimal or near-optimal solutions to complicated optimization problems due to their heuristic natures (Demir et al., 2014; Guo et al., 2013; Potvin, 2009), which have been used widely to handle transportation scheduling problems. Shafia et al. (2012) developed a simulated annealing-based metaheuristic to solve a train scheduling problem. Wang and Yun (2013) proposed a hybrid tabu search approach to handle an inland container transportation scheduling problem. Xu and Gang (2013) developed an adaptive particle swarm optimization-based bi-level optimization approach to solve a construction material transportation scheduling problem. Eskandarpour et al. (2014) presented a multi-start variable neighborhood search technique to solve a bi-objective post-sales transportation network design problem. In recent years, hybrid evolutionary algorithms have attracted more and more researchers' attention and have been applied successfully to various scheduling problems. Among them, the memetic algorithm, developed by Moscato (1989), is one of the most successful algorithms in the field of evolutionary computation (Neri and Cotta, 2012).

It has been shown that the memetic algorithm could provide better optimum-seeking performance than GA over a wide variety of engineering optimization applications (Cattaruzza et al., 2014; Neri and Cotta, 2012; Zhang et al., 2015). However, relatively little attention has been paid on using memetic algorithms to solve transportation scheduling problems. Recently, Zhang et al. (2015) used a memetic algorithm with a customized recombination operator to handle a practical patient transportation problem. The traditional memetic algorithm uses GA to perform the global search, which is very time-consuming for complex optimization problem with large solution space due to the GA's population-based evolution mechanism. In