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Green transportation scheduling with speed control: trade-off between total transportation cost and carbon emission

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ABSTRACT

Transportation has a significant portion in greenhouse gas emission. Efficient transportation scheduling can decrease transportation costs and environmental damages by reducing fuel consumption and greenhouse gas emission. These advantages have made green transportation scheduling more attractive. This paper addresses the problem of integrated green truck transportation scheduling and driver assignment. We propose a bi-objective mixed integer nonlinear programming (MINLP) model to minimize total transportation-related costs (TTC) and total carbon emission (TCE). We consider TTC and TCE as manufacturer measure and environmental sustainability measure respectively. There is a contradiction between two objectives. We consider the ability of speed control for trucks to create the trade-off between TTC and TCE. A linearization technique is utilized to reduce the complexity of the proposed model. The Augmented ε-constraint method is used to solve the model. Also, we develop a constructive heuristic (CH) approach to get high-quality solutions in an efficient CPU time. Some scenarios are applied to evaluate the model and heuristic approach. The results show the model achieves high-quality solutions in reasonable time. Also, the model and heuristic have a better performance compared to scenarios. Statistical tests are done to approve the comparisons.

1. Introduction

Transportation has a great effect on economic growth and is a foundational infrastructure in any country. Efficient transportation scheduling improves logistics performance and supply chain and increases the competitive advantage of companies (Guo, Zhang, Liu, He, & Shi, 2016). People and goods transportation is one of the main reasons for increasing greenhouse gas emission. It leads to climate change and increase of global warming (Fuglestvedt, Berntsen, Myhre, Rypdal, & Skeie, 2008). In 2010, transportation sector emitted about 15% of global greenhouse gas which the road transportation accounted for 10.5% of this amount (ECOFYS, 2010). It is forecasted that the transportation will be responsible for 30–50% of CO_2 emissions by 2050 (Nakicenovic & Swart, 2000). This amount of emission pollutes the atmosphere and has great damaging effects on the environment. Therefore, some policies are needed to turn mentioned disadvantages to the opportunities. We propose a new approach to decrease the damaging effect and get some advantages without any investment. This paper aims to address a multi-period integrated truck transportation scheduling and driver assignment to minimize CO_2 emissions and transportation costs.

There are a large variety of papers in the context of transportation scheduling. Topics include truck transportation scheduling (Zhang, Yun, & Kopfer, 2010; El Hachemi, Gendreau, & Rousseau, 2013), train transportation scheduling (Shafia, Sadjadi, Jamili, Tavakkoli-Moghaddam, & Pourseyed-Aghaee, 2012; Wang & Yun, 2013), block transportation scheduling (Lee, Lim, & Koo, 2009; Roh & Cha, 2011; Joo & Kim, 2014), maritime transportation scheduling (Huang & Karimi, 2006; Nishi & Izuno, 2014; Siddiqui & Verma, 2015; Hennig, Nygreen, Furman, & Song, 2015) and Integrated transportation scheduling with production planning and supply chain management (Xu, Liu, & Chen, 2017 Karaoğlan & Kesen, 2017)

Negative effects of transportation on the environment have led researchers to focus on green transportation scheduling in recent years. Bauer, Bektaş, and Crainic (2010) considered minimizing greenhouse gas emissions in an intermodal freight transportation problem by services scheduling and freight routing. They proposed an integer programming formulation for the problem. Li, Wang, Li, and Gao (2013) studied green train scheduling problem. They proposed a mixed integer programming model to minimize carbon and energy emission and total passengers' time. They used fuzzy multi objective optimization algorithm for solving the model. Kontovas (2014) conceptualized formulate

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for the green ship routing and scheduling problem. They combined ship air emissions and the vehicle routing problem. Huang, Yang, Tang, Cao, and Gao (2016) presented a bi-objective mathematical model to optimize the timetables of urban rail transit systems and operational energy consumption. They used genetic algorithm for solving the problem. Tanimizu and Amano (2016) proposed an integrated scheduling method for production and transportation problem. They presented a bi-objective mathematical model to minimize total tardiness and emitted carbon of vehicles. Guo et al. (2016) focused on green transportation scheduling problem considering pickup time and transport mode selection. They proposed a bi-objective integer nonlinear programming model and developed a memetic optimization approach to solve the model. Guo, Shi, Chen, and Liang (2017) studied an integrated production and transportation scheduling problem. They presented a mathematical model to minimize total production costs and transportation costs. The objective function includes carbon emission cost caused by production and transportation. They developed a harmony search-based memetic algorithm for solving the problem.

We develop a bi-objective mixed integer nonlinear programming (MINLP) model for green transportation scheduling problem which exists in some make-to-order manufacturing companies. The first objective includes minimizing total transportation related-cost as a measure of manufacturing company. TTC includes transport cost, earliness and tardiness cost for delivery and holding cost in the manufacturing company. The second objective includes minimizing total carbon emission as a measure of environmental sustainability. Manufacturing companies have two main resources for transporting the goods, including vehicles and drivers. The attention of drivers' assignment status besides trucks consideration reveals a more comprehensive view on the problem and facilitates the company's operations. It is difficult for companies to assign drivers manually (Sargut, Altuntaş, & Tulazoğlu, 2017). If number of orders is high in the planning period, then more trucks and drivers are needed while the number of drivers and trucks are limited. Also, there is eligibility requirement which is related to the drivers' license i.e. not all drivers can drive any truck. In this situation, the problem will be more difficult. Therefore, we integrate the driver assignment with truck transportation scheduling problem.

There is a conflict between the objectives. We propose new approach to create a balance between them by the truck speed control. Speed control affects the transportation costs and carbon emission, i.e. different speed levels are assumed for vehicles and each level leads to a different TTC and TCE values. The augmented ε-constraint method is applied to solve the proposed bi-objective model. Also, we develop an efficient constructive heuristic to solve the large size problems in suitable times. Table 1 summarizes the research papers on green transportation scheduling. To the best of our knowledge, the proposed bi-objective model integrating the transportation scheduling and drivers' assignment considering truck speed control has not been studied in the literature.

The main contributions of the paper are as follows:

1. Proposing a new mathematical model to integrate the transportation scheduling and driver assignment.
2. Presenting the concept of speed control and green consideration in transportation.
3. Providing an efficient constructive heuristic to solve the problem in large sizes.
4. Analyzing the conflict between transportation costs and carbon emission.
5. Evaluating the proposed model performance compared with different scenarios.

The rest of this paper is organized as follows. Section 2 describes the considered problem and explains the proposed mathematical model. Section 3 presents the constructive heuristic and briefly explains the augmented ε-constraint method. Section 4 presents computational results. Section 5 finishes the paper and brings up some offers for future works.

2. Problem description

Consider a transportation scheduling problem existing in a manufacturing company. When the manufacturing of products is finished, then the company transports the requested quantity of orders to a distribution center. Finally, the orders can be delivered to customers by other companies. The quantity of transported orders is determined based on the customers' demands.

Each order has a delivery date. It is better to deliver orders exactly on the delivery date. If orders reach customers before the delivery date, then they may not require the orders at that time. If orders reach the customers after the delivery date, then they will be dissatisfied and customer loyalty may decrease. So, we use earliness and tardiness penalty costs for orders. There is a holding cost for a finished product which is stored in the company. A certain number of different trucks is available to the company. The trucks differ in terms of capacity and their properties. Each truck has a specific weight and carbon emission factor depending on its type. There are some possible speed levels for trucks. Each level has a certain amount of fuel consumption, carbon emission and duration of transportation. Also, a certain number of drivers is available to the company. Not all drivers can drive any truck. The pickup date of all orders should be determined at the beginning of the planning horizon. An order can be transported by two or more trucks. But all of its demand should be loaded and transported on a single fixed day. In summary, after the company specified the pickup date for an order based on the delivery date, then the trucks and corresponding drivers should be determined to transport the orders.

An MINLP model for a multi-period trucks transportation scheduling problem is proposed to minimize total transportation costs and

Table 1
Summary of the literature on green transportation scheduling.

Article	Type of problem		Vehicle type	Objective function (green aspect)	Speed control		Driver assignment		Solution method
	Scheduling	Routing			Yes	No	Yes	No	
Bauer et al. (2010)	✓	✓	Truck/Train	Min. carbon emission		✓		✓	Mathematical programming
Li et al. (2013)	✓		Train	Min. energy consumption		✓		✓	Fuzzy Mathematical programming
Kontovas (2014)	✓	✓	Ship	Min. carbon emission		✓		✓	–
Tanimizu and Amano (2016)	✓		Truck	Min. carbon emission		✓		✓	Genetic algorithm
Huang et al. (2016)	✓		Train	Min. energy consumption		✓		✓	Genetic algorithm
Guo et al. (2016)	✓		Truck	Min. carbon emission		✓		✓	Novel memetic algorithm
Guo et al. (2017)	✓		–	Min. carbon emission cost		✓		✓	harmony search-based memetic algorithm
Our paper	✓		Truck	Min. carbon emission	✓		✓		Novel constructive heuristic