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Mathematical models for green vehicle routing problems with pickup and delivery: A case of semiconductor supply chain

Sakthivel Madankumar, Chandrasekharan Rajendran*

Department of Management Studies, Indian Institute of Technology Madras, Chennai 600036, India

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ABSTRACT

In this paper, we consider a special case of vehicle routing problem that addresses the routing problem in a semiconductor supply chain. This paper proposes two Mixed Integer Linear Programming (MILP) models for solving the Green Vehicle Routing Problems with Pickups and Deliveries in a Semiconductor Supply Chain (G-VRPPD-SSC). The first MILP model considers the basic G-VRPPD-SSC problem, and the objective is to find the set of minimum cost routes and schedules for the alternative fuel vehicles in order to satisfy a set of requests which comprise pickup and delivery operations, without violating the product and vehicle compatibility, vehicle capacity, request-priorities and request-types, and start/completion time constraints. The second model extends the first model in order to handle the scenario of having different fuel prices at different refueling stations, and the objective is to minimize the sum of costs of operating alternative fuel vehicles, which include both the routing cost and the refueling cost. To relatively evaluate the performance of the proposed MILP models, we consider the Pickup and Delivery Problem in a Semiconductor Supply Chain (PDP-SSC) without the presence of alternative fuel vehicles, and we present the corresponding MILP model. Our model is compared with an MILP model present in the literature. Our study indicates that the proposed model for the PDP-SSC gives better lower bounds than that by the existing work, apart from performing better than the existing work in terms of requiring less CPU time. In all cases, the proposed three MILP models preform quite good in terms of the execution time to solve the generated problem instances.

1. Introduction

The Pickup and Delivery Problem in a Semiconductor Supply Chain (PDP-SSC) is a special case of Vehicle Routing Problem (VRP). The problem was introduced by Lai and Chen [4], and this problem addresses the distribution activities (transportation requests) of wafers in the distribution network of semiconductor supply chain. The distribution network of semiconductor supply chain comprises mask houses, wafer fabrication plants, IC packaging plants and warehouses. The PDP-SSC is a special case of VRP which comes under the class of Vehicle Routing Problems with Pickups and Deliveries (VRPPD) where goods (such as wafers) are transported between pickup and delivery locations. The main objective of the PDP-SSC is to find the set of minimum cost routes and schedules for the vehicles in order to satisfy the set of requests which comprises pickup and delivery operations, without violating the product and vehicle compatibility, vehicle capacity, request-priorities and request-types, and start/completion time constraints.

The PDP-SSC mainly involves transportation activities to complete/serve a set of requests, but the transportation has an impact on environment due to Greenhouse Gas (GHG) emissions. Transportation sector contributes substantive GHG emissions from fossil fuel usage. This indicates that countries may have to concentrate on transportation sector for reducing the GHG emissions [6]. As a part of the steps to reduce the GHG emissions, efforts are made to use or consider alternative fuel sources (biodiesel, electricity, ethanol, hydrogen, etc.) instead of fossil fuel sources [8]. The vehicles that use alternative fuel sources are referred to as Alternative Fuel Vehicles (AFVs). The lack of infrastructure for refueling AFVs poses an additional challenge for operating AFVs because Alternative Fueling Stations (AFSs) are not necessarily distributed evenly across the geographic region. This limitation forces/allows an AFV to stop at one or more AFSs along the route to avoid the risk of running out of fuel in the middle of the route/trip [2].

In this paper, we consider the Green Vehicle Routing Problems with Pickups and Deliveries in a Semiconductor Supply Chain (G-VRPPD-SSC) which is an extension of the PDP-SSC, in which a fleet

* Corresponding author.
E-mail addresses: madankumar.sakthivel@gmail.com (S. Madankumar), craj@iitm.ac.in (C. Rajendran).

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of AFVs is operated to serve the requests instead of regular fuel vehicles.

2. Research problem description and assumptions

We consider the extension of the PDP-SSC presented by Lai and Chen [4] to the G-VRPPD-SSC. The G-VRPPD-SSC is a comprehensive problem in which a fleet of AFVs is operated to serve the requests. To address the distribution activities of wafers in semiconductor supply chain, goods (wafers) are transported between pickup and delivery locations using AFVs instead of supplying the goods from central depot. The constraints related to product/vehicle compatibility, vehicle capacity, request-priorities and start/completion time of operations make this problem quite comprehensive and challenging.

The G-VRPPD-SSC can be described as follows: a set of requests is given, and each request demands a lot size of wafers to be transported from a pickup node to a delivery node. Based on the production policy, the priority of the requests varies between normal priority and hot priority. A fleet of capacitated AFVs is available at the depot, and each vehicle starts from the depot and serves the set of operations, and returns to the depot within the available time window. During the pickup operation, the AFV (with a given capacity) has to visit the pickup node in the transportation network, and for the delivery operation, the AFV has to visit the delivery node in the transportation network. To complete a particular request, the pickup operation should precede the delivery operation of the respective request. If the request is of hot priority, the pickup operation should immediately precede the delivery operation. The priorities of the requests are static and known in advance. The main requirement of the hot priority request is that the AFV has to visit the delivery node soon after it visits the corresponding pickup node. This hot priority makes sure that there is no additional delay introduced in between pickup operation and delivery operation due to refueling of the vehicle at an AFS or due to vehicle serving operations pertaining to some other requests.

Requests can be classified into following three types based on the size of the wafers to be transported between pickup node and delivery node. As assumed by Lai and Chen [4], we consider wafers of two specific sizes (SIZE1 and SIZE2), and the generic size wafers which can be applied to wafers of any size.

- TYPE1 requests: request to pickup/deliver wafers of size SIZE1.
- TYPE2 requests: request to pickup/deliver wafers of size SIZE2.
- TYPE0 requests: request to pickup/deliver generic wafers.

In the fleet, some vehicles are with special facilities dedicated to carry TYPE1 wafers which are referred to as TYPE1 vehicles and some vehicles are dedicated for TYPE2 wafers which are referred to as TYPE2 vehicles, while other vehicles are open for carrying all wafers which are referred to as TYPE0 vehicles. The objective of G-VRPPD-SSC is to find the routes and schedules for all AFVs to satisfy the given set of requests such that the total traveling cost is minimized respect to all constraints.

In this paper, we propose two Mixed Integer Linear Programming (MILP) models for the G-VRPPD-SSC. The first MILP model considers the basic G-VRPPD-SSC, and the objective is to find the set of minimum cost routes and schedules for the alternative fuel vehicles in order to satisfy a set of requests which comprises pickup and delivery operations, without violating the product and vehicle compatibility, vehicle capacity, request-priorities and request-types, and start/completion time constraints. The second model extends the first model in order to handle the scenario of having different fuel prices at different refueling stations, and the objective is to minimize the sum of costs of operating AFVs which include both the routing cost and the refueling cost.

3. Literature review

The literature on vehicle routing problem and its variations is quite vast, and the basic problem is referred to as Capacitated Vehicle Routing Problem (CVRP). The CVRP aims to find the minimum cost routes for the set of vehicles, in order to satisfy the demand of a given set of customers. In the CVRP, goods are transported from central depot to respective customers based on their demand using a fleet of vehicles with uniform capacity. For reference and review of the basic problem and its variants, the reader may go through Toth and Vigo [7].

When the goods are transported between pickup and delivery locations instead of from a central depot, it is referred to as Vehicle Routing Problems with Pickups and Deliveries (VRPPD). The VRPPD can be further classified into two types. The first type deals with the problem where pickup and delivery locations are unpaired in which homogenous goods are transported between pickup and delivery locations. The second type deals with the problem where pickup and delivery locations are paired. This particular problem type involves transportation requests and each request is associated with an origin and a destination, resulting in a paired pickup and delivery locations. For a detailed survey on pickup and delivery problems, we refer the reader to go through the survey article by Parragh et al. [5].

The Green Vehicle Routing problem (G-VRP) was first introduced by Erdogan and Miller-Hooks [2], to reduce the impact on environment due to GHG emissions. G-VRP seeks to find the optimum set of routes for the given AFVs, and each AFV starts at the depot, visits the subset of vertices (customer/AFS locations) and returns to the depot. In this process, a vehicle is permitted to stop at one or more AFSs to ensure that the fuel is available to transport the demands of remaining customers allocated to this AFV. It is also assumed that depot can also act as a refueling station, and all refueling stations have unlimited capacities. Similarly, to reduce the impact on environment, Gajanand and Narendran [3] considered alternative routes between nodes, and formulated a model for the same.

The G-VRPPD-SSC is possibly first studied by us, which is an extension of the PDP-SSC and G-VRP. It deals with the specific problem in the semiconductor supply chain in which wafers are distributed between pickup and delivery locations, and it also attempts to minimize the impact on environment by using AFVs. The G-VRPPD-SSC comes under the class of VRPPD which deals with the paired pickup and delivery locations. The PDP-SSC is NP-hard [4], and the G-VRP is also NP-hard [2]. Hence the G-VRPPD-SSC which is an extension of both G-VRP and PDP-SSC is also an NP-hard problem, because G-VRPPD-SSC is easily reducible to PDP-SSC by operating with regular fuel vehicles.

In Section 4, we propose two MILP models for the G-VRPPD-SSC. The proposed models address a comprehensive green vehicle routing problem. When we exclude the consideration with respect to green supply chain (e.g., use of regular or conventional vehicles, instead of AFVs and AFSs), we come up with the VRP in the context of semiconductor supply chain, and this problem is the PDP-SSC, and we present the model for PDP-SSC in Section 5. We present the computational evaluation of the proposed models for the G-VRPPD-SSC in Section 6.2 and we present the comparison study of the proposed model for the PDP-SSC and the model available in the literature for the PDP-SSC [4] in Section 6.3. In addition we also obtain a lower bound (by relaxing the binary variables) from our proposed models, which can serve as a benchmark for evaluation of future attempts on heuristics.