Discrete Applied Mathematics 205 (2016) 52–61

Contents lists available at ScienceDirect

Discrete Applied Mathematics

journal homepage: www.elsevier.com/locate/dam

Vehicle scheduling under the warehouse-on-wheels policy

Malte Fliedner [a], Dirk Briskorn [b], Nils Boysen [c,*]

[a] Universität Hamburg, Institut für Operations Management, Von-Melle-Park 5, 20146 Hamburg, Germany[1]

[b] Bergische Universität Wuppertal, Schumpeter School of Business and Economics, Professur für BWL, insbesondere Produktion und Logistik, Rainer-Gruenter-Str. 21, 42119 Wuppertal, Germany[2]

[c] Friedrich-Schiller-Universität Jena, Lehrstuhl für Operations Management, Carl-Zeiß-Straße 3, 07743 Jena, Germany[3]

ARTICLE INFO

Article history:
Received 6 April 2015
Received in revised form 16 November 2015
Accepted 18 November 2015
Available online 23 December 2015

Keywords:
Transport logistics
Just-in-time
Computational complexity
Dynamic programming

ABSTRACT

The warehouse-on-wheels (WOW) policy is a widespread concept to implement material supply in just-in-time production systems. Instead of storing part inventories directly on the shop-floor where space is notoriously scare, the transport vehicles that deliver the materials serve as mobile storages, either while waiting in the trailer yard or while docking at inbound delivery gates. We investigate a vehicle scheduling problem under the WOW policy between a single distribution center and a production facility. Multiple containers of parts each associated with an individual delivery date and a – potentially individual – capacity requirement are to be shipped to the factory. The docking time of transporting vehicles is determined by their respective freight from the delivery date of the most urgent container up to that of the least urgent one. Only then, a vehicle may return to the distribution center to transship another subset of containers. We formalize the resulting vehicle scheduling problem under different objectives, investigate the computational complexity of the problem and develop efficient solution procedures for important problem variants.

1. Introduction

In the wake of the Toyota production system (see [16]), the just-in-time principle took its triumphal procession all around the globe. One specific concept to realize just-in-time material supply is the warehouse-on-wheels (WOW) policy. Instead of storing part inventories directly on the shop-floor where space is notoriously scarce, the transport vehicles themselves are employed as mobile storages either while waiting in the trailer yard or while docking at inbound delivery gates at the factory. In this context, we encountered the following WOW setting at a major German car manufacturer.

A distribution center located in vicinity of an assembly plant receives part deliveries from distant suppliers (predominantly from Far East), which are too far away to allow a concerted just-in-time supply directly to the factory. Three to four days before the start of production, the final assembly sequence of cars is fixed [3] and submitted to the distribution center. Here, the required parts are sorted into the sequence of their assembly and packed into transport containers of approximately similar sizes. Each of these containers has a delivery date that defines the exact point in time the part is

* Corresponding author. Tel.: +49 3641 9 43100.
E-mail addresses: malte.fliedner@uni-hamburg.de (M. Fliedner), briskorn@uni-wuppertal.de (D. Briskorn), nils.boysen@uni-jena.de (N. Boysen).

1 https://www.bwl.uni-hamburg.de/om/

2 http://www.prodlog.uni-wuppertal.de/

3 http://www.om.uni-jena.de/

http://dx.doi.org/10.1016/j.dam.2015.11.015

required in the assembly process. Container transshipment between distribution center and factory is executed by a fleet of trucks that is employed according to the WOW policy. The storage space in the old factory building is extremely scarce, so that trucks remain docked with open trailer doors at their delivery gate and each container is removed not before it is actually required in the assembly process. Thus, each truck has to arrive no later than the delivery date of the most urgent container and remain docked up until the delivery date of the least urgent one. Only once this container has been removed, the truck is finally released and may return to the distribution center in order to deliver the next truckload.

This paper aims to solve the resulting vehicle scheduling problem from the point of view of the car manufacturer. A static set of containers is to be partitioned into truckloads, such that capacity constraints are met and the trucks' docking times at the gates are reduced. We formalize the WOW vehicle scheduling problem and provide a thorough analysis of computational complexity for different capacity situations and alternative objective functions.

The remainder of the paper is structured as follows. Section 2 surveys the relevant literature and Section 3 formalizes the WOW vehicle scheduling problem. Then, Sections 4 and 5 analyze the computational complexity of different problem variants and provide efficient exact solution procedures for most of them. Finally, Section 6 concludes the paper.

2. Literature review

Neglecting the WOW aspect, the vehicle scheduling discussed in this work is a special bin packing problem, in that differently sized items (containers) have to be stored in homogeneous bins (vehicles) subject to a particular objective (e.g. minimizing the number of vehicles). Bin packing is among the most elementary problems of operations research, so that plenty of work has accumulated over the decades. A survey is, for instance, provided by Coffman et al. [6]. Extensions of bin packing are denoted as generalized bin packing problems, which have also received a lot of attention. For instance, multi-dimensional problems [15], bins of variable size [12], fragile items [5], items occupying more than one bin [4], restrictions on the number of items per bin [13], and conflicts among items [8,14,17,18] have been considered. In a certain sense the problem studied in this paper can be seen as a special bin packing problem with soft conflicts among items on the basis of their delivery dates. However, we further model time dependencies with respect to the availability of bins and consider different time dependent objectives.

Time dependencies and especially a just-in-time focus are often treated in the domain of machine scheduling. An in-depth review on just-in-time machine scheduling is, for instance, provided by Jozefowska [11]. In the problem at hand however, we have no processing times directly associated with each job (container). Instead the processing time (docking time) is rather the result of a minimum and maximum function on the subset of jobs (containers) jointly transported by a vehicle (machine), which has – to the best knowledge of the authors – not been investigated thus far.

Finally, we take a look into the domain of part supply in the automotive industry. A survey on the decision problems relevant in this field is provided by Boysen et al. [3]. While the peculiarities of the WOW policy have not been considered yet, a recent paper of Boysen et al. [2] treats a special vehicle scheduling problem of supplying an assembly plant from a distribution center. There, however, another delivery policy is considered where a truck is unloaded once it reaches the factory. The earliest delivery date of all transported containers determines the arrival (and unloading) time of each truck. Further the aim there is to minimize the total earliness of container deliveries, which leads to a very different problem structure.

3. Problem statement

Consider a set of items $I = \{1, \dots, n\}$, e.g., containers, boxes, or pallets filled with parts, that are to be transported from a single distribution center to a manufacturer's factory. Each item i is assigned to a delivery date d_i, determining the exact point in time at which it is needed at the factory, and a weight c_i that represents the space requirement of the item in the transporting vehicle. In the following we assume that items are sorted according to non-decreasing delivery dates, so that $d_1 \le d_2 \le \cdots \le d_n$. Note that this is just for convenience of notation, so that we will nonetheless consider a sorting operation necessary, whenever a particular order of items is required in the algorithmic discussion. Item transshipment is executed by a homogeneous fleet of vehicles each with a total loading capacity of C. A single trip from the distribution center to the factory is assumed to last exactly δ units of transit time and is supposed to be the same for the way back. Each vehicle serves as a WOW, so that it has to arrive at the factory to timely supply the item with the smallest delivery date and cannot leave before the largest delivery date of any transported item is due. We will write $s(i) = d_i - \delta$ and $e(i) = d_i + \delta$ for short and refer to them as the start and end date of an item, since any trip that includes item i will need to start no later than $s(i)$ and end no earlier than $e(i)$ at the distribution center. We further define a trip $J \subseteq I$ as a subset of items that are transported to the factory together by the same vehicle. For convenience we will refer to the minimum and maximum item indices contained in a trip as $\min(J)$ and $\max(J)$. The start time and end time of any trip J is denoted as $s(J) = \min_{i \in J} \{s(i)\}$ and $e(J) = \max_{i \in J} \{e(i)\}$, respectively.

Thus, the total utilization time for a trip consists of the travel time from the distribution center to the factory, the vehicle's docking time spanning from the delivery date of the smallest to the highest item index plus the time on its way back, i.e. $e(J) - s(J) = 2\delta + \max_{i \in J} \{d_i\} - \min_{i \in J} \{d_i\}$.