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Innovative Applications of O.R.

Scheduling in-house transport vehicles to feed parts to automotive assembly lines

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ABSTRACT

Due to exorbitant product variety, very limited space, and other factors, organizing efficient and timely deliveries of parts and subassemblies to final assembly within the factory is one of the most pressing problems of modern mixed-model assembly production. Many automobile producers have implemented the so-called “supermarket” concept to transfer material to the assembly line frequently and in small lots. Supermarkets are decentralized logistics areas on the shop floor where parts are intermediately stored for nearby assembly cells, to be ferried there by small transport vehicles (called tow trains or tuggers). This paper tackles the operational problem of drawing up schedules for these tow trains, such that the assembly line never starves for parts while also minimizing in-process inventory, thus satisfying just-in-time goals. We prove strong NP-completeness of the problem and present exact and heuristic solution methods. In a computational study, the procedures are shown to perform very well, solving realistic instances to (near-)optimality in a matter of minutes, clearly outperforming the simple cyclic schedules commonly used in industrial practice. We also provide some managerial insight into the right degree of automation for such a part feeding system.

1. Introduction

In recent decades, logistics problems have increasingly become the center of attention for many companies in the automotive sector. This is mostly due to the exorbitant product variety most automobile producers today offer, aiming to fulfill even niche customer demands. Owing to individually (de-)selectable options (e.g., leather trim or car radio), the number of theoretically available model variants is in the trillions (Boysen, Fliedner, & Scholl, 2009). Seeing that the production rate of a typical automotive assembly line can easily approach 1 car per minute, the enormous amount and diversity of parts required in final assembly becomes obvious. It is practically impossible to keep all those parts in stock at the factory, let alone at the assembly workstations themselves, for any prolonged amount of time. Consequently, almost all automobile manufacturers implement (or aim to implement) just-in-time logistics at least for a portion of their supplies, such that parts are only brought from one production stage to next when and if required.

This puts a heavy strain on the logistics systems as it necessitates a large number of small-lot deliveries. For example, at the Volkswagen plant in Wolfsburg, up to 750 trucks per day need to be processed (Autogramm, 2007); similarly, at the BMW plant in Dingolfing 400 trucks, carrying around 13,000 individual shipments, need to be handled each day (Battini, Boysen, & Emde, 2013). Just-in-time concerns are especially pressing in final assembly itself, where, on the one hand, space is extremely scarce, prohibiting large safety stocks, and, on the other hand, even slight delays can have very dire consequences. In the worst case, if an important part is missing from the workstation that needs it, the whole assembly line has to be halted, leading to hundreds of workers being idle and lost sales of one car per minute.

In order to keep modern mixed-model assembly systems well supplied, many automobile producers use so-called just-in-time supermarkets, that is, decentralized logistics areas on the shop floor, where parts are intermediately stored to then be brought to the assembly line in small lots. Supermarkets mainly consist of a couple of shelves, set up for ease of access, not necessarily space-efficient storage. Parts are brought there in fairly large lots (e.g., pallets) by industrial trucks, which are then unpacked and presorted. When demand at the workstations within the supermarket's area of responsibility occurs, a bin for that station is prepared. These bins often contain complete kits of parts, prepared

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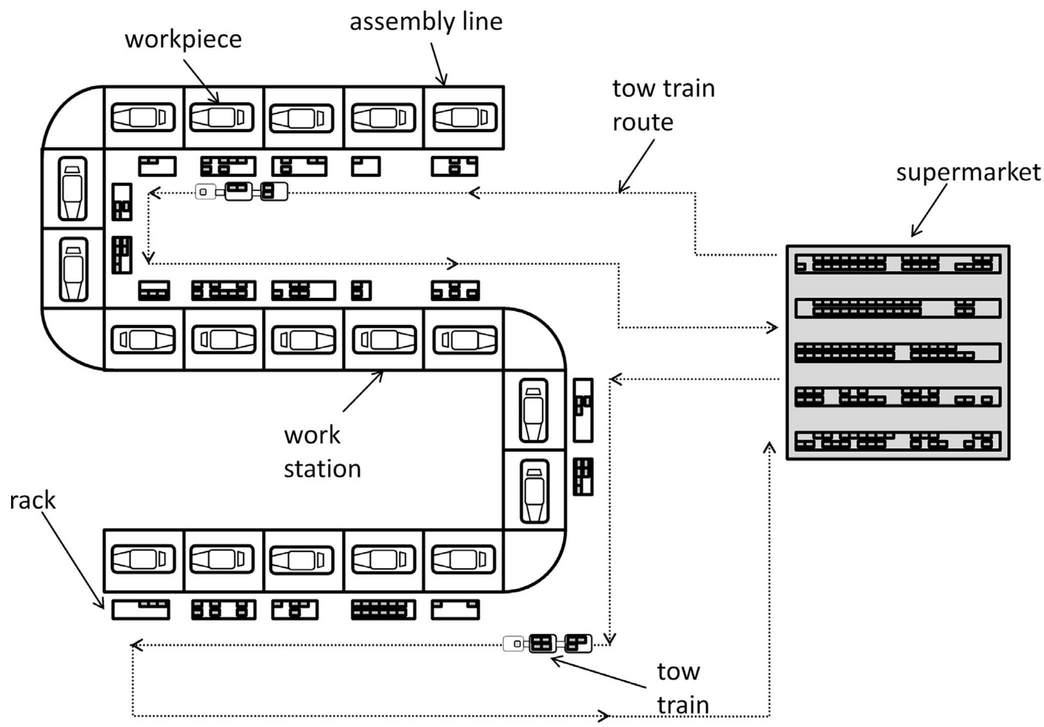

Fig. 1. An assembly line fed parts by tow trains.

for specific models in the exact same order in which the workpieces to be assembled move down the line to reduce the searching effort and unproductive walking times of the assembly worker (Bozer & McGinnis, 1992; Limére, Van Landeghem, Goetschalckx, Aghezzaf, & McGinnis, 2012). Moreover, these comparatively small, standard-size bins can be stored in easily accessible racks, improving ergonomics (Finnsgård, Wänström, Medbo, & Neumann, 2011), which is becoming increasingly important for many manufacturing companies due to an ageing workforce in the industrialized countries.

While industrial trucks are used to take parts in large quantities to the supermarket, these vehicles are poorly suited to distributing small bins to individual stations. This work is usually performed by so-called tow trains (or tuggers), made up of an electrically powered towing vehicle connected to a small number of wagons. The tow train is loaded in the supermarket with the bins of parts destined for the stations that lie on its predefined route. It then sets off to visit these stations one after another to deliver the respective bins. Once it has completed its tour, it will return to the supermarket to be refilled for its next tour. Fig. 1 shows the concept of such an in-house logistics system.

Tow trains usually operate on a strict schedule. Due to the given fixed cycle times in the automotive industry and the predetermined production sequences, communicated to suppliers 3 to 4 days in advance before production starts, the exact moment in time (i.e., work cycle) when demand for a specific part at a specific station occurs can be determined well in advance using the bill-of-materials and the fixed production sequence (Emde, Fliedner, & Boysen, 2012). Some automobile producers are even experimenting with fully automated delivery systems, where tow trains are operated as driverless AGVs (automated guided vehicles), which can dock at specially designed racks at the stations and unload their cargo in a matter of seconds without the need for any human intervention. In these scenarios, the tow train might as well stop at every station on every tour, because the stopover times may be negligible compared to the driving times. Most systems in use today, however, still have human operators. In some assembly plants, at least the bin exchange at the stations is automated (through the use of so-called shooter racks, Emde et al., 2012), although in other plants, empty and full bins still have to be manually swapped. This may require a more substantial amount of time, making the decision which stations to stop at and which stations to skip on a given tour an integral part of the planning problem.

This paper tackles the optimization problem, occurring on a daily basis in mixed-model assembly plants, of determining the schedule (i.e., how often and when does the tow train leave the supermarket to tour the stations on its given route) and the load (i.e., at which stations does the tow train stop on each tour and how many bins should it unload there) of a tow train responsible for one predetermined route.

Note that, while we specifically encountered this problem in several automotive assembly plants we visited, the type of milk run-based part-feeding system described in this paper is not unique to final assembly of automobiles. Indeed, "just-in-time supermarkets" are part of the famous Toyota Production System (Monden, 2011) and are widely employed in lean manufacturing of all stripes. For example, Vaidyanathan, Matson, Miller, and Matson (1999) describe a tow train-based part feeding process they encountered in an exhaust system plant in Fayette, AL; similarly, Akıllığlu et al. (2006) report on an application from a company producing diesel injectors.

The remainder of this paper is structured as follows. In Section 2 we will give an overview over prior work relevant to our problem, Section 3 defines the problem and Section 4 investigates the computational complexity of the main problem as well as of an important special case. In Section 5, we present a MIP model and a heuristic decomposition procedure, which are tested in a comprehensive computational study in Section 6, where we also offer some decision support on the right degree of automation for a supermarket-based part feeding system. Finally, Section 7 concludes the paper.