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Scheduling the part supply of mixed-model assembly lines in line-integrated supermarkets

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ABSTRACT

Line-integrated supermarkets constitute a novel in-house parts logistics concept for feeding mixed-model assembly lines. In this context, supermarkets are decentralized logistics areas located directly in each station. Here, parts are withdrawn from their containers by a dedicated logistics worker and sorted just-in-sequence (JIS) into a JIS-bin. From this bin, assembly workers fetch the parts required by the current workpiece and mount them during the respective production cycle. This paper treats the scheduling of the part supply processes within line-integrated supermarkets. The scheduling problem for refilling the JIS-bins is formalized and a complexity analysis is provided. Furthermore, a heuristic decomposition approach is presented and important managerial aspects are investigated.

1. Introduction

In the wake of an ever increasing product variety offered to fulfill highly diversified customer demands, parts logistics has become one of the greatest challenges in modern automobile production. For instance, at the average sized automobile plant in Dingolfing (Germany) of BMW more than 13,000 containers of parts arriving on more than 400 trucks need to be processed and delivered in a timely manner to the final assembly line each day (Battini, Boysen, & Emde, 2013). The main purpose of parts logistics is to never let the final assembly line run out of parts, because, in the worst case, a stock-out necessitates a line-stoppage with hundreds of assembly workers being idle. In this context, there is a long-lasting and still ongoing dispute among practitioners and researchers alike on the right in-house supply processes (Bozer & McGinnis, 1992; Brynzér & Johansson, 1995; Hua & Johnson, 2010; Limére, Van Landeghem, Goetschalckx, Aghezzaf, & McGinnis, 2012). The basic alternatives are denoted as line stocking and kitting:

- In the former concept, parts are stored in relatively large containers directly at the assembly stations. Each container is filled with identical parts, e.g., all rear-view mirrors of a specific type, so that an assembly worker has to identify the specific parts required by the current car, withdraw them from the respective containers, and assemble them during the production cycle. The main advantages of line stocking are the lack of double-handling and its flexibility in case of unforeseen events (Bozer & McGinnis, 1992). Whenever a short-term alteration of the production sequence or a defective part occur, spare parts are readily available at the stations.
- Kitting means that parts are sorted just-in-sequence (JIS) into relatively small bins before being finally delivered to the assembly line. The decentralized logistics areas where kits are prepared are typically denoted as supermarkets in the automobile industry (e.g., Emde, Fliedner, & Boysen, 2012). Here, kits are stored in bins and loaded onto some waggons, which are coupled to a towing vehicle. Once fully loaded, the tow train travels via a given route to the stations along the line and exchanges empty with filled part bins. A detailed description of the supermarket concept and a literature review are provided by (Battini et al., 2013). The comparatively small bins containing JIS-parts (typically stored in some easy-to-access gravity flow rack) ease the part retrieval process for the assembly workers and reduce inventory at the line where space is notoriously scarce (Bozer & McGinnis, 1992).

The novel concept of *line-integrated supermarkets* introduced in this paper aims to unify the advantages of kitting and line stocking. Parts are stored directly at the stations where kits are prepared by separate logistics workers. Fig. 1 schematically depicts this concept, which has recently been realized at a North-American plant of a major German car producer.

In a line-integrated supermarket, the storage area for parts to be assembled by the respective assembly workers is integrated into

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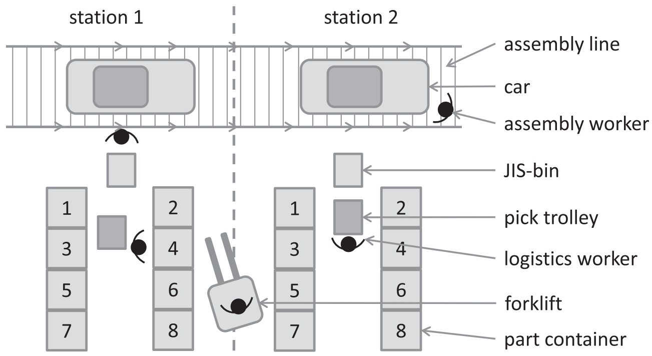

Fig. 1. Part supply via line-integrated supermarkets.

the stations and located directly next to the moving conveyor. At our project partner, this additional logistics area is a 6 meters band all along the line. The interface between the assembly and the logistics area of a station is the JIS-bin (or multiple JIS-bins). From the JIS-bin, the assembly worker withdraws the part, e.g., a specific exterior mirror, required by the car having currently entered the station, and mounts it during the production cycle. The JIS-bin is filled with parts by a separate logistics worker, who packs the picked parts into the JIS-bin just in the right assembly sequence. The logistics worker picks the required parts from the parts containers being located in the logistics area. Each container is filled with homogeneous parts, e.g., all passenger outside mirrors of a specific color, so that the logistics worker has to visit these containers according to his/her current picking order, withdraw parts, and put them into a pick trolley accompanying the pick tour. Once the current order is picked, the worker moves the trolley to the JIS-bin and sorts parts just-in-sequence into the bin. Then, the logistics worker moves to another station in order to restart the supply process. At our project partner, the line has been subdivided into multiple segments each consisting of about a dozen successive stations serviced by a team of a handful logistics workers. Note that, additionally, the replenishment of part containers from some centralized warehouse or a nearby truck dock has to be accomplished, e.g., by forklift.

Line-integrated supermarkets make do without tow trains, so that labor is saved and the amount of double handling is reduced compared to the traditional kitting concept. Furthermore, in case of unforeseen events spare parts are readily available at the stations and the assembly workers' effort for part retrieval is reduced to a minimum. A more detailed comparison of the pros and cons of all three alternatives is provided by the snake-chart depicted in Fig. 2. These properties make line-integrated supermarkets an attractive organizational concept for in-house part supply not only in the automotive industry but for any high-variety assembly process. However, in existing facilities often irremovable machinery occupies plenty space in direct vicinity to the assembly line, so that line-integrated supermarkets are often only an option for greenfield facilities.

The novel concept gives rise to some important decision problems to be solved. This paper treats the scheduling problem of part supply in the logistics areas of the assembly stations. Given multiple stations and their deterministic part demands over time, we aim at a schedule for the refilling of JIS-bins, so that no stock-outs occur and the team size for supplying a given set of stations is minimized. Section 2 formalizes the part supply scheduling problem in line-integrated supermarkets. Then, Section 3 provides a complexity analysis of the main scheduling problem and different subproblems. Section 4 provides a heuristic decomposition approach for the basic problem setting, which is tested in a comprehensive computational study (Section 5). Specifically, we investigate the interdependencies between the part supply process and the

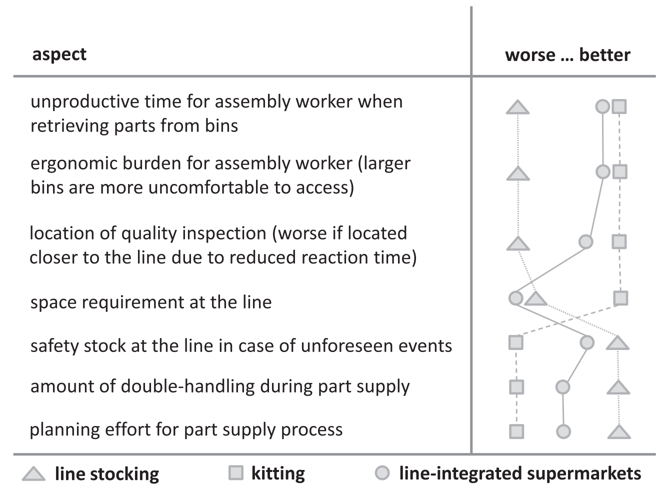

Fig. 2. Comparison of the three part supply processes.

assembly sequence of cars and compare different organizational realizations of line-integrated supermarkets. Finally, Section 6 concludes the paper.

2. Problem description

We aim to schedule the refill events of the JIS-bins by the logistics workers in a given line segment, so that none of the stations ever runs out of parts and the team size of logistics workers is minimized. The former is always the top priority of part logistics in order to avoid costly reactions on stock-outs such as line stoppages. Although over the short run of our operational problem the employed workforce cannot be adapted, minimizing the workforce in our specific part supply setting is a suitable objective, because there are always plenty of alternative tasks on the shop floor for logistics workers to perform.

Specifically, we have a set S of assembly stations, which are to be supplied with parts over a given planning horizon consisting of $t = 1, \dots, T$ production cycles. Note that the set of stations typically does not contain all stations of an assembly line but only a line segment (of successive stations), into which the line has been subdivided in a previous planning step. Each of these line segments is serviced by a specific team of logistics workers, so that our scheduling problem has to be solved for each of these line segments. Note also that all time units are normalized to the duration of a production cycle. A typical cycle time in the automobile industry ranges between 60 and 90 seconds (Emde et al., 2012), so that this assumption does not seem too restrictive. For each station $s \in S$ and all production cycles $t = 1, \dots, T$ the deterministic part demand d_{st} is assumed to be given. In the automobile industry, the production sequence is, typically, finally fixed three to four days before production starts (Emde & Boysen, 2012), so that deterministic information on the retrieval sequence of parts is readily available. As a matter of convenience, we presuppose that each station assembles merely a single part type, e.g., exterior mirrors, in all its available variants, which are collected just-in-sequence in a single JIS-bin. The adaptation required when supplying multiple parts (and applying multiple JIS-bins) per station is very straightforward; we will discuss it briefly at the end of this section. d_{st} defines the cumulative part demand for the specific part type up to cycle t at station s. Initial inventory of parts already being stored in a JIS-bin has already been picked in the past, so that d_{st} only covers those part demands to be picked during the planning horizon. Note that we only consider the aggregated demand per product type, e.g., all passenger's door mirrors, but not any specific part variant, e.g., a special mirror of a specific color.