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The joint line balancing and material supply problem

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ABSTRACT

In production systems of automobile manufacturers multi-variant products are assembled on paced mixed-model assembly lines, which have to be supplied by a lean in-house logistic with containers of different sizes, alternative supply policies and different number of parts. The assignment of operations to workplaces within the assembly line balancing problem and the assignment of containers to supply policies within the material supply problem determine the operational cost of a work system. Up to now in the literature and real-world both problems are solved successively.

We analyze the interdependence of the line balancing and material supply problem in depth and reveal potential productivity gains through simultaneous planning. We set up a practice-oriented assembly line balancing model, which is extended to cover several important logistical constraints of the material supply problem, and solved it with a flexible heuristic on the general assembly line balancing problem, we developed in an earlier paper. In a computational experiment, we determine cost savings through simultaneous planning and show the applicability of our approach within a practice-oriented experiment.

1. Introduction

In production systems of automobile manufacturers, multi-variant products are assembled on paced mixed-model assembly lines, which have to be supplied by a lean in-house logistic with containers of different sizes, alternative supply policies and different number of parts. The productivity of a work system depends on the number of installed workplaces in assembly and logistics needed to produce a defined amount of units: the more wastes of time, such as walkways, idle times or non-value-adding handling operations a work system includes, the higher is the amount of required employees and the lower the productivity (cf. Ohno (1988)).

The number of workers in assembly primarily depends on the assignment of assembly operations to workplaces. An operation (also: task) describes the assembly of a part including all necessary process steps like gathering, walking, assembling and checking. Within mid-term line planning the assembly line balancing problem (ALBP) first defined by Salveson (1955) is set up and solved to maximize productivity in assembly. ALBP is comprehensively discussed in the literature and numerous exact methods and heuristics were developed to solve a broad variety of different ALB problems (cf., e.g., Baybars (1986), Ghosh and Gagnon (1989), Erel and Sarin (1998), Becker and Scholl (2006), Scholl and Becker (2006), Bautista and Pereira (2007), Boysen et al. (2007,2008), Battaïa and Dolgui (2013)).

Parallel to line planning the assembly line material supply planning takes place. Herein, the in-house material flow of containers from the goods inward (source) to the workplaces of the assembly line (sink) is planned by assigning a supply policy to each part. In practice two primary supply policies occur (cf., e.g., Battini et al. (2009), Hua and Johnson (2010), Hanson (2012, Ch. 1), Limère et al. (2012)):

(1) A *directly supplied* part is supplied in a *homogenous container* to the assembly line. In all in-house logistical operations (e.g. goods inward, warehouse, transportation) the container supplied from the supplier is used. Typically a *forklift* transports them to the line.
(2) An *indirectly supplied* part is supplied—together with other parts – in a *mixed container* to the assembly line. Homogenous containers are transported from the goods inward to a near-assembly picking zone (also: *supermarket*). At the picking zone a mixed container is packed for a specific set of vehicle orders with all parts needed to produce these orders. A tow train transports mixed containers within a fixed schedule to the assembly line (cf. Emde and Boysen (2012b)), where instead of multiple homogenous containers for all parts and their variants only one mixed container has to be stored. Thus, in contrast to direct supply the indirect supply of parts saves

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space at the line at the expense of a costly installation and operation of picking zones and tow train transports.

Depending on the chosen supply policy different logistical operations with different time demands have to be performed by the logistical staff. Thus, the number of workers in logistics primarily depends on the assignment of parts to supply policies.

Through assigning assembly operations (and the corresponding parts) to stations the ALBP decides on the number of parts that have to be stored in the supply area of a station. Due to the limited capacity of space in real-world (cf. Bautista and Pereira (2007), Emde and Boysen (2012b)), not all parts can be directly supplied in cost-saving but space-wasting homogenous containers. The (*assembly line) material supply problem* (MSP, cf. Bozer and McGinnis (1992), Battini et al. (2009), Limère et al. (2012)) arises, in which all parts of a station have to be assigned to a supply policy in order to minimize the number of workers in logistics and not to exceed the space capacity of a station. Since the number of parts in a station is determined by the ALBP solution, the line balancing and material supply problem are highly interdependent.

Up to now, literature proposes to solve both problems in successive manner. As already recognized by Bozer and McGinnis (1992), Boysen et al. (2007) and Hua and Johnson (2010) one can expect productivity gains by coupling both problems. We propose such a coupled model in this paper.

At Volkswagen in the recent past a holistic optimization of assembly and logistics instead of a single pointed planning is focused so that a coupling of ALBP and MSP is recognized as a required research field also in real-world. The ALBP and MSP are widely spread at Volkswagen and occur in different time frames. In the planning process for a new model, the ALBP and MSP are set up and solved two years before production starts to determine lean processes in assembly and logistics. In the series operation product changes (e.g. an additional technical variant of part) often lead to an excess of space capacity of a station, so that the assignment of operations to stations or the supply policy may have to be changed. Thus, in every plant of Volkswagen and in every planning department the task of solving ALBP and MSP is part of daily business.

In the last years the interdependence of both problems is growing since the space capacity at a station gets more and more scarcer: First, due to the increased demand of product differentiation and the resulting necessity in spite of mass production to produce customized orders (mass customization) the variant complexity of models ramped up (cf., e.g., Boysen et al. (2008), Sternatz (2013)). Second, due to raising import restrictions the demand of localized production continuously increases at Volkswagen and thus the number of models produced on a line is growing (cf. Sturgeon and van Biesebroeck (2010)). Both trends lead to a dramatically increasing number of parts (and their variants) while the line lengths remained almost constant (constant space capacity). Consequently, more and more parts have to be indirectly supplied to save space and a foreseen ALBP taking aspects of MSP into account may nowadays significantly reduce the number of workers in logistics.

In this paper, we analyze the interdependence of both problems in detail. We propose a first approach to couple both problems from a real-world point of view. Through a joint optimization of the line balancing and material supply problem we show, that it is possible to holistically optimize the work system in assembly and logistics. In addition, we provide design guidelines for real-world applications to reduce logistical costs through an optimal selection of directly and indirectly supplied parts.

Based on a literature review in Section 2 we describe the context of both problems and examine interdependencies (Section 3). A novel model for simultaneous planning holistically optimizes the productivity in assembly and logistics by combining planning instruments of the line balancing and material supply problem. In Section 4 we extend the flexible EMH heuristics of Sternatz (2014) to the problem presented. In a computational test (Section 5), we determine productivity gains through simultaneous planning and show the applicability of our approach within a practice-oriented experiment.

2. Literature review

2.1. Assembly line balancing problem

The simple assembly line balancing problem (short: SALBP) first formulated by Salveson (1955) and classified by Baybars (1986) describes assembly line balancing in its simplest form, in which only precedence constraints of assembly operations and a cycle time limit restrict the assignment of operations to idle time minimized workplaces[1]. These simplifying assumptions significantly restrict the use of SALBP-solving methods in practice. For this reason, research has recently focused on modeling and solving relevant problems for real-world. Here classical SALBPs are generalized by the relaxation of one or more SALBP assumptions to a variety of different GALBP models. An overview of GALBP extensions is, e.g., provided by Becker and Scholl (2006).

Despite intensive research on the line balancing problem aspects of material supply planning are only rudimentarily examined: Bautista and Pereira (2007) extended SALBP to their time-and-space assembly line balancing problem (in short: TSALBP) to consider the space demand of containers and manufacturing equipment in space-limited station. Reducing space demands of operations by alternative supply policies is however, not discussed by them. Scholl et al. (2010) extended Bautista's approach to multiple assignment restrictions between operations by the assignment-restricted assembly line balancing problem (in short: ARALBP). They solved ARALBP by their exact ABSALOM procedure, which is an extension on the well-known SALBP-procedure SALOME of Scholl and Klein (1997). Based on the multi-Hoffmann procedure of Fleszar and Hindi (2003) Sternatz (2014) developed the flexible EMH heuristic, which can be easily applied to a large variety of ALB problems. It is one of the most effective and efficient GALBP procedure in the test bed.

For a given line balance, Bukchin and Meller (2005) determined the optimal container size and thus the number of containing parts. The *range of a container*, calculated by the number of containing parts and the usage rate at the assembly line, indicates how many units can be supplied by a full container of any type. Bukchin and Meller (2005) assumed that the logistical supply process follows a fixed schedule. A reduction in container size may consequently lead to a line stoppage when the range of a container is smaller than the length of the logistical supply cycle and, thus, a part shortage arises. Since the space capacity on a line is limited an arbitrary large container size cannot be realized.

Boysen et al. (2009b) extended the operational mixed-model sequencing problem (MMSP) to supply-specific aspects: For a given line balance and given container sizes, a smoothen container retrieval (i.e. time of supply) in a shift is sought by varying the assembly sequence within the so called level scheduling. On a given sequence Emde et al. (2012) determined the optimal

[1] In literature, the term “station” is often used interchangeably with the term “workplace”, because in SALBP each station contains only one workplace. In real-world, however, a station often contains several workplaces, which perform operations on the same vehicle in parallel but at different mounting positions (cf. Becker and Scholl (2009)). For this reason, in this article, we distinguish between “workplace” (referencing a process object offering time capacity for operations) and “station” (referencing a layout object offering space capacity for containers and equipment).