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The Integrated Assembly Line Balancing and Parts Feeding Problem with Ergonomics Considerations

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Abstract: Assembly Line Balancing Problems (ALBPs) describe a partition of tasks into subsets, each subset forming a station load, to optimize some line efficiency measure under specific task-to-station assignment restrictions. In the literature, the assembly line balancing problem is usually solved separately from the assembly parts feeding problem, which is to determine a supply mode for each part associated with assembly tasks. This leaves significant optimization potential untapped.

In this work, we consider the problems jointly and set up the Integrated Assembly Line Balancing and parts Feeding Problem (IALBFP). In the formulated IALBFP, we distinguish between two alternative parts supply modes: *direct* parts feeding in homogeneous load units (big boxes) and *indirect lean* parts feeding, where parts are supplied in station kits to each station at the beginning of each cycle after some intermediate handing at the supermarket area. In this way, the indirect parts feeding is fully synchronized with operations at the assembly line. We also incorporate ergonomic aspects by increasing processing times of manual tasks by a time increment to recover from fatigue and energy losses.

We formulate a mixed-integer model for IALBP and provide guidelines for the implementation of our integrated planning approach in practice. To our best knowledge, we are the first in the literature to model a lean parts feeding system, which is fully synchronized with assembly line operations. Incorporating ergonomic aspects into IALBFP allows to design a satisfactory assembly system in terms of both ergonomics and productivity and is a further novelty of this work. The implementation of the proposed integrated approach in practice may significantly reduce inventories at the line where space is notoriously scarce, minimize time losses due to unproductive activities and lower fatigue of workers.

Keywords: ALBP, assembly line balancing problem, parts feeding, picking, ergonomics, energy expenditure, rest allowances.

1. INTRODUCTION AND BACKGROUND

Assembly line balancing refers to the partition of tasks into subsets, each subset forming a station load, under some task-to-station assignment restrictions. Parts feeding refers to the storage, transportation and feeding policies of parts associated with assembly tasks. In this paper we argue that, from ergonomic and economic perspectives, the assembly line balancing and the parts feeding have to be considered jointly.

Since consideration of the parts feeding is still uncommon in the assembly line balancing literature, we start with a short overview of its three main interrelated components: parts storage, feeding policy and parts transportation (Battini et al., 2015; Kilic and Durmusoglu, 2015).

There exist two major methods of the parts storage: the so-called *direct* supply, in which parts are stored in bulky load units directly at the assembly line, and the *indirect* supply, in which parts are stored at an intermediate smaller warehouse, located close to the line and called *supermarket*.

Parts storage is closely related to the feeding policy, which describes a choice of container types for the material supply. These may be, for instance,

- *homogeneous load units* containing parts of the same type,
- *station kits*, that is, boxes containing all the parts needed at a station to perform assembly tasks assigned to this station,
- and *travelling kits*, which accompany a workpiece and contain all the parts required for its assembly.

Battini et al. (2009) developed a methodological framework for the design and subsequent management of the assembly feeding system. The authors analyse the impact of various pallet-to-station, trolley-to-station and kit-to-assembly line policies on the production times and, hence, costs. Further, the model of Caputo et al. (2015) allows to choose the right mix of feeding policies in order to minimize the total cost.

Parts storage impacts feeding policies a lot. For instance, in case of the *direct* supply, parts are supplied to the assembly line directly from the central warehouse or from the supplier

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in large *homogeneous load units*. In case of the *indirect* supply, parts are first moved from the central warehouse to the supermarket, where they are repackaged into *smaller bins or station kits* by supermarket operators. Such smaller bins or station kits are periodically delivered to the assembly line stations, they require less space than bulky containers and enable assembly operators to pick parts faster and in more ergonomic way (see Figure 1 for a comparison of the direct and the indirect parts feeding).

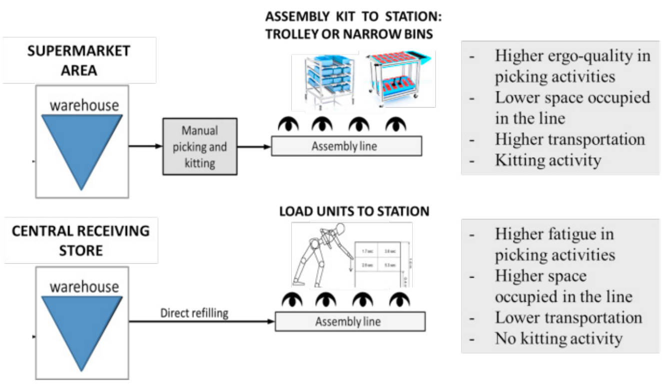

Fig. 1. Indirect vs direct parts feeding in the assembly system

Parts transportation highly depends on the selected type of parts storage as well. The parts can be delivered from the warehouse or the supermarket to the assembly line either with traditional forklift trucks (which is especially common in case of the direct supply) or with special automated systems, like shuttles, AGV/LGV or tow trains.

Decisions on assembly line balancing and parts feeding are highly interdependent, although they have been treated separately in the literature so far. Indeed, on the one hand, parts feeding significantly impacts processing times and ergonomic risks at the assembly line. In particular, indirect parts feeding reduces processing times at the assembly line at the cost of additional handling of parts in the supermarket and by increasing ergonomic burden on supermarket operators. On the other hand, task-to-station assignment determines, which parts will compete against each other for the limited space of an assembly line station.

To our best knowledge, only Sternatz (2015) considers the joint assembly line balancing and parts feeding problem, where the operator needs more time to pick a part, if it is supplied in a homogeneous bulky load unit, than in case it is supplied in a small ergonomic bin or station kit. Following this thread, this paper formulates a new problem, called Integrated Assembly Line Balancing and parts Feeding Problem (IALBFP) describing a lean parts feeding, where indirectly supplied parts are delivered to stations at the beginning of each cycle. In the formulated problem, we take most crucial decisions on parts feeding into account, such as selection between indirect and direct supply policies as well as scheduling operations at the supermarket. Moreover, to our knowledge, we are the first in the literature to introduce aspects of *physical* ergonomics, i.e. to consider risks of getting musculoskeletal diseases (see a schematic representation of our concept in Figure 2).

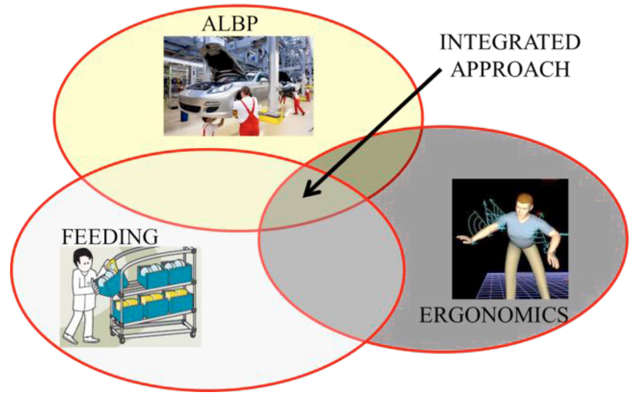

Fig. 2. Main components of the proposed integrated approach

The remaining of the paper is structured as follows. Section 2 provides an overview of the literature. Afterwards, we formulate the IALBFP model and provide guidelines for the implementation of our integrated planning approach in practice in Section 3. Finally, we conclude with overall comments and insights for the future research in Section 4.

2. ERGONOMICS IN ASSEMBLY LINE DESIGN

The literature clearly demonstrates that improving work conditions with respect to physical ergonomics (e.g. by improving stations layouts, postures assumed by assembly workers or decreasing handled loads) may also increase the overall productivity of the system (e.g. Colombini and Occhipinti, 2006; Neumann et al., 2006; Battini et al., 2011).

Several studies extended the assembly line balancing problem to incorporate ergonomic aspects. Carnahan et al. (2011) introduce fatigue and recovery dynamics into the assembly line balancing problem. Otto and Scholl (2011) describe a general framework, how to model a broad class of ergonomic risk functions (e.g. the revised NIOSH equation of Waters et al., 1994, or the OCRA index of Occhipinti, 1998) in the context of the assembly line balancing of type 1. The authors design a two-stage solution approach combining effective branch-and-bound method SALOME (Scholl and Klein, 1997) with a customized metaheuristic simulated annealing for the bilevel variant of the optimization problem. Bautista et al. (2013, 2016) formulate various models for the time and space constrained assembly line balancing problem (TSALBP) with ergonomic risks. Their general modelling approach takes not only physical ergonomic risks into account, but also the so-called psychological comfort (e.g. measured by the Copenhagen Psychosocial Questionnaire). Battini et al. (2015a) introduce a new technique, the Predetermined Motion Energy System, to estimate the energy expenditure rates. The authors examine this technique in a multi-objective framework with four objective functions. Battini et al. (2015b) compare results of two alternative modelling approaches: a multi-objective model based on the energy expenditure and a single-objective model based on the rest allowances.

Ergonomic aspects have received limited attention in the literature on the optimization approaches to the parts feeding (e.g. Limère et al., 2012; Hanson and Medbo, 2012). Several articles examine the impact of the parts feeding characteristics on the resulting ergonomic risks for warehouse