European Journal of Operational Research 216 (2012) 594–604

Contents lists available at SciVerse ScienceDirect

European Journal of Operational Research

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

Production, Manufacturing and Logistics

Resequencing of mixed-model assembly lines: Survey and research agenda

Nils Boysen [a,*], Armin Scholl [b], Nico Wopperer [a]

[a] Friedrich-Schiller-Universität Jena, Lehrstuhl für Operations Management, Carl-Zeiß-Straße 3, D-07743 Jena, Germany
[b] Friedrich-Schiller-Universität Jena, Lehrstuhl für Management Science, Carl-Zeiß-Straße 3, D-07743 Jena, Germany

ARTICLE INFO

Article history:
Received 21 March 2011
Accepted 8 August 2011
Available online 18 August 2011

Keywords:
Mixed-model assembly line
Resequencing
Survey

ABSTRACT

Nowadays, mixed-model assembly lines are applied in a wide range of industries to mass-produce customized products to order, e.g., in automobile industry. An important decision problem in this context receiving a lot of attention from researchers and practitioners is the sequencing problem, which decides on the succession of workpieces launched down the line. However, if multiple departments with diverging sequencing objectives are to be passed or unforeseen disturbances like machine breakdowns or material shortages occur, a resequencing of a given production sequence often becomes equally essential. This paper reviews existing research on resequencing in a mixed-model assembly line context. Important problem settings, alternative buffer configurations, and resulting decision problems are described. Finally, future research needs are identified as some relevant real-world resequencing settings have not been dealt with in literature up to now.

1. Introduction

A mixed-model assembly line allows to produce different models of a common base product in facultative production sequence (lot size one) on a single assembly line. This way, Henry Ford's traditional paradigm of a flow line based mass-production can be coupled with assembly-to-order processes, so that, nowadays, mixed-model assembly systems are applied in a wide range of industries, e.g., in automobile or electronic assembly (see Boysen et al., 2008). An important decision problem in this context is the sequencing problem, which decides on the sequence in which the models are launched down the line. Starting with the seminal work of Wester and Kilbridge (1964) this field of research attracted a lot of researchers and a recent review paper of Boysen et al. (2009) lists more than 200 papers investigating this topic. This stream of research treats initial sequence planning, where all degrees of freedom according to the assignment of a given model mix to the production cycles of a planning horizon exist. However, in real-world applications the resequencing problem, which is to reshuffle a given initial sequence subject to some limited resequencing flexibility, is often equally essential. For instance, consider the following two resequencing settings taken from German automobile industry.

Example A. Due to a rework rate of 85%, a major German truck producer faces sequences of driving cabs heavily stirred up after leaving the paint shop. Note that for other paint shops first-pass rates of about 65% are reported (Ulgen and Gunal, 1998). On the one hand, these altered sequences typically violate sequencing rules. For instances, as some trucks are more than twice as long as others, space restrictions at the stations require that none of these long trucks follow each other in direct succession. On the other hand, the originally planned sequence was propagated to the suppliers and material supply was organized on the basis of the planned sequence. Some parts have already been ordered according to a Just-in-Sequence supply, so that producing an altered sequence will require a short-time reordering of material stored next to the line. To avoid both unwanted consequences, the OEM installed a large automated storage and retrieval system (AS/RS) with 118 buffer places. These buffer places allow for a random access to intermediately stored driving cabs, so that models can be reshuffled and a more desirable production sequence can be fed into final assembly.

Example B. In spite of all security procedures when executing the Just-in-Time (JIT) concept in automobile industry, sooner or later missing or defective parts occur. To bridge the gap until a subsequent delivery of the respective parts, a major car producer allows for a reassignment of customer orders to car models after leaving body shop and paint shop, while keeping the (physical) sequence of workpieces unaltered. The final and irrevocable order binding is executed not before workpieces enter final assembly. This way, an order requiring a missing or defective part can be postponed to a later production cycle, while the respective car body leaving body shop (or paint shop) can be reassigned to another customer order, which requires an identical car body but shows an alternative component specification with all parts being available.

* Corresponding author. Tel.: +49 3641 943 100.
E-mail addresses: nils.boysen@uni-jena.de (N. Boysen), armin.scholl@uni-jena.de (A. Scholl), nico.wopperer@uni-jena.de (N. Wopperer).

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doi:10.1016/j.ejor.2011.08.009

In general, resequencing covers a rearrangement of a given sequence of objects according to some restrictions with regard to permutation feasibility, so that some objective function is optimized. For instance, famous resequencing applications occur in the field of genome sequencing (see, e.g., Stratton, 2008), machine scheduling (see, e.g., Vieira et al., 2003), aircraft landing (see, e.g., Balakrishnan and Chandran, 2006; Lee and Balakrishnan, 2008), or coordination of multi-stage production systems (see Hall and Potts, 2003; Chen and Vairaktarakis, 2005; Agnetis et al., 2001; Dawande et al., 2006; Chen and Hall, 2007; Manoj et al., 2008, 2010). This survey is restricted to resequencing in the context of mixed-model assembly lines. However, to exactly specify the objects to be rearranged and limited resequencing flexibility, two general forms of mixed-model assembly line resequencing need to be distinguished:

- Within *physical* resequencing some kind of resequencing buffer is applied to physically change the sequence of models (Example A). In this case, the objects to be reshuffled are the workpieces and resequencing flexibility is limited by the specific buffer composition.
- If a *virtual* resequencing is applied the model sequence remains unchanged and only the assignment of workpieces to customer orders is altered (Example B). Thus, the objects to be rearranged are the customer orders. The set of customer orders to be potentially reassigned to a specific workpiece is restricted to those models whose specification requires exactly those product attributes already irrecoverably realized within the respective workpiece.

Both kinds of resequencing define the scope of our review and are very common in real-world applications of mixed-model assembly lines. In particular, in automobile assembly either form of resequencing is utilized in nearly any production facility. It is the aim of this paper to develop a conceptional framework for structuring resequencing research. With the help of this framework existing research is reviewed and future research needs are identified. For this purpose the remainder of the paper is structured as follows. Section 2 establishes the framework for structuring the field. Then, by applying this framework existing research is reviewed (Section 3) and future research needs are discussed (Section 4). Section 5 concludes the paper.

2. A framework for structuring resequencing

The basic framework for structuring the field of resequencing is depicted in Fig. 1. Especially, (i) the triggers of resequencing, (ii) the types of buffers, (iii) the decision problems, (iv) the resequencing objectives pursued and (v) the solution approaches applied need to be distinguished and are described in the following sections. Therefore, some initial definitions might be useful. The objects launched down the line are denoted as *workpieces*, e.g., car bodies, which are typically variants of a common base *product*, e.g., vehicle types. While visiting stations, product attributes (denoted as *options*, e.g., a sun roof) are realized by the assembly of different *parts*. A request for a workpiece with a complete option specification as demanded by the customer is denoted as a *customer order*. If a workpiece is (temporarily) assigned to a customer order defining the blueprint for the respective workpiece it is also denoted as a *model*. Finally, the environment to physically alter a model sequence is labeled as a *buffer*, whereas a single storage location is denoted as a *buffer place*.

2.1. Trigger of resequencing

Within an assembly system two kinds of alternative reasons for initiating resequencing exist, so that we differentiate between (i) reactive resequencing and (ii) proactive resequencing.

Reactive resequencing is triggered by unforeseen perturbations like material shortages, rush orders, machine breakdowns or workpiece or material defects. In automobile production, especially the paint shop, where smallest defects in color necessitate a retouch or complete repainting of cars, is a widespread reason for disordered model sequences (Boysen et al., 2010). Obviously, a disordered sequence will violate the objectives pursued by initial sequence planning with the utmost probability, so that a resequencing is to be applied to regain a desirable model sequence. Two different examples for reactive resequencing are given in Examples A and B.

An alternative (or supplement) to reactive resequencing and the investment cost associated with buffer installation would be to initiate improvement projects, which lead to more reliable processes and less sequence perturbations. However, the cost for improvement projects might turn out higher than those for buffer installation, especially if completely reliable processes are aspired.

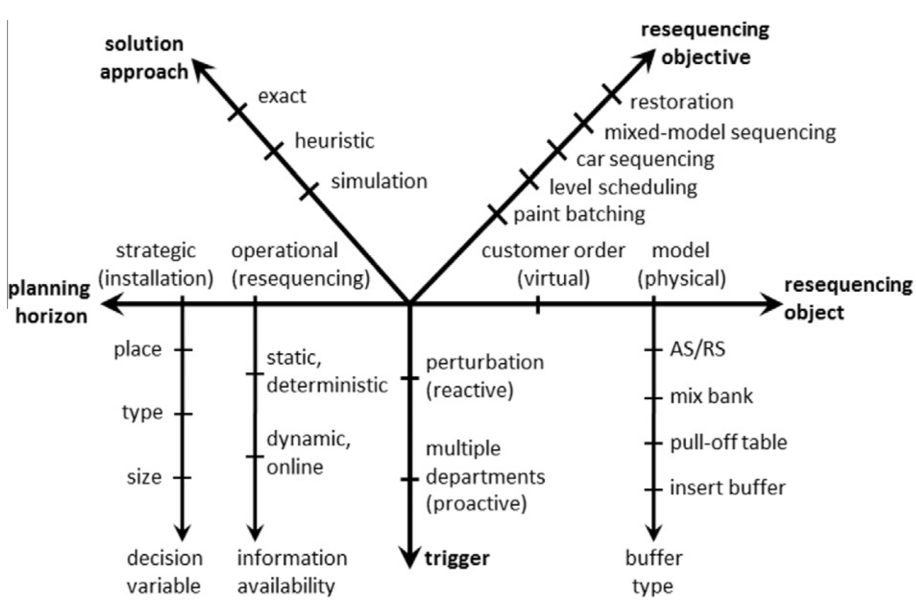

Fig. 1. Framework for classifying resequencing research.