Computers & Operations Research 40 (2013) 98–108

Contents lists available at SciVerse ScienceDirect

Computers & Operations Research

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

A decomposition approach for the car resequencing problem with selectivity banks

Nils Boysen*, Michael Zenker

Friedrich-Schiller-Universität Jena, Lehrstuhl für Operations Management, Carl-Zeiß-Straße 3, D-07743 Jena, Germany

ARTICLE INFO

Keywords:
Mixed-model assembly line
Car sequencing
Resequencing
Selectivity bank
Graph search
Ant colony optimization

ABSTRACT

An important decision problem when mass-producing customized product to order is the sequencing problem, which decides on the succession of models launched down a mixed-model assembly line. To avoid work overload of workforce the car sequencing problem restricts the maximum occurrence of labor-intensive options, e.g., a sunroof, in a subsequence of a certain length by applying sequencing rules. In the real-world, frequently perturbations occur stirring up an initially planed sequence, so that a resequencing is required. This paper treats the car resequencing problem where a selectivity bank, which is a special form of buffer organization consisting of parallel line segments without assembly operations, is applied to reshuffle a given initial sequence and rule violations are to be minimized. The problem is formalized and suited heuristic solution procedures are presented and tested. Furthermore, the impact of differently sized mix-banks on resequencing flexibility is investigated.

1. Introduction

Mixed-model assembly lines like they are applied, e.g., in automobile or electronics industry, require the solution of a short-term sequencing problem, which determines the succession of product models launched down the line. A widespread approach for this decision task is the car sequencing problem (CSP), which is based on a set of sequencing rules (see, e.g., [22]). These rules of kind $H_o : N_o$ restrict the occurrence of a labor-intensive option o, e.g., a sun-roof, to at most H_o within any subsequence of N_o successive models and CSP aims at model sequences, which minimize rule violations. Since its first formulation by Parrello et al. [20] the CSP received widespread attention in practical applications and research. A recent review paper of Boysen et al. [3] surveys more than three dozens of papers introducing different solution procedures for CSP and also reviews alternative sequencing approaches for mixed-model assembly lines.

The vast majority of these papers on sequencing mixed-model assembly lines treats initial sequence planning, where a desirable production sequence (with all degrees of freedom) is determined and communicated to part suppliers. However, in real-world applications the resequencing problem, where a given sequence is to be reshuffled with the help of a resequencing buffer, is often equally essential. On the one hand, typically multiple departments, e.g., body-shop, paint-shop, and final assembly in automobile production, having different sequencing objectives participate in production. Then, a resequencing between these departments allows for an individual sequence reshuffled with regard to each shop's individual objective instead of producing one joint and unchanged compromise sequence. On the other hand, disturbances like material shortages, machine breakdowns or workpiece defects mixing up the initially planned sequence might occur. In automobile production, especially the paint-shop is a major source of (unplanned) sequence alterations due to rework of paint defects (see [4]). Again, resequencing buffers can be applied to regain a desirable model sequence.

There exist different forms of organizing resequencing buffers, which all show individual resequencing flexibility (for a detailed survey see [5]):

- *Pull-off tables*: With this type of buffer organization a model can be pulled off-line into a pull-off table, so that succeeding models are brought forward until the model is inserted again into the final sequence at a later sequence position. This way, a model can be shifted to any later position in the sequence, whereas forward shifting is limited by the number of pull-off tables available. Existing research especially treats pull-off tables if applied for paint-batching (see [15–17]). Only recently, Boysen et al. [4] investigated the CSP if pull-off tables are available for resequencing.
- A typical automated storage and retrieval system (*AS/RS*) in automobile industry consists of hundreds of buffer places and is located prior to final assembly (see [13]). Each buffer place can individually be accessed, so that a facultative sequence (of those models in buffer) can be generated and resequencing flexibility is only limited by the total number of buffer places.

---

* Corresponding author.
E-mail addresses: nils.boysen@uni-jena.de (N. Boysen), michael.zenker@uni-jena.de (M. Zenker).

0305-0548/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.cor.2012.05.012

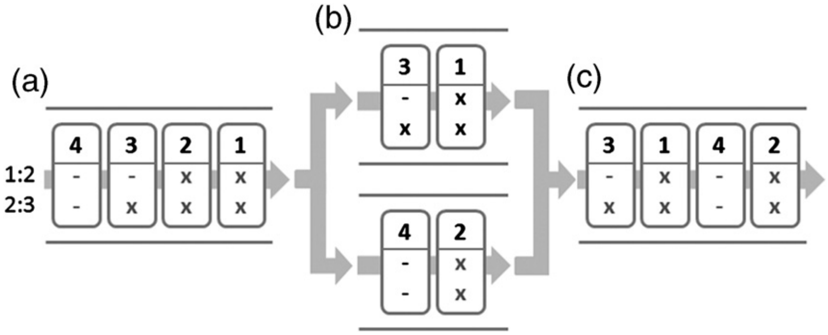

Fig. 1. Example with four models and a mix-bank with two lanes.

- A *selectivity bank* (also denoted as mix bank or parallel line buffer) consists of multiple parallel line segments or lanes (without assembly operations), where car bodies are queued and the first workpiece of each lane can be released into the final sequence. Existing research on this type of buffer organization especially treats paint-batching prior to the paintshop [6,23].

This paper is the first to couple the resequencing version of car sequencing (CRSP) with selectivity banks. Thus, we aim at a reshuffled model sequence, which minimizes the violations of given sequencing rules, where an initial sequence can be reshuffled by applying a mix bank with a given number of lanes and capacity. An illustrative example for this decision task is given in Fig. 1.

Consider an initial sequence of four models ordered from number $i=1,\ldots,4$ according to their initial sequence position. These models require two options constrained by a 1:2 and a 2:3-sequencing rule, respectively, where “x” and “-” denote whether or not a model requires the respective option. Fig. 1(a) depicts the initial sequence, which would result in two rule violations. For instance, option 1 is required in cycles 1 and 2, which violates the 1:2-rule. This initial sequence can be reshuffled by partitioning models among the two lanes of the mix-bank each having a capacity for two models as is shown in Fig. 1(b). Then, by pulling models out off selectivity bank the final sequence results, which shows no rule violations (Fig. 1(c)).

The remainder of the paper is organized as follows. Section 2 gives a detailed description of the CRSP and presents a mathematical model. Then, a solution approach is presented, which divides the solution process into two steps. First, the fill subproblem allocates models to buffer lanes. Then, the final sequence is determined by releasing models out of the mix bank. For a matter of convenience, we describe both problems in reverted order, so that Section 3 describes different graph approaches for the release subproblem. In Section 4, a priority rule based approach and an ant colony procedure for the solution of the fill problem are presented. A comprehensive computational study in Section 5 tests the computational performance of our solution procedures. Furthermore, by varying the number of lanes the impact of varying resequencing flexibility is investigated, so that the practitioner receives some decision support for dimensioning selectivity banks. Finally, Section 6 concludes the paper.

2. Detailed problem description and mathematical program

Consider a given initial sequence consisting of T different models, which are w.l.o.g. assumed to be numbered according to their initial sequence position: $i=1,\ldots,T$. Each model represents a specific workpiece, which is to be assembled according to a customer specification defining whether or not a specific option $o \in O$ is required. This specification is represented by demand coefficients a_{oi}, which receive a value of one (zero), if option o is (not) required within model i. With regard to these options sequencing rules are defined of kind $H_o : N_o$, which restrict the maximum occurrence of option o in any subsequence of N_o successive models to at most H_o. Typically, an initial sequence causes violations of these rules leading to work overload of the assembly workforce. Thus, a selectivity bank consisting of L parallel lanes ($L > 1$) each having a capacity for at most C models can be applied, so that the initial sequence is reshuffled into a final sequence to be fed into the successive line segment (or department). Resequencing flexibility is restricted by the selectivity bank in such a way, that models can be moved into a facultative lane (as long as the lane's capacity is not exceeded), while only the first model of each lane is accessible to be pulled into the final sequence. With these restrictions on hand, CRSP aims at a final sequence minimizing rule violations. Additionally, the following simplifying assumptions are presupposed:

- As is typically given in real-world buffer implementations it is assumed that all parallel lanes show identical capacity to store at most C workpieces. However, it would be easily possible to extend all our solution approaches to integrate lane specific capacities.
- It is assumed that, initially, the mix-bank is empty. This situation is quite unrealistic in real-world implementations as, typically, the CRSP is executed in a rolling horizon. The steady stream of cars is decomposed into multiple smaller CRSPs with in each case only the first x cars being finally released into final sequence. For instance, the major German car manufacturer we supported with our research applies a planning horizon of $T=30$ with only the first car ($x=1$) being finally released. Thus, in a rolling horizon the buffer is partly filled with cars left over from a previous planning run. However, it is easily possible to initialize all our solution procedure with a partly filled buffer, so that for a matter of conciseness we abstain from a detailed description.
- Furthermore, it is assumed that the buffer is large enough to intermediately store the complete initial sequence, so that $T \le L \cdot C$ holds. This assumption allows for a decomposition of the problem into a separate fill subproblem and a release subproblem. However, with regard to real-world implementations this assumption seems not very restrictive. On the one hand, in the real world, typically, the complete initial sequence is broken down into comparatively small CRSPs (as was described above). On the other hand, typically mix-banks in automobile industry are fairly large. For instance, Choi and Shin [6] report on a mix-bank with $L=25$ buffer lanes each having capacity $C=5$. The buffer utilized by our OEM (original equipment manufacturer) has a dimension of $L=10$ and $C=7$.