Proactive Resequencing of the Vehicle Order in Automotive Final Assembly to Minimize Utility Work

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***Abstract*—Mixed model assembly lines are state of the art for mass production in the automotive industry. Over the last decades the production planning and control of those mixed model assembly lines has become more and more challenging due to the continuing trends of mass customization and individualization. The sequencing of the vehicle order is thus an important method to cope with varying processing times and volatile utilization due to these trends. The common vehicle pearl chain limits the potential of sequencing algorithms as the vehicle sequence remains fixed during the complete final assembly. A new approach to minimize utility work in the final assembly is a segmentation of the assembly line into different sections and a proactive rearrangement of the vehicle sequence in a limited manner between two segments. In contrast to existing resequencing methods for final assembly, which focus on restoring disturbed sequences, Proactive Resequencing, as introduced in this paper, is a planned production planning step to create optimal vehicle sequences for different line segments of the final assembly. This innovative concept leads to a new, combined assembly and sequence planning optimization problem, whose purpose is to find a cost-optimal configuration consisting of assembly line segmentations, buffer sizes and types and segment-specific vehicle sequences.**

***Index Terms*—production planning, sequencing, mixed model assembly, minimizing utility work**

I. Introduction

Over the last decades the intensity of competition in the automotive industry has risen to a point where manufacturers are forced to provide unique selling points which set their products apart from their competitors. This fierce competition has resulted in a growing demand for customizable products which in turn has given rise to the increasing number of possible product variants and a growing complexity of products [1]. Today, a typical passenger car is offered in several body styles, engine types, seat configurations, interior designs and numerous other equipment options which leads to an extremely high number of potential variants [2]. For example, a Mercedes-Benz C-Class offers 2^{27} variants for the configuration of the final product [3] and BMW offers its vehicles in 10^{32} theoretically possible variations [4]. This high variety of end products presents a challenge for the production and logistic processes in the automotive industry. An end of these trends is not in sight [5].

This enormous product variety and production complexity effects especially the final assembly, which is typically carried out in mixed-model assembly lines where different variants are produced on the same line in a fixed sequence [6]. This results in varying processing times and thus workloads for the individual stations depending on the models to be produced. Therefore, a key planning problem in the automotive industry is the decision in which sequence the individual vehicle orders will be produced and launched down the line accordingly [7]. This field of research has seen a lot of attention over the last decades. Boysen et al. [8] give an overview of this topic with more than 200 papers. However, sequence planning is only a part of the complete mixed model production planning problem, which will be outlined in the next section.

A. Production Planning Hierarchy

The mixed model production planning problem in the automotive industry consists of a series of different production planning steps. Fig. 1 shows the production planning hierarchy following the work of Boysen *et al*. [9] and Dörmer *et al*. [10], [11].

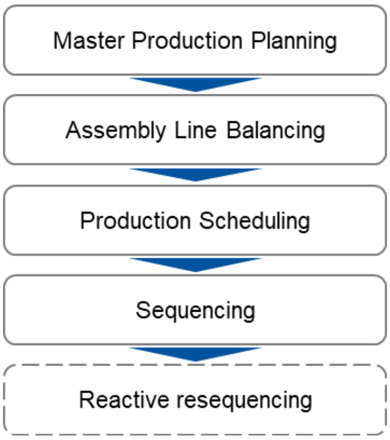

Figure 1. Production planning hierarchy Boysen *et al*. [9] and Dörmer [10], [11]

The production planning process starts with the Master Production Planning, whose goal is to define a company-wide strategy for the procurement, production and

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distribution of the different models and variants. The outcome is a factory-specific, long-term (covering several months) production plan for every model.

Based on these production specifications the Assembly Line Balancing defines the specific assembly line configuration including number of workstations, cycle time, layout and task assignment to the different workstations [12]. The Assembly Line Balancing has to be distinguished between the initial configuration for a completely new production line and a reconfiguration of existing line structures in case of changes in the production plan.

During the Master Production Scheduling, decisions on the type and amount of the product models to be produced are made for several weeks. These are then assigned to planning periods (shifts or days) [13]. As product orders are tied to delivery dates, the primary objective of the Master Production Scheduling is to find an assignment that can minimize complexity and penalties in cases of late delivery. In order to achieve this, factors such as the total capacity or total number of production cycles and the availability of material have to be considered [9].

The Sequencing or Sequence Planning deals with the assignment of each vehicle of the production plan to a specific position within chronological order of the production cycle. The Sequence Planning is an important part of the production planning, as the vehicle sequence influences the demand for the production capacities and material as well as the workload of the workers [9]. In the literature three basic approaches can be found for the sequencing problem: Level Scheduling, Car Sequencing and Mixed-model Sequencing [9]. Level Scheduling is a sequencing approach which aims at smoothing the material demand rates during the production in order to prevent demand peaks of parts in preceding production levels. Car Sequencing uses heuristic sequencing rules which control the production sequence such that the number of consecutive work intensive tasks are limited in a station. Mixed-model Sequencing, on the other hand, targets the minimization of work overloads by considering the individual processing times for each vehicle configuration, station lengths and the line movement in the assembly line [9].

In real world applications, problems or changes in the production or logistic processes occur on short notice such as machine breakdowns, defective material or last minute orders. These disturbances make it necessary to modify the original sequence of production [7]. The alterations carried out in order to overcome these disturbances are implemented during the final step of the mixed-model production planning which is called the Resequencing. So far, Resequencing in the final assembly has only been a reactive measure to cope with disturbances and not to handle varying process times [7].

B. Problem of Fixed Sequences

In the automotive industry the fixed sequence, also called Perlenkette (pearl chain), is one of the greatest goods in the field of production planning. However, the fixed sequence of vehicles during final assembly limits the options to cope with increasingly varying process times due to mass customization as it gets more difficult to determine a production sequence, which fits the complete final assembly with hundreds of work stations. As it is typically not possibly to find a sequence optimal to all workstations, utility work and idle times occur. In order to complete the utility work, utility workers are then either assigned to help the regular workers or take over uncompleted tasks at the station ́s boundaries [14]. The costs associated with the use of utility workers are often denoted as model-mix losses [15].

II. Proactive Resequencing During Final Assembly

As discussed above, the variance in the processing times coupled with the rigid sequence of different workpieces in a mixed-model assembly line leads to the problems of idle time and utility work. Resequencing provides a possibility to change the order in which workpieces are processed. However up until now, this step is only carried out as a reactive measure in case problems, such as machine breakdowns, arise.

A. Introduction of Proactive Resequencing

An approach to reduce utility work and idle time is the planned change in the sequence of workpieces fed down the assembly line during final assembly (hereafter denoted as Proactive Resequencing). The principal idea behind this approach is, that minor changes in the vehicle sequence can already lead to utilization improvements for the subsequent assembly line segments. With this concept the basic sequencing problem changes from determining a single, rigid vehicle order for the complete final assembly to the problem of finding a set of vehicle sequences, each locally optimal for its specific line segments.

In order to facilitate this Proactive Resequencing in the automotive final assembly the originally planned or already installed assembly line has to be divided into different segments or sections. Between two following segments small resequencing buffers, such as pull-off tables [7], need to be implemented in order to enable a physical sequence change for the following line segments (see Fig. 2).

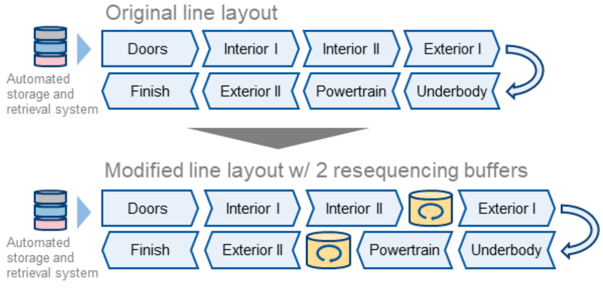

Figure 2. Assembly line modification for proactive resequencing

B. Research Context

Boysen *et al.* [7] developed a framework for the classification of different resequencing approaches, which is depicted in Fig. 3. Besides the objective, the object, planning horizon and solution approach the trigger of resequencing is a main distinction criterion. It has to be noted, that this framework and the underlying research review lacks the concept of a pre-determined sequence change during final assembly [7]. However, Boysen et al. use the term proactively triggered resequencing for the planned rearrangement of the vehicle sequence between different production departments (e.g. between paint shop and final assembly). Due to completely different objectives (e.g. paint batching) and buffer types (automated storage and retrieval systems) used for the resequencing between different departments the Proactive Resequencing introduced in the paper cannot be associated with this denotation.

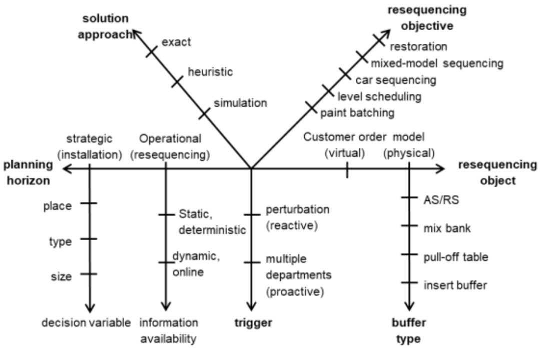

Figure 3. Framework for classifying resequencing research [7]

When applying the classification framework, the proposed Proactive Resequencing approach characterizes by the resequencing objective mixed-model sequencing, physical resequencing object with pull-off tables as buffer type, and a combined strategic and operational planning horizon (see Section III). The solution approach remains to be outlined in future research.

A change to the framework by Boysen *et al.* is proposed for the classification of the resequencing trigger: the proactive trigger should to be distinguished between multiple departments (different resequencing objectives) and within final assembly (constant objective), so that the Proactive Resequencing forms a new sub-branch (see Fig. 4).

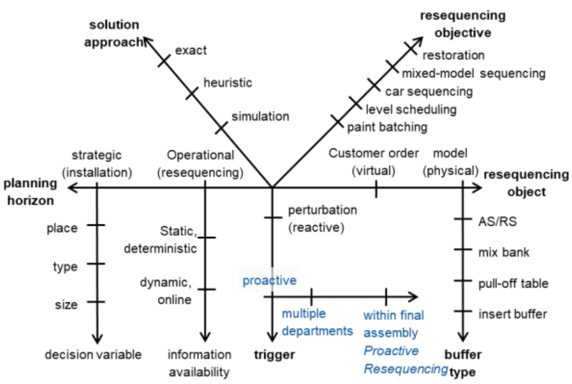

Figure 4. Modified resequencing classification framework

III. Planning of Proactive Resequencing

In order to implement the concept of Proactive Resequencing there are two steps involved (see Fig. 5). These are as follows:

1. Identification of suitable segmentation points in the assembly line and planning of the specific buffer configuration (single strategic decision)
2. Determination of a set of sequences, which minimizes the total model-mix losses (frequent operational decisions)

The decision on number, locations, sizes and storing logic of resequencing buffers (step 1) is part of the Assembly Line Balancing and typically happens on a strategic level way before the day-to-day Sequencing (see section I). In the concept of the proposed approach of Proactive Resequencing the Assembly Line Balancing and Sequencing problems become strongly interdependent on each other. However, these problems have completely different time frames. While the assembly line configuration is a long to mid-term planning problem with a planning horizon of several months or even years, the Sequencing is a short-term planning problem which involves decisions made per day or shift. There is thus a requirement to anticipate the sequencing decision at the line configuration level.

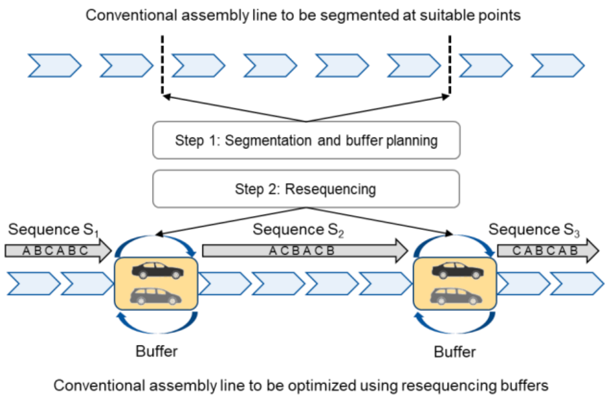

Figure 5. 2-Step approach to get to proactive resequencing

A. Step 1: Segmentation and Buffer Planning

As additional buffers take up space in the factory layout, increase capital lock-up and raise the order tracking complexity these resequencing points entail additional costs. The goal of the first step of the Proactive Resequencing Planning is therefore to make a decision on the number, sizes and places of the pull-off tables, such that the sum of the negative effects by additional resequencing buffers and the personnel expenses for utility work (model-mix losses) are minimized:

$$\min C_{tot} \tag{1}$$

$$C_{tot}=C_W+C_B \tag{2}$$

C_W: Sum of personnel expenses related to the utility work in final assembly (model-mix losses)

C_B: Sum of costs related to the resequencing buffers

It is obvious that only a limited number of resequencing buffers with limited capacity (pull-off tables) will lead to an economically efficient degree of resequencing. In order to calculate the personnel expenses the amount of utility work has to be determined. This can be done by simulating the assembly processes with the use of historic data or forecasts representative for the production plan (incl. the individual processing times of different configurations at each workstation) and an abstract assembly line model. The quality of the buffer planning can be increased by the use of different instances for the simulation. The description of the optimization model incl. the simulation of the assembly based on reference data will be outlined in future research. The resulting optimization model can be used both for the initial configuration as well as for a constant reassessment of the buffer installation in order to determine a necessary reconfiguration of the assembly line (see Fig. 6).

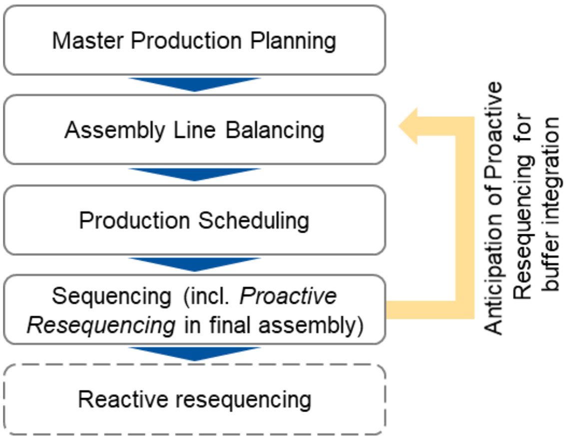

Figure 1. Modified production planning hierarchy with integration of proactive resequencing

B. Step 2: Resequencing

Based on the set of resequencing buffers resulting from the segmentation and buffer planning (step 1), the production plan for a specific production period and the individual configurations of these vehicles orders it is the goal of the second step to find a set of sequences, each optimal for its specific line segments. It has to be noted, that theses sequences are not independent from each other, but are actually coupled with the preceding sequence by the type and size of the resequencing buffers.

This leads to a second optimization problem, which is similar to regular mixed-model sequencing [8], for which different solution methods exist. A specific formulation of this problem and suitable solution methods will be outlined in future research.

IV. Conclusion

A. Summary

This paper outlines an innovative approach for vehicle sequencing in the automotive final assembly in order to react to varying processing times due to the trends of mass customization and individualization. The concept of Proactive Resequencing aims at reducing model-mix losses connected to suboptimal sequences for different line segments. The concept constitutes a new branch of resequencing approaches for the car sequencing problem as it combines the strategic decision of buffer planning with the regular optimization of vehicle sequences based on the individual processing times. Furthermore, the proposed planned rearrangement of the vehicle sequence the final assembly has not been outlined in sequencing research before.

B. Future Research

After the first introduction of the concept of Proactive Resequencing in this paper a couple of research questions remain unanswered. This includes the mathematical formulations for the long-term optimization problem of buffer planning and the short-term resequencing problem. Furthermore, a holistic solution to the strategic and operational resequencing problem is of great interest.

Moreover, an analysis about the cost potentials of the concept based on a real application or reference data found in the literature will be of interest.

Additionally, the effects of different product and process specifications, such as station overlapping assembly processes, on the resequencing places will have an influence on real world applications of Proactive Resequencing and therefore need to be studied in detail.

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References

[1] J. Lamothe, K. Hadj-Hamou, and M. Aldanondo, "An optimization model for selecting a product family and designing its supply chain," *European Journal of Operational Research*, vol. 169, no. 3, pp. 1030–1047, 2006.

[2] P. G. Brabazon, B. MacCarthy, A. Woodcock, *et al*., "Mass customization in the automotive industry: Comparing interdealer trading and reconfiguration flexibilities in order fulfillment," *Production and Operations Management*, vol. 19, no. 5, pp. 489–502, 2010.

[3] A. Röder and B. Tibken, "A methodology for modeling inter-company supply chains and for evaluating a method of integrated product and process documentation," *European Journal of Operational Research*, vol. 169, no. 3, pp. 1010–1029, 2006.

[4] N. Boysen, M. Fliedner, and A. Scholl, "Level-Scheduling bei variantenfließfertigung: Klassifikation, literaturüberblick und modellkritik," *Journal für Betriebswirtschaft*, vol. 57, no. 1, pp. 37–66, 2007.

[5] A. Kampker, M. Bartl, S. Bertram, *et al*., *Agile Low-Cost Montage*.

[6] N. Boysen, M. Fliedner, and A. Scholl, "Assembly line balancing: Which model to use when?" *International Journal of Production Economics*, vol. 111, no. 2, pp. 509–528, 2008.

[7] N. Boysen, A. Scholl, and N. Wopperer, "Resequencing of mixed-model assembly lines: Survey and research agenda," *European Journal of Operational Research*, vol. 216, no. 3, pp. 594–604, 2012.

[8] N. Boysen, M. Fliedner, and A. Scholl, "Sequencing mixed-model assembly lines: Survey, classification and model critique," *European Journal of Operational Research*, vol. 192, no. 2, pp. 349–373, 2009.

[9] N. Boysen, M. Fliedner, and A. Scholl, "Production planning of mixed-model assembly lines: Overview and extensions," *Production Planning & Control*, vol. 20, no. 5, pp. 455–471, 2009.

[10] J. Dörmer, *Produktionsprogrammplanung bei Variantenreicher Fließproduktion*, Springer Fachmedien Wiesbaden, Wiesbaden, 2013.

[11] J. Dörmer, H. O. Günther, and R. Gujjula, "Master production scheduling and sequencing at mixed-model assembly lines in the automotive industry," *Flexible Services and Manufacturing Journal*, vol. 27, no. 1, pp. 1–29, 2015.

[12] C. Becker and A. Scholl, "A survey on problems and methods in generalized assembly line balancing," *European Journal of Operational Research*, vol. 168, no. 3, pp. 694–715, 2006.

[13] H. Meyr, "Supply chain planning in the German automotive industry," *OR Spectrum*, vol. 26, no. 4, 2004.

[14] A. Lesert, G. Alpan, Y. Frein, *et al*., "Definition of spacing constraints for the car sequencing problem," *International Journal of Production Research*, vol. 49, no. 4, pp. 963–994, 2011.

[15] R. Koether, "Improving productivity in Model-Mix-Assembly," in *Toward the Factory of the Future*, H. J. Bullinger and H. J. Warnecke, Eds., Springer Berlin Heidelberg, Berlin, Heidelberg, 1985, pp. 761–766.