COMPUTER-BASED ASSEMBLY LINE BALANCING

Within the framework of assembly planning, car makers are faced with the problem of assembly line balancing. A solution proposed by the Munich-based company Combinatic GmbH results in cost savings, in particular if the diversity of variants assembled on a single line is high while at the same time quantities are high and cycle times are low.

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MOTIVATION

The assembly line balancing problem (ALBP) generally involves assigning the elementary assembly tasks and their resources to the operators along the line as optimally as possible regarding one or several objective functions, ❶. Furthermore, various constraints have to be considered for the assignment in order to ensure the practicability of the line balance. Due to changes in the production programme and/or varying constraints for the assembly process, line balances may be redefined several times a year and remain constant over a long period of time only in rare cases.

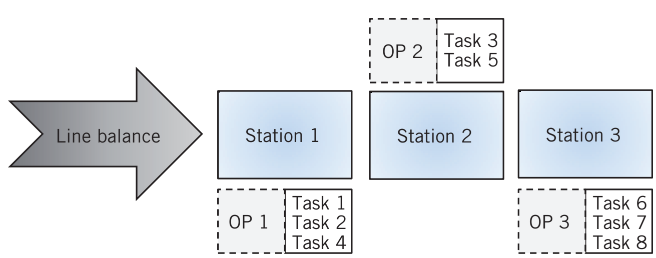
In practice, the effects of line balancing are manifold and strongly affect process efficiency. For instance, the workload of any operator and consequently the number of necessary operators greatly depend on the line balance, as does the robustness of the assembly process. In this context, it is particularly important to mention that the line balance may cause cycle time spreads for the individual vehicle variants, potentially leading to qualitative problems in the process. Additionally, in-plant logistics are also significantly influenced by the line balance.

SOLUTIONS

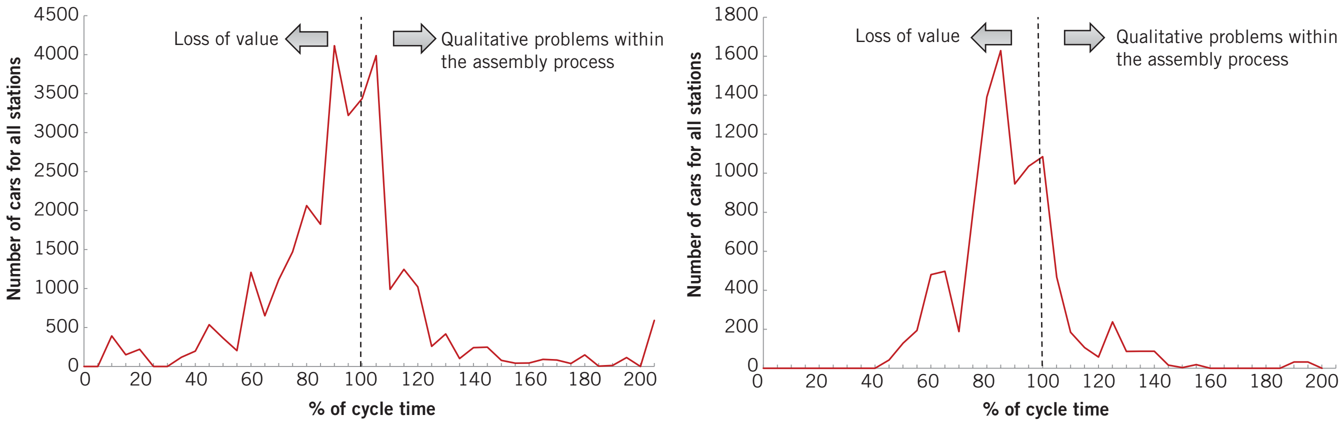
Despite numerous constraints, the number of theoretically possible line balances typically increases exponentially with rising number of tasks and operators. Even for some hundred tasks and operators, it is thus possible that more feasible line balances exist than atoms in our universe. Nevertheless, in case of a low diversity of car variants and small number of operators considered, the ALBP can be managed in practice by well-trained industrial engineers or team leaders. Based on their long process experience, they are usually able to define a good line balance by applying shop floor strategies in combination with existing IT time management systems without simulating all, or at least a vast majority, of the theoretically possible line balances.

However, as a result of increasing complexity in terms of vehicle variants as well as the number of tasks and operators, this approach unveils two major drawbacks. Firstly, personnel costs to ensure a good line balance increase. Secondly, the immediate effects of a new task-operator assignment on the cycle time spreads for all car variants can hardly be quantified by an industrial engineer. Consequently, it is realistic to assume that the quality of line balances constructed with shop-floor strategies will decline in the case of mixed-model assembly lines. In a series of joint projects with Quadriga Consult, it was found that this problem

Task list
Task 1: Mount clip
Task 2: Clip on catalysator
Task 3: Connect fuel pipe to engine
Task 4: Dismount spindle
Task 5: Disconnect wiring harness
Task 6: Insert wiring harness
Task 7: Set screws on gear box
Task 8: Affix exhaust pipe holder



❶ Example of line balancing with eight tasks and three stations



❷ Two charts illustrating deviations of different car variants from the cycle time, observed at two OEMs

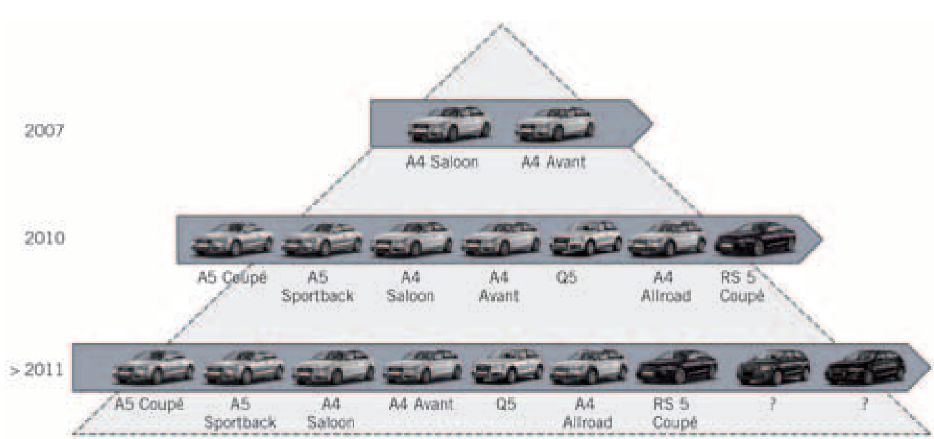
still persists for most car makers, although the negative effects of suboptimal line balances are very well perceived in practice. As an example, the cycle time spreads for several assembly line zones at two OEMs (which apply shop-floor strategies) are shown, ❷, thereby clearly illustrating the loss of value as well as the spreads above 100 % cycle time for some of the car variants within the production programme. In both cases, the production planning management confirmed the negative effects of the cycle time spreads and expressed the desire to avoid them as much as possible through appropriate methods.

SOFTWARE SOLUTIONS

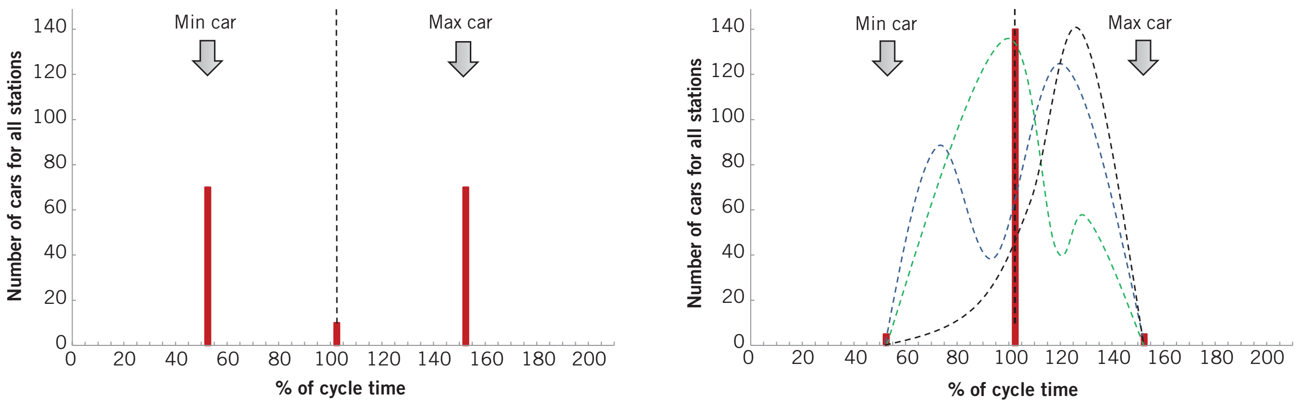
Considering the future increase in model and variant diversity, ❸, a deterioration of the previously described situation is to be expected. Thus, the use of an appropriate IT system for line balancing seems reasonable in order to reduce the amount of work for industrial engineers and to ensure a high quality of the line balance, which ultimately is supposed to reduce cost. In fact, certain efforts in this regard have been made by various software companies and academic institutions. However, the proposed software solutions to date cannot cope with the obvious complexity of the ALBP and hence simplify the problem instead. As a consequence, car makers usually dispense with their use in practice.

At this point, only a few of the shortcomings, which primarily manifest themselves in practice, will be pointed out. Firstly, many systems merely offer “support” for manual line balancing, and then only for small, isolated zones of the line instead for the entire assembly line. Besides, calculations and optimisations often use a minimum, maximum and average equipment level instead of a complete vehicle programme comprising hundreds or thousands of different vehicle variants. Such a reduction in complexity can lead to undesirable results, ❹. Finally, we have to emphasise that the few IT systems which autonomously perform line balancing require either an enormous amount of work to gather data for the optimisation model or assume only a fraction of the constraints in practice, thus resulting in non-practicable line balances.

On the basis of the initial situation described above, Combinatic GmbH, a company offering software solutions for very large combinatorial problems in various industries, developed the software module called AOP-LB for computer-based optimisation of the ALBP in the automotive industry. This software module is part of the AOP platform (Automotive Optimisation Platform), providing solutions to problems specific to the automotive industry. During its development, which was accompanied by industrial engineers and production experts, the focus was on practicability in particular. For example, the software no longer considers the line balancing problem in isolation but allows a holistic optimisation of the entire assembly line to be carried out across numerous zones, including all relevant constraints. This is an important feature, since practice has proved that the greatest benefits of computer-based line balancing, compared to established line balancing strategies (for example shop-floor), can be achieved for problems involving at least 1500 tasks and 60 operators. Moreover, the software takes account of the complete production programme, consisting of several hundreds or thousands of car vari-



❸ Development of car variants illustrated by the example of the B-segment of Audi AG



❹ Example of an undesired line balancing result if line balancing is based on a calculation with minimum and maximum equipment levels (here: min car = 50 % of cycle time, max car = 150 % of cycle time) – the potential distribution of cycle time spreads between 50 and 150 % may be very poor (Figure left) or very good (Figure right, red bars); beside these two distributions, many more might be possible (Figure right, coloured curves)

ants, as a calculation basis for the optimisation. Therefore, a very realistic optimisation output can be obtained with respect to the workload of any operator and cycle time spreads. Data gathering for the software can be easily conducted by industrial engineers and team leaders, and the optimisation model can be finally saved in a database. Hence, personnel costs for the maintenance of the model are low after its initial definition. In addition, the graphical user interface of the software illustrates all relevant statistics and results with respect to the line balance.

Compared to current line balancing methods, the AOP-LB software module enables the user to compute qualitatively better line balances with significantly less resources and in substantially less time. Consequently, assembly costs will be reduced. In fact, several projects accomplished in the plants of European OEMs revealed tangible cost savings through the use of the software. A correlation between potential cost reductions was generally observed due to the line balancing optimisation and diversity of vehicle variants in combination with high quantities. According to experience gained in joint projects involving Combinatic and Quadriga, savings of roughly 12 to 15 Euro per assembled vehicle can be achieved. ❺ provides an overview of the cost savings that are possible due to the optimisation software at different times of the production cycle. Even if the precise savings cannot be completely predicted, a key benefit of Combinatic's line balancing software already exists in its ability to compute different scenarios (for example, different car programmes, different degrees of flexibility along the assembly line, etc.) in a short amount of time. In this way, important guidelines can be recorded and solution scenarios initiated that would not have been possible without computer-based line balancing.

Before start of production	1 Faster and better planning decisions : Fast optimisation of various scenarios during planning phase of a new model reduces the probability of suboptimal plannning decisions and investments.
Start of production	2 Earlier normal volume production : Ramp-up of a new model can be started with an almost perfect line balance and allows an earlier normal volume production.
Production	3 Increased capacity utilisation : reduction of work force along the assembly line by approximately 5 % through increased average workload : additionally, harmonisation of work load across operators
	4 Enhanced assembly process quality despite higher capacity utilisation : reduction of deviations from cycle time for different product variants by 30 to 60 % : reduced deviations from cycle time result in lower rework rates (estimated 15 to 25 %) : additional improvements regarding process quality, e.g. ergonomic aspects and space usage
	5 Release of expert resources for more value-creating activities : After initial data gathering and processing, effort of production planners/engineers for line balancing is reduced by 50 to 70 %.

❺ Benefits of the AOP-LB software module for line balancing – the numbers represent the average values of several projects conducted at five European OEMs; the comparison was based on the existing line balancing strategies (mostly shop-floor) of the corresponding OEMs