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An analytical framework for handling production time variety at workstations of mixed-model assembly lines

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Abstract

In recent years market demands have shifted towards customized products. As a result many manufacturing companies face an increasing variety of their product range. As it is not profitable to install new assembly lines for each product, assembly lines have to be able to handle different products in batch size one. In literature these lines are called mixed-model lines. They follow the logical principal of flow production but are capable of producing different products while needing minimal modification of assembly processes at the workstations.
While mixed-model lines help manufacturing companies handling product differences profitably, they result in a number of challenges for the production process. One major challenge is related to the varying assembly times at a single workstation due to different products.
Actions have to be taken to cope with assembly time that is over cycle time, in order to avoid stops in a flow production. For economical reasons manufacturing companies have to be able to work at a high workload utilization on average. Therefore it is necessary to have a detailed look at the workstations' situation regarding production time variety.
To address this, an analytical framework for assembly lines, based on a mixed-model line principle, is given to identify workstations that face high complexity regarding production time variety. This analytical framework contains several aspects focusing on production time variety as drifting probability, utilization and statistical dispersion. By using this framework, companies can apply their actions and line balancing more precisely to the situation at a workstation. Thus, manufacturing companies are able to handle complexity effectively and to reach a high workload utilization in their mixed-model assembly line.

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Keywords: Assembly; Poduction; Productivity; Stability

1. Introduction

Since the invention of the automobile 130 years ago, production systems have been developed in order to adapt to changing technologies and customer needs. The basic idea of producing cars in a flow system, introduced by Henry Ford, is until today the dominant production system in the automotive industry [1]. In the beginning, the production lines were established as single-model lines: Standardized and similar products were produced in flow by workers who executed a particular work operation. Therefore learning effects could be realized quickly and workers could have a lower qualification level [2]. As a consequence manufacturing companies were able to gain advantages in productivity and high work utilization. However, at the end of the 20th century and the beginning of the 21st century the automotive industry faced major shifts in market demands. Automotive customers demanded new products more often in a shorter period of time, therefore product lifecycles became shorter and the need for ramp-ups increased in the automotive industry [3]. Also, manufacturing companies had to provide the market with more customized products. As a result, mass production nowadays is often times described by the term mass customization. Altogether the variants of products increased and made production and its environment more complex and turbulent [4].

As a consequence, establishing an efficient and profitable production has become more difficult as product configurations and variants increased [5]. Fig. 1 shows the impact of individualization for production companies.

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Increasing product differentiation diminishes the marginal utility while marginal costs increase.

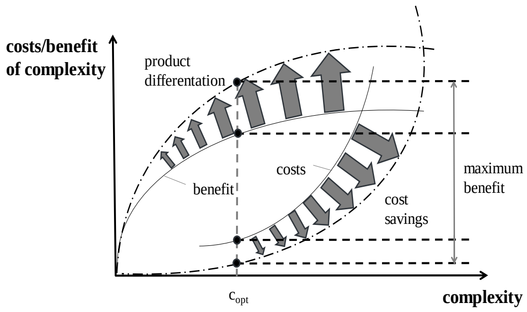

Fig. 1. Benefit and cost interdependencies of complexity [6]

By increasing the variety of the product range, the handling of complexity in product design and production becomes a key factor for a manufacturing company's success: Product complexity must be matched with a flexible and complex manufacturing system [7]. Since several years manufacturing companies have reacted to the increasing product variety by changing its former single-model production lines into mixed-model production lines, which is particularly evident for assembly lines. In a mixed-model assembly line product variants are assembled in flow and in batch size one [8]. This sort of assembly line is more flexible and provides productivity despite high variety of the product range [9]. Obviously the assembled products need to have a certain similarity in order to have a short set-up time for each product [10]. Fig. 2 shows the flow production principles of a single-model assembly line, a multi-model assembly line and a mixed-model assembly line, with its set-up and product characteristics.

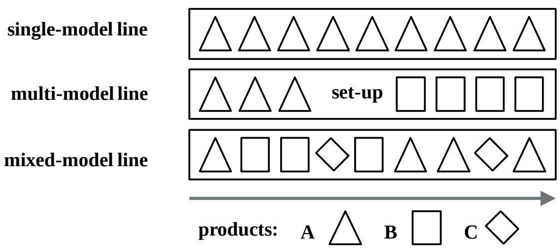

Fig. 2. Flow production principles [10]

In a mixed-model assembly line there exist new challenges for manufacturing companies in particular due to different work operations and varying production time for the different variants. Balancing the line, the drift of workers and the model sequencing make a mixed-model line more difficult to run efficiently [5,11]. The varying production time of the product variants at the workstation cause this situation. In terms of assembly lines the production time is equivalent to assembly time, i.e. the time a worker needs to finish the job on the product at the workstation. Therefore the focus of this paper is on identifying and assessing workstations with high production time variety. This supports the stabilization of the workload and helps increasing the workload utilization and thus the efficiency of a mixed-model assembly line.

2. Drifting in a mixed-model line

One goal of balancing a mixed-model assembly line is achieving similar cycle times for each workstation, which is impossible to achieve due to the different products, having different production time [11]. Another effort to increase efficiency in an assembly line is the sequencing of products: In order to stabilize the cycle times for each workstation, production control systems influence the succession of products, passing through the assembling process. As a result, products requiring high production time are followed by products requiring low production time. As different products and their variants initiate different production time at different workstations, installing sequences has its limits and cannot be implemented for every workstation.

As different products arrive in sequence, different work operations need to be executed based on the different configurations of the products. Therefore products require different production times at the workstation. As a result drift occurs. The term drift describes the deviation from the cycle time of an assembly line and can be either positive or negative [11]. As a consequence a worker in a flow system type assembly line faces products that exceed cycle time and products that fall short of cycle time. From an efficiency point of view manufacturing companies try to reduce this idle time [12]. But obviously exceeding cycle times, i.e. positive drift (see Fig. 3), harm the stability of an assembly line. Workstations that face large positive drift can easily become the bottlenecks for assembly lines [13] .

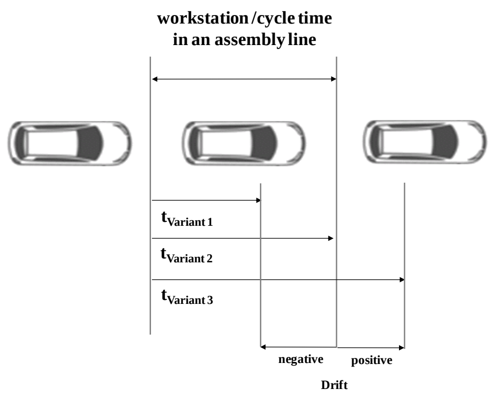

Fig. 3. Drift of worker in a mixed-model assembly line producing cars

3. Efforts to reduce production time variety

There are several efforts to reduce volatile production times and its consequences in mixed-model assembly lines. Some strategies like modularization of product design, design for assembly or integration concepts for assembly lines focus on reducing parts and as a consequence, these efforts aim at decreasing production time [7,14]. These efforts influence the structure of the product variants or production and therefore need a long time for preparation and implementation. Therefore other efforts focus on controlling the effects of different variants in an assembly line.

Efforts on reducing the effects can be divided into efforts before the actual production process and efforts during the production process. Manufacturing companies established production planning, a section that is closely connected with the distribution sector. Therefore actions can be taken to level a production program regarding the diversity of the product variants in advance. Production planning can level volatile production time by establishing sequences within a day of a product program.

Despite the efforts of production planning, there are still challenges left for running a mixed-model assembly line. Strategies to reduce production time volatility during the production process aim at increasing the flexibility within the assembly line [15]. By installing buffers between a group of workstations, problems within these groups can be limited for a period of time. Drift areas for workstation give a worker the opportunity to extend and shorten his work area. Assembly lines also provide workstations that focus on special configurations of a product.

Moreover, there are strategies during the production process targeting on adding capacity to the main assembly line. Often times there are supervising workers supporting certain workstations when products with a high production time arrive. Besides that, stopping the assembly line is possible in order to finish a product. This should be avoided as stops diminish the efficiency of an assembly line. Furthermore, manufacturing companies install downstream areas to correct quality related problems. This can also be seen as adding production capacity to an assembly line in order to deal with product variety; this rework can be done in the line as well and requires a high qualification degree of those workers next to additional planning and controlling efforts [1,15].

To choose the best strategy and to handle production time varieties in the most effective way a detailed understanding of the specific situation of the individual workstations is needed. However, manufacturing companies mainly focus on average utilization rates and idle time reduction. Thus, a detailed analysis of production time varieties in a mixed-model assembly line from different perspectives is missing, which would be necessary for a further stabilization and increase of workload utilization.

4. Analytical framework to handle production time variety

The analytical framework described in this paper contains three elements which help to visualize and thus handle production time variety at the individual workstations of a mixed-model assembly line from different perspectives.

The first element of the analytical framework, described in chapter 4.1, is the calculation and visualization of a moving average of an upcoming production program respectively a production sequence. From an individual workers perspective in a workstation of a mixed-model assembly line, this workload of the next products is the most important figure regarding production time varieties. By visualizing this moving average, periods of high and low workload become transparent and workers can adjust themselves to the upcoming situation in advance.

In mixed-model assembly lines a far drifting of workers out of their supposed working area during such periods of high workload should be avoided. Thus, the second element of the analytical framework is the plotting of a drifting curve, described in chapter 4.2. A visualization of the potential drifting curve can be used by supervisor workers to support individual workers in advance and avoid an escalating in periods of excessive workload.

The third element of the analytical framework is the classification of workstations according to their average utilization and workload dispersion, described in chapter 4.3. By focusing not only on the average workload but also on the dispersion of assembly times, production planners can identify instable workstations of mixed-model assembly lines and use this systematic analysis for assembly line balancing.

4.1. Average utilization of an upcoming product sequence

First, the average utilization of an individual workstation for an upcoming product sequence is calculated in terms of a moving average. By calculating the simple moving average for the next, e. g. five products of the production program, the short-term workload of the respective workstation becomes obvious and can be visualized, see Fig. 4.

For the workers and their supervisor in a mixed-model assembly line, this utilization rate of the next few minutes of production is far more important than the average utilization of the whole production program of one day, which is the main figure of assembly line balancing nowadays.

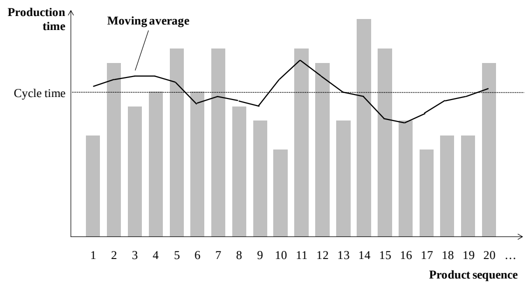

Fig. 4. Moving average for a certain number of upcoming products

The number of products which should be used in the calculation of the simple moving average is depending on the flexibility of the individual workstation to cope with production times which exceed the cycle time as well as on the usage of this figure. A small number of products is used for inflexible workstations and short-term workload visualization, e.g. for the corresponding worker. Whereas the moving average for a more flexible workstation or a supervisor worker is calculated for a larger number of products.

4.2. Drifting of workers during periods of excessive workload

The second aspect of the analytical framework illustrates the drifting of a worker during periods of excessive workload in a production program. The premise for this aspect is that a worker in the assembly line is not allowed to work ahead of the production program, i. e. he will not start to work on a specific product before it is entering the working area of his workstation.

If the production time of a product exceeds the cycle time of the assembly line, the workload of the subsequent products is cumulated as long as the sum of their production times exceeds the available production time for these products. In this case the worker is not able to finish a product according to the standard operating procedure as he is still drifting downstream the assembly line into the subsequent working areas. The calculated figure, which is in fact a cumulative moving average, is visualized in form of a drifting curve, see Fig. 5.

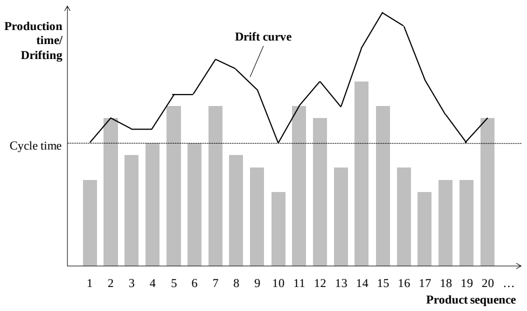

Fig. 5. Drifting curve for a production program

Depending on the individual workstation, a certain figure for drifting may be possible and acceptable. However, drifting leads to a deviation from the standard operating procedure and may result in stress situations for the respective worker as well as disturbing interactions with subsequent workstations of the assembly line.

4.3. Classification of stations by utilization and dispersion

In the third aspect of the analytical framework the production time variety itself is analyzed. Hence, not only the time difference between the maximum and minimum production time of a workstation but also the dispersion of production times is analyzed. Therefore, for each individual workstation the utilization as well as the dispersion of a certain production program, e. g. of one working day, is calculated.

The utilization is generally calculated as the relation between the average production time of the products of a production program and the cycle time of the assembly line. The dispersion of production times, for example, could be calculated as standard deviation or mean difference from this average utilization rate. Following this, every workstation is inserted into a matrix which is built by the two dimensions "utilization" and "dispersion", see Fig. 6.

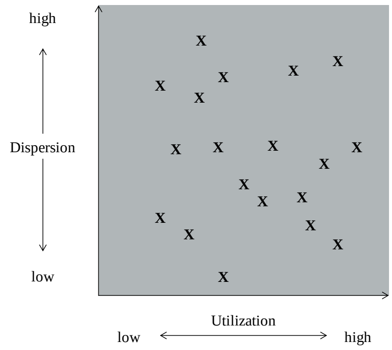

Fig. 6. Matrix containing individual workstations

In this matrix the relation between the average utilization and the dispersion of production times of individual workstations is shown. This relation characterizes the stability of an assembly process at the respective workstation. Thus, this matrix is called "stability matrix".

Workstations having a high workload utilization as well as a high dispersion of production times are classified in Area A (instable), see Fig. 7. They tend to be instable as they are not able to absorb production times which exceed the cycle time. A low utilization rate enables workstations to balance a high dispersion of production times over time. Those workstations are classified in Area B (balanced), see Fig. 7.

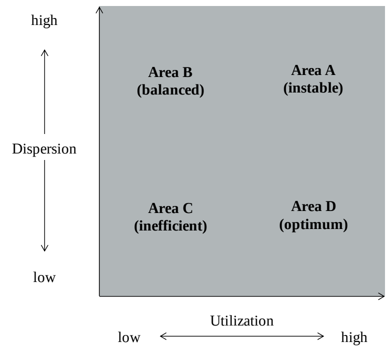

Fig. 7. Areas of the stability matrix

Area C (inefficient) contains workstations which have a low dispersion of production times as well as a low utilization rate, see Fig. 7. Thus, they are neither efficient nor need their potential to balance dispersions of production times. Finally, workstations can be classified in Area D (optimum), which means that they are highly efficient and do not need to balance varying production times as they have a low dispersion of production times, see Fig. 7.

5. Application of the analytical framework

The visualization of the average utilization for an upcoming production program may be used in a worker information system or for the monitoring of a certain assembly group by their group leader or supervisor. Depending on the specific user and usage of this information, the number of products for which the simple moving average is calculated needs to be adopted. Moreover, following the idea of a control chart, this visualization could contain warning and control limits as well, see Fig. 8. These limits could be adopted to the circumstances of the specific workstation.

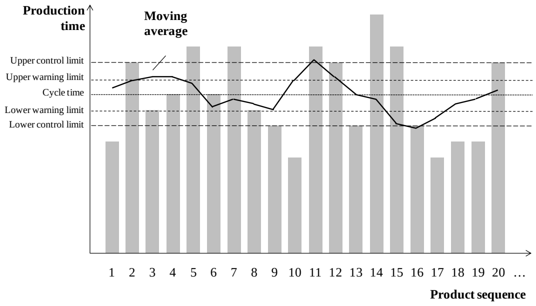

Fig. 8. Moving average with warning and control limits

Displaying and monitoring this moving average of an upcoming production sequence in this way supports workers and supervisors of a mixed-model assembly line by handling varying production times. As the workers regularly rotate their workstations, e. g. about every two hours, this short-term workload is by far more relevant for them than the average utilization of a workstation for the production program of a whole day.

Moreover, the visualization of the drifting curve helps to identify upcoming bottlenecks in advance and thus to avoid upcoming problems with production time varieties. As before, adding individual upper warning and control limits to the illustration of the drifting curve could be reasonable to highlight critical situations, see Fig. 9. These maximum areas for drifting could be defined and visualized for the individual workstations, e. g. according to the layout of the mixed-model assembly line or limitations of the production technology.

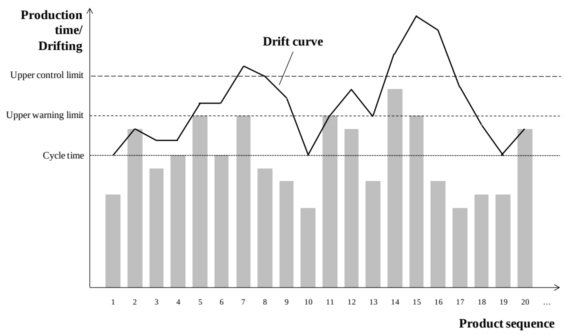

Fig. 9. Drift curve with upper warning and control limits

Furthermore, by applying the stability matrix, the balancing of an assembly line does not only focus on workstations with a low average utilization or a high production time variety but also on workstations having an unbalanced relation between workload utilization and production time dispersion. In order to stabilize a mixed-model assembly line, both situations of unbalanced workstations (located in Area A and Area C) have to be addressed and developed to an acceptable relation of utilization and dispersion. Workstations having this balanced relation are located in the illustrated diagonal between the upper left (low utilization, high dispersion) and the lower right (high utilization, low dispersion) corner of the stability matrix, see Fig. 10.

In comparison to that, reaching the optimum (Area D) of highly efficient workstations with a low dispersion of production times is only the second step of the approach to cope with production time variety, see Fig. 10.

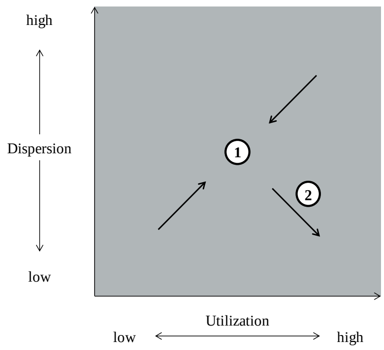

Fig. 10. Stability matrix with two-step approach (arrows)

6. Conclusion

The analytical framework outlined in this paper helps to visualize the complexity of a mixed-model assembly line in terms of production time variety. Varying production time are a main reason for instabilities and inefficiencies in a mixed-model assembly line.

The different elements of the framework make the workload of the single workstation transparent from various perspectives and therefore help to gain a holistic overview of the situation regarding production time variety. Thus, the complexity of a mixed-model assembly line regarding production time variety can be assessed. As a result, the need as well as the opportunity for action to reach a high utilization and stability of a mixed-model assembly line become obvious.

Applying the described analytical framework can help companies to handle production time variety and to stabilize their mixed-model assembly line by identifying both periods of excessive workload at individual workstations as well as specific workstations.

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