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Procedia CIRP 54 (2016) 215 – 220

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6th CLF - 6th CIRP Conference on Learning Factories

Method for configuring product and order flexible assembly lines in the automotive industry

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Abstract

In the last few years the number of offered vehicle derivatives in the multi variant serial production of the automotive industry increased. The existing assembly lines have to manage many ramp ups. It is necessary to increase the product and order flexibility of existing assembly lines to manage these challenges. This paper details the preconditions to learn, which assembly configurations fulfill the requirements of existing, further and future products. Therefore the developed method uses degrees of freedom in the assembly order.

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Keywords: automotive industry; assembly; requirements; planning; flexibility; strategy

1. Introduction

The multi variant serial assembly of the automotive industry is confronted with different challenges like a growing number of car models and global demand changes. It can be managed within the production network but only in a restricted corridor. Therefore, it is necessary to have product and order flexible assembly lines.

Today normally one vehicle architecture can be realized on an assembly line. Vehicle architectures are the platform for different cars, like a front or rear driven architecture. The different car models, also called vehicle derivatives, are based on these architectures. But even the number of the vehicle derivatives, which can be assembled on the same line, is restricted. There are different reasons, like different assembly times between the car models, so they cannot be assembled on the same line economically [1]. The same assembly processes would be located at different positions in the line.

An assembly line normally is planned and configured for one vehicle architecture and their derivatives. The product changes and the ramp-up of new products have an impact on the existing assembly configuration. It has to be analyzed, if they can be assembled on the same line and which reconfigurations are necessary. Each reconfiguration causes costs. These costs can be reduced, if a strategic configuration can be detected, which will allow to assemble different cars with different ramp-up dates.

This paper is based on the modularization of factories and products, synchronizing of the assembly and product life cycle and harmonizing of different assembly configurations [2, 3, 4]. The target is to learn, how existing assembly lines have to be reconfigured, that they can fulfill future product requirements. This is based on already existing learning factory approaches, which allow changing the order of different assembly elements [5, 6].

Before detailing the developed method to increase the flexibility of assembly lines, flexibility has to be defined. In this paper the definition follows the view of WESTKÄMPER. A system is called flexible, when it is reversible adaptable to changing circumstances in the context of a principle preconceived scope of features [2].

In this context flexibility is the ability of an assembly line to be able to react to demand changes in quantity and derivatives in a specific scope.

An analysis in the automotive industry has shown that the same vehicles can be assembled in a different order. These

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doi:10.1016/j.procir.2016.03.051

degrees of freedom can be used to harmonize the assembly processes of vehicle architectures and an existing assembly configuration. A precondition to configure such product flexible lines is the vehicle independent modularization of the assembly processes. The results are assembly modules, which are identical for all the architectures and assembly lines (figure 1).

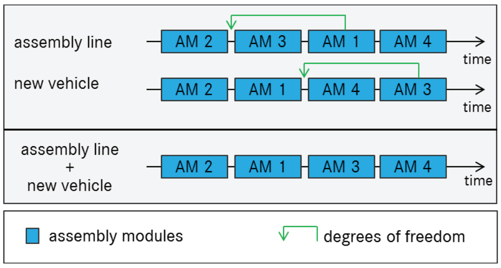


Figure 1: Using degrees of freedom to enable the planning of product-flexible assembly lines

In the following chapters, the preconditions for an adaptable assembly line will be discussed. Further on the method to modularize and configure assembly lines, which are able to handle future products, will be detailed.

2. Preconditions of future assembly lines

An assembly line is comparable with the human immune system. An immunization allows reacting to unknown threats. Also an assembly line can be immunized. A company has to learn how an assembly line has to be configured to increase the product flexibility [7]. Therefore it is necessary to reconsider today´s preconditions (figure 2).

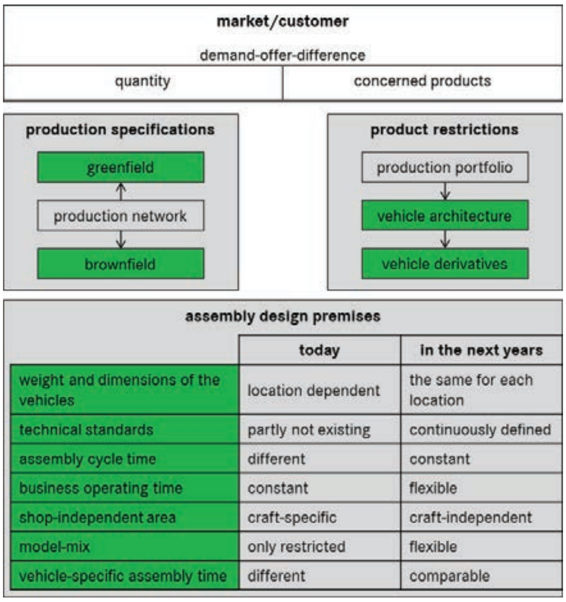


Figure 2: Preconditions of future assembly lines

At the beginning, the market demand has to be determined. Afterwards it can be analyzed, which quantities of the different vehicle derivatives are needed. Based on this information, decisions can be made, whether it has to be planned in a green- or in a brownfield.

A greenfield planning means to plan a new assembly line. That is necessary, if there is not enough capacity in the production network or a new vehicle cannot be integrated in an existing line. Otherwise it is a brownfield planning.

In a brownfield, the assembly time, the business operating time and the area are already defined. Instead of adopting the current conditions of the existing line, they can also be further developed. In this paper, a brownfield planning is focused.

Before starting the planning of an assembly line, the basic requirements need to be defined, which are shown in figure 2. Those were considered in the past. But in the future, there is a need to rethink them. The further development of today's preconditions will be amplified in the following chapters.

2.1. Weight and dimensions of the vehicles

There are many restrictions, which are vehicle dependent:

- the weight
- the dimensions (length, width, height)
- the pick-up points

During the planning process it has to be ensured that present and future vehicles can be assembled on the lines. For example, the conveyor system has to be compatible with the vehicle specific pick-up points and it must be able to handle the heaviest cars. Also the dimensions of the assembly stations have to be big enough. Based on these restrictions, technical standards can be defined.

2.2. Technical standards

The degree of automatization is the most important part of the technical standards for the assembly processes. Countries with a high wage level are called high-cost-countries. In these countries the degree of automatization is normally higher than in low-cost-countries. That is why two different standards are described, for the low- and the high-cost-countries. Automatization is to ensure the product/process quality and/or to improve the working conditions used in several locations.

The benefits of technical standards in automatization are:

- reduced construction costs and less planning time (reason: one-time planning)
- higher transparency and better effects of improvements, (reason: adoption of optimization results to each identical process)

A premise therefore is the consideration of weight and dimensions of the vehicles (chapter 2.1) and the same cycle time of the different assembly lines.

2.3. Assembly cycle time

Today, the cycle time distinguishes between the assembly lines, even if the same cars are assembled. Further on, the assembly cycle time is used to increase or reduce the output. Different cycle times lead to a different assembly content of the stations. It would be impossible to define technical standards like explained in chapter 2.2. Each assembly line has to be planned separately. That causes high costs, which can be eliminated by harmonizing the cycle time. After this it will be possible to plan once and adopt the result to the other assembly lines. Changes in the output can be managed within the business operating time instead of changing the assembly cycle time. If the cycle time and the work content remain constant, higher learn curve effects will be realized [8].

2.4. Business operating time

If the cycle time is constant, the increasing of the business operating time will lead to a higher output and the other way around [1]. If all the assembly lines have the option to increase the operating time, there will be a much higher flexibility to increase the worldwide output or vice versa. The precondition is that all assembly lines have the same flexibility. Otherwise the line with the lowest flexibility will be the restrictive factor.

2.5. Shop-independent area

Today the area of a plant is separated in different shops. If the area can be used for each shop, there will be the option to adjust the area distribution retroactively. Therefore, fixed installed assembly stations need to be mobile to avoid relocation activities, which cause high costs and too much time. A flexible area distribution enables an expansion of single shops. If vehicles with a longer assembly time are launched, the assembly line has to be extended. A constant cycle time makes an extension of the assembly line necessary. The whole assembly time divided by cycle time is the amount of needed stations. The needed number of stations multiplied by the length of the stations equals the length of the whole assembly line. The needed area of the assembly line is the multiplication of the length and the width. Further areas have to be added: pre-assemblies, logistics, rework, quality checks, buffers, inverters, driveways, strategic meaningful open area and so on. It will be optimal, if all vehicles have the same assembly time.

2.6. Vehicle specific assembly time

The time needed to assemble a car on the final line distinguishes between the vehicle derivatives and their configurations. Within line balancing, time differences can be harmonized. But that is not possible, if the deviation between the assembly times is too high. That is the reason why today only a specific number of vehicle derivatives (based on the same architecture) are assembled on one line. With a constant cycle time, a higher assembly time leads to a longer assembly line (chapter 2.5). The target is to realize comparable assembly times over all vehicle architectures, derivatives and configurations. Today differences in the assembly time are managed within a restrictive model-mix.

2.7. Model-mix

Today an assembly line is planned for a defined number of vehicle derivatives of the same architecture. The maximum output and the sequence of these different derivatives are restricted because the assembly times are not constant over all vehicles. The reason therefore is that the assembly tasks are configuration dependent. Different assembly times in the stations, depending on the vehicles, can be compensated within the so-called “drifting”. When the vehicle specific assembly time is higher than the cycle time, the employee floats to the next station. If the following car needs less time the employee can catch up the lost time. A flexible assembly line would have the option to react to each model-mix scenario. If all vehicle architectures/derivatives have the same assembly time, there will not be any model-mix restrictions anymore. The cycle time spreading can be reduced by modularizing the products and harmonizing the different assembly times of these modules.

3. Cross-architectural modularization of assembly processes

The explained premises are the frame conditions of adaptable assembly lines. Before using the degrees of freedom to configure cross-architectural assembly lines, the assembly processes have to be modularized.

Products and processes can be modularized. The product structure represents the parts of the whole end-product. It begins with the final product and ends on the component level. The components can be listed on more than one level, depending on the product structure. To reach a higher level, the parts before have to be assembled. On the upper levels there are product modules, which are the result of assembling submodules [3].

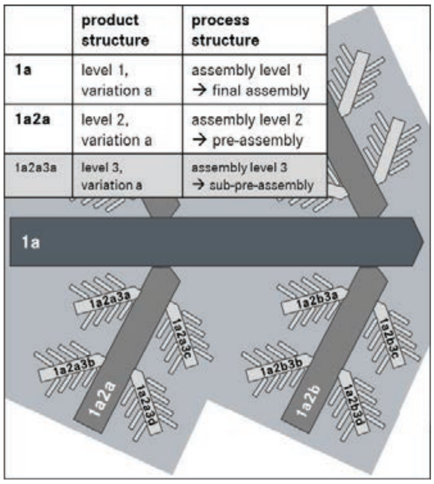


Figure 3: Harmonizing of the product and assembly structure

There will be some benefits, if the assembly lines have the same structure as the product. In this case, the final line is on the highest level, where the final product is assembled and the submodules are assembled in the pre-assembly lines (figure 3). The benefits are:

- changes in a product module only affects the linked assembly module

- only the pre-assembled parts are assembled in the main line, so the length and complexity of the final line is minimized
- there is less cycle time spreading in the final line, because only the main parts with comparable assembly times are mounted, which are independent of the customer individual configuration

Compared to a product module, an assembly module is characterized by an assembly time and technical operating resources.

In the multi variant serial assembly the pre-assembled product modules are delivered within the logistics to the assembly modules in the final line. The product modules are directly linked to the assembly modules [7].

After harmonizing the product and the assembly structure, the assembly modules can be defined.

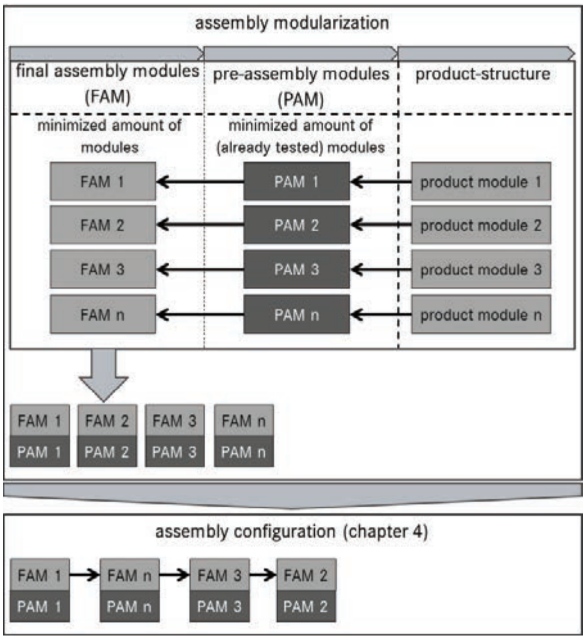


Figure 4: Modularizing and configure the assembly line

To minimize the complexity in the final assembly line, only the pre-assembled product modules on the highest level (level 1 in figure 3) in the product structure are assembled. Examples are the flaps (doors, hood, trunk lid), which are linked to the chassis. These parts have to be mounted in the main line, even if they cause cycle time spreading. The pre-assembly modules (PAM) can be linked to the final assembly modules (FAM). The modularization can be started by beginning at the product structure or at the assembly structure. It is independent if they are identical like shown in figure 3. The results are the different assembly modules. The degrees of freedom allow different possible assembly configurations. They have to be detected and evaluated. This will be detailed in the following chapter.

4. Configuration of a product and order flexible assembly line by using degrees of freedom

On this consideration level, the pre-defined and standardized assembly modules apply for each vehicle. This is a precondition to analyze the ability to integrate new products on existing assembly lines. The degrees of freedom can be considered within an adjacency matrix, a possibility to save precedence graphs [4].

4.1. Determining the degrees of freedom within adjacency matrices

The modules are listed in the column and the row of a matrix. In the cells of the matrix, the following question has to be answered: whether there is a directional dependency between the different modules or not [4]. Such a matrix represents all degrees of freedom. The matrices have to be filled for all architectures and the existing assembly line, on which they have to be assembled. Afterwards, the matrices have to be harmonized. The result is a matrix with the lowest degrees of freedom, which fulfills the minimum of identical degrees of freedom of all the architectures and the assembly line. The path dependency between the modules makes an assessment of possible configurations impossible. The degrees of freedom are only considered between two modules. That ensures an objectively filling of the matrix by the experts. The premise is that all possible configurations can be generated, even if they are completely different from already existing assembly orders. It will not be manageable anymore, if all the assembly parts are modularized. There will be too many modules for which the degrees of freedom have to be filled in. The numbers of cells, which have to be filled in, are represented in the following formula:

Table 1: Formula to calculate the number of degrees of freedom to fill in

$y = \frac{x^2 - x}{2}$	
y	amount of cells, for which the degrees of freedom has to be determined
x	amount of modules

For example: If there are 30 modules, the experts have to fill in 420 cells. In the classic adjacency matrix, there would be 870 (30^2-30) cells to be filled in. This can be halved, within a higher information concentration per cell. Instead of giving a binary answer the experts have to choose one of the following three possibilities:

- A: to go from x to y,
- B: to go from module y to x,
- C: to go from modules x to y and from y to x.

Afterwards it can be transformed into the classic adjacency matrix, but the process to fill in is much leaner and needs less time (figure 5).

Instead of evaluating the degrees of freedom between different architectures also the degrees of freedom of an already existing assembly line can be detected, because the assembly modules are the same. It is possible to match them. This allows answering the question, whether a new or further architecture can be assembled on an existing assembly line in a brownfield planning and which reconfigurations are necessary. That is the transformation from a static assembly line to a flexible, learning line.

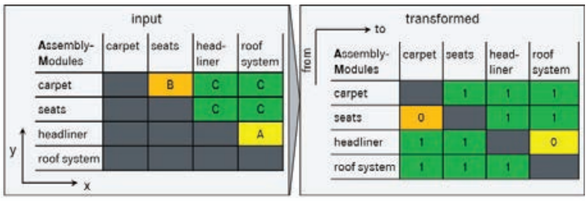


Figure 5: Table to fill in the degrees of freedom

The cross-architectural degrees of freedom allow generating all theoretical possible configurations. If there are too many modules and/or degrees of freedom, there are some problems, which are explained in the following chapter.

4.2. Challenges during the configuration of possible alternative assembly orders

Today´s computing power is a restriction, if there are too many configuration alternatives to generate, especially for exact solving methods like the full enumeration. Further alternatives are heuristic solving algorithms, but they cannot ensure, that the optimal configuration is found [4].

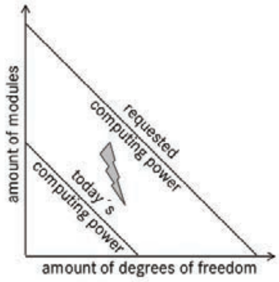


Figure 6: The interdependence between the amount of modules and degrees of freedom

A solution might be the summarization of the modules, but the disadvantage is, that the process is influenced by personal preferences of the experts. The configuration would be comparable with already existing ones. Also the degrees of freedom have to be rated objectively. Thereby the experts have to answer the question, if there is theoretical order flexibility between two modules. This is done for each module pair. The benefit is that the experts have not to think about the path dependency. Path dependency can be explained within the following example: When module 1 has to be before module 2 and module 3 has to be before module 1 then module 3 automatically has to be before module 2.

4.3. The solution to configure an approximate optimal assembly order

The solution is to build all possible assembly configurations until a critical level is reached (full enumeration). Then the process to generate the alternatives stops (step 1 in figure 7). The already generated configurations are evaluated. Therefore, criteria like the conveyor position, have to be defined before. A change in the height causes costs. That is the reason why the configuration with less as possible changes in height should be chosen. There are lots of further possible criteria. The best rated ones are chosen (step 2 in figure 7). Based on these ones the configuration process continues (step 3 in figure 7).

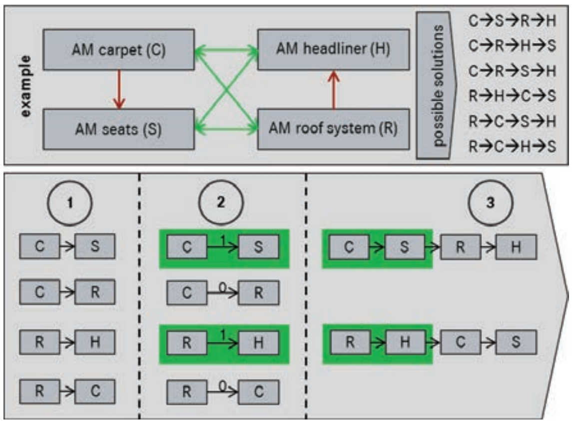


Figure 7: An objective pre-modularization of assembly modules

All these possible configurations are also rated based on the criteria. The result is an approximate optimal assembly configuration. The benefit is that there is no subjectively pre-modularization of the assembly modules necessary. These ones are generated fact-based. The negative aspect is that the result can be the non-optimal configuration. The optimal configuration has to take all possible configurations in account. Otherwise an alternative can be preferred, which is not the best solution; it is good in the first assembly steps, but not over all existing ones. That is also the reason, why approaches to search the shortest way cannot be used. If there are fewer degrees of freedom, it is possible to skip step 2. The result would be the optimal configuration.

This method allows answering the question, if a product can be integrated on an existing assembly line and which reconfigurations will be necessary. The company learns, to manage the assembly configurations.

After the choice of the assembly configuration, the assembly circumstances, which are not included in the modules, can be located in the assembly line to get a more detailed assembly configuration.

5. Locating the flexible time blocks

There are two different types of modules; the defined and the flexible ones. The defined modules were explained before (see chapter 4). Those are the modules, which are assembled to the basic product directly. But there are also other parts, which have to be assembled in the final line. Examples therefore are doormats, operating instructions, grommets and temping. It does not make sense to modularize the whole assembly line, especially not for the flexible parts, which can be realized on different positions in the line. The defined modules include the needed assembling time. But the sum of the assembly times of the defined modules is less than the whole vehicle needs. Therefore, also the other parts, the flexible time blocks, have to be positioned on the line. That allows the exact positioning of the defined modules.

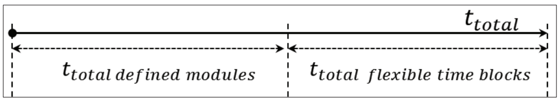
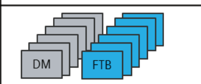
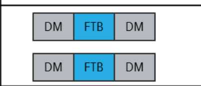
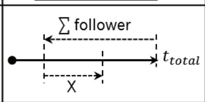
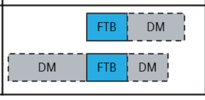


Figure 8: The sum of the assembly time of all defined modules and flexible time blocks represents the assembly time for the whole vehicle

There are four possibilities to locate the flexible time blocks shown in table 2.

Table 2: Locating of the flexible time blocks

possibilities	graphics	usability
complete modularization of the defined modules and the flexible time blocks		✗
constant allocation of the flexible time blocks		✗
definition of the starting point		✗
dependent allocation of the flexible time blocks		✓

It is not possible to modularize the whole assembly line, because the flexible modules would have too many degrees of freedom, there would be too many possibilities to configure the lines (chapter 4.1).

A constant allocation of the flexible time blocks also is not possible. The reason therefore is the time of the flexible time blocks is dependent of the order of the defined assembly modules. The result is not representing the reality. The locations of the modules in the line are wrong.

The definition of the starting point for each module is a complex task, because the starting points are dependent on the prefixed modules.

The only usable solution is to allocate the flexible time blocks after pre-configuring the assembly line. That allows using the flexible time blocks to harmonize the time differences between the vehicle architectures.

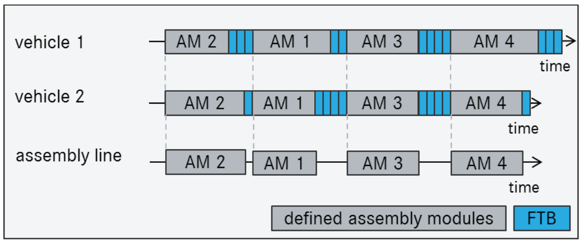


Figure 9: Using flexible time blocks to harmonize assembly times

Finally, the architecture specific adjacency matrices can be used to reduce the throughput time within blocking, interchanging and parallelizing the modules.

6. Conclusion and Outlook

The developed method is based on the modularization of final assembly processes. These assembly modules are valid for existing assembly lines and products. This is the precondition to research, which reconfigurations are necessary to integrate new products on an existing assembly line. Modifications on product and process level increase the degrees of freedom and offer a wider solution area.

The rating of the possible configurations is based on strategic relevant criteria. This method supports the learning factory by focusing on strategic dimensions during the assembly planning process. The benefit is that the planning process is with less human bias and allows checking possible assembly line configurations in a short period of time. There is no standardized precedency graph anymore. The impact of changes in the degrees of freedom and the strategic criteria are transparent and influence the configurations. That allows a permanent learning and immunization of existing final assembly lines. The result is an assembly line, which is product and order flexible and fulfills strategic goals.

7. References

[1] Askar G, Sillekens T, Suhl L, Zimmerman, J, Flexibility Planning in Automotive Plants, Physica Verlag 2007, 235–255.

[2] Westkämper E, Factory Transformability: Adapting the Structure of Manufacturing, in Reconfigurable Manufacturing Systems and Transformable Factories, 2006, 371-381.

[3] Wiendahl, HP, Reichardt J, Nyhuis P, Handbook factory planning and design. Heidelberg: Springer, 2015.

[4] Scholl A., Balancing and sequencing of assembly lines. 2nd ed. Heidelberg, New York: Physica-Verlag, 1999.

[5] Riffelmacher P, Kluge S, Kreuzhage R, Hummel V, Westkämper E, Learning factory for the manufacturing industry. Digital learning shell and a physical model factory. CAPE Proceedings 2007,120-131.

[6] Westkämper E, Digital - Real Learning Factory for Manufacturing Engineering. 3rd Conference on Learning Factories : Increasing resource efficiency through education and training, 2013, 170-181

[7] Küber C, Westkämper E, Keller B, Jacobi H. Planning method for the design of flexible as well as economic assembly and logistics processes in the automotive industry. In: CIRP Conference of Manufacturing Systems 2016, 556-561.

[8] Löffler, C.; Westkämper, E.; Unger, K. Changeability in Structure Planning of Automotive Manufacturing. Procedia CIRP 3, 2012,167–172.