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Planning method for the design of flexible as well as economic assembly and logistics processes in the automotive industry

Christian Küber[a,]*, Engelbert Westkämper[b], Bernd Keller[c], Hans-Friedrich Jacobi[d]

[a, b ,d]*Graduate School of Excellence advanced Manufacturing Engineering, Nobelstr. 12, Stuttgart 70569, Germany*

[a ,c]*DaimlerAG, Mercedesstr. 162, Stuttgart 70546, Germany*

* Corresponding author. Tel.: +49 (0) 176/30922128. *E-mail address:* Christian.Kueber@gsame.uni-stuttgart.de; christian.kueber@daimler.com

Abstract

The automotive industry is facing the fluctuation in demand regarding the variation and amount. Therefore the flexibility and changeability of an assembly line has to be calculable as well as the interaction between the assembly and logistics processes have to be considered in order to keep competitiveness.

This paper proposes a generic method, how to make a strategic decision between flexibility/changeability, economic efficiency as well as assembly and logistics processes.

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Keywords: Assembly; Cost; Flexibility; Flexible manufacturing system (FMS); Logistics; Planning; Productivity; Standardization; System

1. Introduction

Henry Ford once said: „Any customer can have a car painted any colour that he wants so long as it is black [1]."

The mass production in the automotive industry changed to the multi variant serial production, caused by the customer request for individualized products. Over the past years the amount of offered car models, also called vehicle derivatives, increased. An example is the number of vehicle derivatives, Daimler AG offers in the compact car segment, which grew over the last 12 years from originally one to four. Also the variance within the vehicle derivatives has increased. For the BMW X3 there are 90.000 ceilings, 3.000 doors and 324 rear axle variants offered [2].

The number of variants leads to the need of product-flexible assembly lines, with the benefit of a higher degree of capacity utilization, compared to a solitary line, and therefore less investment is necessary [3].

Assembling a large number of vehicle derivatives is not the only challenge factories have to deal with. They also need to manage the variant mix and quantity changes within the vehicle derivatives economically.

The variation, the increased number of offered vehicle derivatives and the need of efficiency affect the logistics and assembly processes likewise. That's why the planning of assembly and logistics processes and their interaction is becoming increasingly important and thus the demand for pre-installed flexibility and adaptability will increase. There is a trade-off between optimizing the assembly and logistics processes, so that the interaction has to be determined methodically to realize low capital investments and a high operating efficiency.

Another trade-off is between flexibility and economic efficiency. Installed flexibility causes further capital investments which increases the unit costs.

An approach, which takes these trade-offs into account, would support the decision-making process while the strategic planning of assembly and logistics processes with focus on economic and flexibility.

In this paper, the terms flexibility and changeability will be defined, before analyzing the interdependence between flexibility/changeability and economic efficiency. After the consideration of the conflict between the aims of optimal logistics and assembly processes, the developed Strategic Decision Square (SDS) will be discussed. The further chapters

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show how decisions inside the SDS can be made. In addition, the need of modularization and the differentiation between product and process level is shown to expand the flexibility, which is limited through the product complexity. Finally, the results will be transferred in a systematic approach.

2. Economic efficiency, flexibility and changeability

2.1. Definition of flexibility and changeability

There are numerous definitions of flexibility and changeability. In this paper the definition follows the view of Westkämper. A system is called flexible, if it is reversible adaptable to changing circumstances in the context of a principle preconceived scope of features. A system is changeable, if it has specific process, structural and behavioural variability to react to changes on its own terms [4].

Based on these definitions, flexibility and changeability can be defined in the context of this paper with focus on the final assembly and intra logistics processes as following:

Flexibility is the ability of a system to be able to react to known, internal requirements in the context of a principle preconceived scope of features. These requirements include changes in quantity and derivatives in a specific scope.

Changeability is the ability of a system to react to unknown, external requirements that cannot be predicted.

2.2. Needs for flexibility and their enablers

A company can be compared with the human immune system. The human immune defense only can react to known threats. External germs can be dangerous, because the body does not know how to fight them. The solution is the immunization. Transferred to assembly and logistic processes this means that the purpose is to plan these processes including the ability to react to known and prognosticated requirements. In the automotive industry, these requirements are changes in the car models, the model mix variation and changes in the comprehensive model quantity. A company can react to these needs of flexibility within the organizational and technical flexibility, the so called flexibility enablers.

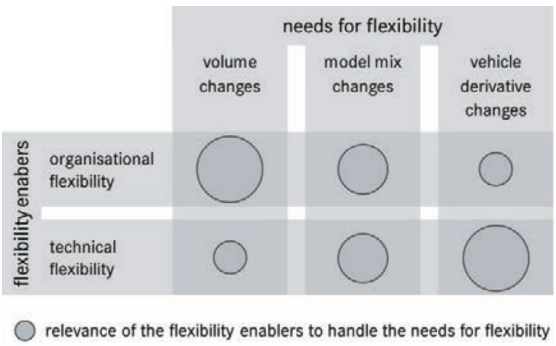

Fig. 1. Needs for flexibility necessity and flexibility enabler

Model mix changes

Different vehicle derivatives normally have a different assembly time. The assembly line has to be laid out to the highest time-consuming operations, which increase the output loss for the assembly line. The reason therefore is the difference between the assembly time of an maximum (highest time-consuming operation) and a minimum (lowest time-consuming operation) vehicle derivative [3]. Today time differences between specific assembly processes, caused by different vehicle derivatives and configurations, are balanced by mixing the throughput of cars, resulting in similar/identical average assembly times per station (a high configured car after a low configured one). The problem is a limited scope to react to model-mix-changes.

Volume changes

Not only the model-mix at a constant output level, also the output of a process can change, caused through fluctuations in demand. There are two possible scenarios. If the number of units is rising, the maximum throughput is defined through the maximum business operating time. If the demand drops, the minimum amount of units is defined through the point at which the company doesn’t earn money anymore. The problem is, that the processes can´t be planed for a defined quantity, they have to be able to realize volume changes economically.

Vehicle derivative changes

In the beginning of the planning process, the location of the company, including the assembly, will be determined. Further, the lead model and its vehicle derivatives for this specific location are defined. The immunization is important to enable the processes to realize further and future planed vehicles. Today, the processes are planned for specific vehicle derivatives. If these derivatives are changing, the whole assembly and logistics processes have to be adapted to the new product requirements. This means a complex planning process and high additional costs.

There are two flexibility enablers, the organizational and the technical one, which depend on each other.

Organizational flexibility

The precondition of the organizational flexibility is the qualification of employees, so that they are able to assemble different and further vehicle derivatives. In terms of the organizational flexibility, human capacity can be raised or lowered by changing the working hours. This depends on the local legislation and collective agreements [3, 5, 6]. Today there is a low level of automation in the assembly processes. This leads to high personnel costs, especially in high cost countries. That is the reason for focusing a high workload. The problem is the different assembly time dependent on the vehicle derivatives. This has to be taken into account while the planning process.

Technical flexibility

The technical flexibility is limited through the technical realization for specific scope of possible assembly processes. Regarding the volume, the maximum output limits the maximum capacity, which consists of the maximum possible operating time. Is the maximum capacity not sufficient, the technical capacity must be expanded through additional investments [5]. The problem is to determine the degree of technical flexibility, which is needed to react to the volume, model mix and vehicle derivative changes from a strategic point of view.

2.3. Interdependence between flexibility and economic efficiency

In an inflexible system the optimal operating point at maximum economic efficiency can be realized for a fix number of units. A flexible system isn't planed for an optimal operating point and has a lower economic efficiency in the static point compared to an inflexible system. The flexibility of a system normally goes along with higher investments. The benefit is a slight reaction of unit costs to quantity changes. Nevertheless a more flexible system can be more economical if the further investments for the flexibility are less than the costs for adapting an inflexible system to new requirements. The further investments for flexibility are known and calculable. The benefits as a result of the higher degree of flexibility are not calculable. This is dependent on the needs for flexibility [3, 6]. They only can be taken into account within different scenarios. Comparable to the human immune system, explained in chapter 2.2, the assembly and logistics processes only can react to changes (needs for flexibility), which were considered while the planning process. Immunized processes are able to react to preconceived future requirements.

3. Interdependence between assembly and logistics processes

The assembly and the intra logistics processes influence each other. Usually the logistics support the assembly. Determined by the growing number of variant parts, the logistics become more and more important and cause an increasing share of the whole costs. That's why the logistics can not only be seen as a supporting process. An example is Toyota. In earlier days the parts were supplied directly to the assembly line. Nowadays they use the basket of goods, a prepacking of vehicle specific components. Even if the basket of goods is not as efficient as the conventional concepts, it has the benefit of enabling a higher number of vehicle derivatives [6]. This shows the interdependence between the logistics and assembly processes and that they can´t be seen separated.

4. The Strategic Decision Square (SDS)

4.1. A decision space, no optimal operating point

In the preceding chapters the interdependence between flexibility, economic efficiency, logistics and assembly processes was explained. If the processes are able to react to changes, there is no optimal operating point, there only exist trade-offs. The question is, in which point such a system should be planned? This point depends on different scenarios and strategic decisions. Therefore the so called Strategic Decision Square was developed, which is the basic of all considerations during the planning process of intra logistics and assembly processes.

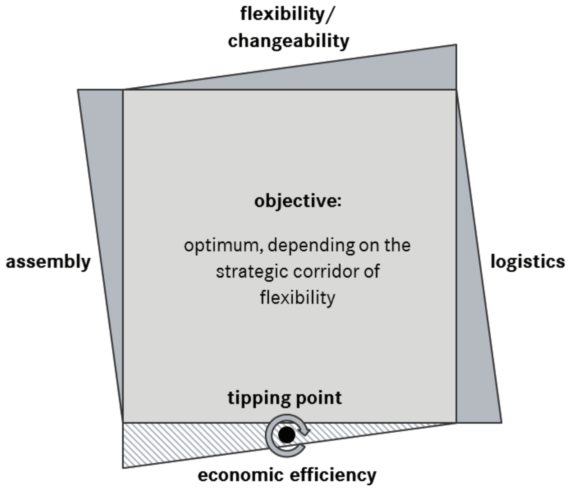

Fig. 2. Strategic Decision Square

This Strategic Decision Square explains the interdependencies and can be used on the production network level just as on the process level. Conceptual and technical alternatives can be integrated and analyzed within this SDS. Some examples on conventional process level can be seen in fig. 3.

Example 1: A fix conveyance can be installed with less investment than a flexible conveyance but it is more flexible to changes with regard to new/further vehicle derivatives, which involve different assembly heights.

Example 2: The logistics within basket is much more flexible than the logistics areas at the line. This is an advantage for the assembly, but not for the logistics, because the logistics costs rise, caused by a further material handling steps.

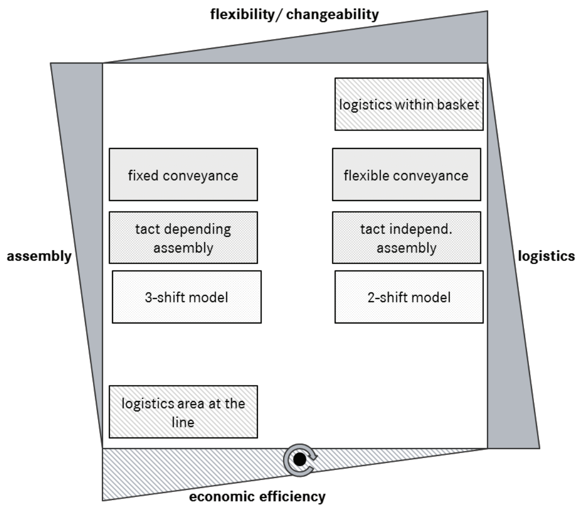

Fig. 3. Strategic Decision Square (examples)

There are usually interdependencies between the intra logistic vs. the assembly and the flexibility vs. the economic efficiency. But in a dynamic surrounding, which involves the need for a company to adapt to new situations, a higher economic efficiency and a higher flexibility can be realized in the so called tipping point.

4.2. Tipping Point

Hernández constituted, that a higher changeability leads to higher investment. These further investments can be redeemed earlier, if the system is able to react more cost efficient to changes [7]. Transferred to the SDS, it only makes sense to invest into flexibility, if the flexibility is really needed. The cost efficiency for a specific timeline and a calculable feasibility of the flexibility necessity influence this decision.

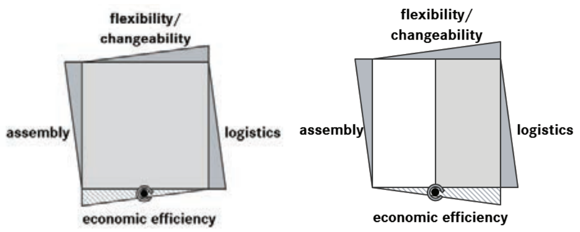

Fig. 4. SDS without Tipping Point (a) and with Tipping Point (b)

This also affects the SDS. If there is a tipping point, all alternatives on the right side are potentially possible. If there is no tipping point, the whole area is relevant.

5. Combination of scenarios and activity-based costing to make decisions in the SDS on all levels

All costs, which are independent of the amount of produced units, are called fix costs. These costs also include one-time investments, so the cost for automation is also considered. Increasing quantities result in a lower fixed cost percentage per unit and the other way around. A maximum flexibility is reached, if the cost per unit stays constant, even if the amount, vehicle derivatives and the model mix changes. There are three steps in order to make a decision:

Flexibility enablers

The interdependence between the costs of intra logistics and the assembly was already described in chapter 3. If the material is variable, the costs depend on the amount of units. The material also affects the whole costs. Today, engineers focus on minimizing the time to assemble a car, the engineered hours per vehicle. Clipping usually needs less time than screwing, that's why more and more clips are used. Nevertheless screwing can be cheaper if the clips cost more in purchasing than the additional cost for the screwing process. Also if specific assembly solutions need a specific logistics handling, it could be cheaper to decide for a not optimal assembly method. This example shows why the unit costs should be calculated for all alternatives on basis of the material, logistics and assembly costs. If material costs are constant and there is no choice for different components, than the material costs can be ignored.

Flexibility necessity

For the different alternatives the unit costs are calculated for different scenarios. These time dynamic changes are the needs for flexibility: vehicle derivatives, model mix and volume changes.

There are new cost types for making the needs for flexibility calculable:

- vehicle derivative changes: cost/change
- model mix changes: technical utilization ratio
- volume changes: wage addition

Two further important points are the qualification of the employees and the quality. It has to be ensured, that the qualification is sufficient. Especially to make sure, that the product has the required quality. Here the quality is not taken into account, because this is the prerequisite for choosing alternatives. In addition, a low quality leads to rework, which causes further costs.

Strategic decision

The target is not to find an ideal solution that does not exist. The decision depends on the accelerated strategic flexibility.

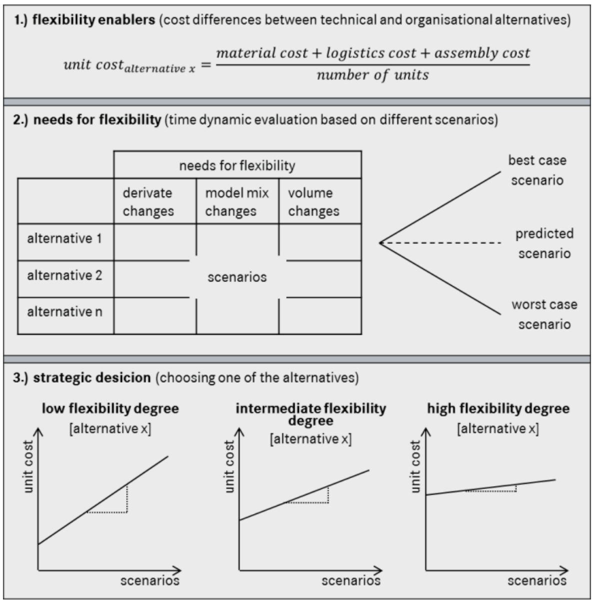

Fig. 5. Scenarios and activity-based costing

With this approach it is possible to determine the tipping point depending on different scenarios (volume, model-mix and vehicle derivative changes) and strategic decisions can be supported.

6. A planning method including product and process modularization

In the previous paragraph the interdependencies between flexibility vs. economic efficiency and assembly vs. logistics processes were shown. These ones build a square, the SDS, which can help to choose the most suitable alternative, because a decision for something means a decision against another option.

The basic to assemble a vehicle is the part list, the product structure and the assembly priority plan. This plan shows the relations between the predecessor and following assembly processes [8].

Each part of a vehicle can be linked to the process, in which the part is assembled. A part, independent if it is from a supplier or assembled in a preassembly, has to be delivered to the assembly station. This is the responsibility of the logistics.

In an assembly priority plan, the degrees of freedom of assembly sequence are obvious. Beside the processes, which have to be directly before or after another one, there are assembly steps, which have the degree of freedom to be assembled before and after multiple assembly steps [9]. As long as the vehicle derivatives are assembled on a line by balancing the effect of different assembly times by planning an exact variant mix, the assembly process has not the flexibility and ability to independently regulate the model mix. Further problems are the restricted degrees of freedom, when a new model is implemented. That's the reason, why the final assembly processes should be balanced over all derivatives within standardization of the assembly steps and identifying the degrees of freedom. Several product and process levels exist, from the car to the single assembly station. To plan the processes methodically, it should start at a level with a comparable technical standard eminence graph.

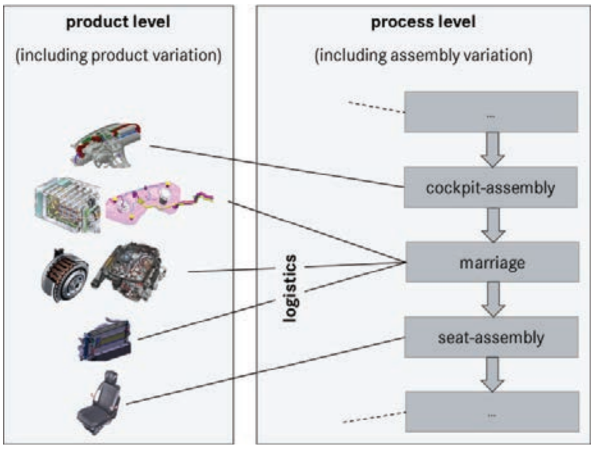

Fig. 6. Dependence of the product and process (logistics and assembly) structure

A structure matrix can be used to constitute a predecessor and successor process in a matrix [10].

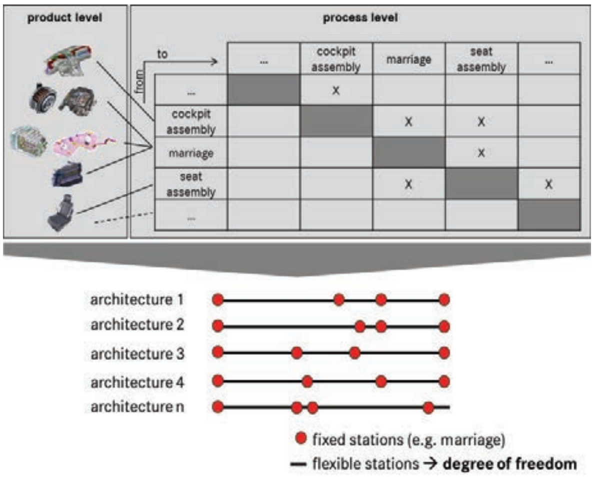

Fig. 7. Degrees of freedom inside the assembly priority plan

Modularization is a further possibility to reduce the problem of different assembly times. Furthermore it is economic, because the modules are used in more than one vehicle derivative [11]. In this context, there can be variant modules, which exist of multiple components. But they must have a comparable assembly time, geometry and interface, so that they don't affect the assembly process. An example therefore is the cockpit. As long as the assembly process and time is the same, it doesn´t matter if the cockpits have different surfaces and technical configuration. It only affects the logistics, which has to make sure, that the vehicle specific cockpit is at the right time at the right assembly station.

The target is to plan flexible and changeable assembly and logistics processes. Therefore the product and the process level have to be considered. The process level is composed of the assembly and logistics processes and the interdependencies can be explained with the Strategic Decision Square. The product level is linked to the process level. The degrees of freedom concerning the assembly sequence is dependent on the assembly priority plans of current and future vehicle derivatives, which have to be realized on the same line.

Within this planning method, an economic sensible flexibility inside intra logistics and assembly processes is planned top down. Afterwards the changeability is planned bottom up.

In the beginning, it has to be made sure, that all planned derivatives can be assembled on one line. This is done from the top to the bottom, starting at the vehicle level gradual breaking down to the station level. Different assembly times should be harmonized and ideally it should be ensured that comparable assembly processes are conducted at the same assembly station. Alternatives, regarding the assembly and logistics processes, are evaluated within the SDS. Then it is ensured, that the planned and known future vehicle derivatives can be assembled on one line. Afterwards it has to be checked, if the processes also can react to unknown requirements by including changeability. This is planned bottom up. Maybe there are further stations needed or fix installed constructions should be made moveable.

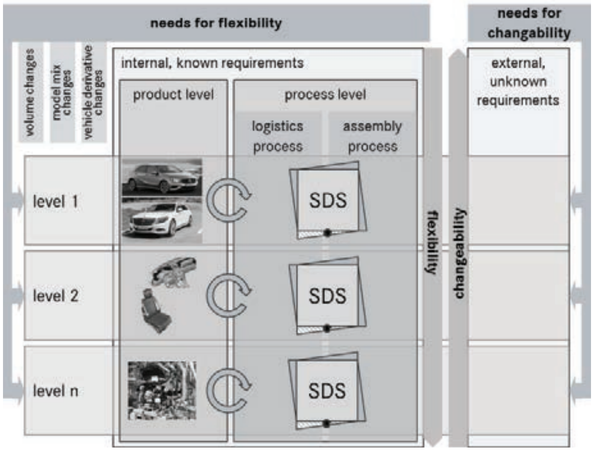

Fig. 8. Generic method for planning flexible logistics and assembly processes

The result is an assembly and logistics system, which can react to known and handle unknown requirements by focusing on the product and process level.

7. Conclusions and outlook

This paper introduces a Strategic Decision Square (SDS), which supports the decision-making process while the strategic planning of logistics and assembly processes. Different time-dynamic scenarios, which consider model-mix, volume and vehicle derivative changes, affect the unit-costs, depending on the investment level and the costs to react to the changes. Thus different possible alternatives can be evaluated by analyzing how the cost structure reacts to changes.

This is part of the planning method, which also includes the dependence between the product and the process levels taking the high variant final-product into account.

The next step is to analyze different standard eminence graphs to identify differences and overlaps between the vehicle derivatives and variants. The target is to show the degrees of freedom and using them systematically during planning assembly and logistics processes in regard to changes in the vehicle derivatives, model-mix and volume.

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