# Technologies and Systems for
# Assembly Quality, Productivity and Customization

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# Cost impact assessment of production program changes: a value stream oriented approach

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**bstract:** High capital production assets require an adequate workload to benefit from economies of scale. This and an ever increasing umber of product variants often lead to enlarged batch sizes resulting in heightened work in process due to safety stocks and dditional changeover. In times of economic volatility, changing production programs cause fluctuations in capacity demand along the lue stream. Fixed costs have to be distributed over an ever changing amount of products – batch sizes and production costs are ermanently altered. To assure the success of investment decisions, various assessment methods for new machines and their capacity ch as the calculation of Net Present Value or Internal Rate of Return exist. These methods imply a predicted production program and sociated costs. In contrast, follow-up costs along the value stream are often untended in the calculation of future scenarios and anned measures. Possible impacts of a change of the production program (volume and variants) are mostly unknown.

The aim of the developed calculation model is the estimation of the flexibility of costs (elasticity) depending on these various cost rivers (units, variants and batch sizes). It supports the forecast of possible impacts regarding uncertain future developments and scloses that section of the value stream responsible for cost related effects and where necessary measures for improvement should e located.

**ywords:** Production Costs, Flexibility, Product Variants

## Introduction

The capability of a production system, to produce different oduct variants and different volume at an acceptable speed and st, results in production flexibility [1]. However, an increasing oduct variety causes an increasing changeover effort on isting production equipment. To assure an adequate machine orkload, higher lot sizes have to be formed. This, again, is ntrary to the principles of Lean Production, which demand low ork in process (WIP) for a short throughput time and hence quire small batch sizes [2,3].

*ll we are trying to do is shorten the time line..."*
*iichi Ohno, Toyota Production Chief after WWII*
*he easiest of all wastes and the hardest to correct is the waste time"*
*nry Ford, Founder of Ford Motor Company*

As another apparent issue, a change of production program investments in the existing bottleneck can lead to a shift of the ttleneck in the value stream [4], which possibly changes the uctures and efforts in support and logistics. Moreover, if not nned properly, investing into production equipment metimes triggers a spiral that can be described as follows: her assets need a higher workload – batch sizes are raised, throughput time worsens while simultaneously does flexibility of the production to accommodate to different product variants [5]. A shift of the bottleneck changes the behavior of current inventory and WIP within the value stream, as well as the corresponding allocation of thereby occurred costs and the level of costs.

Due to the complexity of the relationship between a changing number of product variants, its impact on the value stream and resulting costs, the estimation of these impacts and cost changes is difficult. Existing approaches to assess flexible production systems often focus on technical scope of producing different product variants at increasing quantity [6, 7, 8]. They evaluate production systems regarding an existing or predicted production program [8] or use predetermined cost factors without including their origination or shift due to changing production structures. [10, 11, 12].

However, the consideration of the whole value stream is essential to model altering conditions and bottleneck situations and hence facilitate the balancing of capacities. On this account, a proceeding that describes this correlation, considers all costs along the value stream and plots them against an altered production program (product variants and volume) is needed.

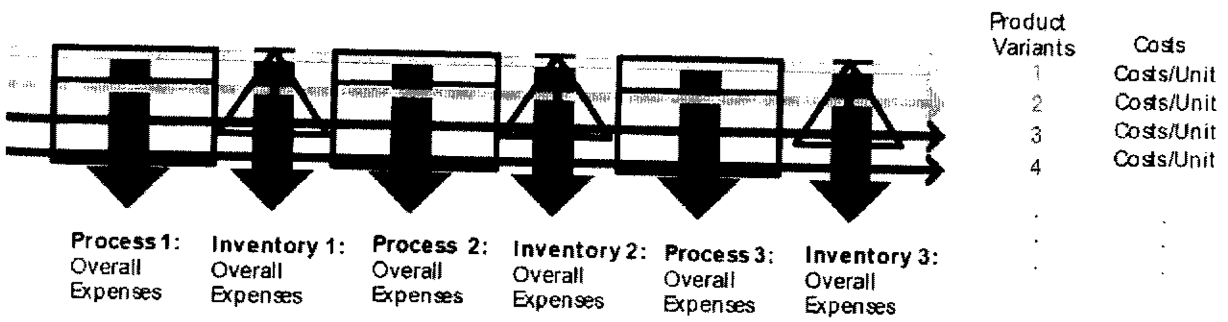


**Figure 1** Approach to the method: costs per unit along the value stream

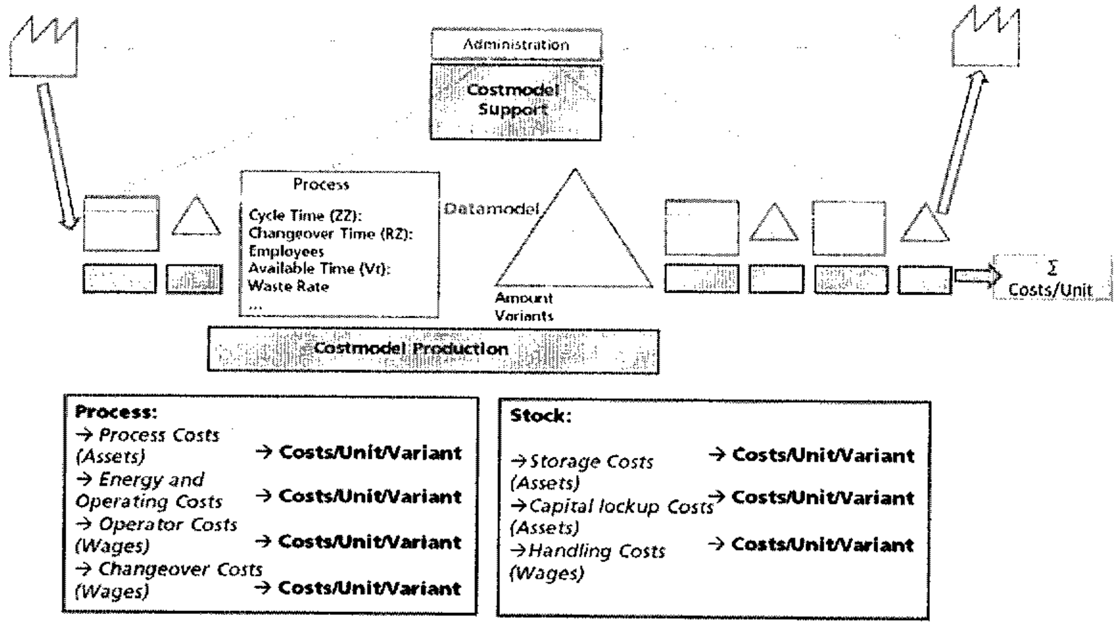


**Figure 2** Cost types along the value stream

This paper describes the principles of an approach enabling the user to specify the developing of costs of each variant in the considered value stream, to reveal cost changes after a change of the production program and to localize sources of possible cost hikes along the value stream. To afford such an analysis of all relevant impacts, costs along the value stream are assigned according to their dependency on produced units, different variants and the connected batch sizes. The value stream thereby is divided in production processes and inventories (Figure 1). Moreover, support processes depending on the production can be included [5].

Compared to Activity Based Costing, which is a continuous calculation scheme, the presented method is used to forecast future costs with respect to possible scenarios in the production program. Thereby, potential over- and under loads of processes and employees are included in the cost calculation to foresee future additional costs or prevent shortfalls respectively [13].

## 2. Cost types along the value stream

Costs and expenses dependant on product variants are sited in the production area and its support activities. Expenses in production consist of wages, material and stock (current assets) and capital assets. The factor input needed for manufacturing is primarily dependent on the volume of manufactured product, the number of product variants, the resulting days of inventory and batch sizes (and connected number of batches).The relevant cost types along the value stream are depicted in Figure 2.

The cost units of the corresponding support processes are primarily composed of wages and salaries. The level of these expenses depends on several cost drivers, i.e. number of customer orders or timed transaction cycles.

According to the method of Activity Based Costing, all activities of these cost units can be divided in activity quantity induced (aqi) costs and activity quantity neutral (aqn) costs and will be related to the corresponding cost drivers [13]. Those cost drivers who are activated by the production process are once more the volume of produced goods, the amount of product variants and the amount of lots produced.

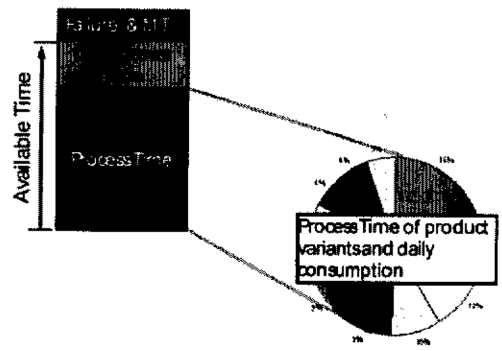


**Figure 3** Constituent parts of the EPEI [14]

## 3. Connection of production units and product variants by the EPEI (Every Part Every Interval)

The basic concept of the described approach is the connection of production processes and inventories along the value stream and the calculation of variant-dependent costs with the help of the EPEI. If a value stream produces more than one product variant with the same production processes, usually changeover processes are needed. These changeover efforts must also be accomplished during the tact time, which represents the average costumer's request frequency.

In a best case scenario, process and changeover time for one specific part or good fit into the tact time and a one-piece-flow production is possible. Since changeover times in several industries are time consuming, this presumption is not always realistic. To meet the tact time anyway, production batches are formed to reduce the number of changeovers needed. Forming batches delays the production of other product variants, since the whole batch has to pass a process before another product variant can be started [2].

Hence not all variants may be produced in one day. This relationship can be described by the indicator EPEI. It specifies how long it takes to produce all product variants in their corresponding batch sizes. It considers the daily consumption, which has to be met, but also the necessary changeover times incurred for the several product variants. The EPEI is defined as [2, 14]:

$$EPEI_{Process} = \frac{\sum_{i=1}^{n} CO_i}{A_t - \sum_{i=1}^{n} PT_i * DC_i}$$

**Equation 1** Every Part Every Interval

*with*

$i = 1...n$ Amount of product variants

$CO_i$ changeover time of variant i

$PT_i$ process time of variant i

$DC_i$ daily consumption of variant i

$A_t$ tecnical availability (plan capacity)

$A_t - \sum_{i=1}^{n} PT_i * DC_i$ = remaining time for changeover

EPEI describes the relationship of necessary changeover time for all product variants with respect to available working hours for changeover efforts. This in turn is described by the available working hours for production per day minus the sum of process time needed to satisfy the daily consumption (Figure 3).

The EPEI depicts, that all product variants can be produced within a specific time period. This period demands the formation of batches, which secure the stocking up to meet the costumer's demand of every product variant. The level of the batch sizes relates to the necessary days of inventory and arises directly from the EPEI. The higher the EPEI the longer inventory must last to meet daily consumption of each variant. If the amount of product variants and with it the necessary changeover effort increases, the EPEI rises and so does inventory. If production volume increases, available time for changeovers decreases, batch sizes have to be raised and inventory increases again.

This ratio calculates the period a process needs to produce all variants and equals the days of inventory which have to be produced to always meet daily consumption of all variants. It can be bounded above by limited storage areas available after a process and bounded below for example by determined supply cycles or the dependency on means of transportation.

## 4. Conjunction along the value stream

The conjunction of the separate cost types along the whole value stream results from batch sizes and tied-up capital. The amounts contained in inventory arise from the batch sizes of previous and subsequent processes. It includes the value of the material of the product as well as value created in previous processes. Moreover, the additional purchased parts must be considered by their replacement price and their value must be accumulated over the following inventories to calculate their tied-up capital (Figure 4).

Every batch causes efforts in logistics for current inventory and warehousing as well as in corresponding support areas [13]. However, such effort may not be accumulated since no value was added. The number of batches plays an important role in calculating overall efforts within the value stream. The number of batches arises directly from produced batch sizes and the yearly requirement.

Bottlenecks govern batch sizes within the value stream based on its limited capacities, determining the smallest possible batch of each variant that enables meeting daily consumption. The same batch sizes should be assumed for all previous processes. If a previous process produced smaller batch sizes, this would increase changeover efforts without decreasing inventory space, since the following process still needs a higher batch size. It ist only the waiting time that may be decreased, at the expense of the synchronisity of production. If a previous process produced larger batch sizes than the bottleneck, this would increase the inventory without generating additional capacity. If different batch sizes can't be avoided, they should at least be a multiple of each other to ease production planning and control.

After the bottleneck, batch sizes can be smaller, because this raises flexibility towards the customer as production is able to switch faster to other product variants. Higher batch sizes after the bottleneck do not lead to a useful generation of capacity (because there is no higher throughput at the bottleneck) and overall decelerate the process towards the costumer (Figure 4).

## 5. Approach

To calculate the described cost types and their conjunction, first the initial state must be identified.Therefore, process data

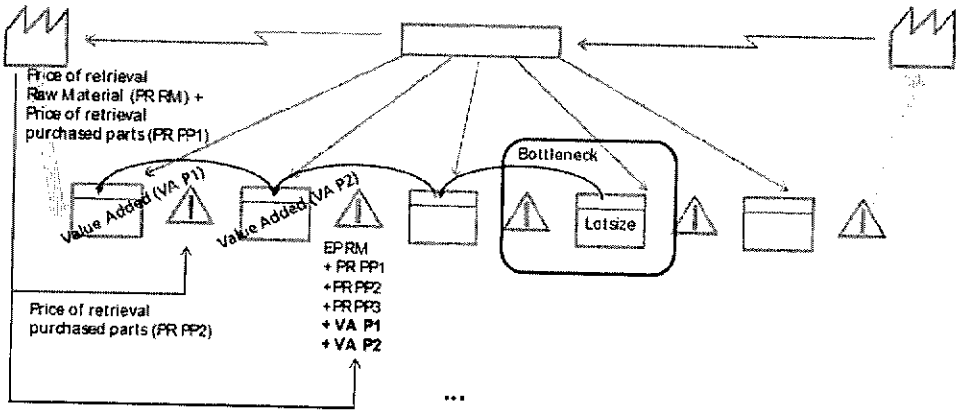


**Figure 4** Conjunction along the value stream

defined by the value stream analysis has to be mapped for all existing product variants. The result is a production program with process and changeover times, corresponding shift models and the required tact time determined by the costumer.

Further, all assets, wages, material costs and other expenses have to be compiled and assigned according to their dependency on produced units and different product variants. For the calculation of inventories in the value stream this means data generation of purchased parts and material regarding prices of retrieval, floor space required, container sizes, etc. as well as logistics efforts in time per batch.

The necessary data for production processes are divided in machine data and operator data and describe the process and changeover times for both. To cover the support areas, all activities in the relevant cost units as well as their cost drivers must be identified. General information has to contain the mentioned shift models, assets and direct costs. If the aim is a break-even-analysis, a revenue function must be dedicated.

With the help of this data basis the described cost types can be calculated and disposed to the different variants according to their different process and changeover times. If the capacity of one machine or operator is not utilized completely, all expenses have to be distributed to all goods produced by a utilization factor [13].

$$f_{CU,j} = \frac{A_{t,j}}{CN_{PT,j} + CN_{CO,j}}$$

**Equation 2** Utilization factor

*with*

$j = 1 \ldots m$ process j

$f_{CU,j}$ factor of capacity utilization

$A_{t,j}$ capacity available

$CN_{PT,j}$ capacity needed for process time

$CN_{CO,j}$ capacity needed for changeover time

Finally the units produced and the number of variants (the production program) can be levered and an estimation of costs in a scenario of production program changes can help the user value existing or future production structures.

## 6. Summary and Conclusion

With the presented approach, scenarios for production program changes in existing or future production structures regarding their impacts on the level and the allocation of the costs along the value stream can be depicted.

If it is possible to picture interrelationships between product variants, production volume (units produced) and costs in 3 dimensions, the related revenues and critical production programs can be identified. If probabilities and corresponding cash flows are deposited, the results can be used for investment appraisals or discounted cash flow methods. Finally, this approach will allow an in depth comparison of different production structures.

The proposed approach will be the basis of a calculation tool that is developed. Currently the system specifications and the conceptual design of the calculation tool are in progress. For an extensive testing phase and in order to secure the viability of the approach an experimental setup of the solution is envisaged.

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