

Technologies and Systems for Assembly Quality, Productivity and Customization

Proceedings of the 4th CIRP Conference on
Assembly Technologies and Systems

Editor: Professor S. Jack Hu

May 20- 22, 2012, Ann Arbor, Michigan, USA

M UNIVERSITY OF MICHIGAN

Table of Contents

Invited Keynote

What is Assembly?.....	1
D. E. Whitney	

Assembly Processes and Technologies

PR1: Single-sided piercing riveting for adhesive bonding in vehicle body assembly	3
Y. Liu, L. Zhang, W. Liu, P. C. Wang	
PR2: Ultrasonic-assisted adhesive handling of limp and air-permeable textile semi-finished products in composites manufacturing	7
J. Fleischer, A. Ochs, S.F. Koch	
PR3: Process technology and device for joining of metal with non-metal components for composite-metal structures	11
R. Neugebauer, M. Putz, M. Pfeifer, E. Jäger, R. Marx	
PR4: Spatial alignment of joining partners without fixtures, based on component-inherent markings.....	17
J. Fleischer, J. Elser	
PR5: Gripper design for tolerance compensating assembly systems	21
F. Dietrich, J. Maaß, K. Kaiser, A. Raatz	
PR6: A cladistics approach to classification of joining and fastening methods.....	25
A. Ziout, A. Azab	
PR7: Cell stacking process of high-energy lithium-ion cells	33
J. Kurfer, M. Westermeier, G. Reinhart	
PR8: Interpretation of multi-axial gripper force sensors	39
K. Tracht, S. Hogueve, S. Bosse	
PR9: Calibration of reconfigurable assembly cell using force feedback and vision.....	43
S. Dransfeld	
PR10: Picking precision in assembly using robots and flexible feeders.....	47
S. Dransfeld, L. E. Wetterwald	
PR11: Influence of welding sequences on compliant assembly geometric variations in closure assemblies	5
A.F. Nagy-Sochacki, M.C. Doolan, B.F. Rolfe, M.J. Cardew-Hall	
PR12: Estimation of the Weldability of Wingle-Sided Resistance Spot Welding.....	5
D. Kim, Y. Cho, Y. H. Jang	

Reconfigurable Assembly Systems

- R1:** MS design methodology for automotive faming systems BIW 59
A. Al-Zaher, Z. J. Pasek, W. ElMaraghy
- R2:** Assessing the structural complexity of manufacturing systems layout..... 65
V. Espinoza, H. ElMaraghy, T. AlGeddawy, S.N. Samy
- R3:** Optimising the process chain and achieving flexibility in rear axle alignment – an integrated view
of chassis assembly 71
R. Müller, J. Eilers, C. Janßen, A. Herrmann, I. Müller-Gräff, G. Heiduczek, P. Durant

IDEAS

- IDEAS1:** Configuration model for evolvable assembly systems 75
P. Ferreira, N. Lohse
- IDEAS2:** Evolvable Assembly Systems: entering the second generation..... 81
M. Onori, J. Barata, F. Durand, J. Hoos
- IDEAS3:** Operational characterization of evolvable production systems 85
H. Akillioglu, A. Maffei, P. Neves, J. Ferreira
- IDEAS4:** IADE – IDEAS agent development environment: lessons learned and research directions 91
L. Ribeiro, R. Rosa, A. Cavalcante, J. Barata
- IDEAS5:** Distributed bayesian diagnosis for modular assembly systems – a case study 95
M. S. Sayed, N. Lohse

Assembly Quality

- Q1:** Geometry assurance versus assembly ergonomics - comparative interview studies in five
manufacturing companies 101
M. Rosenqvist, A. Falck, R. Söderberg
- Q2:** Compensation of shape deviations for the automated assembly of space frame structures..... 105
J. Fleischer, M. Otter
- Q3:** The impact of clamping and welding sequence on the dimensional outcome of a single-station
compliant assembly: a production case study 109
T.I. Matuszyk, M.J. Cardew-Hall, P. Compston, B.F. Rolfe
- Q4:** Non-nominal path planning for increased robustness of robotized assembling..... 113
D. Spensieri, J. S. Carlson, R. Söderberg, R. Bohlin, L. Lindkvist
- Q5:** Statistical shape modeling in virtual assembly using PCA-technique 119
B. Lindau, L. Lindkvist, A. Andersson, R. Söderberg

Q6:	A bio-inspired approach for self-correcting compliant assembly systems	125
	L. J. Wells, J. A. Camelio	

Man-Machine Collaboration

M1:	Human operator and robot resource modeling for planning purposes in assembly systems	131
	J. Provost, Å. Fasth, J. Stahre, B. Lennartsson, M. Fabian	
M2:	The influence of assembly design methods on work exposures – an analytical examination	137
	J. Egbers, G. Reinhart, A. Hees, W.P. Neumann	
M3:	Training by augmented reality in industrial environments: a case study	141
	S. Iliano, V. Chimienti, G. Dini	
M4:	Interaction between complexity, quality and cognitive automation	145
	T. Fässberg, Å. Fasth, F. Hellman, A. Davidsson, J. Stahre	
M5:	A hybrid human-robot assistance system for welding operations - methods to ensure process quality and forecast ergonomic conditions	151
	F. Busch, C. Thomas, J. Deuse, B. Kuhlenkoetter	
M6:	Design for collaboration: a development of human-robot collaboration in assembly	155
	J. T. C. Tan, T. Inamura, T. Arai	

Assembly System Planning

PL1:	Adaption of processing times to individual work capacities in synchronized assembly lines.....	161
	G. Reinhart, M. Glonegger, M. Festner, J. Egbers, J. Schilp	
PL2:	Automatic assembly path planning for wiring harness installations.....	165
	T. Hermansson, R. Bohlin, J. S. Carlson, R. Söderberg	
PL3:	Conceptual DFA method for electric vehicle battery systems.....	169
	A. Tornow, A. Raatz	
PL4:	Beyond human tetris: simulation-based optimization of personnel assignment planning in sequenced commercial vehicle assembly	175
	L. März, W. Mayrhofer, W. Sihn	
PL5:	Assembly path planning by distance field based shrinking	179
	S. Björkenstam, J. Segeborn, J. S. Carlson, R. Bohlin	
PL6:	A classification of carrier and content of information	183
	T. Fässberg, Å. Fasth, J. Stahre	
PL7:	Cost impact assessment of production program changes: a value stream oriented approach.....	187
	J. Gottmann, W. Mayrhofer, W. Sihn	

PL8: Discovering design structure matrix for family of products	191
M. Kashkoush, T. AlGeddawy, H. ElMaraghy	
PL9: Enhanced mixed integer linear programming for flexible job shop scheduling	195
V. Roshanaei, H. ElMaraghy, A. Azab	
PL10: Allocation of maintenance resources in mixed model assembly systems	199
W. Guo, J. Jin, S.J. Hu	
PL11: Product architecting for personalization	203
C. Berry, H. Wang, S. J. Hu	
PL12: Automatic creation of virtual manikin motions maximizing comfort in manual assembly processes	209
R. Bohlin, N. Delfs, L. Hanson, D. Högberg, J.S. Carlson	
PL13: An assembly decomposition model for subassembly planning considering imperfect inspection to reduce assembly defect rates	213
J. Ko, E. Nazarian	

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

J. Gottmann^{a,b}, W. Mayrhofer^{a,b}, W. Sihna^{a,b}

^aVienna University of Technology Institute of Management Science, Austria

^bFraunhofer Austria, Austria

Abstract: High capital production assets require an adequate workload to benefit from economies of scale. This and an ever increasing number of product variants often lead to enlarged batch sizes resulting in heightened work in process due to safety stocks and additional changeover. In times of economic volatility, changing production programs cause fluctuations in capacity demand along the value stream. Fixed costs have to be distributed over an ever changing amount of products – batch sizes and production costs are permanently altered. To assure the success of investment decisions, various assessment methods for new machines and their capacity such as the calculation of Net Present Value or Internal Rate of Return exist. These methods imply a predicted production program and associated costs. In contrast, follow-up costs along the value stream are often unintended in the calculation of future scenarios and planned 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 drivers (units, variants and batch sizes). It supports the forecast of possible impacts regarding uncertain future developments and discloses that section of the value stream responsible for cost related effects and where necessary measures for improvement should be located.

Keywords: Production Costs, Flexibility, Product Variants

Introduction

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

"If we are trying to do is shorten the time..."

ichi Ohno, Toyota Production Chief after WWII

"The easiest of all wastes and the hardest to correct is the waste of time"

Henry 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 bottleneck in the value stream [4], which possibly changes the pictures and efforts in support and logistics. Moreover, if not planned properly, investing into production equipment sometimes triggers a spiral that can be described as follows: Other 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.

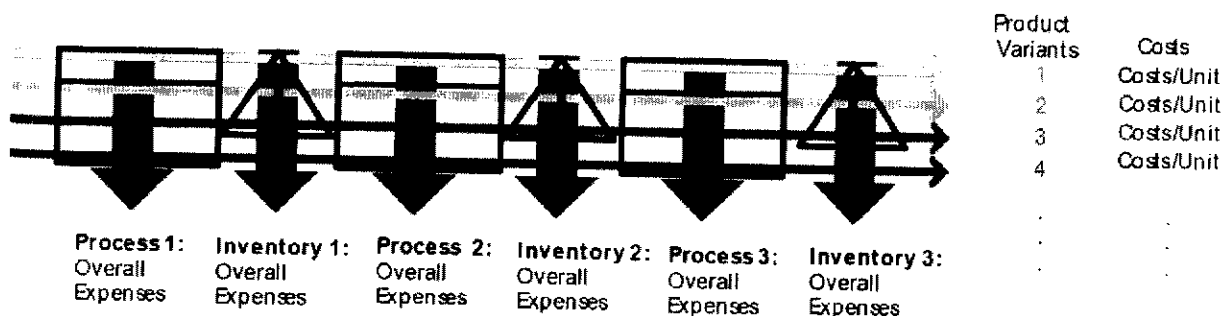


Figure 1 Approach to the method: costs per unit along the value stream

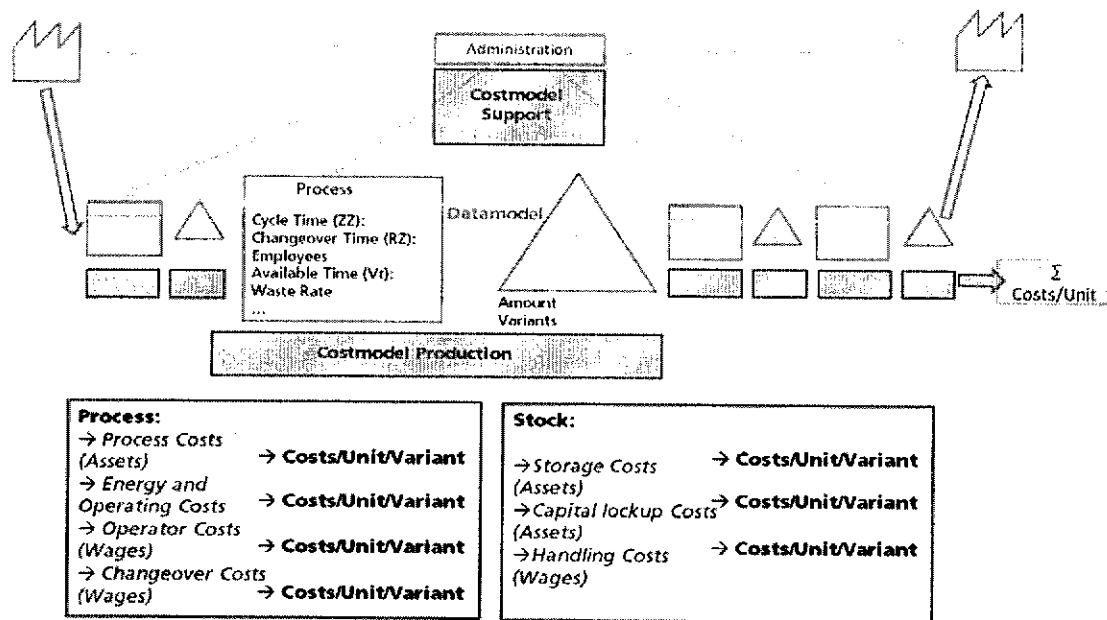


Figure 2 Cost types along the value stream

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.

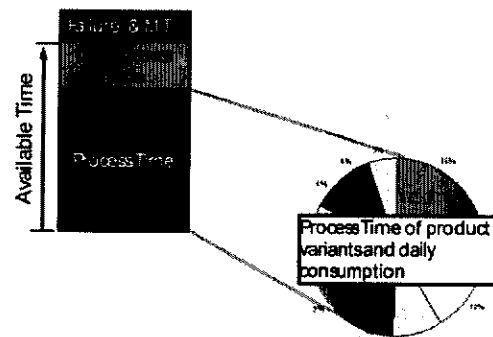


Figure 3 Constituent parts of the EPEI [14]

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 customer'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

$i = 1 \dots n$ 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 technical availability (plan capacity)

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

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 customer'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 is only the waiting time that may be decreased, at the expense of the synchronicity 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 customer (Figure 4).

5. Approach

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

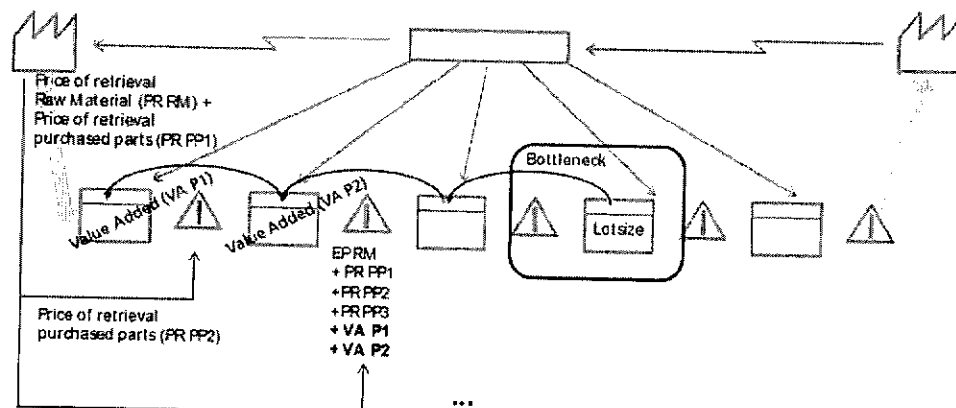


Figure 4 Conjunction along the value stream

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 customer.

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

$j = 1 \dots m$ 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.

References

- [1] Pujawan, N., 2004, Assessing supply chain flexibility: a conceptual framework and case study, *Int. J. Integrated Supply Chain Management*, 1/1:79-97.

- [2] Rother, M., Shook, J., 2000, *Sehen lernen*, LOG_X Verlag GmbH
- [3] Kuhlmann, P., Edtmayr, T., Sihn, W., 2011, Methodical approach to increase productivity and reduce lead time in assembly and production-logistic processes, *Annals of the CIRP*, 4:24-32.
- [4] Sethi, A.K., Sethi, S.P., 1990, Flexibility in Manufacturing: A Survey, *The International Journal of Flexible Manufacturing Systems*, 2:289-328.
- [5] Son, Y.K., Park, C.S., 1987, Economic measure of productivity, quality and flexibility in advanced manufacturing systems, *Journal of Manufacturing Systems*, 6/3:193-207
- [6] Kobylka, A., 2000, Simulationsbasierte Dimensionierung von Produktionssystemen mit definiertem Potential an Leistungsflexibilität, *Wissenschaftliche Schriftenreihe des Institutes für Betriebswissenschaften und Fabrikssysteme*, Heft 24.
- [7] Möller, N., 2007, *Bestimmung der Wirtschaftlichkeit wandlungsfähiger Produktionssysteme*, Herbert Utz Verlag.
- [8] Cisek, R., 2005, *Planung und Bewertung von Rekonfigurationsprozessen in Produktionssystemen*, Herbert Utz Verlag.
- [9] Volkart, R., 1997, *Finanzmanagement. Beiträge zu Theorie und Praxis*, Versus Verlag.
- [10] Lanza, G., Peter, K., Rühl, J., Peters, S., 2010, Assessment of flexible quantities and product variants in production, *Annals of the CIRP*, 3:279-284.
- [11] Schaefer, C., Pfnür, A., 1999, *Investition unter Ungewißheit am Beispiel der Bereitstellungsentscheidung immobilärer Ressourcen*, Arbeitsbereich öffentliche Wirtschaft am Fachbereich Wirtschaftswissenschaften der Universität Hamburg, Nr.25.
- [12] Rogalski, S., 2009, *Entwicklung einer Methodik zur Flexibilitätsbewertung von Produktionssystemen*, universitätsverlag karlsruhe.
- [13] Schunter, J.G., Zirkler, B., 2007, *Vom Standard Costing zum Value Stream Costing*, VDM Verlag Dr. Müller.
- [14] Erlach, K., 2007, *Wertstromdesign*, Springer-Verlag.