OPTIMIZATION OF PRODUCTION RAMP-UP BY USING A SIMULATION FOR PERSONNEL REQUIREMENTS PLANNING

Gisela Lanza[(a)], **Anna Sauer**[(a)]

[(a)] Karlsruhe Institute of Technology, wbk Institute of Production Science, Kaiserstraße 12, 76131 Karlsruhe

[(a)]Anna.Sauer@kit.edu

ABSTRACT

Today there is a strong innovation competition; this is why the number of product models constantly increases and the reduction of product life cycles causes a more frequent occurrence of production ramp-ups. Therefore, it is inevitable that the existing resources, especially human resources should be used efficiently in order to ensure an ideal ramp-up. Hence, the planning of these resources has become an important challenge also in a ramp-up. This paper presents an approach developed at the Institute of Production Science (wbk) of the Karlsruhe Institute of Technology to optimize the forecast of personnel requirements during ramp-up. It describes a method providing support to the calculation of the necessary manpower for every single ramp-up phase in order to realize an economic optimum. Therefore, the paper focuses on the simulation of the ramp-up process within its dynamic planning variables, organizational basic conditions, its verification and results.

Keywords: simulation, ramp-up management, personnel planning

1. INTRODUCTION

Companies have to accelerate the development, production and supply of their products in order to be internationally successful on a competitive basis in the current economic situation. The increasing number of models and versions of products can be ascribed to the enormous pressure of innovation, in order to ensure the companies' market shares in the long run (Schuh, Riedel, Abels and Desoi 2002). This leads to shorter product life cycles, implicating an increasing number of production ramp-ups in a set time interval (Abel, Elzenheimer and Rüstig 2003). Especially resource management plays a decisive role for the earliest possible market entry timing, which can be traced back to the so-called lost sales. These are missed sales, which are caused by a delayed market entry. Due to shorter product life cycles it will hardly be possible to recover lost profits (Kuhn, Wiendahl, Eversheim and Schuh 2002). Due to the fact that the capability of responding quickly is an important issue during ramp-ups, the correct planning of resources is essential. Moreover, the exact personnel requirement planning is an outstanding feature and regarding to the amount of unforeseen situations it is difficult to handle. Therefore, the Institute of Production Science (wbk) of the Karlsruhe Institute of Technology has developed a method to optimize the planning of personnel requirements during a production ramp-up by using a simulation.

2. PRODUCTION RAMP-UP

The production ramp-up can be described as the transfer phase from the stage of product development to a stable series production (Clark and Fujiomoto 1991). The primary ramp-up objective is represented by the achievement of production quantity objectives in due time, the so called "time to market". This primary objective is based on the performance goal and the efficiency goal of the ramp-up. Whereas the performance goal evaluates the achievement of the planned efficiency of the whole plant, the efficiency goal describes the best possible employment of resources or costs concerning the performance goal. Therefore, the reduction of the personnel costs is also important. The performance goal optimization to maximize the overall equipment effectiveness (OEE) includes an improvement of every single parameter, such as availability or quality rate (Nakajima 1988). The OEE is a key performance indicator, which quantifies how effectively a manufacturing plant is utilized. It is defined as the product of availability, performance and quality (Lanza 2005).

3. STATE OF THE ART

To justify the developed simulation's approach some existing models are described in their characteristics: First there are forecast and simulation based methods. *Winkler* (2007) presents a ramp-up project management based on an operational network, which should realize control and mastery of the ramp-up processes (Winkler 2007). *Lanza* (Lanza 2005), *Rottinger* (Rottinger 2005) and *Coordes* (Coordes and Spieckermann 2001) developed simulation based methods considering the quality of the production processes or the personal structure. These methods are not able to implement improvement processes which are very important during production ramp-up. Furthermore, they do not consider any time-variant effects and are only partially suitable for the ability to plan resources especially for highly complex problems. Second there are ramp-up supporting controlling systems. The method developed by *Laick* (2003) is able to guide and design production process systems (Laick 2003), but still does not consider any time-variant effects and machine models as well as processes. Third there are learning curve models to map ramp-up curves, but they have in general the same deficits as the models described so far. As an example of a model in the department of knowledge management to support the ramp-up, the model developed by *Zeugträger* (Zeugträger 1998) may be mentioned based on aspects of the learning organization and on the provision of information. Additionally to the deficits depicted in the other departments the models in this sector are not suitable to map connected systems and interactions. Furthermore, there are models based on the ramp-up supporting in networks. *Weinzierl* for example focused on the support of the decision making process in the flied of strategy ramp-up management (Weinzierl 2006). Nevertheless, these model types have apart from other deficits no control loop character.

The general target of the developed method should be to shorten the ramp-up phase by using a simulation (Verein Deutscher Ingenieure 2000). During the ramp-up phase the simulation can predict the order flow, to plan the work in process, to evaluate troubleshooting measures and to predict resource requirements. In contrast, former ramp-up simulation methods focused more on material flow and were not able to illustrate the personnel aspects adequately (Coordes and Spieckermann 2001). Therefore, it is necessary to develop a new approach meeting all of the following requirements: Regarding the production system it has to deal with different machine models and processes. The method should consider time-variant effects as well as interactions. Moreover, it should include exact improvement procedures. It is also necessary to prove if the method fulfils the character of a control loop. Therefore, it should be able to plan resources, to make some forecasts and to evaluate preventively.

4. DESCRIPTION OF THE METHOD

The developed method to support the personnel requirements planning during a production ramp-up is divided into four phases where the essential step is described by the simulation. First of all every phase will be introduced before the simulation itself will be explained in detail. The method is described by the exhibition of dependencies between resources and target figures during the production ramp-up.

Figure 1 shows the methods' software architecture. The model can be divided into three levels. The lowest level, the data level, includes essential configuration data and functional data. Also the planning results will be saved at this level to make them available at any time. The second level, the logical level, is responsible for the execution of functions and methods during the planning run. It supports partial aspects of the model, for example the model configuration, the opening procedure, the improvement process and the preparation of decision for the optimization of human resources, which are part of the interactive level.

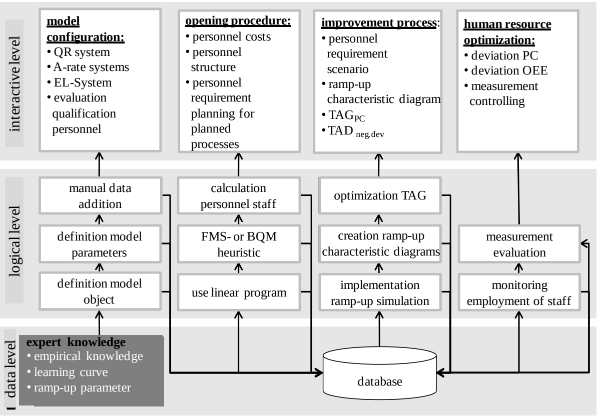

Figure 1: overview software architecture

The interactive level is responsible for the systematic documentation of the model parameters. First it contains the configuration of the planning method, including the OEE-values and the evaluation of existing personal regarding the ramp-up tasks. The second stage of the interactive level, the opening procedure, contains the setup of a linear program, providing an initial solution as a launch setting for the simulation. The complexity of the calculations and the number of variables related to this problem decide whether a linear program can be used or if an initial solution can only be reached with the help of heuristics (Sotskov 1991). Therefore, a heuristic is used to solve problems with a high complexity and a large number of variables. Two alternatives are possible as heuristics, which lead to different initial solutions for the planning of human resources, depending on the special circumstances. There are the FMS-heuristic (heuristic fixed-member set) and the BQM-heuristic (heuristic best qualified member of staff). These heuristics are aiming at the processing of all accumulating operations with a firmly defined number of staff members. Subsequently, the heuristic method's results serve as initial variables for the improvement process, representing the third stage of the model. This process consists of a simulation and a feedback loop, reflecting a target-performance comparison. The improvement process, which is based on the ramp-up simulation, enables the identification, the evaluation and the removal of shortage of staff with the help of ramp-up control loops. The personnel planning scenarios will be measured by the target figures "personnel costs" and "negative deviation of the optimal OEE". During every single phase of the ramp-up, ramp-up characteristic diagrams will visualize them to support the ramp-up manager. An evaluation of the logical level realizes the estimation of the impact of in the database integrated measures and the choice of personnel structures.

Furthermore, time-variant effects that are typical for ramp-ups influence the developed model and they are adapted in the simulation's result. These effects represent the basic conditions for the production ramp-up like learning effects in human resources and thereby change process times. As one central aspect of this model, the human resources' learning curves clearly emerge during the ramp-up phase and therefore represent a significant input variable for the ramp-up simulation.

5. SIMULATION MODEL

There are two simulation techniques predicting ramp-up target-figures, effectiveness or flow simulations and scenario techniques (Nyhuis, Heins, Großhenning, Fleischer, Lanza and Ender 2005). Specified effectiveness or flow simulations are primarily used. In particular the flow simulation is a valid method supporting the planning of complex systems (Kuhn, Reinhart and Wiendahl 1993). It can be used for the planning and also for the ramp-up and series production (Verein Deutscher Ingenieure 2000). In the VDI (German Engineer Association) guideline 3633 the use of flow simulation is described within the relation to the ramp-up and represents a basic principle regarding the standard for the analysis of ramp-up procedures, warm-up periods and transitions among defined operating conditions (Verein Deutscher Ingenieure 2000).

The integrative ramp-up simulation will be implemented by using the simulation software PlantSimulation (version 10.1). It allows a structured and comprehensible transfer of complex production systems to computer models (Tecnomatix 2008).

Below the parameters of the simulation model are described in detail. All relevant objects and influences, given a statement about the influence of certain personnel structures on the ramp-up target figures, are integrated in the simulation model. Along with control factors and planning data, the input data consisting of the technology of the machine, the ramp-up curve, the learning curve and existing resources, are incorporated into the integrative simulation model and therefore constitute its data structure.

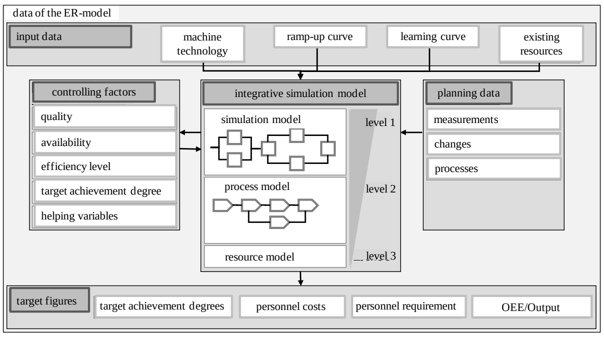

Figure 2: scheme of the ramp-up simulation

The integrative simulation model itself can be divided into three areas. Figure 2 shows the ramp-up simulation's scheme. The first area of the integrative simulation model describes the simulation model, the second one depicts the process model and the third area consists of the resource model. Data about the predicted production system including the technical structures is stored in the simulation model and represents the improvement procedure's real integrative component where the input variables, control factors and planning data are incorporated and transformed into target figures. The ensuing process model implements the considered business processes and their impact on the technical simulation model. The output of the respective business models mostly represents manipulations of OEE-performance parameters. There is a link between the process model and the underlying resource model that allows resources to be transfer.

The flow of the simulation algorithm can be divided into the preparation of the simulation, the initialization and the simulation run. After preparing the simulation, the simulation variables are set to zero, the heuristic planning results are loaded and the input data of the simulation will be made available to the model via an open database connectivity interface. The simulated algorithmic planning run starts as soon as the simulation application is initiated.

In the end, results of the simulation will be used for an evaluation process that is going to simplify the decision making related to the optimal use of resources.

6. VERIFICATION

In order to be able to compare the results and to support a decision, two target figures will be identified, describing the system. On the one hand it involves the average negative deviation from the OEE to the optimal OEE, if the OEE-curve does not achieve the optimal OEE ($OEE_{neg.dev}$) and on the other hand it involves the personnel costs (PC). OEE_{Sim} means the simulated OEE. Two normalized target achievement degrees (TAD) are developed allowing comparison between different ramp-ups and their targets (formular 1 and 2).

$$TAD_{PC} = 1 - \frac{PC_{Sim} - PC_{\min}}{PC_{\max} - PC_{\min}} \quad (1)$$

$$TAD_{\overline{OEE}\ neg.dev} = 1 - \frac{\overline{OEE}_{neg.dev,\,Sim} - \overline{OEE}_{neg.dev,\min}}{\overline{OEE}_{neg.dev,\max} - \overline{OEE}_{neg.dev,\min}} \quad (2)$$

In order to provide evidence of the model's functionality and to optimize the forecast of the personnel requirements during ramp-up, the verification of the personnel requirement planning model is shown by an example in the engine production. This will be done to prove a realistic situation in the planning algorithms.

To verify the functionality of the ramp-up simulation, taking a look at the several ramp-up objects is necessary. Therefore, the quality of the learning curve function, the development of the employees' efficiency, the development of the OEE_{Sim}, the effects of some improvement processes, the correlation of the business process capacity utilization and the resource capacity utilization are especially regarded.

In order to verify the implementation of the learning behaviour and the increase of the efficiency, which is thereby achieved, it is necessary to simulate a human resource with a repetitive task and to register the efficiency level of the resource as well as the operations durations. Formula 3 describes the calculation of the efficiency level of an employee *j* out of the functional area *i*. The formula shows that with an increasing number of operations done for example in the area of fault removal a_{ij} the efficiency E_{ij} of the regarded employee increases up to a certain limit. This limit is determined by the irreducibility factor *M* and the degression factor *b* (De Jong 1957). If the processes are very labour-intensive a value of M=0,25 and a learning rate of 70% may be recommended. According to formula 4, this results in b=0,51. The learning rate is a constant percentage by which the number of factor inputs will be reduced by the doubling of the cumulative outputs (Laarmann 2003).

$$E_{ij} = 100 * \frac{1}{M + \frac{1-M}{a_{ij}^{b}}} \tag{3}$$

$$b = -\log_2 (learning \quad rate) \tag{4}$$

Formula 5 exploits the result of E_{ij} to calculate the expected process time $t(E_{ij})$. In this context t_{100} is the process time with efficiency E_{ij} of 100.

$$t(E_{ij}) = t_{100} * \frac{100\%}{E_{ij}} \tag{5}$$

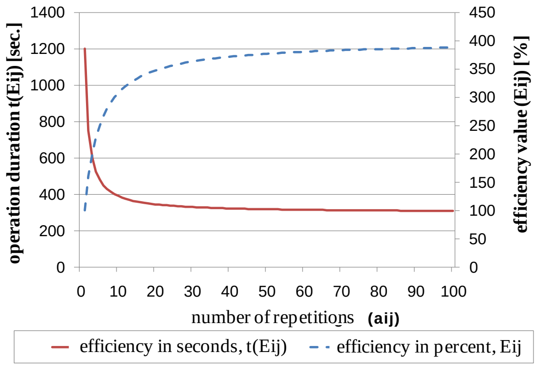

Figure 3: E_{ij} and *t(Eij)* values of the ramp-up simulation

Figure 3 shows the simulated values of the operation duration and the efficiency levels of one employee. The results were calculated with M=0,25 which causes an efficiency limit of 400%. With an increasing number of repetitions (a_{ij}) the limit of the operation duration converges to 300 seconds. This complies 25% of the initial time for the regarded operation. These results correspond to the learning curve theory of De Jong and prove a correct implementation of the method (Rendel de Jong 1956).

An additional functionality of the ramp-up simulation is the implementation of improvement measurements. These measurements change machines or their components in their performance attributes. In order to prove this functionality, a system composed of one machine and a set of measurements (100 single measurements) changing the quality rate is shown. First an improvement measurement with x_{QR}=10% is planned for every five days which increases the quality rate gradually. X_{QR} is the percentage improvement of the quality rate. Since day 55 there is every day a measurement like this planned to recognize the convergence against 99%. Figure 4 shows the values for the quality rate's development of one machine, calculated by the simulation application.

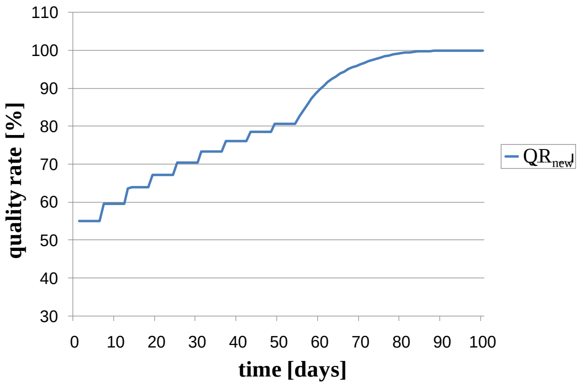

Figure 4: development of the quality rate during a simulation run

In order to verify the failure rate (λ), a failure rate of 30% and an operating time of 100 days are assumed for each machine. It is necessary to split the failure rate in a continuous and a discrete part. The irreducibility factor is fixed with M=0,95. For recognizing the influence of the discrete improvement measurements a measurement which should reach an improvement of x=25% is planned at time t=10 and t=20. Therefore, the failure rate gets reduced to a minimum of ε_{LE}, which represents the maximal level of efficiency and forms the lower bound of the failure rate. Figure 5 proves the effectiveness of the improvement measurements at time t=10 and t=20. Therefore, the functionality of the failure rate's calculation is verified.

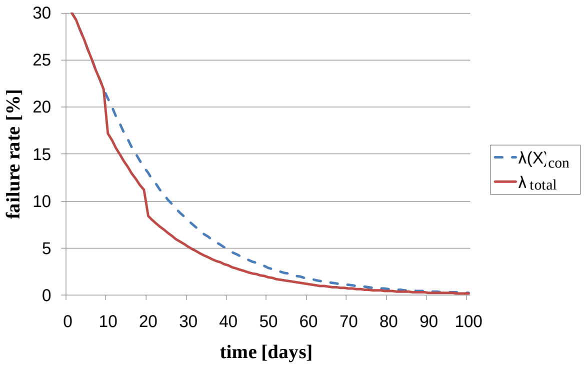

Figure 5: implementation of the failure rate

The average negative deviation of the OEE_{Sim} is used as control parameter of the ramp-up simulation. The OEE_{Sim} of the entire system is defined as the product of the availability of the machines (A_{Sim}), the efficiency level (EL_{Sim}) and the quality rate (QR_{Sim}).

Figure 6 maps the aggregated single values of the $OEE_{Sim}(P)$ of the entire system. The aggregation is calculated with the stepwise aggregated single values in the line level, the machine level and the component level of the ramp-up simulation. Based on this, the algorithm for the personnel requirement can be used and bottleneck analysis can be executed.

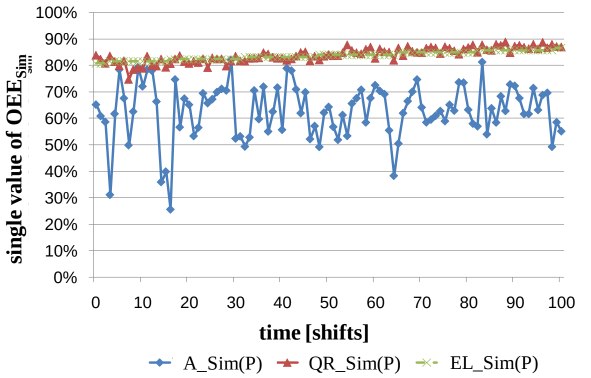

Figure 6: prognosticated A_Sim(P), QR_Sim(P), EL_Sim(P)

7. VALIDATION

The result of the ramp-up simulation consists of various scenarios, emerging from individual simulation experiments. These are based on different control parameters and on the heuristic personnel output configuration.

In order to validate the simulation model and to give an overview, a practical example of the personnel requirement planning is given. The example focuses on maintenance activities of a crankcase line with an aspired OEE of 70%. The actual personnel requirement is depicted during a time period so that the possibility to achieve enhanced results by using the simulation model can be demonstrated. Some improvement processes in the maintenance activities are in progress in period three (Figure 7), therefore it is necessary to plan with a larger number of employees.

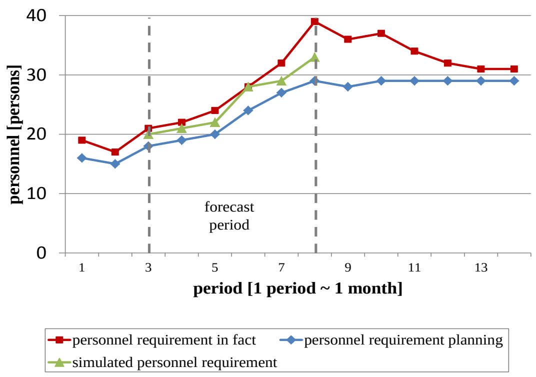

Figure 7: Comparison of the personnel requirements in fact and the simulated personnel requirements

Figure 7 visualizes the results of the personnel requirement planning calculated with conventional methods and calculated by using the simulation model. In addition, the de facto needed staff members are also marked in the same coordinate system. The figure indicates the possibility to achieve enhanced results by using the simulation model, which is presented in this paper. Nevertheless, it should be noted that the simulation model does not produce the personnel requirement as result being needed in fact. The reasons for that are some not provided processes creating the deviation between the actual personnel requirement and the personnel requirement planned by simulation. In this example a $TAD_{\overline{OEE}\ neg.dev}$ of 0.87 is realized.

Actually the personnel requirement calculated by the simulation model is indeed more accurate than the conventional personnel requirement planning.

8. CHARACTERISTIC DIAGRAMS

Concluding, the simulation results disembogue in characteristic diagrams. These diagrams support the ramp-up manager in every ramp-up phase (Figure 8) by visualizing the most important ramp-up goals and the personal requirements. The lower evaluation of the diagram shows the personnel requirement, which is necessary in order to reach the efficiency target. Due to that, the output is simulated depending on the personnel requirement. The upper evaluation of the target achievement degrees gives the planner information on how the personnel requirement affects the target achievement degrees.

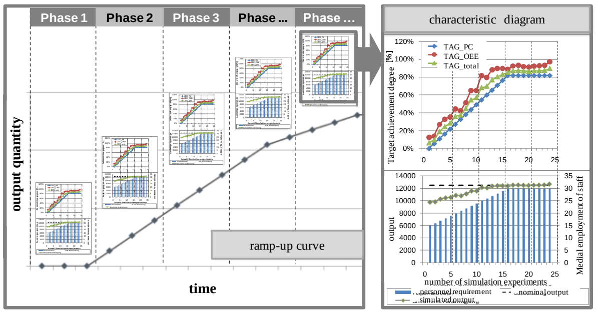

Figure 8: characteristic diagram

9. SUMMARY

The personnel requirement planning during production ramp-up plays a decisive role for the earliest possible market entry timing. Especially during the production ramp-up there is a great need regarding the research of the planning of personnel requirements. With the planning method presented in this paper and implying a simulation as main approach, it is possible to support the ramp-up manager in planning the personnel requirements economically at every stage of the production ramp-up. So it is guaranteed that the personnel requirement planning can always be displayed according to the current situation. Moreover, it can realize the economic optimum in order to reduce the costs of production. The simulation described in this paper is specified. The use of simulation during the implementation phase allows a realization of virtual plant performance tests with a stepwise integration of order types and product versions while gradually increasing the utilization of available capacity. Furthermore, it allows the analysis of problems, their impacts and new requirements during the production ramp-up. In the end characteristic diagrams can visualize the scenarios. This approach's distinguishing element consists of the integration of time-variant factors like learning curves into the simulation model. Therefore, it is possible to get close to an optimal personnel requirement planning at every stage of the production ramp-up.

Altogether, the ramp-up simulation in the form of an improvement procedure is an excellent planning tool for production ramp-ups, especially in terms of personnel resources.

ACKNOWLEDGMENTS

We extend our sincere thanks to the Deutsche Forschungsgemeinschaft (German Research Foundation) for supporting this research project LA 2351/4-1 "Ressourcenplanung im Produktionsanlauf" ("Resource Planning during Production Ramp-Up").

REFERENCES

Abele, E., Elzenheimer, J., Rüstig, A., 2003. Anlaufmanagement in der Serienproduktion. *ZWF Journal, Zeitschrift für wirtschaftlichen Fabrikbetrieb*, 98 Journal 4, pp 172-176.

Bol, G., 2003. *Induktive Statistik*. 3rd edn.. Oldenbourg: Oldenbourg Verlag

Clark, K. B., Fujiomoto, T., 1991. Product Development Performance – Strategy, Organization, and Management in the World *Auto Industry. 1st edn. Harvard Business School Press:*pp97-101.

Coordes, M., Spieckermann, S., 2001. Die Ablaufsimulation der virtuellen Prozesskette am Beispiel des neuen Audi A4. Flexibel und kostengünstig, In: *4. Düsseldorfer Produktionstage*, Tagung; VDI-Ges. Produktionstechnik 1597. Düsseldorf: VDI-Verlag, pp 81-96.

De Jong, R.J., 1957. The Effects of Increasing Skill on Cyle Time and Its Consequences for Time Standards. *The Official Journal of the Ergonomics Society 42 (1957)*, Journal 1: pp 51-60

Kuhn, A., Reinhart, G., Wiendahl, H-P., 1993. *Handbuch Simulationsanwendungen in Produktion und Logistik.* 1st edn. Braunschweig, Wiesbaden, Vieweg

Kuhn, A., Wiendahl, H.P., Eversheim, W., Schuh, G., 2002. *Fast ramp-up, Schneller Produktionsanlauf von Serienprodukten – Ergebnisbericht.* Dortmund: Praxiswissen Verlag.

Laarmann, A., 2003. Lerneffekte in der Produktion. *Deutscher Universitätsverlag*. Bochum

Laick, T., 2003. *Hochlaufmanagement: sicherer Hochlauf durch zielorientierte Gestaltung und Lenkung des Produktionssystems*. Dissertation, Technische Universität Kaiserslautern.

Lanza, G., 2005. *Simulationsbasierte Anlaufunterstützung auf Basis der Qualitätsfähigkeit von Produktionsprozessen.* Dissertation, Universität Karlsruhe TH.

Nakajima, S., 1988. *Introduction to TPM*. 1st edn. Productivity Press, Inc., Cambridge Massachusetts.

Nyhuis P., Heins M., Großhenning P., Fleischer J., Lanza G., Ender T., 2005. Simulationsunterstützte Wirkbeziehungsanalyse im Produktionsanlauf. *ZWF Zeitschrift für wirtschaftlichen Fabrikbetrieb 100 Journal 12*; pp 746-75.

Rottinger, S., 2005. *Mehrphasige Personalentwicklungsplanung für Fertigungssysteme auf Basis des Technologiekalender-Konzeptes*. Dissertation, Universität Karlsruhe (TH).

Schuh, G., Riedel, H., Abels, I., Desoi, J., 2002. Serienanlauf in branchenübergreifenden Netzwerken. Eine komplexe Planungs- und Kontrollaufgabe. *wt Werkstattstechnik online*, 92 Journal 11/12: pp 656-661.

Sotskov, Yuri N., 1991. The complexity of shop-scheduling problems with two or three jobs. *European Journal of Operational Research*, 53; pp 326-336.

Tecnomatix, 2008. *Simulation and Optimization with Plant Simulation.* Available from: http://www.emplant.de [Accessed 03 January 2012].

Verein Deutscher Ingenieure (Hrsg.), 2000. VDI-Richtlinie 3633 page 1, *Simulation von Logistik-, Materialfluß- und Produktionssystemen - Grundlagen, Entwurf*. Beuth, Berlin.

Verein Deutscher Ingenieure (Hrsg.), 2000. VDI-Richtlinie 3633 page 2, *Simulation von Logistik-, Materialfluß- und Produktionssystemen - Grundlagen, Entwurf*. Beuth, Berlin.

Weinzierl, J., 2006. *Produktreifegrad-Management in unternehmensübergreifenden Entwicklungsnetzen – Ein ganzheitlicher Ansatz zur Entscheidungsunterstützung im strategischen Anlaufmanagement*. Dissertation, Universität Dortmund.

Winkler, H., 2007. *Modellierung vernetzter Wirkbeziehungen im Produktionsanlauf*. Dissertation, Leibniz Universität Hannover.

Zeugträger, K., 1998. *Anlaufmanagement für Großanalgen*. Dissertation, Universität Hannover.