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FLEXIBLE WORK ORGANIZATION IN MANUFACTURING – A SIMULATION-SUPPORTED FEASIBILITY STUDY –

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ABSTRACT

This paper looks at the question of what conditions are required to make work organization in manufacturing more flexible. Therefore, we have derived hypotheses for the extent of flexibilization of manufacturing systems. In the foreground are various forms of working times and different skills of staff. The related hypotheses are tested using a personnel-centered simulation procedure as part of a feasibility study. This study is based on representative models of one-of-a-kind production, medium-scale and large-scale series production. The simulation approach makes it possible to quantify the effects of flexible working times and staff assignments in addition to verifying the proposed hypotheses.

1 FORMS OF FLEXIBILIZATION IN MANUFACTURING

The flexibilization of the work organization in manufacturing may include a number of different aspects: They range from job rotation between under-loaded and over-loaded workplaces, the higher qualification and the subsequent employment of multi-skilled staff to demand-oriented flexible working hours. These measures can lead to advantages for the operation department and for the staff, but also to disadvantages. Regarding job rotation and the employment of multi-skilled staff advantages may lie in the timely processing of orders, while on the part of employees occasionally the increase of wages comes into play. The latter can then be seen as a disadvantage on the part of the business, while employees could see increased demands to be disadvantageous.

Regarding the flexibilization of working hours, a discrepancy in interpretation is apparent in the discussion (Boulin, Lallement, Messenger, and Michon 2006; Burgoon, and Raess 2007). From the employer's perspective, the main objective is to use flexible working hours to combat fluctuations on the sales markets while avoiding increased labor costs as a result of increased wages for overtime. However, no deductions are made from wages during temporary periods with reduced workloads. It is therefore possible to talk about a settlement of interests, particularly at manufacturing companies, when long-term phases of increased or reduced work in response to the state of the economy are involved. In the service sector, on the other hand, it is usually a question of covering fluctuations in personnel capacity demand over the course of a day or a week, but also as a result of seasonal fluctuations in demand, that are known from past experience.

These kinds of systems have become well-known as "flexitime". Particularly on short time scales, this can create conflicts with regard to finding a balance between work and private lives. Such conflicts are deleterious to the well-being of employees. Potential consequences include absenteeism or even poor health. The individual employee would ideally prefer a working time model based on his or her personal

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requirements and preferred working hours. Thus, the employees may benefit from a flextime arrangement, with the side-effect that the daily commute becomes more staggered in areas of concentrated economic activity.

2 POSSIBILITIES AND LIMITATIONS OF FLEXIBIZATION IN PRODUCTION AND SERVICE UNITS

The flexibility of work organization was significantly starting in the 1970s (Euler 1993, p. 521), when the term work structuring not only aimed at the fulfillment of given work tasks, but also at the creation of attractive jobs. Job enlargement, job enrichment, job rotation and teamwork were keywords that discussed alternatives to traditional rigid division of labor, which appeared to be too monotonous and only little flexible, especially with regard to assembly lines. With a delay of 15 years and more these approaches have also been realized in large industrial firms, especially in the automotive industry. At present, however, again a decline to a greater division of labor can be observed which is mainly justified by increased training times and personnel costs.

Compared to these developments, the debate about the flexibility of working hours started a lot later. The flexibility of working hours in Germany has above all been impacted by the extension of opening hours in the service sector. This liberalization mainly took place in retail as the result of a law enacted in 2003 (LadSchlG which stands for the German Store Closing Act). As a result, it became clear that employees‘ working hours cannot coincide with extended opening hours, but rather that staggered working hours based on the advent of customers are required that vary in duration for full-time, part-time and minimally employed employees. Some simulation studies have already been conducted to look at the capacity-related structuring of working time models in the service sector (Zülch, Stock, and Bogus 2003; Zülch, Stock, and Hrdina 2008).

It is currently against the background of that demographic change (European Commission, Eurostat 2011, pp. 62) will lead to a decreasing number of the working population, but with a net increase of older workers. As a consequence, this results in a change of employees' requirement regarding their working hours. Upto then, the flexibility of working hours was mainly influenced by the demand of the market. Flexible working hours have already been practiced in some manufacturing companies in the form of flexitime. However, the arrangements in place are mainly limited to administrative functions and those that are upstream of production. Further flexibility measures were agreed to at some companies in the course of the economic crisis in 2009 and 2010. These mainly served to cope with reduced market demands by implementing non-working shifts which would then be offset by extra shifts in the hoped-for recovery since 2011, which did in fact occur in Germany. In contrast to the arrangements in the service and administrative units, however, these were aimed at achieving a long-term balance between capacity demand and the capacity level rather than reacting to short-term fluctuations in demand.

This raises the question of whether flexibility arrangements are possible in production units (i.e. parts manufacturing and assembly) that give the individual employee a greater degree of sovereignty over their working hours. This would boost the appeal of working in those units, and improve the work-life balance of employees. Knauth (2002, p. 53) rightly pointed out that a distinction is to be made between flexible working hours where the timing and duration of daily working hours are primarily determined by the employer and arrangements where the control largely rests with the individual employee. In the first case he uses the term “working hours flexibility”, while he refers to the latter as “working hours sovereignty”.

The extent to which flexible work organization and especially flexible working hours are possible clearly depends to a significant extent on the way the work is divided up within the work system in question. The more self-contained the work performed by each individual employee is, the easier it is to introduce an element of flexibility. Furthermore, an employee can only perform a self-contained work, if he is qualified for this enlarged or enriched work. In this respect, the flexibility of a work system increases with the qualifications of its employees. Also this hypothesis will be investigated here.

In the field of industrial engineering, self-contained work is referred to as a decoupled work system following the principle of job division by quantity. This form of work organization is very common in the service sector, e.g. for cashiers in retail or telephone operators at a call center. In manufacturing, this form of job division is found in connection with single-machine operation and complete assembly workstations. With coupled workstations, on the other hand, all members of the work group must be present for the work to be done. This is referred to as job division by type. Examples include surgery teams in hospitals and employees assembling devices on a conveyor belt (Figure 1).

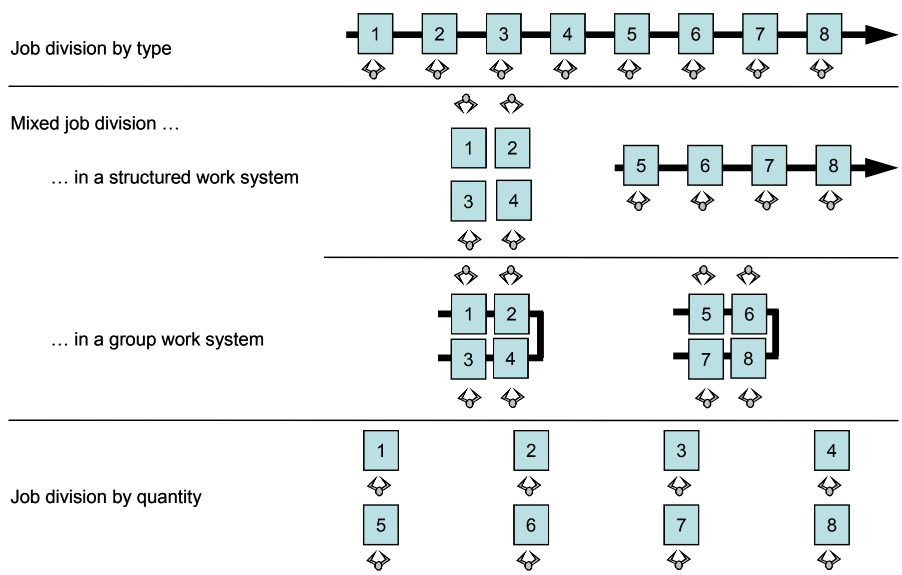


Figure 1: Division of jobs by type and by quantity

Based on this we can put forward the hypothesis that it is easier to introduce flexibility in industrial manufacturing units when the individual workstations are not as closely linked in terms of the organization of the work process. A further hypothesis is that a decoupled work system is more able to compensate for irregular arrivals of orders when more employees can be universally assigned to the individual workstations within the system. Also, the potential for sovereignty with regard to working hours depends on the qualification of employees.

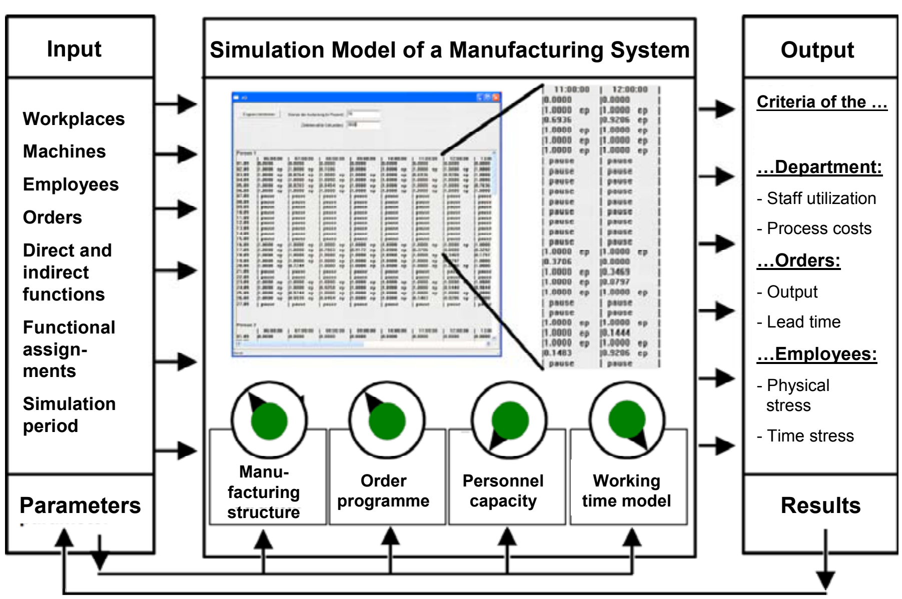


Figure 2: Simulation approach for working time models in parts manufacture and assembly systems

3 DYNAMIC ASSESSMENT OF WORK ORGANIZATION USING SIMULATION

In the following assessment, these hypotheses will be verified based on a feasibility study using simulation. Simulation studies have proved useful as preparation for the introduction of new forms of work organization as they allow for the prospective evaluation of potential arrangements based on a number of parameters, eliminating the need for elaborate pilot projects. However, this requires access to a corresponding personnel-centered simulation tool that can model complex work systems, including the interactions between staff and equipment, and assess them based on production, customer and personnel-related performance indicators (Figure 2).

The *OSim* (*O*bject *Sim*ulator) simulation tool, which was developed by the ifab-Institute of Human and Industrial Engineering of the Karlsruhe Institute of Technology (formerly the University of Karlsruhe, Germany) and first presented at the 2000 Winter Simulation Conference (Zülch, Fischer, and Jonsson 2000; see also Zülch 2006; Zülch, and Stock 2011), was used for the purposes of this feasibility study. *OSim* is an event-driven, time-discrete simulator that uses a predefined order program for the simulated production period and discrete object models for personnel and machine resources. The order program consists of throughput plans in the form of networks that represent templates for individual orders and can be initialized multiple times within the simulated production period. The nodes of a throughput plan represent the work operations required to process an order in the event of its instantiation, while the arcs represent the relationship between them as dictated by the constraints of production technology. At least one personnel or machine resource must be assigned to each work operation. Figure 3 shows a selection of throughput plans for sequential and networked production orders.

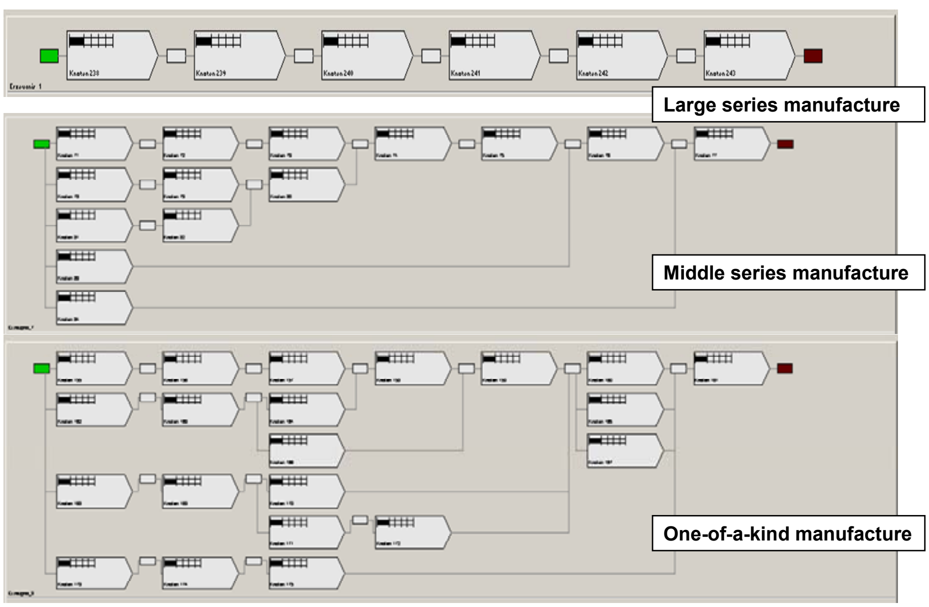


Figure 3: Throughput plans for sequential and networked production orders

Similar work operations can be combined into functions which are then each to be assigned to personnel and/or machine resources. The assignment of functions to machine resources generates a function-equipment matrix whose individual elements are referred to as functional elements, which determine the capacity demand for the simulated production period in connection with the aggregation of all corresponding operations with their standard times. This capacity demand must be covered by a corresponding capacity level of resources, although this can be different for the two types of resource as illustrated by the example of multiple machine operation. Figure 4 shows the overview of the two types of resource in the function-resource matrix.

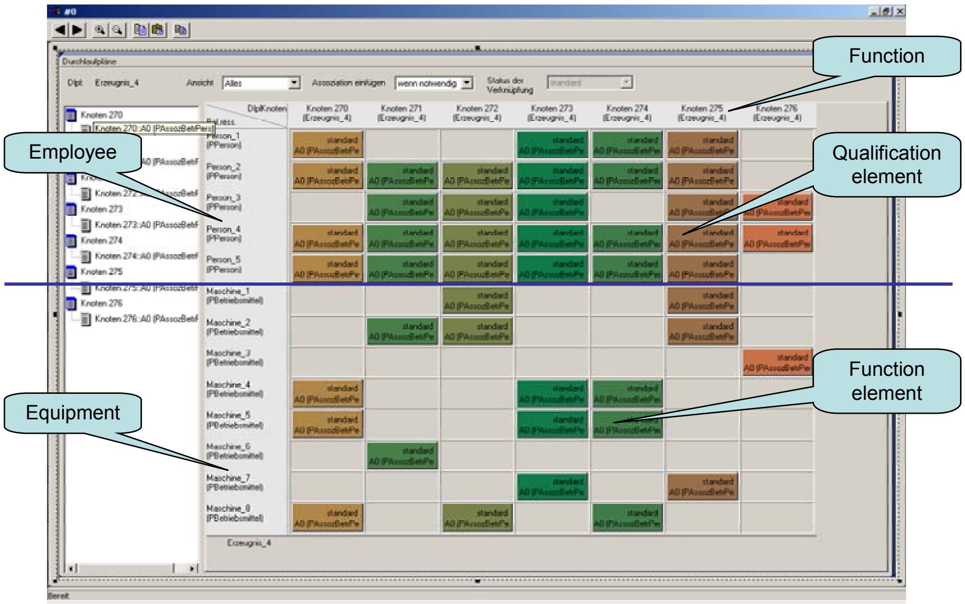


Figure 4: Modeling functions, employees and equipment in a function-resource matrix

The simulation model allows one or more functional elements to be assigned to a person, which are then referred to as that person's qualification elements. This makes it possible to model both specialized and universally assignable employees, as well as various potential forms of cooperation and group work. An employee's qualification therefore consists of one or more qualification elements. The same applies to equipment that can be used to carry out a range of functions, such as drilling and milling using a machining center.

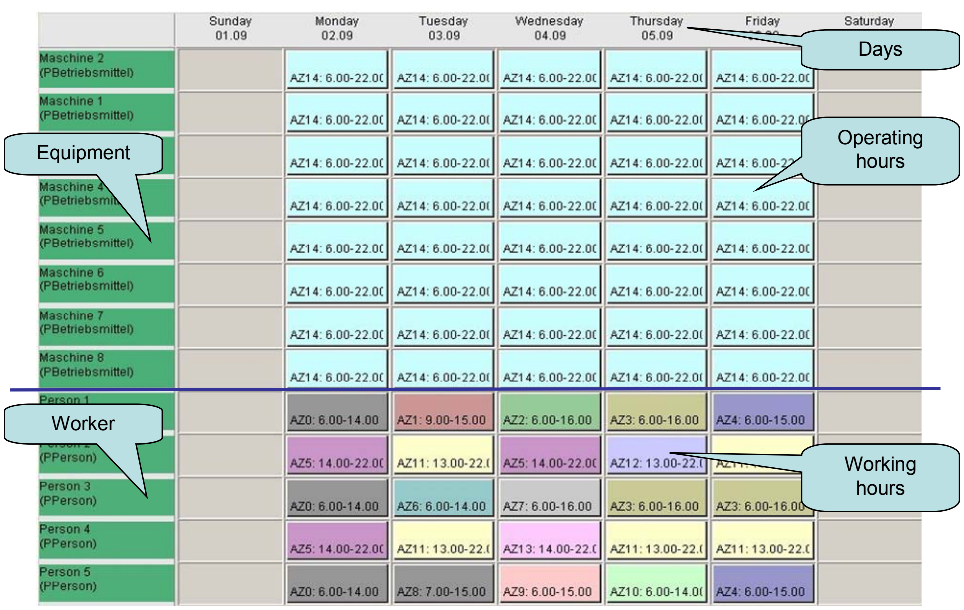


Figure 5: Operating and working hours in a parts manufacture workshop

Employees with the same qualifications are grouped together as a personnel type. The various personnel types can be assigned to different working time models. This makes it possible to cover fluctuations in capacity demand with an adjusted capacity level thanks to overlapping working time models. Figure 5 shows the assignment of equipment to operating hours (a simple two-shift model in this case) and the changing working hours of employees in connection with the capacity-based assignment of personnel.

4 FEASIBILITY STUDY LOOKING AT THE POTENTIAL FOR FLEXIBILIZATION IN MANUFACTURING

The following simulation study looked at whether and to what extent improvements can be made to a standard shift-based model by introducing different qualification levels of the employees and flexible working hours. In order to reduce personnel-related bottlenecks in the manufacturing process capacity-based assignments of personnel were modeled. The *OSim* simulation tool was used to evaluate the various scenarios.

4.1 Manufacturing Systems investigated

The general aim of the feasibility study was to investigate which types of manufacturing and personnel structures are particularly suitable for flexible working hours, depending on a varying order program. In particular, the following variables could be compared with each other:

- Varying order programs combined with or without the adaptation of personnel capacity to fluctuating demands,
- Different personnel structures with a variable number of staff and their capabilities,
- Selected strategies for improving a given working time model, and
- Different initial working time models, which may lead to different best solutions when using a certain planning heuristic.

Table 1: Experimental design of the simulation study for the analysis of flexible working organization in manufacturing

Attribute	Characteristic		
Type of manufacturing:			
Batch size	Large series	Medium-scale series	Single piece
Number of throughput plans	Small: 4	Moderate: 8	Large: 12
Complexity of throughput plans	Low, sequential	Moderate, networked	High, networked
Number of machines	8	9	14
Order intake:			
System workload	80%	100% (initial scenario)	120
Arrival intervals	Regular (evenly distributed) (initial scenario)		Random (irregular)
Personnel structure:			
Number of staff	8	10	8
Qualification	High (universalists)	Moderate	Low (specialists)
Likelihood of bottlenecks	Low	Moderate	High
Operating / working hours:			
Operating hours	16 Hours (2 shifts) 320 Hours in 4 weeks		
Working hours	2 Shifts, 8 hours / day		Flexible, capacity-based working hours

Such a design of experiments would result in a huge number of possible scenarios with regard to their suitability for flexible working hours in manufacturing. Therefore, the feasibility study was restricted to three different, representative manufacturing structures. The manufacturing processes involved differ in terms of the complexity of their throughput plans, as illustrated by Table 1:

- Large series manufacturing of a small number of different products with low complexity,
- Medium-scale series manufacturing of a larger number of identical products with moderate batch sizes,
- One-of-a-kind manufacturing of complex products with small batch sizes.

In the initial scenario, all employees work a two-shift system based on 40 hours per week. When generating flexible working hours, care is taken to ensure that only one shift is possible per day of work, and that the weekly maximum of 40 hours is not exceeded. Overtime is compensated using shorter or non-working shifts, with the result that all working time models produce the same capacity level over the simulation period of four weeks. In addition to the forms of manufacturing already mentioned, a range of different personnel structures were also modeled:

- A specialist structure in which the individual employees are only qualified to perform a limited number of the necessary work operations,
- A moderate personnel structure with some higher qualifications, and
- A universalist structure in which every employee can perform all of the functions.

In this regard we can put forward the hypothesis that more qualified employees will be better able to cope with fluctuations in demand than the less qualified. Furthermore, flexible working hours should make it easier to compensate fluctuations in demand than a rigid shift system. For this reason, scenarios were simulated based on a (statically calculated) utilization of personnel at 100% (i.e. the theoretical capacity level). This was then varied with scenarios, in which the respective manufacturing system was under-loaded at 80% of the normal order program of 100% or over-loaded at 120%, and where the manufacturing orders were distributed evenly with constant intervals, or stochastically.

In general, the range between under-load and over-load resulting from demand fluctuations can be defined rather freely and was chosen here following assumptions in existing literature (Wildemann 1991, p. 52 and pp. 72). The workload of 100% indicates that there is a balance between the timely capacity of staff and the time required for execution of the orders. On the other hand, a workload of 80% and 120% respectively means that only this portion were handled by the same number of staff. While the (static) workload is an input data of a simulated scenario, the (dynamic) utilization of resources is a result of it.

Within the mentioned scenarios, the order program was generated using different arrival patterns of orders. For this purpose, regular order arrivals with uniform inter-arrival times as well as stochastic arrivals were modeled. For irregular arrivals, logarithmic as well as exponential distributions of inter-arrival times were assumed.

4.2 Flexible Personnel Assignment Strategies

The generation of flexible working hours follows the principle of the capacity-based assignment of personnel. To this end, the simulation procedure examines whether any single resource would be dynamically utilized over and above a predefined usage threshold (about 80%). In this case, the respective resource is dynamically considered a bottleneck. The assignment of personnel is then adjusted to remedy the bottleneck, which can happen using the following strategies:

- Extending or reducing the working hours of individual employees,
- Temporally assigning of under-loaded employees to over-loaded workstations,
- Changing the personnel capacity level by adapting working hours, or
- Improving the qualifications of the employees already incorporated in the model.

For changing the personnel capacity level two further strategies can be used in the examined case:

- Reduction of the duration of the second shift in under-load situations, and

- Prolongation of shift durations in over-load situations, which is then compensated by free shifts.

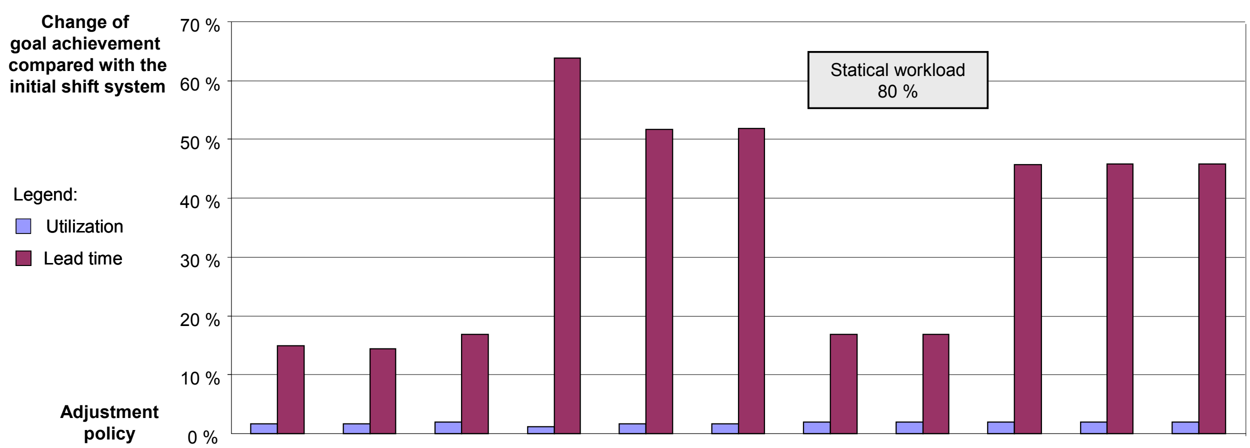
By using a working time account, the heuristic ensures that each employee is assigned to only one shift per day and that the maximum allowable working time of ten hours per day and 40 hours per week is not exceeded during the simulation period. In addition to the individual strategies, combinations of strategies were also modeled. Ten iterations were carried out for each of the resulting scenarios in order to take stochastic effects into account, and the mean of the results was calculated.

5 MODEL VALIDATION AND SIMULATION RESULTS

5.1 Model Validation

Both, the modeling constructs used here and their implementation in the simulation tool *OSim* can be considered valid: The method is based on the simulation of networks for manufacturing orders which is a construct that has been recognized in industrial engineering as valid since decades. The implementation in *OSim* has been shown as valid in many research and application projects since it was first published in 2000 (see references above). Basically, a model created by a simulation tool can only be validated using a historical case by comparing real and simulated results. Models created for a planning or feasibility study can therefore not be strictly checked for validity.

Alternatively, the functionality of a simulation tool can be validated based on logically expected results when tested by varying input parameters. This was done here on the basis of a real, not further reported example: Results of the real manufacturing situation were compared with the simulated processes by increasing the order program until it led to staff shortages. As expected, lead times of orders increased. The real lead times only deviated from the simulated ones by 2 to 5%. On this basis, modeling using *OSim* can be considered valid.



Adjustment policy											
Working time adaptation	x				x		x		x		
Overload help		x				x		x		x	
Reduction 2nd shift			x				x	x	x	x	x
Prolongation & free shifts				x	x	x			x	x	x

Figure 6: Effects of flexible working times and personnel assignments on performance indicators

5.2 Simulation Results

By simulating these scenarios using the *OSim* tool it was possible to demonstrate the quantitative effects of making working organization more flexible. The utilization of resources, the lead times for orders and the costs of the manufacturing processes were used for the purposes of evaluation.

These figures were relativized using the concept of the degree of goal achievement (Wedemeyer 1989; see also Zülch, Grobel, and Jonsson 1995). The degree of goal achievement converts a performance indicator into a value between 0% as the worst case and 100% as the optimal value. These values are idealized limits that often cannot be achieved in reality, and certainly not for all performance indicators at the same time. A simple example is the degree of goal achievement for utilization of resources: The pessimal value of 0% can not be achieved if the manufacturing system is working at all; the optimal value of 100% is practically not possible, even not in an assembly line. A more complicated example is the degree of goal achievement for lead time: 100% is achieved if only one order per machine and person is being operated in the manufacturing system; 0% is not feasible since even a single activity needs some lead time for its processing.

Figure 6 hints on the results of the feasibility study for capacity-based flexible working hours in comparison to the rigid two-shift system used in the initial scenario. As an example, the under-load situation with about 80% static work load is shown. The author has proved elsewhere (Zülch 2011, p. 25) that work organizational measures in under-load situations can lead to more significant improvements than in the case of over-load. The x-axis labels describe the different strategies to remedy the bottlenecks which can occur due to demand fluctuations. The strategies have an impact upon utilization and lead time.

The single effects are compared to the initial situation. While the improvement in resource utilization reached a few percent, the lead time increased noticeably. Both performance indicators were again measured as a change in the degree of goal achievement compared to the initial shift system. It was found that all measures combined can bring about an improvement, but that changes in the working hours of individual employees in particular improve the production logistics parameters. Also, the temporary extension of individual shifts was found to be advantageous regarding the goal achievement for lead time. This can be explained by that large orders could be processed entirely through overtime assignments. As mentioned above, overtime was compensated by free shifts until the end of the simulation period.

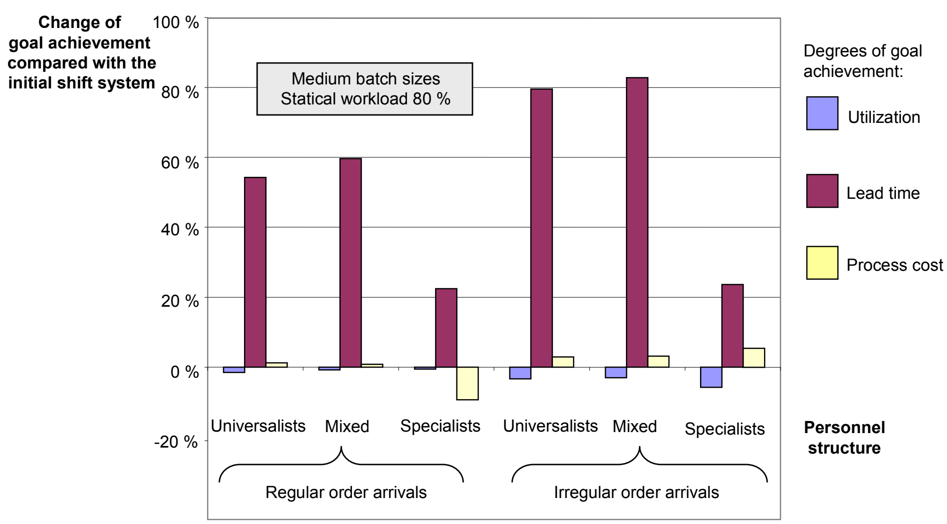


Figure 7: Effects of different personnel structures and varying order arrivals on performance indicators

In an expanded simulation study, both the personnel structure and the order intake were varied with medium-scale series manufacturing. Figure 7 shows that significant improvements can be achieved with regard to lead time assigning more highly qualified employees based on the example of a system utilization of below 80%, even though the utilization of the individual employees actually falls slightly. When employing specialists the improvements in the production logistics figures are less marked, although the manufacturing process costs fall more rapidly than with more highly qualified personnel structures.

The effects are much less pronounced given a static workload of 100%, and less still with 120%. This is due to the fact that with an adjusted personnel structure, there is only little room for improvement in these cases through flexible working hours and re-assignment of employees due to the fact that the personnel are already working at high utilization rate.

6 CONCLUSIONS AND FURTHER DEVELOPMENT

The results of this feasibility study show that the achievement of both production logistics and monetary targets can be improved using capacity-based, more flexible working hours arrangements and through re-assignment of multi-skilled employees from under-loaded to over-loaded workstations. However, the effects will be achieved the less, the higher the manufacturing system is loaded. In most of the analyzed cases the applied strategies could improve the results concerning the degrees of goal achievement when comparing them to the given initial situation. Furthermore, making working hours more flexible has a greater positive effect than improving the level of qualification. This confirms the key hypotheses concerning the advantages of flexible working hours. These include the improved ability of such working time models to react to fluctuations in the arrival patterns and volumes of manufacturing orders in the form of a system over-load. The effects with regard to the utilization of resources, order lead times and manufacturing process costs could not only be identified as trends, they were also quantified with the help of the simulation.

However, the target criteria used in this feasibility study are limited to the evaluation of manufacturing processes. The personnel-based criteria relating to the appeal of work and an improved work-life balance were not taken into account. First investigations involving the service sector show that making working hours more flexible based solely on the capacity required for operations can indeed be detrimental to individual employees (see Zülch, Stock, and Leupold 2011 for a more in-depth discussion of this problem). This was only partially taken into account in the procedure to generate flexible working hours by adhering to minimum and maximum periods of continuous work in the space of a day.

Conflicts resulting from overlaps between working hours and private needs or interests were not regarded here, but represent a significant criterion from the employee's perspective with his or her private social role depending on their nature and severity. Investigating this based on cases from the service sector is currently the subject of another research project that has already been reported on extensively (e.g. Zülch, Stock, Schmidt, and Leupold 2011). One key field of research for the future is therefore transferring findings from the service sector to manufacturing in order to be able to help improve the work-life balance of employees by creating adjusted working time models.

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