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SIMULATION OF WORKERS IN MANUFACTURING SYSTEMS

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ABSTRACT

Besides the logistic system the working structures in a company become increasingly important. With the introduction of flexible working structures, the role of workers in a simulation has to be redefined. It is essential to model workers in varying levels of detail. These levels have to match the levels of detail in the simulation of material flow. A specification was developed that summarizes the requirements to accomplish this. While being independent of the actual tool used, it provides assistance to the modeler when creating a simulation of workers. For each worker, additional attributes like creation of value, mental stress or physical strain are collected and evaluated. To describe the workers' disposition a central control instance is used. A prototypical implementation is demonstrated by means of examples.

1 INTRODUCTION

Due to restructuring of production, the role of workers in a company increasingly changed over the past several years. A transition from the manufacturing system, organized by Taylor's principles, to flexible, self-organizing working structures took place in several domains. Different structures evolved, often in a company specific fashion. To be able to estimate the effectiveness of these flexible systems, a simulation model has to be very detailed. It is necessary to gather additional input data and to include specific model components. Our approach integrates workers with existing models of logistic systems. A worker specification was developed that describes the structure of modeling components, the required input data and the interfaces to other modeling components. The specification uses the HLA standard to specify the interfaces. This enables us to make the specification nearly simulator independent.

The stronger consideration of the workers in simulation models is denoted as integrated resp. worker-oriented simulation. In worker-integrated simulation the main point is the evaluation of the logistic system, while in worker-oriented simulation special factors influencing the workers get analyzed. The increasing level of detail by worker modeling requires an increasing effort in the whole modeling process. In the following sections we will present methods and techniques helping to decrease the effort for worker-oriented simulation.

In the presented analyses particular thought had been given to flexible working structures because of the large scope for development of the workers and the interdependence between disposition strategies and efficiency of the logistic system. One of the major problems in modeling flexible working structures is the description of disposition strategies. The possibilities range from simple, centrally coordinated worker pools to the decentralized, distributed approach of intelligent agents. Several publications (e.g. /BERNHARD97/) show that the effort of gathering strategies and implementing decentralized worker management is very high, even for rather small systems. Therefore, in our approach a central worker control based on decision tables is used. The condition for the integration of flexible working structures into simulation models is a comprehensive analysis of the general and company-specific properties.

2 TEAMWORK IN MANUFACTURING SYSTEMS

The goal of our approach is to assist planning teams in the introduction of team work. Simulation models aid in evaluating systems of different working structures. One problem in the model creation phase is the amount of company-specific factors to be considered when developing an individual solution.

In the literature there are several definitions of flexible working structures. Mostly, they are very general and do not translate into a specification, because they are not suited for derivation of requirements. Partially only specific aspects of working structures are described, thus not allowing for a general applicability to the many kinds of working structures. There are several methods of the application in a simulation model.

When developing a worker specification to describe flexible working structures, different levels of abstraction can be chosen. One possibility is to choose a very general form of specification by strongly abstracting the influencing factors and thus creating a basis for comparison. Consequently, such a general approach scarcely yields company specific results, and for a real implementation much extension would be necessary. Using this approach we achieve a level of abstraction that is not overlapping the modeling of the technical system and does not meet the requirements of worker-oriented simulation.

Another approach is specifying the list via a list of attributes, with application dependent weights and degrees of freedom. This allows the consideration of company specific aspects. This is essential in generating the required predictions for evaluation of different working structures. The implementation of this approach leads to increased effort in the modeling phase.

There are a couple of design principles used in structuring a worker system that are applied to a differing extent. The approach allowing all principles to be used is the approach of semi-autonomous working groups. The basic dimensions of group work can also be assumed as essential features of flexible working structures (see Figure 1).

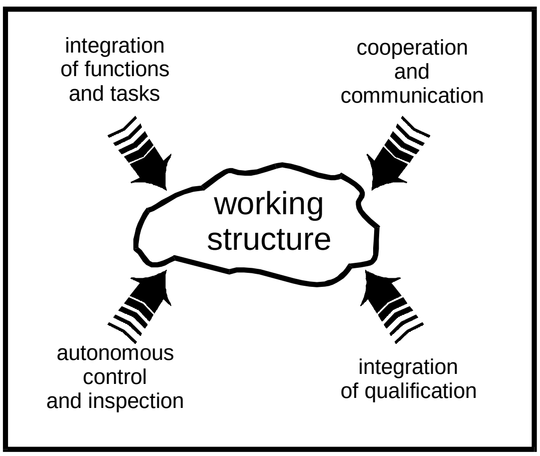

Figure 1: Design Characteristics of Working Structures

These characteristics can be further detailed. The integration of functions and tasks for example consists of planning, process preparation, process assurance, execution, and inspection. The adoption of the process preparation enables the workers to arrange the order of jobs by themselves. These activities can be adopted in the group to different extents. The workers in a group take over additional responsibilities and tasks, especially in the dispositional area, and they receive additional degrees of freedom. But also there are new activities, like mutual assistance in the execution of tasks. Incorporating this mutual assistance in a simulation model requires much effort up to now. The considered group size usually ranges from 5 to 15 workers.

Of special importance in flexible working structures is the qualification of the workers. The qualification constitutes the base for decision making in the disposition. The method commonly used in simulators ("able to do job" and "not able to do job") is insufficient here.

In the simulation system an option must be provided to adjust the amount of integration of single activities and to allow experiments.

The four characteristics include a plethora of requirements, influencing factors, and degrees of freedom that have to be described in a specification to be used in a simulation.

3 WORKER SPECIFICATION

The worker specification is a description of the data necessary for modeling workers in flexible working structures and their mutual relations. It assists the modeler in gathering and preparing of the required input data as well as providing a form of documentation. Furthermore the effort for the acquisition and preparation of the input data is reduced, because we specify what kind of data is needed.

For our worker specification we choose a combination of formal and informal approaches. The description of the interfaces between the single modules and other model components uses HLA ((High Level Architecture for Modeling and Simulation). HLA was developed as a standard in describing distributed simulation systems, but is applicable in monolithic simulators, too. It describes the interacting of components and the attributes and parameters used in the interaction. The internal structure of the components and their behavior is explained separately in an informal specification. So we defined primarily interfaces and protocols for communication. To implement the characteristics, they have to be translated into algorithmic form.

1. Integration of functions and tasks
   Due to the integration of functions and tasks the possible range of decisions and activities for the workers increases. The added activities have to be considered in the qualification of workers and need to be incorporated in the working schedule.
2. Cooperation and communication
   The cooperation and communication between workers can be modeled by a central component connected to all other elements. Strategies have to be implemented

there to control the various forms of cooperation. These have to be adjusted for a specific application.

3. Autonomous control and inspection
Appropriate strategies describe the behavior, as far as it is determined. The specification contains standard rules that can be extended and complemented.
4. Integration of qualification
This means to assign certain tasks to less skilled workers for practice. This too can be accomplished by rules.

Depending on what information and input data is available, a system can be modeled in differing levels of detail. The specification has to be constructed in a way supporting these levels of detail.

To model workers in a material flow system three additional basic components are needed:

- the workers themselves,
- the time management for the workers, and
- a controlling facility holding the disposition strategies and information.

In our approach a central worker disposition is used, making the workers themselves passive. Thus the modeling effort, as relative to use of decentralized structures for worker disposition, could be reduced. It became obvious, however, that with this form of worker description the autonomous organization of groups could be implemented only in part. The achieved results have to be interpreted in such a way that a group can handle a certain order volume, if the group behaves conforming to the disposition strategies. In the real company with autonomous organization, however, an increasing performance is to be expected.

The workers are represented in a data structure without own internal behavior. They hold an extensible series of attributes.

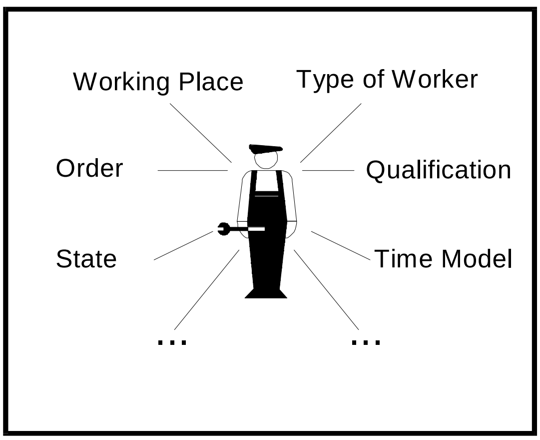

Figure 2: Attributes and Variables in Component "Worker"

Additional attributes can contain data about physical and non-physical strain, occurring dangers, or creation of value by the worker.

The workers' time management allows the distinction between machine working hours and human working hours. This decoupling fulfills a basic requirement for worker oriented simulations. It is hierarchically structured, flexible, and allows for flextime. If needed every worker can have a separate time model. The time model interacts with the corresponding worker, and feedback from the worker to the time model also is possible. Thus breaks, for example, can be shifted according to the actual situation.

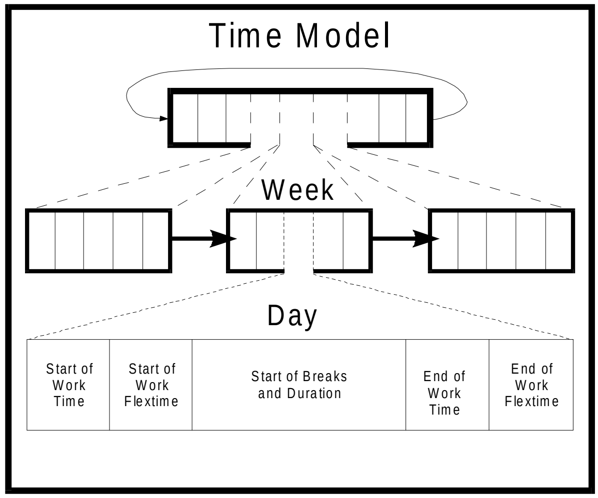

Figure 3: Structure of the Time Model

The worker management is used to describe the decision processes in the system. With flexible working structures, such a central disposition does not exist. In the specification, however, it is needed to provide the necessary information for the central worker disposition that has to be implemented in the model. It is a logical component of the specification. The effort for a peripheral disposition, e.g. by using intelligent agents, is oversized.

In the worker management all information concerning the current system state plus all additional information needed for disposition is available in one place, thus allowing the decision making to use arbitrarily complex strategies. The specification provides simple standard strategies that can be extended depending on the application. All the strategies are experimental data in the simulation model. The worker management is the one element of the specification holding the specific values of the individual attributes.

The specification provides all information needed to model flexible working structures. The implementation can be done in any desired simulation system.

4 IMPLEMENTATION

An example implementation of the specification was done using different simulators. The simulators were tested with regard to their suitability in implementing the specification, thus testing their ability to model flexible working structures. The modeling effort was estimated. As an example model an assembly group was chosen, because it is a typical application domain of flexible working structures.

4.1 Description of the System

In the group transmissions are manufactured; they have to be assembled one after another on five stations. The transmissions move in cars guided by rails. Overtaking a car is not possible. A group of workers is responsible for the whole assembly.

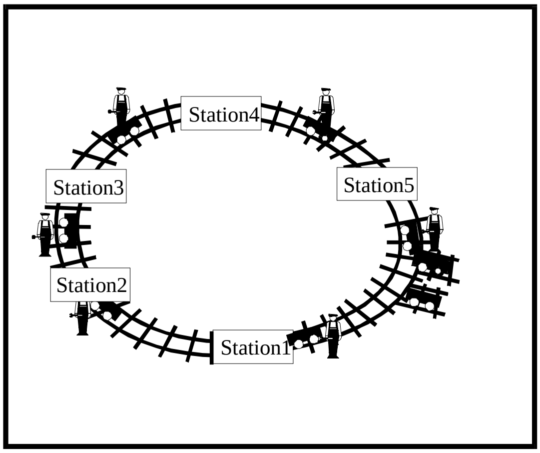

Figure 4: Layout of the Example Model

Before the modeling an analytical estimation was performed. Here all qualifications of the participating workers were gathered, and it was analyzed what qualifying requirements resulted from the expected order streams. In result of this analysis the qualifying potential of the workers and the qualifying requirements for the planned system could be estimated. This data was transferred to the simulation model and constituted a base for the implemented disposition. The modeling effort could be substantially reduced.

Differing approaches in introducing flexible working structures were evaluated using the simulation model. The assignment of tasks to workers and the qualification of the workers are experimental parameters. Workers can be assigned to individual stations and permanently do the same operation with the transmissions. If there is no task at one station, the waiting worker will support the activities at a different station. Another approach is having one worker accompanying all assembly of one transmission, thus moving with it from station to station. The range of decision freedom in the group lies in determining the order of executing orders and assigning workers to orders.

The impacts on the performance of the workers and the produced quality are manifold. If one worker always performs the same activities, it can result in monotony, that can have negative effects. But frequently changing activities can lead to stress, learning and unlearning come into effect. To the company, economic success matters. The alternative with the largest profit will be chosen. But how to find the best alternative?

4.2 Simulation

The simulation was done using the component based simulator WITNESS, and the simulation language GPSS/H and Proof™, among others. The existing "worker" component in WITNESS is without extension not suited for modeling flexible working structures. WITNESS doesn't provide a programming interface, so the concept of the "worker" cannot be changed. It has, however, a rule system, allowing some basic features to be implemented.

The assignment of qualification to workers is not a 1:1 relation, but controlled by variables with a value $0 <= x <= 1$. The worker assignment is done on request by a machine. A rule is evaluated that chooses the worker based on the qualification variable. Other variables depend on the qualification, like the processing time. As the qualification is a variable, it can be changed in the course of the simulation.

The use of GPSS/H allowed the implementation of the specification. The specification simplifies the the worker modeling by providing the required information and rules. Depending on the simulation system these can be fully or partially implemented.

By integrating the simulation model into an expert system, experimenting with the model and changing parameters is easy.

Evaluation of worker-oriented simulation provides assistance in finding solutions to worker-oriented problems. The modeling of workers according to the developed specification allows worker-related conclusions. Even though the consequences of certain circumstances, like monotony, cannot be determined in a generalized way, and thus cannot be used in the simulation run itself, it can be determined if there was a situation leading to monotony. The evaluation of these circumstances can be done after the simulation and result in changing parameters and additional runs.

All data for the simulation is stored in data bases. These can be enhanced or extended to allow further evaluations. So it is possible, by acquiring danger or stress related information, to make a strain analysis. By coupling to a calculation module economic results can be estimated, too.

A comparison of the existing qualification potential for fully qualified workers as opposed to partially qualified workers can be seen in Figure 5 and Table 1.

Worker-oriented simulation allows the estimation of the workers' influence on the logistic system and the system's influence on the workers with a higher accuracy.

But you have to keep in mind that even in these models the workers are abstract elements. Individual specifics and fluctuations are ignored. Our analyses have shown that further advance of the level of detail will increase the modeling effort, but scarcely improve the rating of the system.

The specification we developed assists the modeling of flexible working structures in simulation models. Special attention is given to the modeling of workers, without neglecting the material flow. Modeling of the workers is possible in varying levels of detail, depending on the application and available data. By experimenting with the created model through parameter changes, a proper variant for the working structure can be found.

Table 1: Part of the Qualification Table

Worker	Task 1	Task 2	Task 3	Task 4	Task 5
Worker 1	1	1	0.5	1	1
Worker 2	1	0.5	1	1	0.5

5 RESULTS AND CONCLUSIONS

The consideration of the workers in simulation models is useful for systems with high rates of manual operations. Thereby different levels of detail are possible. The level that is chosen depends on the simulation goals and the specifics of the company. That is why it is impossible to define a general worker element.

The integration of workers in simulation models requires additional effort and therewith additional costs and longer development times. These additional requirements are not restricted to the worker elements but apply to the logistic system, too. The degree of abstraction has to be chosen in a way that the integration of workers is possible and useful.

The additional effort in modeling is maintainable if further information is expected, for example statements about creation of value by individual workers, or statements about physical and non-physical stress, and danger.

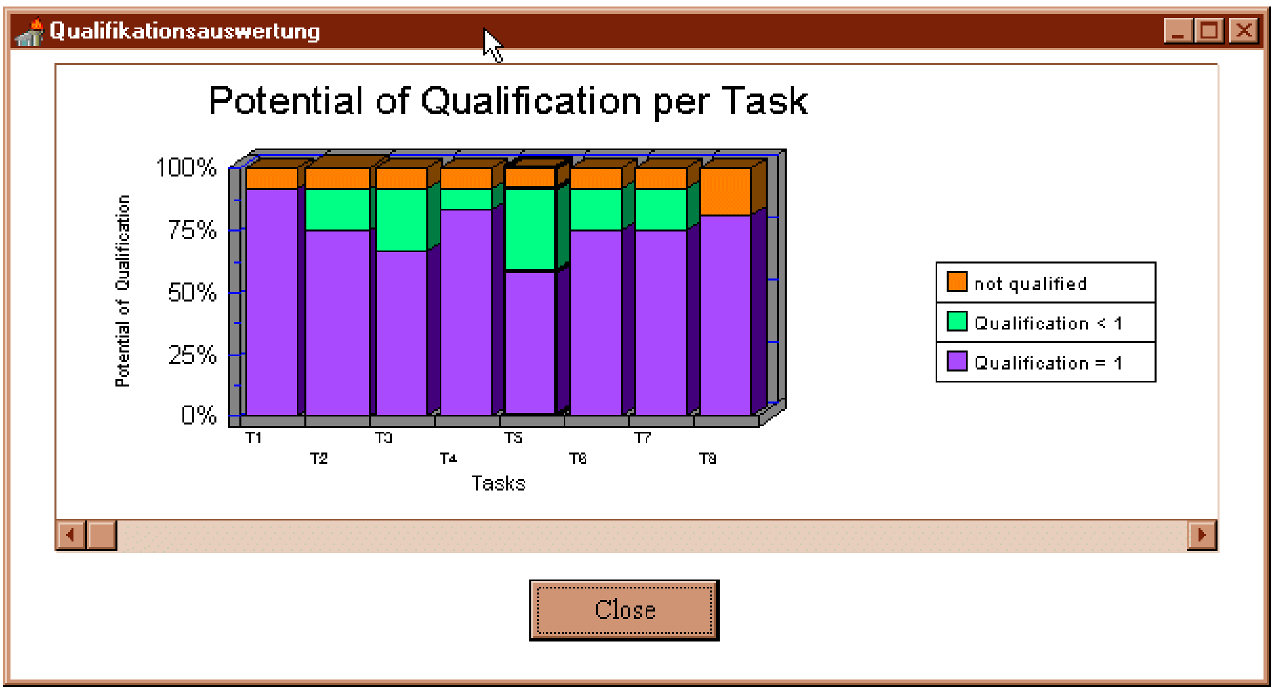

Figure 5: Qualification of the Workers

Furthermore, experiments with the working structures are possible. In this case the detailed modeling of workers is necessary to draw the consequences about the efficiency of the logistic system.

When modeling flexible working structures it has been shown that the implementation of a central worker disposition is sufficient.

In these models may be evidenced that a given amount of tasks can be handled in a given time. In real companies with utilization of self-optimization a higher efficiency is expected.

The worker specification we developed is our contribution to reduce the effort in creating personal-oriented simulation models. A general solution cannot be found because of the differing levels of integrating workers.

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