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# INCORPORATING FINANCIAL AND ERGONOMIC CONSIDERATIONS INTO MODELS OF MANUFACTURING SYSTEMS

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## ABSTRACT

This contribution describes a modular concept by which simulation results can be post-run interpreted under different aspects (multifunctional interpretation). The extension of classic simulation models for materials flow systems and manufacturing systems by economic, ecological and environmental aspects as well as the advantages and limits of this approach are discussed in this paper. A gear manufacturing was chosen as an example to demonstrate the application of a multifunctional interpretation.

## 1 INTRODUCTION

Classic simulators are able to model technical processes in manufacturing and material handling systems with a sufficient degree of details. They are used by factory planners to check and improve plans of technical systems. During the last years these tools were extended with components to support the modelling of flexible manufacturing systems, automated production lines and automated materials flow processes.

But today the consideration of worker, costs and environmental factors becomes more and more important in designing of technical systems. Criteria like qualification, work organisation, compensation of employees and work structuring must be more integrated into the planning process and for that reason also into the planning tools. At the same time economic and ecological questions gain more and more importance.

To support the assessment of such aspects it is necessary to provide and process additional data and methods for the application in computer-based planning tools. In such a way the reliability of planning results could be improved and qualified statements about ergonomics, economy and ecology of manufacturing systems and materials flow systems could be available already during the planning stage.

Conventional simulators only allow limited assessment of a materials flow system. Normally they are based on state variables of flows of material and resources in location and time. Such models do not fully suffice e.g. for the introduction of new work structures like team work. Often it is necessary to allow a view on simulated systems under different aspects. In this case the simulation results are to be prepared under various viewpoints and for different user groups. We refer to this process as multifunctional interpretation of simulation results. The problem analysis must clear up which questions of different user groups should be answered by the simulation system, how the additional result data could be generated out of the model data, which additional input data are to be provided and how these data are to process.

The classic form of a simulation study can deliver the planning team many necessary information about the materials flow and can show an insight into the process. The modelling of the behaviour of materials flow systems and manufacturing systems in location and time is the basis of the development of expanded models. Banks (1996) claims 80 to 85% of the time that an item is on the manufacturing floor is expended in material handling or waiting for material handling to occur. Therefore the planning tools are often concentrated on the modelling of these items, especially on the states of flowing objects and technical resources. Theses models can be generated very precisely for flexible manufacturing systems with a high level of automation. They deliver results which are well suited for the assessment of the planning. The strain of the employees, ecological or economic aspects are normally modelled only if they directly influence the production sequences or if they are requested as target figures or factors of evaluation of the modelling.

## 2 BACKGROUND

Today's simulation tools are equipped with extensive components for the assessment of states and behaviour of manufacturing systems and materials flow systems. The simulation results are delivered in a processed form as compressed result data. They include for instance the utilisation rate of transport devices and manufacturing facilities, the utilisation of storage space, or the throughput time of items or orders. These data allow the materials flow planner an effective assessment of technical systems, their performance and their performance limits. Besides most simulators offer primary result data. These are for instance trace protocols. The animation trace file is a special form of primary result data which allows a post run animation.

With the help of the animation components in today's simulation tools, the experienced user gets various possibilities, for instance to assess the modelled processes and to put the system states in a proper place due to their history.

Classic simulation models are state models of operands, operators and operations (process stages). The model structure and the kind of result data are determined by the aims of the simulation study. In multifunctional models not all result data must be generated by the simulation tool. Primary result data can be connected and interpreted with extended input data. The dataflow is shown in Figure 1.

The interpretation makes is possible to gain an extended evaluation under different aspects. Therefore it is necessary that the simulation model is designed, structured and detailed in a proper way. The methods described in this contribution concentrate on the form of post-run evaluation above explained to make simulation results accessible to a multifunctional interpretation.

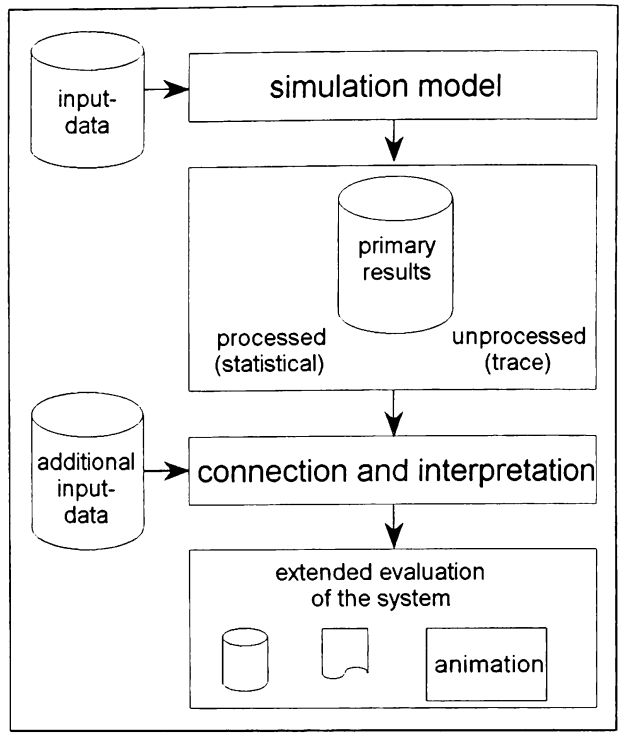


Figure 1: Data Flow

## 3 EXTENSION OF SIMULATION TOOLS

One aspect of the extension of simulation tools is for instance the detailed modelling of workers. In classic simulation models statements about single workers are only possible in an abstract way. Often only the utilisation of the worker is given indicated. Qualifications as the ability to carry out a production sequence at a workplace are normally defined in simulators, but only to distinguish between "The worker can make this job" and "The worker can not make this job".

But it is not enough to use only the state modelling of technical systems if it is necessary to assess different work structures concerning their demands on the worker. Components allowing a distinguished estimation of physical strain and qualification must be integrated.

Two different approaches are possible for the necessary extension of simulation tools. On the one hand there is the possibility to expand the simulators with further functions. The result would be specialised simulators. Some simulator developers follow this way for instance to model value added processes in much more detail. This approach is very expensive and demands an individual's own solution for each simulator. The second approach consists in a post-run combination and assessment of uncompressed result

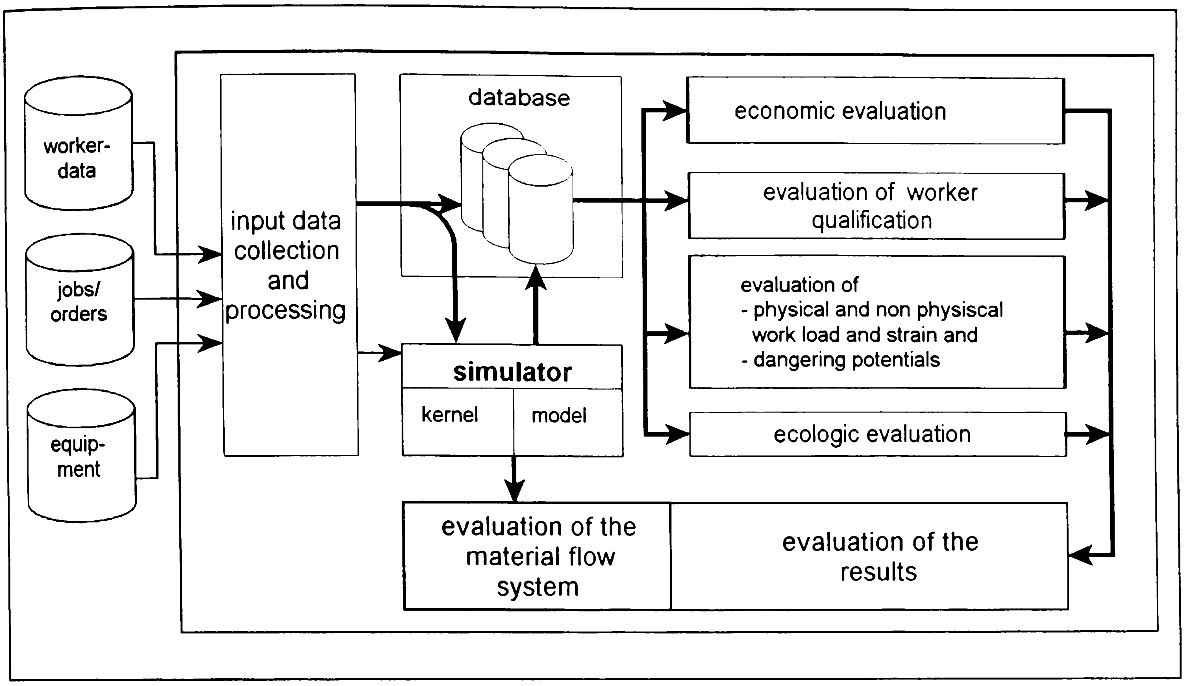


**Figure 2: Components and Interfaces of the System**

data produced by the simulator with additional information. Additional modules allow an assessment under various viewpoints. The structure and components of such an approach are shown in Figure 2.

### 3.1 STRUCTURE OF THE SYSTEM

The precondition for the winning of additional information is a simulation model that describes the analysed system very detailed. It must have a clear connection of all manufacturing sequences to machines, items and workers. The series of manufacturing sequences (processes) are to be recorded in trace protocols. Also the writing of trace protocols of changes in states of system components must be possible. Both forms of trace protocols constitute as primary result data the basis for the extended data evaluation.

The multifunctional interpretation system has the following basic functions:

- input data collection and processing,
- interfaces to the simulation model,
- assessments,
- help and documentation systems and
- data base interface.

The assessment modules can be chosen in relation to the aims of the simulation study. The following modules were developed in connection with research projects and simulation studies for the industry:

- assessment of load, strain and danger potential of workers,
- assessment of the value added by the manufacturing process and
- estimation of the environmental danger potential by the manufacturing process.

For the generation of additional information, additional input data are to be collected and to be processed. The generated data can be stored and managed in a data base.

The simulation model generates data which can also be stored in the data base. The internal assessment methods of the simulation tools are used for the assessment of the system behaviour in location and time. The user gets his other results about the system in the usual and accepted way from the simulation tool. The simulation tool creates also the animation corresponding to its implemented abilities.

The additional assessment tools deliver the extended interpretation and evaluation of the simulation results. The users get further aspects, assessment criteria and data for their decision making. Trace protocols generated by the simulator provide the basis for the estimation. All modules use the trace protocols by connecting the events and processes with additional data. Due to the modular concept chosen it is possible to integrate different assessment tools. The components run under a uniform user interface.

### 3.2 DATABASE

Data are managed in a relational data base. In this data base a redundancy free data management is aimed. The data formats are chosen in such a way that they allow a platform independent exchange. Therefore we use the ASCII format.

The data necessary for the extended result evaluation must be collected and committed to the evaluation components. The events or processes must be assigned to the trace protocol to connect the additional input data with the result data generated by the simulator.

Events and processes are the elementary components of the state model. Manufacturing sequences for the evaluation processes are built from these events and processes. Every working sequence consists of several working activities which are connected to a working task. These working sequences are not interruptive. They are processed by a worker or a team at a defined location, on a defined item with defined devices. The combination of working activities to a working sequence is realised in the stage of the additional data collection. There are two ways to determine the duration of a working sequence. On the one hand the duration is determined by input data, on the other hand the duration is computed by the simulator.

The application of this concept demands a trace file generated by the simulator with the following contents

- start,
- end,
- working location,
- working item and
- worker

for each working sequence. The combination of working sequences and primary simulation results is realised by a connection file which is represented by a matrix. Various evaluation components can generate multifunctional interpretations from these combined result data.

Another kind of data connection is the extension of state protocols generated by the simulator with additional data. These state protocols are necessary for the evaluation of data which can not be collected from working sequences.

### 3.3 INTERFACES AND RESULT DATA EVALUATION

The extended result data evaluation is also realised by a modular concept. This allows the integration of various evaluation modules related to the requirements of the users. The result data evaluation is post run. This method has the advantage that the computed simulation results can be interpreted under various viewpoints. The disadvantage is that the results of the

| viewpoint | object | state | primary result | evaluation | result |
|---|---|---|---|---|---|
| | type: resource (operator) | | | | |
| ecology | forklift truck | transport | duration | energy consumption/ period | energy consumption/ operation |
| | | | duration | heat<br>noise<br>carbon dioxide emmision | environmental load |
| economy | | busy | duration | work costs | cost / period |
| | | idle | duration | waiting costs | idle cost/ period |
| ergonomy | worker | in work | duration | work load | stress level |
| | | wait | duration | recreation time | stress level |
| | type: issue (operand) | | | | |
| economy | part | processing | duration | increase in value<br>yes | increase in value/ period |
| | | quality checking | duration | increase in value<br>yes (partially) | |
| | | transportation | duration | increase in value<br>no | |
| ecology | | | duration | heat loss | energy demand |

Figure 3: Examples for added costs and values

evaluation can not be used for the decision making during the simulation run.

The connection to different simulators was one of the main aims in the development of the interfaces. A high acceptance by a user can only be reached, if the modules work with his or her simulator and the additional costs for modeling are low. For different viewpoints and users we provide different modules. The functionality of the modules shall be described in the following paragraphs.

The module for the economic evaluation allows a detailed analysis of the cost behavior of the simulated system and the added value. For the usage of this module it is necessary that the user can combine every working sequence with its cost and added value (Figure 3). This kind of economic analysis is at this time directly supported by some simulators. The advantage of the external evaluation module is that the user can choose the form of the evaluation according to the available data. The module allows the calculation of direct costs (for example consumption of operating resources and energy) and indirect costs ( for example floating capital).

Another module was developed for the estimation of load and strain of workers. The evaluation component for the physical work load and strain was developed in the project EMSIG and described in Ehrhardt (1994). Investigations in several firms have shown that the physical load and strain of workers becomes more and more important. The activities done by the workers include a lot of control tasks with a high level of responsibility. The estimation of mental load and strain of the worker is much more difficult than physical work load, because the individual differences are much higher. The evaluation component includes methods used in ergonomic investigations in firms.

The qualification of workers is very important for reengineering manufacturing systems. Materials flow simulators generate often only results about the utilization of workers. The developed evaluation module takes into consideration how well a worker is qualified for an activity. It compares the qualification of the worker with the requirements of the working process. The interpretation of the results allows the determination of necessary training for the workers already in the planning stage.

Many manufacturing sequences include danger potentials for the workers. The danger potential is caused by the working sequence but also by the substances used and by the environmental conditions. A special evaluation module supports the user in the estimation of kind and duration of danger potentials in the planning stage.

All Modules work separately on the same database. Often it is necessary to combine the results of the different evaluation models with each other and with the primary simulation results of the technical system. Therefore we developed a separate component which compresses and presents combined result data.

## 4 MODEL OF AN ASSEMBLY SYSTEM

The developed modules were tried in a simulation study supporting the reengineering of a gear manufacturing. The planning team consists of materials flow engineers, work structuring engineers and quality managers. Different variants of the system were analysed and evaluated under different viewpoints with the help of the simulation model. The variants differ in the chosen form of the working structures and layout of the material flow system.

The main goal in the restructuring of the manufacturing system is an increased performance with lower throughput times.

The simulation results allow statements about:

- performance of the system and the throughput time of items,
- cost and added value,
- demand of qualification,
- load and strain of workers and
- possible danger potentials.

For the development of the model we used the simulation language GPSS/H™ and for the animation the system PROOF™.

## 5 SUMMARY

Traditional simulation models for materials flow systems and manufacturing systems describe and insight the processes, technical performance and the system behavior in location and time using discrete events and states. The primary results are related to these goals.

The integration of additional aspects like ecological, economic and ergonomical evaluation demands extensions of the model. This can be done with two different approaches. The first one is the extension of the simulator and the other one is a post run interpretation. The post run interpretation is usable if the decision making is not influenced by the additional evaluation.

A multifunctional interpretation can be realised with various simulators which are able to generate trace files in the described form. The presented modular concept of evaluation modules and files allows the interpretation of primary simulation result data under various viewpoints and user interests. The evaluation methods were successfully used with result data of different simulation tools. This approach opens up several new application fields for traditional simulators and models.

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