THE CONTRIBUTION OF SIMULATION FOR THE
MANAGEMENT OF AN AUTOMATED WORK-CELL

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ABSTRACT

The high productivity of an automated work-cell can only be taken advantage of, if there is a sufficient solution for its inherent management task. This task comprises very demanding decisions within this work-process for its design, planning and control, in particular in respect of the dynamic complexity of the system and of the required short response time. An adequate computer support in this decision process is indispensable. As important method in this context simulation is discussed as to its methodological aspects and its possible range of application based on successful projects realized in practice.

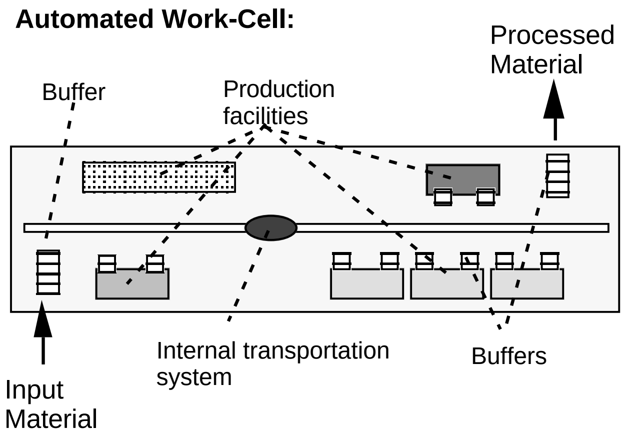
1. INTRODUCTION

Automation is one mean to improve efficiency in today's manufacturing processes. Normally, the degree of automation is increased by introducing stepwise new automated work-cells. The management of these work-cells, in itself an individual task, has to guarantee the integration into the global manufacturing process. In this paper, the possible contribution of simulation for the management of an automated work-cell will be discussed and illustrated referring to our practical experience.

2. DEFINITION OF WORK-CELL

In general, such a work-cell can be characterized as follows:

As input in a work-cell we have a material flow, within the work-cell a transformation process takes place, which produces as output a flow of processed material. The transformation process within the work-cell is automated, human laborers have only supervising duties besides the set-up operations, which are not automated in contrary to an FMS (Flexible Manufacturing System). A work-cell comprises several production facilities and an internal transportation system.



3. DECISION ANALYSIS

Within the management task, potential contributions of simulation can be expected in the field of logistics. (Stecke 1985, Banaszak 1991).

A decision oriented analysis of the logistic system we deal with, reveals the following decision problems:

- Which configuration of production facilities and internal transportation system are best for a particular well defined practical production task?
- In which sequence a package of orders has to be processed, considering aspects of set-up and throughput time?
- Among the feasible alternatives in the process flow paths of an order, which one is to chose?
- In which sequence the internal transportation orders have to be processed?

4. SIMULATION METHODOLOGY

In this case the appropriate methodical approach for a simulation analysis is discrete event simulation. The first step in this analysis is to develop an adequate model of the real system. Adequate means as simple as possible focused on the decisions to be questioned. In an automated system most of the decisions have to be taken autonomously within the system, intelligent algorithms for planning and control are required therefore. To be able to test them by simulation, appropriate interfaces within the simulation model have to be conceived.

5. MODELING LOGISTICS SYSTEMS

Logistic Systems, modeled in view of a decision oriented analysis, can in general be represented by a small number of basic elements. Therefore it is possible to define a very general Meta-Model of a logistics system valid for a large number of applications, as e.g. production, inventory or transportation systems, in the following way:

The foundation of the Meta-Model is a directed graph. A node represents a location, where specific information is stored and specific decisions are to be taken. An edge establishes a connection between nodes to enable a flow within the network defined by the graph. The flow comprises on one hand flow elements with individual characteristics. On the other hand, the flow can consist of information which is accessible to extend the local information basis. The direction in the graph always indicates the direction of the flow. The flow elements are able to move along the edges, to stop and wait in a node and to consume different kinds of resources as long as they are available. The information within the system is partly globally partly only locally available. The flow in this system runs according to a controlled time table.

This Meta-Model of a logistics system was used as guideline to develop our own simulator.

6. THE SIMULATOR 'HIDES'

For a simulator particularly tailored for the simulation of logistics systems in its dynamic aspects we propose therefore the following basic elements:

- **Entities,** as flow elements in the network which can be individually characterized and identified.

- **Stations,** as one type of nodes in a directed graph, representing specific locations within the network, where specific activities within the flow process occur. Stations are introduced according to the functional requirements of the logistics system and do not correspond necessarily with a geographical location. Every station has associated its logic element. At the beginning of the network there is always a station without predecessor, at the end one without successor.

- **Logic elements,** which control the flow process in a decentralized way. The entities arriving at the associated station are handled by the logic element according to a general default proceeding or an individually defined protocol containing activities as to generate, duplicate, split, modify and remove the arriving entities. In addition any algorithmically defined control logic can be implemented.

- **Queues,** as second type of nodes, where entities can be stored in the network. A queue has always exactly one station as successor, whereas a station always has to be followed by at least one queue. The queuing rules are configurable either statically or dynamically through commands received from the logic element associated to the succeeding station.

- **Resources,** as abstract elements, which can be allocated dynamically from a station by entities. They contain information about their availability and their behavior and are not directly visible in the network.

Stations and Queues as nodes define a network in which directed edges of the following types enable a corresponding flow:

- **material flow channels** allowing entities to move from one node to the other along the edge.

- **information flow channels** allowing information transfer and/or modification as well as signal emission along the edge in a well-defined manner. No movement of entities is allowed over these edges

System control and information management are organized as follows:

Whereas global **system control** is in accordance with the standard discrete event simulation, there is a decentral system control implemented in logic elements. These elements control the entity flow using only selectively available information. For **information management** three levels of availability are introduced:

- **Global information** available from everywhere at anytime.

- **Local information** of a station available only for entities which have entered this station.

- **Selected information** available by explicitly defined information flow channels. The local information basis for a logic element can be extended herewith.

In the real world, logistics systems are in general very large and very complex. To perform the modeling task efficiently a top-down approach is indicated with a stepwise increase in degree of detail. As a consequence, we get a model in different hierarchical abstraction levels. To support such a proceeding in modeling, our simulator provides the building of **subnets**. In a network containing various subnets on different hierarchical levels a strictly logically consistent **hierarchical structure** is enforced. A subnet is always incorporated in a station in which the subnet substitutes the logic element.

To facilitate the **debugging** the syntactical structure of the nodes (stations, queues) and the subnets as mentioned above is strictly enforced.

To perform the above specified kind of simulation analysis for logistics systems, our institute has developed its own specific simulator, HIDES (Highly Interactive Discrete Event Simulator), designed for general purpose use with the following main characteristics (Ulrich et al. 1993):

- A powerful modeling basis as previously described which comprises only a small number of elementary elements is available to support the model building process efficiently.
- A top-down proceeding within a simulation analysis is enhanced by a possible use of hierarchical model structures.
- The object-oriented programming concept is particularly appropriate for this kind of simulation analysis. Our realization of a simulator bases therefore on this concept.
- To offer the best possible working environment with a user-friendly man-machine interface enabling interactive modeling with direct graphical display on screen, we have chosen Smalltalk-80 as programming language.

Until now we have applied this simulator successfully for several projects improving its functionality continuously, but we need some more projects to reach a standard, sufficient for public use.

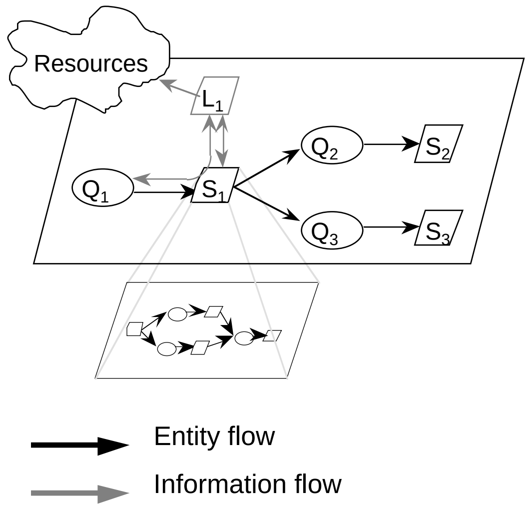
The following description with a figure shows a modeling example in HIDES:

1) Entity e arrives at *queue* Q_1

2) *Queue* Q_1 sends a message to *station* S_1 indicating the arrival of entity e

3) *Station* S_1 gives control to *logic element* L_1

4) *Logic element* L_1 checks the relevant system state and sends a message back to *queue* Q_1 indicating whether entity e can be forwarded to *station* S_1 or not



5) Entity e arrives at *station* S_1. *Logic element* L_1 controls the actions to be performed. If the *station* has a defined subnet, the entity is forwarded to the first *station* of this subnet. After reaching the last *station* of the subnet the entity returns to *station* S_1

6) *Logic element* L_1 decides whether entity e should be disposed of or forwarded to Q_2 or Q_3.

7. SIMULATION FOR MANAGEMENT TASK

In a traditional work-cell without automated internal transportation system, several laborers are required for the operation of the various production facilities. The management task is delegated to these operators who perform their task as local managers within their open range for activities, using all their skill and experience for their decision making process. Their need for decision support is relatively small, whereas for automated processes a computer based decision support is indispensable to profit in full extend of the higher production performance.

To introduce automation within the management task, a formal analysis of the production process is required. A static analysis of the process is often not sufficient, because a lot of restrictions within the system can only be taken into account in a dynamic context.

Examples of that kind of restrictions are:

- A continuous process interrupted by a batch process, e.g. an oven in a continuous manufacturing process.
- Time consuming manual set-up operations on various production facilities, e.g. set-up magazines in chip production.

- A coordination of several part production flows to a main stream in production, e.g. assembly of parts for a product component.
- Limited buffers for intermediate storage which may contain only material of one order.
- Automated test facilities integrated in the work flow, where orders are only released for further processing if totally completed.

In this managing task contributions of simulation could be the following:

For the **design** of a automated work-cell, be it in marketing for sales or for internal use, a configuration of production facilities and transportation systems can be tested in respect of its performance and stability by various simulation runs. This can be useful to judge internal investment projects as well as for proposing the best suitable configuration of a work-cell for an external customer with a specified and guaranteed performance.

Example: A new operation had to be integrated into the work-cell requiring specific production facilities, which could operate in parallel. The question was how many facilities to install in a specific case. This question could be answered by simulation before the hardware was available.

The **planning process** of a work-cell has to be integrated into the planning process of the whole company. Normally the following interaction takes place: Periodically a package of orders out of the previous production step is delivered to the work-cell to be processed within a determined time span. Before starting the manufacturing process within the work-cell, sequence and allocation of resources have to be determined for the order package on hand. An efficient algorithm has to be developed.

In view of the prevailing kind of restriction the optimization method to choose will most probably be a kind of heuristics possibly extended by approaches from the field of artificial intelligence to be able to deal with a network of distributed local intelligence (Pan and Tenenbaum 1992).

Simulation is not only extremely helpful for the development of an intelligent planning support, but also later within the operational planning process for continuous verification of proposed solutions or more specific time estimations.

Example: A verification by simulation of proposed order schedules determined according to a developed planning algorithm showed a bottleneck in the work flow caused by the lack of a buffer after a production facility. This deficiency could not be eliminated by an improvement of algorithms as simulation analysis confirmed, an additional buffer was introduced therefore, which improved system performance considerably

In an automated work-cell the **control process** is focused on the internal transportation system, which includes normally the necessary algorithms as software integrated into the system. For the development of these algorithms a simulation model can replace the real system because it is possible to use an identical interface to the algorithmic control software.

Example: In a internal transportation system a local control was installed. Simulation analysis revealed an insufficient performance of the system because of a lack of coordination with the superposed control structure. To improve the local control of the transportation system an important question was, what part of information should be available locally as information basis for the local decisions. Technical restrictions of the real system as well as implementation costs for the new control software had to be considered. The specific capability of HIDES, the possibility to model explicitly an information flow in the system, was particularly helpful and enabled us to work out a far better solution.

8. CONCLUSIONS

The results of successful simulation applications in electronic industry show, that industry can afford the longer the less not to take advantage of the possible important contributions of simulation in various contexts of its managing task. In particular for implementing intelligent planning and control concepts simulation has its promising application in design as well as within planning and control processes

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