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Stock-keeping Processes in the Framework of Computer-aided Engineering Education in CIM

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This paper is a short report on aims and first results of a sub-project within the TEMPUS Joint European Project, 'Computer-aided Learning and Simulation Technologies' (JEP Contract No 1087–90). The sub-project concerns computer-aided engineering education in the field of computer-integrated manufacturing (CIM). Its aims are the development and validation of concepts and prototype subsystems for the configuration, simulation, valuation and explanation of essential objects, processes and aspects of CIM. This paper concentrates on the first prototype subsystem that has been completed recently. This is a subsystem for the configuration, visualization and explanation of stock-keeping equipment, for the simulation of corresponding stock-keeping processes and for the valuation of the configurated equipment within a CIM-environment.

INTRODUCTION

THE increasing complexity of technical systems is a challenge to engineering education. In the manufacturing industry, the increase of system complexity concerns not only single components (as machines, manufacturing centres, transportation and stock-keeping equipment) of plants, but above all the integration of many or all of these components on the bases of computer technology [1, 2].

The complexity of CIM and its interdisciplinary character leads to serious difficulties in teaching in this field. For instance, it is very boring to hear again and again that in a CIM-environment a lot of objects and processes are interacting, thereby influencing each other in a complex way, that standardization is a prerequisite for CIM, that the interface problem is most essential, but that all these aspects are difficult to understand and explain. To give students and other interested persons a rough idea of CIM, physical models of manufacturing processes are sometimes used. However, these models are relatively expensive and/or have a limited functionality. Above all, they can demonstrate only certain reactions of material objects on the output of software programs controlling these objects, but not the 'inner' functionality of software. One consequence is that, for instance, the field of computer-aided design (an essential part of CIM) is a priori excluded from the modelling of CIM-solutions by physical models.

On the other hand, using computers, displays and special software, in principle *all* objects, processes and aspects of CIM can be modelled, visualized, evaluated and explained. Considering this, the difficulties in educating students in the field of CIM, and the demand for innovative means for this process, the idea came up to develop and validate concepts and prototype subsystems (software) for the configuration, simulation, valuation and explanation of objects, processes and aspects of CIM.

This has been done in the framework of the TEMPUS Joint European Project 'Computer-aided Learning and Simulation Technologies'. Finally all these subsystems should be integrated into an extendable, modular system for computer-aided learning and training in CIM.

THE MAIN DEMANDS ON THE SYSTEM

Such a system should help to teach, demonstrate and illustrate the essential aspects of CIM, especially the 'I' in CIM, i.e., the aspects of process integration. The main demands on such a computer-aided engineering education system are discussed below.

Modelling of real objects

Students must be enabled to model easily at least those real objects that compose typical CIM-systems, i.e., some machines, manufacturing centres, some kinds of transportation facilities and stock-keeping equipment, workshop halls, offices and plant areas for the supply of raw material and for product delivery (output of the plant). Of course it is not required to model all these objects on the bases of a CAD-system in detail, which would be rather time-consuming. Specialized software should enable students to create their models by selections of predefined (and simplified) object models and by specifications of their parameters. An essential modelling aspect is the functionality of the objects. Finally the models have to be visualized and explained. This refers to geometry, structure and functionality. Means of visualization and explanation are computer graphics (simplified images of reality and abstract schematics), animation (e.g., simulation of functions, movement of robots), labels, designations and texts. Using multimedia technology, static images (stills) of real objects and videos demonstrating them in action (movement) should be accessible. Furthermore audio could be integrated for explanation and other didactic purposes.

Process modelling and process interaction

It must be possible to model easily all essential aspects of processes of a concrete CIM-environment, including input and output of the entire CIM-factory. To demonstrate, explain and evaluate process integration, a tutor or the students themselves must be able to model the interaction between the processes. It should be possible to influence the degree of realism of process models to focus on different aspects of a CIM-solution. Furthermore certain processes should be carried out as (or nearly as) in reality. For instance, CAD-processes should be carried out by students on the basis of some relatively simple, commercially available CAD-system embedded into the entire computer-aided engineering education system. Finally it is an important aspect that the latter system should and could be able to visualize and explain interfaces and data structures directly within the framework of complex process simulation (which is impossible by classic forms of teaching in this field).

System extensions

In the case of using physical models for engineering education purposes, students surely learn more in the process of designing and constructing such models than by observing them in action. The situation may be similar in the case of a computer-aided engineering education system. The system should be extendable by students themselves. Students have to be encouraged to develop and integrate their own modules. A precondition for this is, of course, the clear definition and documentation of all interfaces and control mechanisms of the entire system.

Learning by doing

Students or groups of students should be able to configurate their 'own' CIM-system, performing tasks specified by the tutor. They have to reach this goal by modelling (configurating) the single objects of the corresponding plant, by modelling and interfacing the main processes and by the valuation of their solution.

Learning by competition

It should be possible to carry out competitions between individuals or groups of students on the efficiency of the design and control of CIM-solutions specified on the bases of the computer-aided engineering education system.

MODELLING STOCK-KEEPING EQUIPMENT AND CORRESPONDING PROCESSES

The first research and development phase (within the framework of the TEMPUS-project mentioned above) aims at a prototype subsystem by which CIM-systems in the area of computer-aided design, production planning and manufacturing of bended sheet-metal parts can be modelled, simulated, visualized, explained and evaluated for engineering education purposes. Software developments have been carried out for:

- computer-aided layout of the entire sheet-metal plant;
- computer-aided preparation of manufacturing processes, inclusive of nesting of the developed parts on the plates of sheet metal raw material;
- the configuration of stock-keeping equipment;
- the simulation of stock-keeping processes.

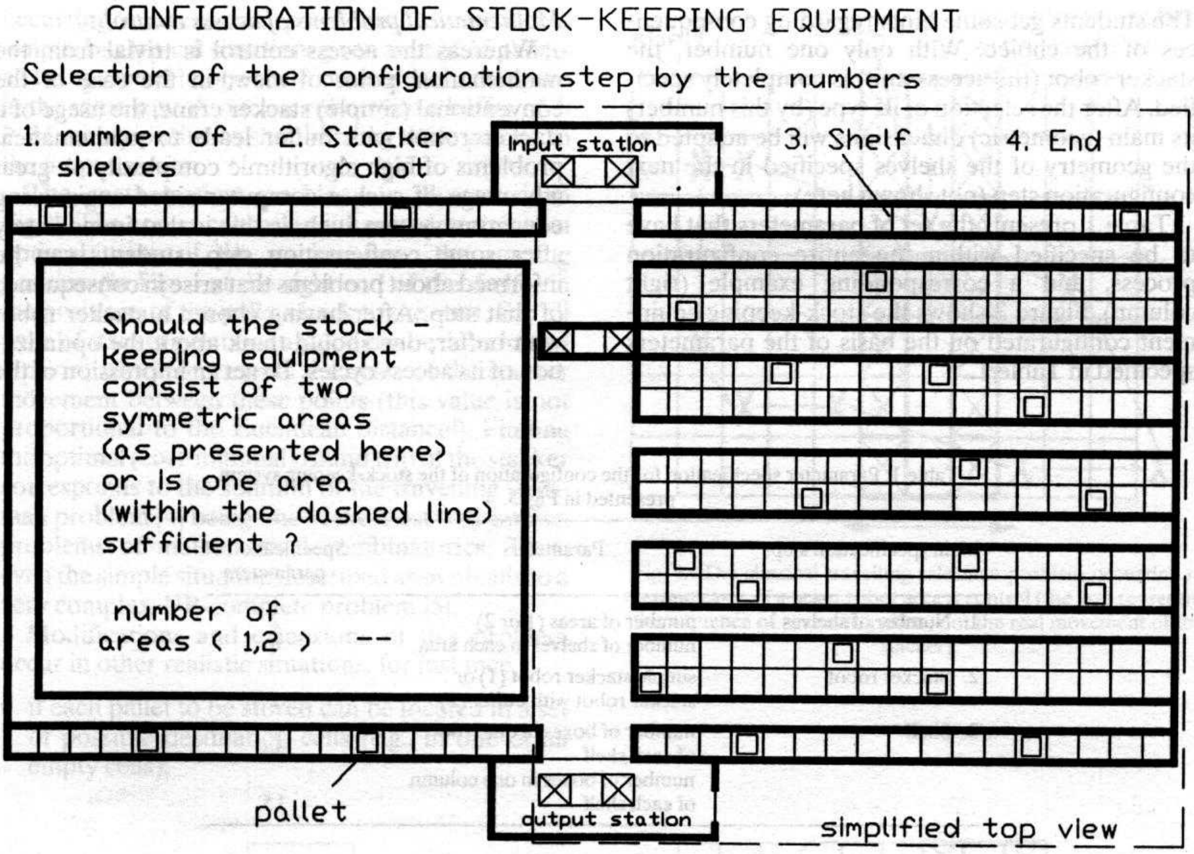
The most advanced developments are the last two. Therefore, in the following, the subsystem 'stock-keeping equipment/stock-keeping processes' and its utilization in a computer-aided engineering education environment will be presented in more detail.

Configuration of stock-keeping equipment

The students are allowed to configurate such an equipment by setting a set of parameters. The meaning of these parameters and certain consequences of the configuration process are explained in an expressive way by graphics, designations and texts (e.g., with hints). The configuration process starts with a graph showing the simplified top view of a typical store, consisting of rows of shelves. The main components are designated. The first configuration step concerns the question, should the entire store consist of two symmetric areas or only of one set of shelf rows (Fig. 1).

In each configuration step the simplified top view on a typical store (i.e., the first picture displayed in the configuration process) is modified. Windows are opened for questions, hints and additional graphics for the presentation of components of the entire stock-keeping system to be modelled. For instance, Fig. 2 shows the selection of a stacker robot. The system offers two possibilities:

- a classic stacker crane (called 'simple stacker robot' in Fig. 2);
- a stacker robot with buffer (as offered by COMAU S.p.A. [3]).



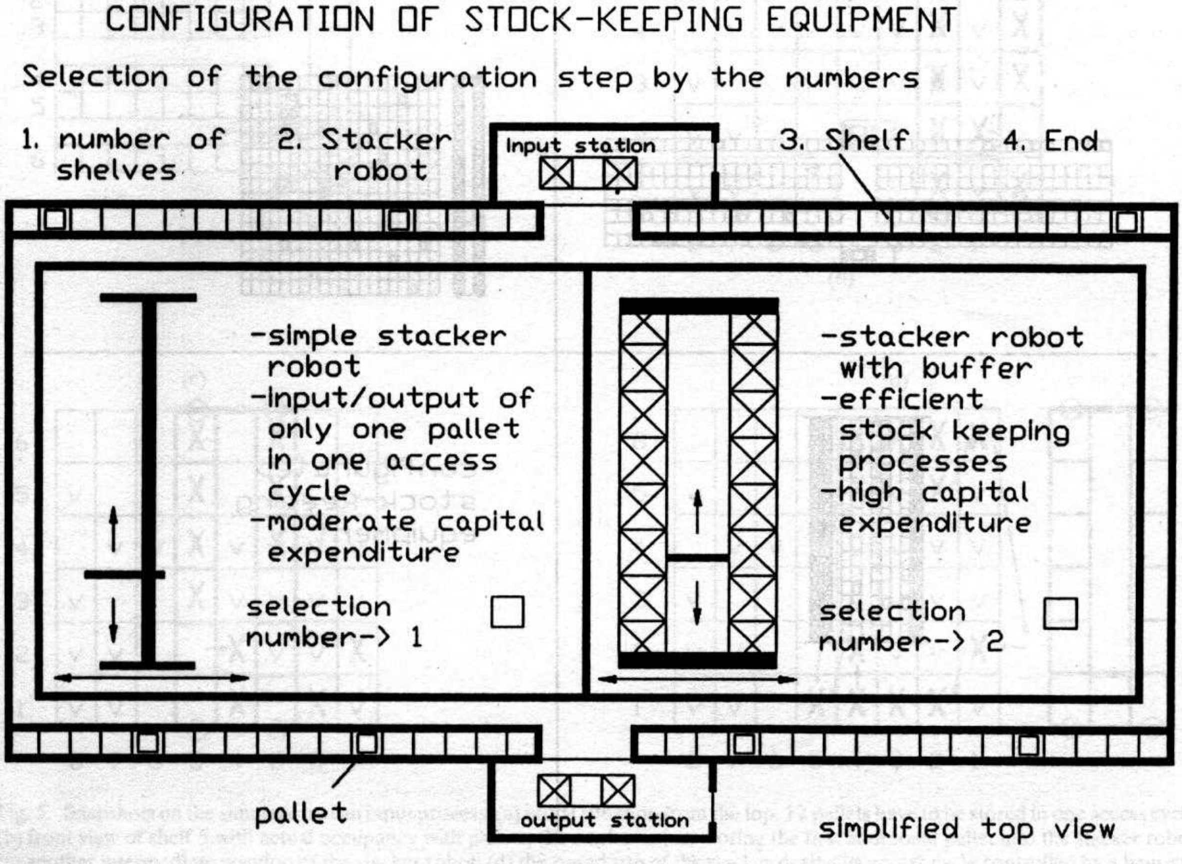
CONFIGURATION OF STOCK-KEEPING EQUIPMENT

Selection of the configuration step by the numbers

Should the stock - keeping equipment consist of two symmetric areas (as presented here) or is one area (within the dashed line) sufficient ?

number of areas (1,2) --

Fig. 1. One step of the configuration of stock-keeping equipment (black-and-white copy of colour graphics on the display of a PC).



CONFIGURATION OF STOCK-KEEPING EQUIPMENT

Selection of the configuration step by the numbers

-simple stacker robot
-input/output of only one pallet in one access cycle
-moderate capital expenditure

selection number-> 1 ☐

-stacker robot with buffer
-efficient stock keeping processes
-high capital expenditure

selection number-> 2 ☐

Fig. 2. Specification of the type of stacker robot.

The students get some hints regarding consequences of the choice. With only one number, the stacker robot (the access unit) is completely specified. After the selection of its type (by this number) its main (geometric) dimensions will be adapted to the geometry of the shelves specified in the next configuration step (not shown here).

Table 1 presents the set of parameters that have to be specified within the entire configuration process, and a corresponding example (right column). Figure 3 shows the stock-keeping equipment configurated on the basis of the parameters specified in Table 1.

Mathematical problems of access control

Whereas the access control is trivial from the mathematical point of view, in the case of the conventional (simple) stacker crane, the usage of a stacker robot with buffer leads to mathematical problems of high algorithmic complexity. A great advantage of such a computer-aided engineering education system such as this is that immediately after some configuration step, students can be informed about problems that arise in consequence of that step. After having chosen a stacker robot with buffer, one should think about the optimization of its access cycles. To get an impression of the

Table 1. Parameter specification for the configuration of the stock-keeping system presented in Fig. 3.

Main specification steps	Parameters	Specification of parameters
1. Number of shelves	number of areas (1 or 2)	2
	number of shelves in each area	6
2. Stacker robot	simple stacker robot (1) or stacker robot with buffer (2)	2
3. Shelf	number of boxes in one row of each shelf	20
	number of boxes in one column of each shelf	15

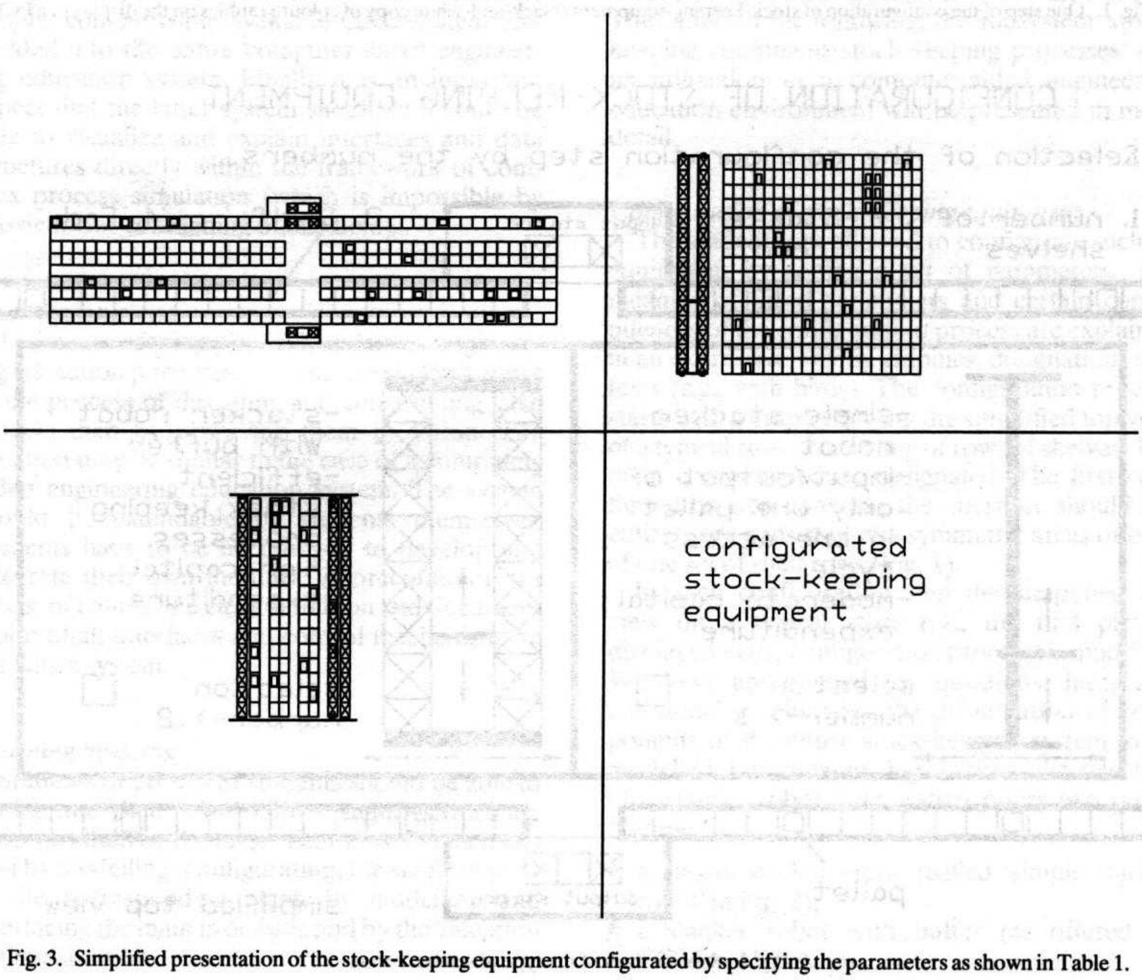


Fig. 3. Simplified presentation of the stock-keeping equipment configurated by specifying the parameters as shown in Table 1.

occurring mathematical problems we consider a simple, but typical situation: given a set of *M* pallets all being stored in one shelf, but not more than two in the same row. A stacker robot with a buffer of $N \geqslant M$ empty positions should bring these pallets to the output station.

The mathematical problem is illustrated in Fig. 4. The access control unit has to determine an optimal route of the stacker from the starting position (in Fig. 4 at the right end of the shelf) via the positions of the pallets back to the start. For all pairs of stacker positions a value can be determined a priori, which represents the costs of the stacker movement between these points (this value is not proportional to the Euclidean distance!). Finding the optimal (cost-minimal) round trip of the stacker corresponds to the solution of the travelling salesman problem [4] being one of the most well-known problems of mathematical combinatorics. Thus, even the simple situation described above leads to a very complex, NP-complete problem [5].

Modifications and extensions of this problem occur in other realistic situations, for instance,

- if each pallet to be stored can be located in a set of possible destination cells (e.g., in one of all empty cells);

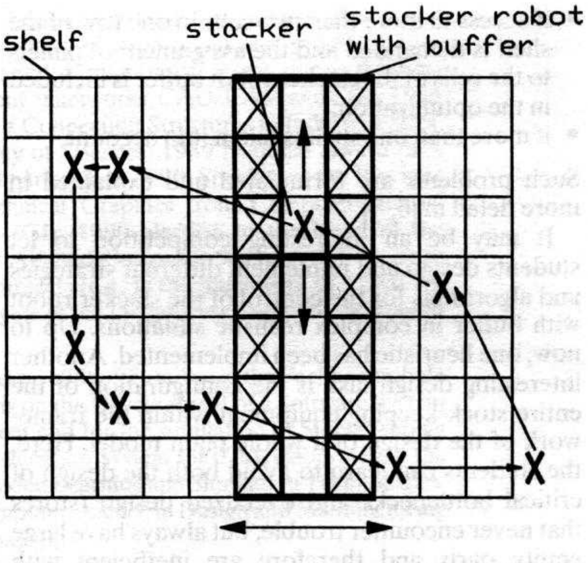
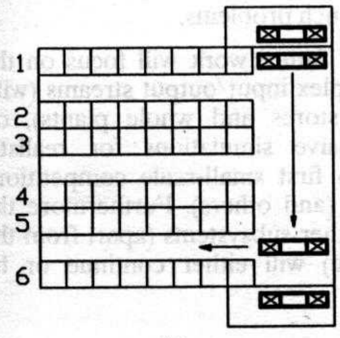
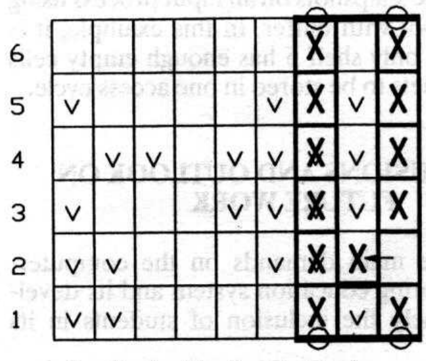


Fig. 4. The classical travelling salesman problem occurring in certain cases of stacker robot access control (the arcs represent the sequence of access to pallets, not the real movement of the stacker).



(a)



(b)

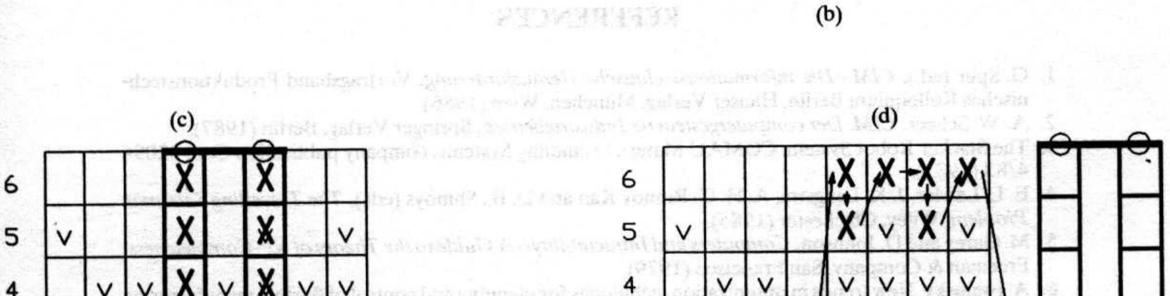


Fig. 5. Snapshots on the simulation of an input process: (a) initial situation from the top; 12 pallets have to be stored in one access cycle; (b) front view of shelf 5 with actual occupancy with pallets; the stacker is just storing the first additional pallet into the stacker robot; (c) another intermediate position of the stacker robot; (d) the round trip of the stacker during its access cycle controlled by a heuristic procedure.

- if access to more than two cells in one row of the shelf is demanded and the assignment of pallets to the cells of the stacker robot buffer is included in the optimization;
- if more than one shelf is taken into account.

Such problems are formulated and explained in more detail in [6, 7].

It may be an interesting competition to let students design and implement different strategies and algorithms for the control of the stacker robot with buffer in complex realistic situations. Up to now, one heuristic has been implemented. Another interesting design task is the configuration of the entire stock-keeping equipment within the framework of the design of a whole plant model. Here, the students can learn to avoid both the design of critical bottlenecks and oversized design (stores that never encounter trouble, but always have large empty parts and therefore are inefficient with respect to costs).

Simulation of stacker robot access

After the configuration of the stock-keeping equipment and the implementation of procedures for the control of its access units, simple and complex access tasks can be simulated on the colour display. Figure 5 shows black-and-white copies of some snapshots on an input process using a stacker robot with buffer. In this example, it is assumed that only shelf 5 has enough empty cells for all the pallets to be stored in one access cycle.

CONCLUSIONS AND OUTLOOK ON FUTURE WORK

One of the main demands on the computer-aided engineering education system and its development, namely the inclusion of students in its design, implementation, testing and successive extension, has already been met. Up to now five (three Czech and two German) students have been working on this part of the TEMPUS-project. One of the authors has done the practical studies in his sixth term (technical computer science) and written his diploma thesis [8] on the subsystem for modelling stock-keeping equipment and stock-keeping processes. It turned out that students of computer sciences and related fields are able to understand the main goals of the development of a computer-aided engineering education system for CIM. They are able to develop subsystems on the basis of descriptions of demanded subsystem functionality. Furthermore they have a good feeling for the presentation of knowledge from the didactic point of view.

With such systems as discussed here, students are able to learn with fun. They also learn to:

- become aware of interdependencies of different processes;
- thinking in an adequately complex manner;
- avoid oversized and bottleneck design;
- foresee consequences of single design steps on the entire design;
- become aware of mathematical problems often hidden by details of engineering aspects;
- utilize the power of mathematical methods for the solution of such problems.

The next steps of future work will focus on the modelling of complex input/output streams (with respect to both stores and whole plants), on performing extensive simulations for realistic examples, and on first small-scale competitions between students (and others). Furthermore the development of other subsystems (apart from the stock-keeping one) will either continue or be initiated.

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