



# Integrated application of real-time expert systems for FMS evaluation and control

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## ABSTRACT

The paper describes some applications of expert systems (ES) for flexible manufacturing systems (FMS). A complex FMS simulation tool is shown with different connection possibilities to expert systems to have a good evaluation performance and the make steps toward automatic control. The interfacing problems of the software modules are also discussed. In the recent stage of the research rapid prototype programs are under test, and the future goal of CIM Research Laboratory (CIMLab) is to solve industrial problems with these tools and softwares.

## INTRODUCTION

The key issue of manufacturing automation is the application of up-to-date, effective manufacturing and assembly systems. Serious steps were done world-wide to introduce Computer Integrated Manufacturing (CIM) systems.

The CIM systems and often their products are so expensive that it is worth evaluating their parameters already in the design phase. The result should be the most reliable system which has minimal installation and operation expenses. Some per cents of decrease in investment and operation costs may be great sums even in the case of one system. The losses caused by break-downs of the system should be decreased by high reliability and by means of fast reconfigurations.

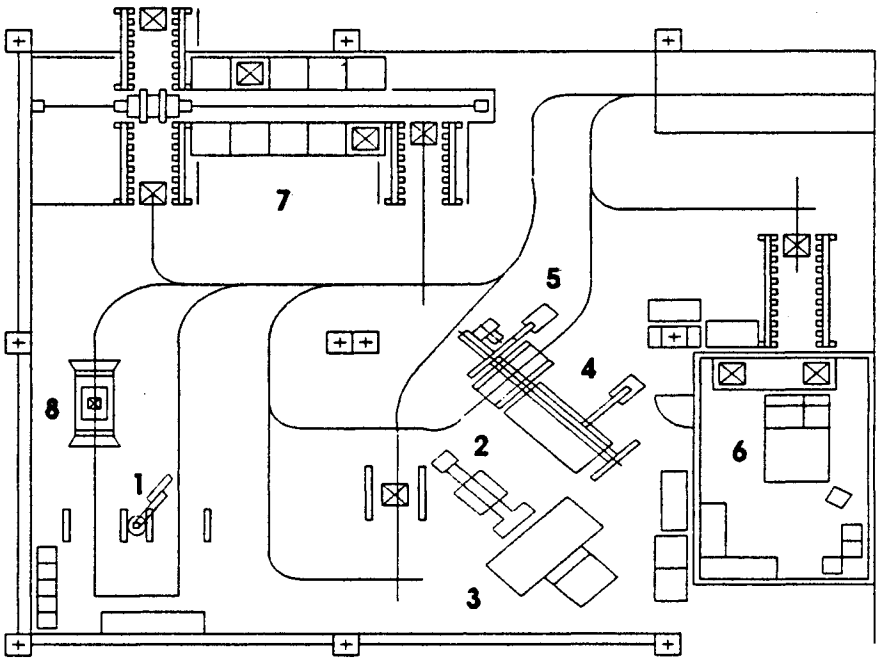
Because of the complexity and the stochastic behaviour of FMSs there are no 'simple' procedures (e.g. based on input/output relationships) to design and operate them. There is a world-wide research to apply different methods to assist this design and operation. Many research and some real industrial projects prove that one of the best promising topics is the application of the expert (knowledge based) systems. In most cases expert systems are used only for special purposes in a 'normal' (viz. traditional programming) environment.



Better performance is expected by means of co-operating expert subsystems (eg. Kovács[4]) or by expert systems realised on parallel computers (eg. Riley[1]).

The first part of this paper is going to deal with different, but corresponding possible applications of expert systems in the FMS area. The second part will describe how it is possible to build some of these parts together to have a flexible FMS simulation tool. The third part will show the technical questions of the interfacing of the software tools used in the project.

The rapid prototype programs to solve the above tasks are under test and the first practical example to which they are applied are the simulation (animation), quality assurance and control of the manufacturing cell of the CIM pilot plant at the Technical University of Budapest (Fig. 1 ). This pilot CIM system has four cells: the storage cell (7), the manufacturing cell (2+3+4+5), assembly cell (1) and the measurement cell (6). An AGV is transferring pallets from the storage to the other cells and back to the storage. The control of the AGV is solved together with the control of the storage cell.



- 1. UNIMATE PUMA 760 assembly robot
- 2. FANUC M3 robot
- 3. Polyax TC3 manuf. center
- 4. EEN400 CNC lathe
- 5. IGM Re kard MR08 Portal robot
- 6. Opton UMC850 measuring machine
- 7. ROBOPLAN storage

Fig. 1. CIM Pilot Plant at the Technical University of Budapest

## EXPERT SYSTEM APPLICATIONS FOR FMS

### Evaluation of FMS performance

It is a common experience in the CIM research and application, that the users of an FMS or even of a more simple system with partly automatically driven equipment, don't exactly know the performance and capabilities of their system. It means the correct capacity values, the real reserves, the weaknesses of the system, etc. An off-line analysis can help to answer to these problems.

On other hand, in the design and building phase of an FMS a good tool is also needed to modify and optimise the future performance.

Simulation can help in evaluating the performance of planned and of working FMSs. After evaluating the simulation results, the number or the capacity of machine tools, transport facilities, buffer sizes, etc. can be increased or decreased. The bottle-necks of the system can be detected before the expensive real operation of the FMS.

Another domain of FMS simulation is when simulation is used for creating the manufacturing schedule. There are different methods (mathematical, heuristics, etc.) for scheduling. Each of them has advantages and drawbacks. Scheduling with simulation is usually fast and reliable. During the simulated manufacturing process, which is based on the process plan, the starting and finishing time of each operation can be recorded, and later on a schedule can be built up based on this information.

Combining simulation systems and knowledge based methods seems to be a good idea in order to solve both the analysing and scheduling problem. The ES has power for decision making during simulation and - in off-line mode - to find the best parameters of the simulated model.

This theory is under development (the prototype version is already running) in CIMLab in a complex simulation system. The next chapter will discuss it.

### The effects of quality assurance to the FMS

The quality of products has an increasing role in the market competition besides other factors as e.g. "One-of-a-Kind Production". There are different methodologies for product quality assurance like Total Quality Management (TQM) (eg. Ranky[8]) or Taguchi method (eg. Disney[15]) during the product life cycle. Quality should be designed into the product and the processes involved when designing, fabricating and maintaining it through its life cycle. The careful evaluation of performance in the system design phase involving also product and system quality aspects can result in a good balance between costs and quality.

Because of the quality control, measurement actions with classifications are included into the manufacturing processes. The simulation of an FMS can



be used to examine the cost and delay effects of these measurements. The waste can be calculated with statistical quality control (SQC) methods (eg. Kimbler[7]). Effects of optimal and forced technology can be also parametrized.

The simulation system discussed in the last chapter is modified to be able to solve such problems. The basis of the analysis is the running of the simulation more times with different SQC and technology parameters and using more probability distributions of the results of the measurements. In this approach the job of the ES is the setting the parameters and the intelligent comparing of the simulation results.

This system is realised as a part of the complex simulation system introduced in the next chapter.

### Coupling problems of expert systems and real devices

Because of the real-time possibilities of some expert systems cell-control/supervision systems for assembly and manufacturing cells can be implemented using them.

It can be stated that an appropriate expert system shell is suitable for implementing a model of a flexible manufacturing cell, since it is able to represent the structure of the cell in a manageable manner, it gives response for an inquiry in a few seconds, and it manages the continuously arriving external data.

The main problem of these types of solutions is to reach of the real devices, industrial network elements from the expert system. The ES interfaces are generally C (or other programming) language structures and routines, instead of direct supporting industrial networks and devices. So nearly each implementation requires special software development to cover this gap between the devices and the ES.

From the different industrial networking point of view the MAP 3.0 (Manufacturing Automation Protocol) network is an international OSI standard. According to the OSI (Open System Interface) network protocol model the 'manufacturing specific' part of the MAP protocol is in the application layer - the MMS (Manufacturing Message Specification) [9]. This is a tool to cover the special features of the different devices, and across the network each MAP node looks like a VMD (Virtual Manufacturing Device) with defined type of objects and services. In other words the MMS gives a widely used method for description and specification of manufacturing objects and the connections among them. There are some very important features of this approach:

- More and more products in the shop-floor level (PLCs, CNCs, RoCs) support MAP 3.0 instead of proprietary networks, and in this network MMS is



the language of the real (logical) communication. For 1992 on the main computer platforms the MAP is reachable (often as third party products).

- Companion standards help implementing MMS for the controllers. The objects and services of the MMS give possibility for using it in the higher information levels of the factory. Research projects are running (eg. Fieldhouse[2]) to examine the usage of the MMS in the cell and area levels.

So the topic is to examine how to put the MMS accessible from an expert system. A project in the CIMLab is established to develop an MMS interface of G2 expert system from Gensym [12]. A C program communicates with the G2 and via linked library MMS messages can be sent and received to the MAP network (see Fig. 2). The MMS-EASE software package is used from SISCO [6]. Examining G2 two alternative solutions can be solve the problem.

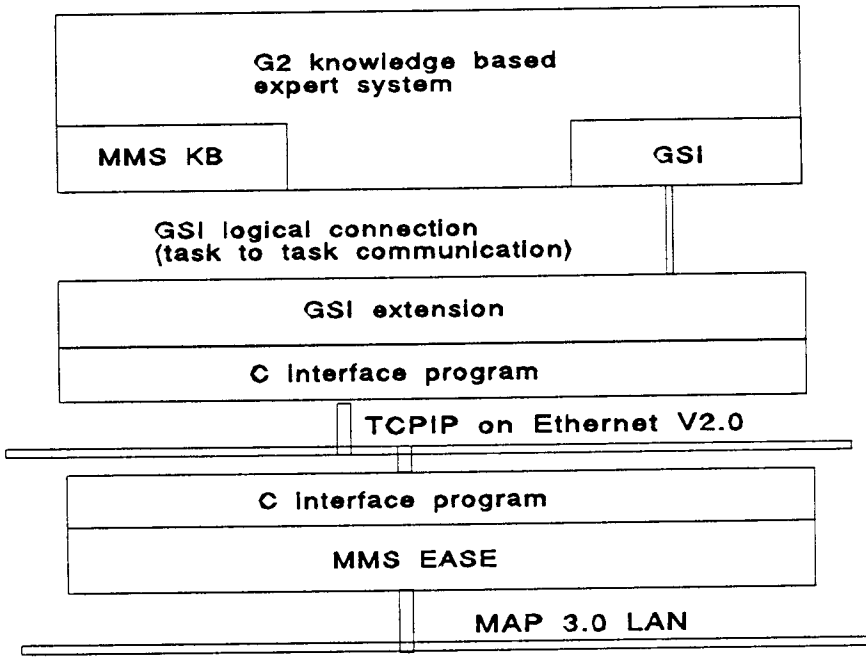


Fig.2 G2 interfacing to a MAP network (prototype solution)

1. It is possible to define object types which correspond the MMS objects, the attributes of the objects are the same as in the MMS standard. Via GSI (G2 system interface) the C program running parallel can read and write these values. The advantage of this approach is that a G2 KB can 'see' the same view of the devices as they support themselves to the MAP network. The disadvantage is that the G2 realisation of the MMS services is poor, they do not mean more than simple reading and writing data.



2. If G2 external procedure calls are used, all MMS services can be realised with special procedures. It is a reversed situation, the KB can use easily the services, but has to take care about the objects. The second solution has been chosen, because there was no need to use the MMS objects directly inside the G2. Because of the big number of the MMS services, the first tests implement only some of them (context management, VMD and variable). The test environment has another problem, that the MMS-EASE and G2 were running on different UNIX machines (Motorola DELTA and Sun SPARCstation). So the interface C program was divided into two parts and a simple TCP/IP software solved this communication problem (see Fig. 2).

These efforts established the tool to move with the results described in the earlier paragraphs from the simulation to the real control in the future.

## A COMPLEX SIMULATION SYSTEM USING KNOWLEDGE BASED MODULES

An experimental KB Simulation in a special rule based simulation language called CS-PROLOG (Communicating Sequential Prolog) (eg. Futó[10]), has been developed in CIMLab (eg. Kovács[3]). Unfortunately the system became too big to handle some memory problems, so we started to develop a new system which reflects the idea of connecting a traditional simulation system to expert systems.

At the same time it was realised that some quality control and scheduling aspects can relatively easily be incorporated into the system by applying separate advisor systems which are communicating with the simulation, answering possible questions. The simulation scheduler with quality assurance is called SimSched-Q.

Architecture and knowledge bases of SimSched-Q The architecture of the system can be seen in Fig. 3. The system consists of four main modules: Preparation Expert System (PES), Simulation-Animation System (SAS), Advisor Expert System (AES) and Evaluation Expert System (EES).

**The Preparation Expert System (PES)** collects all input data for the simulation and according this modifies the variables of the simulation model. The inputs are: the process plan or schedule; the orders and priorities of the workpieces; timing data; measuring instructions for quality assurance (vic. SQC). The main feature of the PES is the capability of multiply simulation of the same problem in different conditions. This knowledge base will contain rules to chose the appropriate simulation inputs.

**The Simulation-Animation System** executes the simulation with the inputs generated by the Preparation Expert System. The simulation can be used for scheduling and examining the quality control effects as well. Both functions need many decisions, which are partly made in the Simulation-Animation system itself and partly made by the Advisor ES. If the simulation



needs help from the AES the simulation stops, sends its question to the AES and waits for the reply. During the simulation a graphical animation - like an animation movie - helps to understand and follow the simulated manufacturing process on the computer's screen.

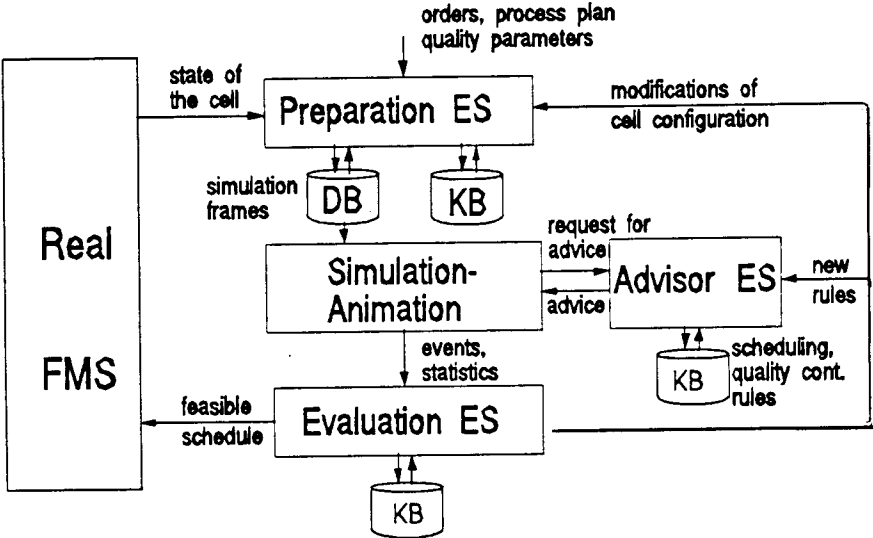


Fig. 3. The architecture of SimSched-Q

**The Advisor Expert System (AES)** is co-operating with the simulation. The knowledge base of the AES consists of scheduling and quality control rules, but they are separated. They mean two modes of the simulation. As there is a big amount of unstructured knowledge to handle and there are several conditions to be fulfilled at the same time only such a knowledge based advisor can be used effectively. Rules for on-line priority determining and choosing among the alternative paths belong to the scheduling part of the knowledge base, measurement evaluation and unexpected event handling rules belong to the quality control KB.

The AES waits for the questions of the simulation on certain decision points. Receiving the question (data) the AES starts its inference process and sends back the concluded answer referring to the schedule or the quality of the product.

**The Evaluation Expert System (EES)** evaluates the results of the simulation which are the utilisation statistics of all equipment in the FMS and the manufacturing schedule. If there was an input schedule given to the system the resulting schedule will be a checked version of it. If the scheduling capability of the system is used - without input schedule - an original schedule will be produced by the simulator and checked by the EES. The knowledge



from human experts and from experience which help in deciding on acceptance or rejection.

Depending on the knowledge base of the EES it can decide whether the schedule and the cell configuration is acceptable or not, and in both cases modifications can be suggested. These suggestions may be the application of new rules by the Advisor ES or the modification of the original conditions of the manufacturing cell by the Preparation ES.

Prototype version of SimSched-Q

The prototype configuration of the Simulation Scheduler System with Quality Assurance can be seen in Fig. 4.

The **Input Module** collects the manufacturing task, the schedule (if there exists) and the cell configuration from the user. In this prototype version this module has no KB, it gives a user interface to get the parameters of the simulation system. It has been written in Turbo C using the Zortech C++ Windows library on an IBM PC/AT under DOS.

The **Graphical Layout Planner (GLP)** is a part of the SIMAN/Cinema simulation/animation software system (eg. Pegden[5]) and allows the user to define the connections for the CINEMA animation between the graphical symbols of the resources and the resource identifiers of the SIMAN simulation model. AutoCAD drawings have been used as the input of the GLP.

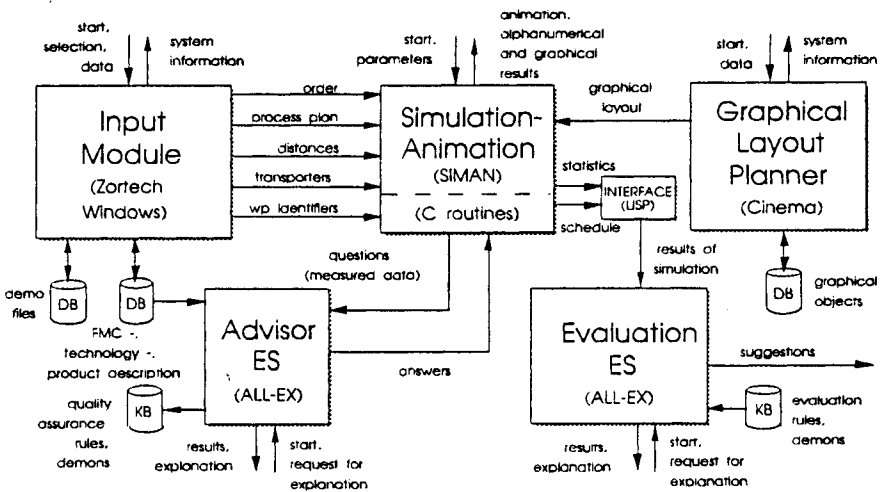


Fig. 4 Prototype version of SimSched-Q

The **Simulation-Animation System** has five main parts according to the SIMAN software. The Model Frame consists of the model of the simulated system. It means the whole process of all (manufacturing, transporting storing



etc.) devices named STATION in the SIMAN. The Experimental Frame contains the actual parameters of the simulation model. The orders, the process plan or the schedule, the timing parameters and the data related with the quality control belong to this. According to our future plans the second frame will be generated by the Preparation Expert System, but in this version it is done manually yet with the Input Module. The SIMAN Run Processor has been extended with C routines. These routines keep the contact with the Advisor ES, and writes the manufacturing schedule records.

The Advisor ES (written in ALL-EX expert system shell [11]) contains feature based expert knowledge on the production means and products and on quality control and scheduling. For example in the quality assurance mode the AES waits for the simulated measured values of certain workpieces, and decides whether the workpiece is good, repairable or waste.

Scheduling rules help in different decisions as e. g. which workpiece can leave the storage first, which resource is more advisable for a certain operation, etc. In the recent prototype version the well-known Round Robin strategy (rotating priority) is implemented.

The Evaluation Expert System (also ALL-EX) has only simple tasks in the prototype to check basic inconsistencies of the outgoing schedule.

The working prototype version of the Simulation Scheduler System proved that knowledge based systems can efficiently help the work of traditional simulation systems.

#### The limits of the application of the prototype SimSched-Q

The application of the ALL-EX shell for the advisory systems was successful enough to have a rapid prototype, but because of some problems we were forced to find another expert system shell.

The ALL-EX system is running on an AT386 (33 MHz, 8 Mbyte) under OS/2. Comparing this environment with the performance of the ALL-EX, it is clear that the ALL-EX version we have is rather poor in speed. Memory allocation problems appear growing of the KB. In the communication point of view the prototype uses files on discs, and the open networking solution (TCP/IP) is poorly supported for OS/2.

The parameters of the real-time expert system shell G2 and some preliminary experiments with it were rather good to start to think about realising all our expert/advisory systems in G2 and about the G2-SIMAN interfacing.

Using G2 and SIMAN Knowledge Based Simulation-Scheduling-Quality Control Programs will be created to support the evaluation and better performance and control of working FMS and to be used in the design (planning) of new FMS implementations. In the present phase of the project



we analysed the problems of connecting G2 and SIMAN, then a test version of the interface was designed and coded.

## CONNECTING A SIMULATION PACKAGE WITH A REAL-TIME EXPERT SYSTEM

There are possibilities of applying knowledge base (KB) routines in simulation, or applying simulation built into the KB reasoning system. See (eg. O'Keefe[13]) about the taxonomy of connecting simulation and expert systems.

The SimSched-Q, (as it can be seen in Fig. 3) uses a combination, where the simulation data and model are prepared by a KB system, there is another KB system that gives advises during the simulation run, and finally a third KB system evaluates the simulation results.

On modelling level the system can be identified as a deep coupled composite intelligent model in the preparatory and the simulation phases, and a shallow coupled one in the result evaluation phase (eg. Mezgár[14]).

There are several advantages of using G2 for FMS and FMC control, and on the other hand SIMAN are widely used to model and simulate (and animate) the same kind of systems. In spite of the fact that G2 has its own simulation possibility, because of some special features of SIMAN (automatic controlling of AGVs, good statistics, etc.) we began to deal with the connection of G2 with SIMAN.

### I/O possibilities of SIMAN

There are three different ways of communicating with SIMAN. Data inputs can be done by means of the Model Frame and Experimental Frame, outputs can be collected in files written by the SIMAN Run Processor in the SIMAN Summary Report. On-line communication can be achieved via the SIMAN commands READ and WRITE, which are rather far from the basic philosophy of SIMAN, and were added only to the version IV. Another way of communication is the application of C and FORTRAN language routines that can be linked to the SIMAN routine library. This way an extended SIMAN Run Processor will be used when the simulation runs. The application of these routines can be the best way to be used for real-time communication.

### G2 I/O possibilities

The G2 real-time expert system shell has four interface possibilities which can be used for external interfacing. The Foreign Function Interface gives a possibility to call external C and FORTRAN functions. The G2 File Interface (GFI) is a way of communicating with G2 by means of I/O files. The G2 Standard Interface (GSI) makes it possible to communicate with external processes, as e.g. with an external simulator. The G2 Simulator Interface (GSPAN) is a network-oriented interface to connect G2 with external simulators.



From the point of view of SIMAN all the four possibilities could be imagined depending on the timing requirements, and on the amount and quality of data that should be exchanged. However to have a real-time, on-line connection only GSI and GSPAN can be taken into account.

### G2-SIMAN real-time interfacing

In the case of implementing the system /outlined in Fig. 3/ for PES and EES purposes any of the previously given methods can be used for interfacing from both the SIMAN and G2 side, however the simplest implementation solution can be gained by using GFI together with the READ/WRITE facilities of SIMAN. This way all communications are performed via files, and there is no need to use the networking possibility of G2.

For connecting G2 as Scheduler advisor the SIMAN interfacing with C (and FORTRAN) routines is the only way to be used. The routines should be written to co-operate with G2 and they should be activated in the SIMAN Model Frame in the appropriate moments. From the G2 side GSPAN and GSI could be equally used, however, as SIMAN is not object-oriented, the advantages of GSPAN cannot be gained, so the application of GSI is suggested.

In the first prototype of interfacing SIMAN and G2 the solution we decided was a simple message exchange via two files over a TCP/IP network using NFS. The logical queue is only one message deep and the handshaking conditions are the existence of the files. The main reason of this decision is the following. The G2 is running on a SPARCstation under UNIX, the SIMAN on IBM AT under DOS. The SIMAN with the application requires nearly 600 Kbyte RAM memory, so a TCP/IP package needs on the PC which uses as little memory as possible. A Sun software called PCNFS [16] solved this problem. In the next phase the development kit of the PCNFS will be used which allows direct socket programming with the Berkeley socket programming tool. As an other solution SIMAN is available also for SPARCstations.

The higher level of the interface is the exchanging information between SIMAN and G2 in a task written in C. The GSI has a certain way of sending and receiving variables (called GSI variables) to an external task. The G2 programmer has to take care of defining GSI variables and building up the relations between them and the other part of the G2 program (vic. knowledge base). SIMAN offers an other way of interfacing. The linked C program can call more than library routines which give back the SIMAN data. This method is easy to use, but has more limits of reaching the information.

To cover the logical interfacing problems of the two softwares, a special object oriented representation of FMS elements is under definition which is suitable for G2 and SIMAN.



## CONCLUSIONS

A good, close to optimal design and operation of complex, real-time, stochastic systems, as flexible manufacturing systems cannot be reached by the application of only traditional (procedural) programming, but the application of artificial intelligence means is required together with sophisticated modelling and simulation.

Some examples and results were shown how to combine a traditional simulation/animation package (SIMAN/Cinema) with advisory expert systems written by using different expert system shells (G2, ALL-EX) and with C programming to get solutions to some aspects of simulation, quality control, scheduling and control of flexible manufacturing systems.

We think that based on our preliminary results programs for the industrial projects can be written to assist in the evaluation, design and operation of FMSs and the results can be generalised to other complicated design and operation areas as well.

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