A Knowledge Based and a Hybrid System to Evaluate Flexible Manufacturing Systems

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Abstract

Computer aided simulation can assist both in the design and operation of flexible manufacturing systems (FMS). A proper simulation model of a given FMS could be the best tool to validate it and to evaluate its performance. System control can be solved by separating the control from the FMS with a communication interface. In this case it is possible to use the simulated system for investigations instead of the real system. Such simulation systems can be built up using expert system shells. In this paper an FMS simulation system (SSQA) will be introduced with the hybrid application of expert systems and a traditional simulation software. The system has some evaluation, scheduling and quality control power as well, according to the implemented advisory systems which communicate with the simulation package. As an alternative of the hybrid system a pure knowledge based (KB) system is discussed. The comparison of the two systems using the same CIM pilot plant is also given.

1 Introduction

The manufacturing process in a manufacturing system is defined by the manufacturing schedule which is created from process plans and actual orders. Process plans describe the manufacturing of every types of parts in operation order, the alternative machines, tools, etc. to all operations and the time period of each operation. The actual order contains the number of parts required. The manufacturing schedule has the information of the process plans (the time periods and dedicated machines and tools instead of alternatives) plus the starting times of the operations. A good scheduler can take into account the duration of transportations and setups as well if they may not be neglected. In this point of view the control of an FMS means to produce all necessary information for each equipment of the system in time and to activate them by an information transfer.

This way a scheduler with real-time capabilities is the key of computerized control of an FMS. That is the main reason why we prefer the application of real-time software even for simulation where it were not necessary.

A simulation model is a perfect tool to evaluate the performance of FMSs as different schedules can be examined with minimal costs, and different system problems, as break-down situations, etc. with necessary re-scheduling can be investigated.

2 Simulation of flexible manufacturing systems

2.1 Advantages of simulation for manufacturing applications

The simulation procedures can be used during the life cycle of an FMS.

- For capacity planning the bottle-necks of the system can be detected before the expensive real operation of the FMS starts. After evaluating the simulation results, the number of machine tools, transport facilities, buffer sizes, etc. can be modified.
- Simulation can help in evaluating the performance of planned and of working FMSs as well by checking the production schedules versus expectations or by means of comparing different schedules.
- By the means of simulation it is possible to estimate the earliest shipping time of products ordered or to resolve feasible sequence and size of batches manufactured.
- 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 these information. The power of schedules produced by simple simulation is generally not comparable with schedules resulted

from sophisticated, specialized scheduling algorithms, but they are produced definitely faster and are reliable. They have advantages in the case of often needed re-scheduling.
- Intelligent simulation can be used for quality control as well. Using multiple simulation the effect of the usage of statistical quality control can be estimated to the batch sizes and due-dates. Having data of quality analysis of a given operation the measurement process can be also simulated.
- Unexpected events (machine breakdowns, high priority orders etc.) can be examined, too.

The selection of programming tool (e.g. traditional, object-oriented or special simulation language) is resolved by the aim and environment of the given simulation [8].

2.2 Decision making in simulation

Creating manufacturing schedules with simulation there are several decisions - even if only simple algorithms are used - which can hardly be processed with the generally available if-then-else structures of traditional simulation languages. For example:

- if there are more than one workpieces in a parallel buffer (temporary storage), the question is which workpiece can leave the buffer first, or
- if more than one machine tool is suitable for a certain operation, one should be chosen,
- etc.

Combining simulation systems and knowledge processing methods can solve the problem of decision making during simulation. This combination will result in the so called knowledge based (KB) simulation.

3 Experimental KB Simulation Systems for FMS

3.1 Application of CS-PROLOG

The first Knowledge Based FMS Simulation system developed in the CIMLab of CARI [4] was written in a special rule based simulation language, CS-PROLOG (Communicating Sequential PROLOG) [2], which is a PROLOG language extended with simulation facilities. When the system began to grow different problems of the PC based system appeared making the developing harder. The speed performance of the PROLOG program was decreasing radically.

3.2 Application of hybrid systems - SSQA

Then a new system (SSQA - Simulation-Scheduler-Quality Assurance) was defined which reflects the idea of connecting a traditional simulation system to expert systems (deep coupled hybrid system). At the same time it was realized that some quality control and scheduling power can relatively easily be incorporated into the system by applying separate advisor systems which are communicating with the simulation.

SSQA will consist of a traditional simulation system coupled with three expert systems. The four main modules: Simulation-Animation System (SAS), Preparation Expert System (PES), Advisor Expert System (AES) and Evaluation Expert System (EES). AES is deep coupled to SAS, while PES and EES are shallow coupled (Fig. 1).

- The Preparation Expert System (PES) collects all input data for the simulation and creates the simulation model. In this case in breakdown situations PES initiates the creation of a new schedule.
- The Simulation-Animation System (SAS) executes the simulation model generated by the PES. Both scheduling and quality control functions need many decisions, which are made in the Advisor ES. If the simulation needs help from the AES the simulation halts, 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.
- The Advisor Expert System (AES) is the slave of the simulation. It waits for the questions of the simulation on certain decision points. Receiving the question the AES starts its inference process and sends back the concluded answer. The knowledge base of the AES consists of scheduling and quality control rules. Workpiece and resource priority rules belong to the scheduling part of the knowledge base, and measurement evaluation rules to the quality control.
- The Evaluation Expert System (EES) evaluates the results of the simulation which are the utilization statistics of all equipment in the FMS and the manufacturing schedule.
  The EES has a statistical evaluation power, too. It is applied when not only one, but several simulation runs are processed in a row and all results are evaluated together. The number of such simulation runs (10-100 or more) depends on the size of the FMS, on the number of different parts to produce, on their batch sizes and on the available scheduling and quality control algorithms implemented in the advisory system (AES). The calculation of this number is a complicated task, and we do not yet have a good method for it, so recently blind guess methods are used.

Depending on the knowledge base of the EES it can decide whether the schedule and the cell configuration is acceptable or not, and in this latter case modifications can be suggested. These suggestions may be the activation of other rules by the Advisor ES or the modification of the original configuration of the manufacturing cell by the Preparation ES.

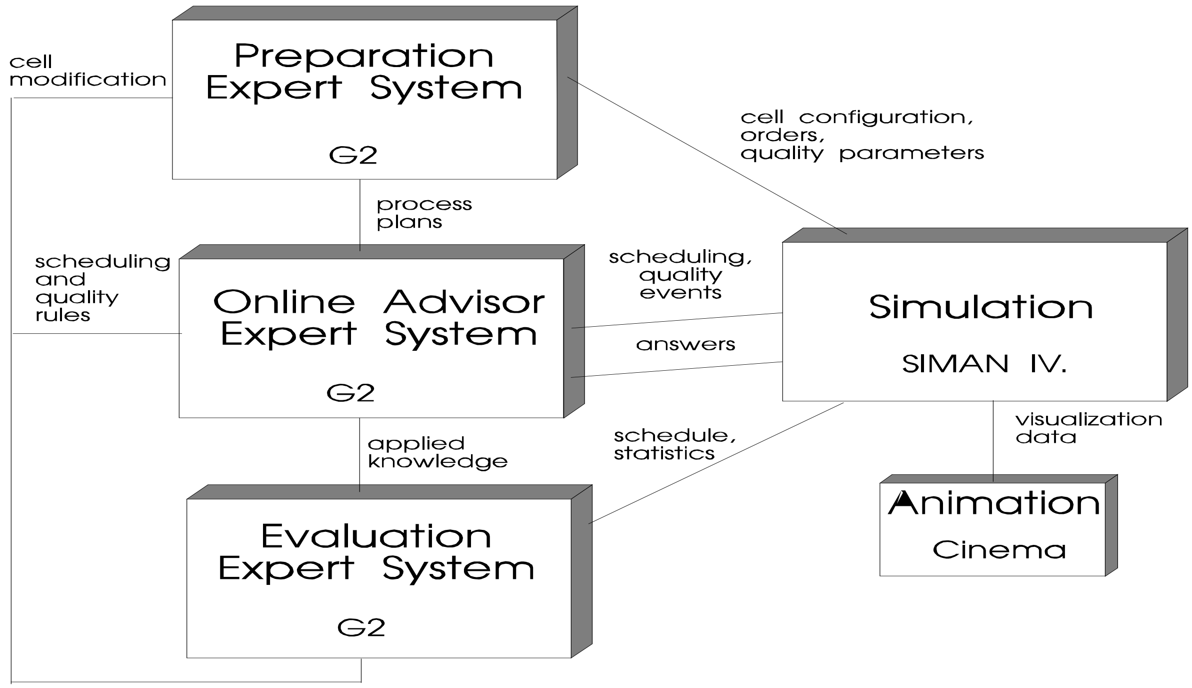

Fig. 1 The main modules of SSQA (the hybrid system)

3.2.1 The prototype version of SSQA

In the prototype version (see [7] for more details) an Input Module substitutes PES. It collects the manufacturing task, the schedule (if there exists) and the cell configuration from the user. It is running on IBM PC/AT under DOS using the Zortech C++ Windows library.

The Simulation-Animation part of the system is a SIMAN/Cinema [1] based module. The SIMAN Run Processor has been extended with C routines to keep contact with the Advisor ES.

The Advisor ES in the prototype was written in ALL-EX expert system shell [3], under OS/2 operating system. The AES waits for the questions of the Simulation system, which are the simulated measured values of certain workpieces, and decides whether the workpiece is good, repairable or waste. The AES can access to different databases (order, product - part, technology, machine etc.) that contain the actual numerical information of the listed items. The scheduling rules in the prototype version were implemented in the SIMAN. This solution has some limitations (the development time of the SIMAN model is long, and only simple scheduling rules could be implemented).

The prototype Evaluation AES (written also in ALL-EX expert shell, under OS/2) checks whether all types of products have been produced in the required quantity and before the given date. Then it evaluates the utilization of machines and produces statistical data, if necessary. Finally, it determines which machine tool or other equipment is a bottle-neck.

3.3 Application of G2 to build advisory systems

The work with the SIMAN/ALL-EX based hybrid prototype version of SSQA proved that knowledge based systems can efficiently help the work of traditional simulation systems.

The testing and evaluating of the prototype version showed that ALL-EX did not have enough power to serve as an on-line expert system for the simulation. Communication, speed and memory problems were analyzed. So more accepted and commonly used AI tools were examined (MULISP, CLIPS, NEXPERT, G2). The real-time expert system G2 [5] was chosen because of its high speed, communication features and built-in capacities (procedures, rule classing, user-friendly support of development). Comparing the costs of the potential simulated FMSs the price of G2 was acceptable.

At the beginning SIMAN/Cinema were running on a PC, while a SUN SPARCstation was used for G2. To run the two systems together an interface between SIMAN and G2 [6] was developed. Both the network interface software and the application of SIMAN on a real size problem have high memory requirements which is rather difficult to provide under the DOS. So in the last version the SIMAN/Cinema is running also on a SUN, too. This way three tasks are running parallel: the G2 knowledge base, the SIMAN simulation and a communication server.

All the knowledge of the advisors implemented in ALL-EX was transformed into the appropriate formats of G2 without major problems.

3.4 Simulation and advisor ESs in the same G2 KB

Checking and learning the G2 possibilities an experimental system was developed where all programs were written in G2 to solve the tasks of knowledge based simulation, quality control and scheduling of an FMS. The structure of the system is given in Fig. 2. The natural advantage of this system is that neither interfacing nor co-operation problems appeared in comparison to the previous prototypes, where G2 had to cooperate with SIMAN/Cinema.

The main difference was caused by the G2's object-oriented view of a system. All elements of the simulated system are now represented by G2 objects. There exists a hierarchy between the objects which makes the attribute inheritance possible. In the following some of the classes we have defined are listed, together with their attributes (inherited attributes are not mentioned):

- workpiece (state, present-station, next-station, current-station, type, colour, process-plan, option)
- process-plan (first-element, type, colour, is-required, sum-of-is-in, sum-of-is-req, sum-of-is-prod)
- place (state, level, layer, machine-name, entry-x, entry-y, time-to-begin, time-to-finish)
  - workplace (state)
  - store place (state)
- cell-unit (state)
  - transport-device (state, dest-x, dest-y, speed, speed-level, radian)
  - cell-equipment (state, place-list)
    - store (wp-list, place-list)
    - machine (place-list)

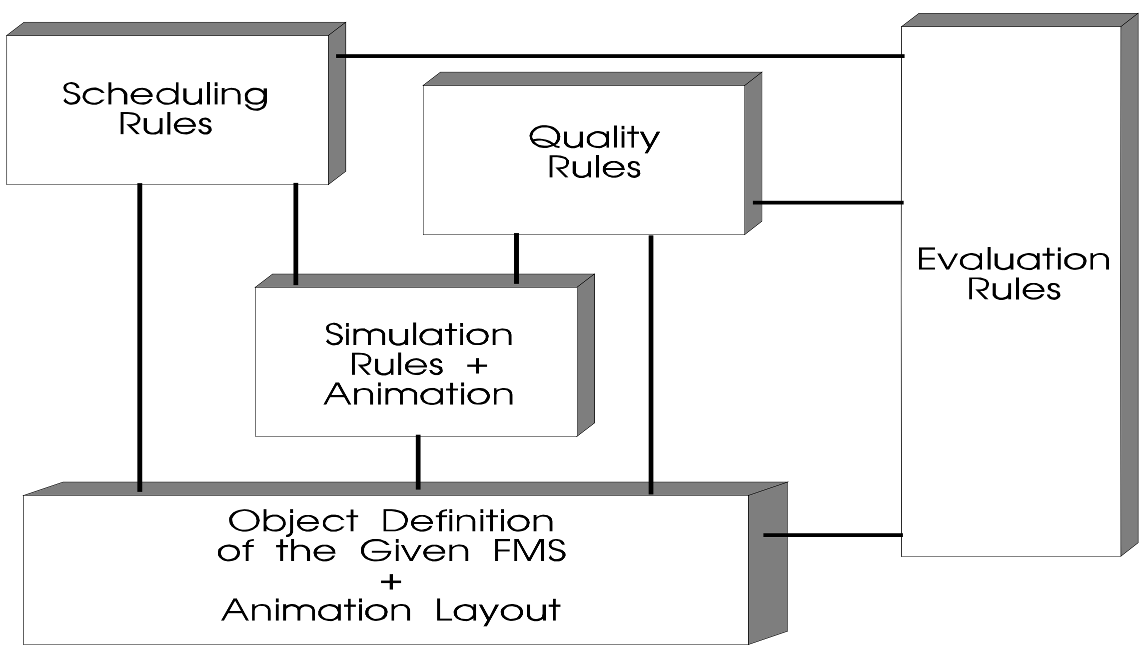

Fig. 2 The knowledge bases of the pure G2 system

4 Comparison of hybrid and pure G2 solutions

Both experimental systems was developed to simulate a real system - the pilot FMS of the Technical University of Budapest. Fig. 3. shows the layout of the system.

There are four cells (assembly /1/, storage+AGV /7/, measurement /6/, machining /2,3,4,5/) in the system. The machining cell consists of a CNC machining centre /3/, a CNC lathe /4/ and two robots /2,5/. The system has an input buffer and each machine tool and station has one input/output buffer, one automatic pallet changer and one working space.

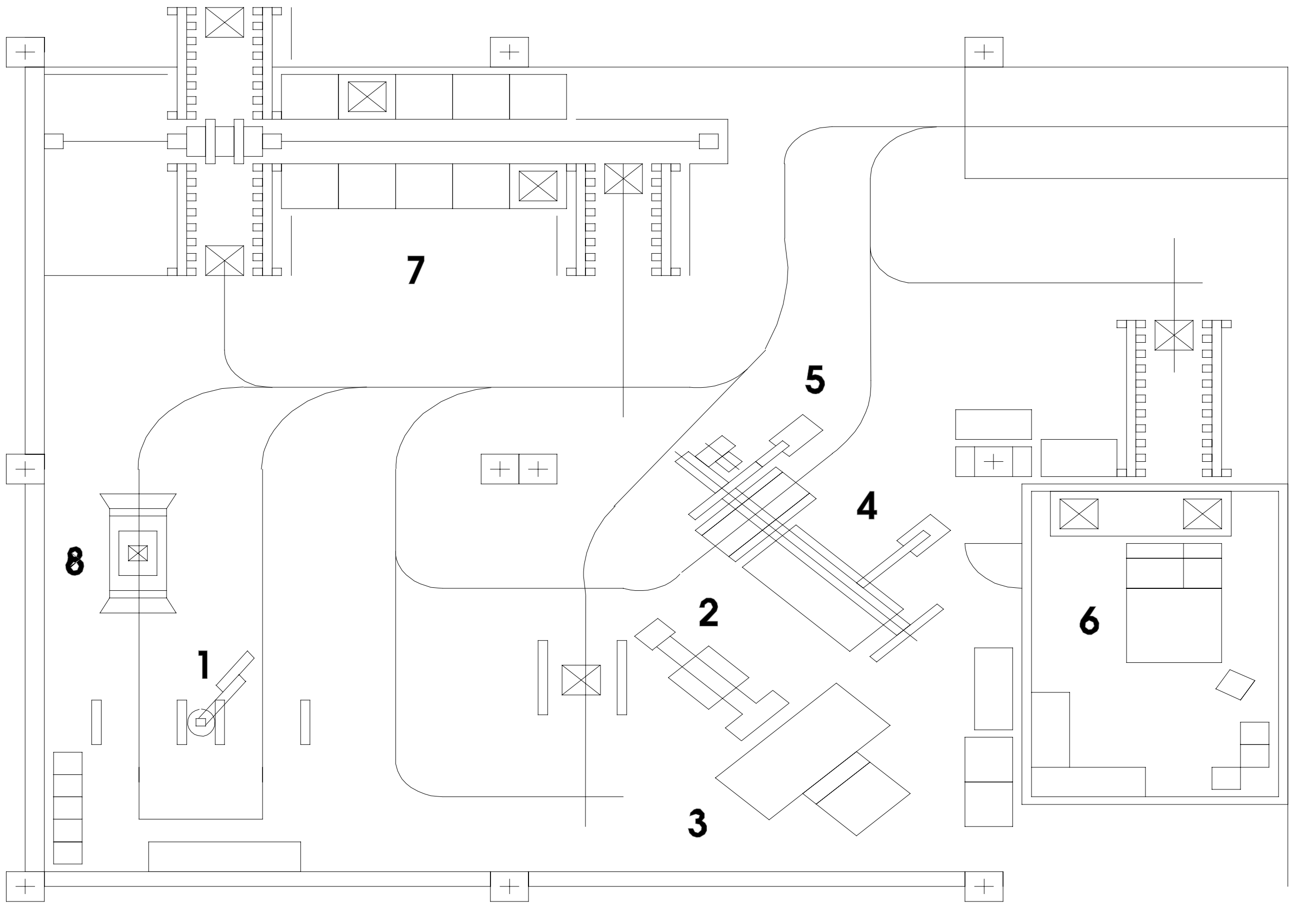

Fig. 3 Pilot FMS in the Technical University of Budapest

In the simulation point of view both system handles parallel the parts (workpieces). But the SIMAN is a conventional simulation program directed by entities (workpieces), describing every resource (storages and machines) containing commands (event generations, delays), conditions (variable checking, resource occupying), branches etc. An entity is going through the sequences of different resources.

On the contrary, the work of the G2 system is directed by rules. There are rules which fire on their activating (initially ..., unconditionally ... rules), others fire when a variable receives a value (whenever ..., if ..., when ... rules) and, finally, rules can be fired in an explicit way as well (invoke ... rules, focus on ... actions). The development of the simulation model in SIMAN is easier than in G2, especially if animation is needed.

In the scheduling and quality assurance point of view the SIMAN has only a reduced set of scheduling strategies and no built in tool for quality. It means that the most parts of these aspects must be programmed in "C". G2 rules and objects are pretty good to code such applications keeping the feature of easy modification.

5 Some experiences with the scheduler advisor

For all experiments a task was used where 4 different parts should be produced and checked on the CIM pilot plant given in Fig. 3. All parts have different process plans and the batch sizes vary from 0 to 30. As the Input Storage of the system has 10 slots the experiments would have been meaningless if the sum of the four batch sizes had not been bigger than 10.

Both systems (Fig. 1. and Fig. 2.) were checked with the same experimental data and the final results were compared and the resulting data are processed recently.In the experiments real process-plans and timing data were used from the simulated FMS..

5.1 Input sequence - schedule relationship

In this experiment a preliminary sequence of the different raw pieces is determined to the ten-slot input storage before of entering to the CIM system to see the effects of these sequences to the final schedule which was basically evaluated based on total throughput times. The time-span of individual process-plans were the characteristic input data of each part. These times were measured by generating individual schedules for each part as they were the only single parts in the system.

The following algorithms were checked:

- random input
- equal distribution input
- the part from the largest batch first

Several different batch sizes of all parts were checked with all algorithms with all available (in the AES) scheduling systems. The results are rather interesting, the statistical evaluation will take some more time, as no direct relationships could be determined, except for extreme batch sizes (e.g. 20,1,1,1, etc.).

5.2 Experiments with different scheduling methods

As it was mentioned earlier recently only the Round Robin strategy is built into the simulation system itself and four more algorithms are implemented in the AES, and these were tested.

These are:

- parts with shortest operation first/next
- parts with longest operation first/next
- parts with shortest process plan first/next
- parts with longest process plan first/next

As the experimental data do not show too much direct relationships further statistical analysis of the results and further scheduling algorithms to be tested are needed. As the results depend a lot on the process plans of the different parts, it will be hard to give suggestions on the scheduling algorithms to be used, but test runs with more of them could be the good solution.

6 Conclusions

A hybrid and a pure KB simulation program was developed with scheduling and quality assurance features for FMS evaluation. Their comparison shows that the hybrid system can save the advantages of both selected tools. The cost of it was the development of the interface.

The implementation in SIMAN and G2 was fast enough, G2 was excellent to make the different experimental program runs. Data preparation is - however - a tedious and time-consuming activity.

We are convinced that the application of these up- to-date means (SUN SPARCstation, G2, SIMAN/Cinema, networks) will lead our CIMLab to have a useful Knowledge Based Simulation-Scheduling-Quality Control program package to support the evaluation and better performance of working FMS and to be used in the design (planning) of new FMS implementations. Recently test-runs of the prototypes are done using the data of 2 factories in Hungary and 1 in Korea.

Finally it has to be mentioned that using the discussed hybrid program structure a potential system control is supported. In this case the real FMS environment should be used instead of the simulation. So one main direction of our recent R&D work is real-time FMS control.

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