Knowledge Based Simulation for FMS Scheduling

Z.Letray *, S.Kopascsi *
Jihyung Park **, Mujin Kang **
(* Computer and Automation Institute, Hungray
** KIST, CAD/CAM Laboratory)

1. Introduction

The FMS(Flexible Manufacturing System) was introduced to the part manufacturing industry more than twenty years ago. Considering the vast capital investment and today's competitive environment, it is very important to effectively manage and control the FMS including the day to day disturbances while meeting customer requirements.

Up to date many researches on planning, scheduling and control of FMS were carried out mainly by the analytical approach. Unfortunately, scheduling theory and parctice are often far apart and many mathematically perfect models simply do not work in practice because of the unrealistic assumptions and incorrect conditions that are incorporated in such models. Moreover, these approaches require long computation time to obtain the optimal solution and can't handle the dynamic disturbances of FMS./1.-5./ Practically, FMS is operated by human expert's experiences and simple dispatching rules./6./

Discrete event simulation is a useful tool for predicting the dynamic behavior of a given FMS.

This is accepted as being of great importance in both the planning and scheduling of FMS operations. Simulation runs can be made in parallel with real-time operation and compared. But, simulation provides no interpretation or explanation of its output: it just generates numbers and leaves their interpretation up to the user. In order to overcome these limitations, it is necessary to incorporate knowledge base into simulation. The knowledge base systems or expert systems can be built by utilizing the problem-solving expertise derived from human experts, textbooks and heuristics.

One of the most appropriate ways of implementing a control system for a real scale FMS with the functions of simulation, scheduling and monitoring is to bulid knowledge based systems or expert systems based on the heuristics and simulation system./7.-9./

In this paper, a prototype knowledge based simulation system for FMS scheduling is described that will be part of a control system for the target flexible manufacturing system. The knowledge based system is integrated with a simulation system to form a proposed knowledge based simulation system.

2. Proposed Systems Architecture

2.1 The Knowledge Based Simulation Scheduler Concept

There are several scheduling systems in the market which use mathematical models and can provide an optimal schedule for systems with medium complexity. However, in practice most of the scheduling problems are too large to make this approach feasible. Therefore interest has focused on heuristic approaches like simulation.

A fast knowledge based simulation scheduler can be very useful in machine breakdown situations as well, because conventional scheduler usually requires very long time to create a new schedule after a failure. Using simulation methods in scheduling there is no need for building big mathematical models, a more simple simulation system can be applicable in generating "sub-optimal" solution in complex scheduling situation. Many sources suggest that the decisions (e.g. "which AGV to choose") during the simulation of the manufacturing process can be made using heuristics. Applying a high level simulation language there is a possibility to define huristic rules for the conflict resolution. Additionally, the decision making capability of a simulation system can be raised combining a traditional simulation system (e.g. SIMAN) and a decision supporting expert system (for example written in CLIPS).

In such an architecture the distribution of rule bases is possible: some basic rules (e.g. "if the next station is busy than workpiece should go to the storage") can remain in the simulation system, and more complex rule-hierarchies can be defined in the knowledge-based part.

2.2 The roles of the expert systems connected to the simulation module

In that architecture, the main tasks have been defined and the module structure is shown on Fig. 1.

The Preparation Expert System PES should prepare (create or modify) the simulation model and provide the necessary input for the Simulation Scheduler (SS). During simulation the system can enter into a dialog mode with the Scheduler Advisor (SA) in order to resolve more serious conflicts. The results of the simulation (schedule) can be evaluated by the Evaluation Expert System (EES).

The task of the expert systems is described as follows:

- Relying on process plans for each part which includes prepared routing-variations PES chooses the routing-alternative which is probably the most suitable routing for the given situation (included failure situation as well, with decreased number of resources).

- the PES should perform another task, as well: according to the current configuration, it can modify the relevant parts of the simulation frames (model- and experimental frames in SIMAN).

- According to the simulation circumstances (new frames and new routing), simulation module starts. At decision points (e.g. resource allocation) conflicts are resolved using either built-in (i.e. in SIMAN) basic simulation rules, or - in case of more severe conflicts (e.g. AGV transport or pallet-changer problems) - the simulation module enters into an interactive mode with the Scheduler Advisor. During the run of SS a new schedule is generated, on-line. In case of certain unfulfilled requirements (due-date violation) or errors (unresolvable conflicts) the simulation stops and appropriate messages for the Evaluation ES (EES) are generated.

- If the simulation session terminates (succeeded or failed) the Evaluation ES examines the simulations results. There are four main cases:

= if the newly generated schedule is acceptable, (i.e. there was no error during simulation, utilization figures conform with the restrictions and even other constraints are fulfilled) then new schedule is feasible for the real FMC,

= if there was no error, but any of the requirements (included due-dates) are not fulfilled then the new schedule is not accepted. In this case,

A./ simulation starts again and SA is requested to use different rules, if any.

B./ if A./ does not give any acceptable solution then PES is informed and requested to try to find another routing alternative.

= in the case of unresolvable conflicts, PES is informed and requested to try to find another routing alternative.

= if the previous steps don't give a solution or in case of any other error (e.g. error in SIMAN) there is no way to create an acceptable schedule.

The interconnection between the modules of the Knowledge Based Scheduling and Simulation System is one of the most crucial point in order to achieve an efficient solution. Both the form and the content of the communication must be dealt with.

PES provides input for SS off-line and the case is similar for SS and EES. Meanwhile, the connection between SS and SA must be on-line. In the realization of the interconnection between the expert systems, we plan to use a cooperating expert systems paradigm. The elaboration of this paradigm is one of the main research topic of our Joint Korean-Hungarian Project.

3. Systems Design

The complexity and the originality of the software architecture introduced above requires a systematic approach for requirement specification and function definition process. This should be done by an interdisciplinary team: experts in mechanical engineering, process planning and production scheduling, simulation and expert systems. The communication of these people and the coordination of the work needs a systems design methodology. The Structured Analysis Technique and Technology (SATT) has been developed in Hungary (CAI HAS) and was successfully applied in CIM projects in the last ten years. We decided to use this methodology for the functional definition of our system.

The main task of the target SW system shown on A0 "main functions" (see. Fig. 2) is to model the components and behaviour of an FMC, run the model by simulation (A1) and evaluate the results (A2) in order to generate a feasible schedule.

The main functions of the simulation have been defined in the block 12 "Simulate" (see. Fig. 3). On Fig. 4 the block 121 "prepare simulation model" is a function for creating or edit the modules of a simulation source program for the given manufacturing situation. Input data that are necessary for building this particular model has been provided in external representation (predefined configuration, process plan, routing etc. or new cell status after a machine break-down, as well as requests for information generation).

In the level of the actigram "A12 simulate" we can make a decision for the performing mechanisms. The implementation of A121 can be done by a system programmer (later using an interactive program or a preparation ES) using SIMAN. This simulation language allows the system programmer to model the cell components (elements of the configuration) including their working algorithms and the orders (loading sequence, process plan, due-dates etc.) The results of this high level programming activity are the SIMAN specific "model-frame" and the "experimental frame".

After linking these frames, we are ready to run A123 "perform simulation" using the SIMAN Run-processor which can occasionally be extended with user written FORTRAN or C language routines.

During the simulation the program should be able to activate the separate A13 "advice in scheduling" function (see. Fig. 3) and receive 'solutions for conflict resolution' on-line. Some parameters of the simulation (or rather the animation) running (speed, zoom etc.) can be controlled by the user, 'occasional user input' and customized output should be provided via the output processor or user written external routines.

In our first implementation during running, the SIMAN program is not connected to any external input data source. If the need for any change in the structure or in the data (parameters) of the model- and/or the experimental frame arise, modifications can only be made off-line by editing these frames (manually, later using an interactive program or a preparation ES).

The function "123 perform simulation" had been further decomposed considering the SIMAN language capabilities, using the structured analysis strategy as follows:

According to the SIMAN language conception, the components and the definitions of their behaviour (i.e. the whole FMC) are modeled by the model- and experimental frame. Every actions during the simulation has been initiated by the entities when passing through the blocks of the model frame. Data (conditions, parameters) for the activities are picked up by the built in mechanism of SIMAN, from the experimental frame (i.e. not directly from any external source).

Entities make decisions in conflict situation, as well. When the resolution of a given conflict seems too complex, entities may request for advice from the external Scheduler Advisor (SA) expert system written in CLIPS. Therefore, subfunctions are identified from the viewpoint of the workpieces that are represented by SIMAN entities.

The control (e.g. "start activity") of those subfunctions is performed by the arrival of the entities. Workpieces -as entities ('wpe,) - carry the necessary manufacturing information in the form of attributes (e.g. wp-type, next operation number, next machine, duration of machining)

Following the route of the workpieces in the cell or the path of the entities going through the SIMAN blocks, respectively, we could define the lowest level subfunctions and the algorithms for the performing SIMAN mechanisms (see. Fig. 5).

4. Implementation

The SIMAN high level simulation language is a proper tool for modeling general systems, but the language contains several features that make it particularly useful for examining manufacturing systems. Therefore we will use SIMAN in solving the simulation task.

A SIMAN program basically consists of two parts, the model frame and the experimental frame. The model frame is for describing the working concepts and some basic elements (like automatic pallet changer) of the manufacturing cell. The main goal of the experimental frame is to define the number and capacity of the resources placed in the manufacturing cell. We can define the manufacturing routing either in the model frame or in the experimental frame, but it is more reasonable in the experimental frame.

The main concept of the SIMAN system is that entities (in case of manufacturing system, workpieces) are created, passing through the so called blocks of the model frame and execute the statements which are represented by the blocks.

After a run of simulation a summary report is prepared, which can consists of utilization statistics, counter values, and special reports.

In the system being developed the loading sequence and the process plan is given in an external data base. A special program converts the data into the required format, which becomes the part of the experimental frame. The experimental frame also consist of the basic parameters of cell elements, like capacities of the resources, the distances between the cell elements and so on. In the model frame we have defined the working algorithm of the individual stations (i.e. load, unload and inspection station, storage, machining centers, washing machine).

Every workpiece arrives in the load station, where the fixturing to a pallet is done. After fixturing the workpiece leaves the load station according to the process plan and the state of the stations. A special flag sings whether the next station required in the process plan can accept the workpiece (in the current configuration each station except the storage can accept only two workpieces at the same time). If the next station is reserved for at least two workpieces, than the workpiece will be carried to the storage. The storage capacity must be enough in every situation. From the storage each workpiece keeps asking the next required station. If the next station can accept the workpiece, then the workpiece reserves one place for itself, and asks for an AGV in order to go to the next station. In the life of the workpiece in the cell the last step is the defixturing at the unload station, then the workpiece leaves the cell.

During the simulation several reports and examination can be made. The most important report is about each step of the workpiece in the cell. We can call this report as schedule of the workpiece, and we can create from this schedule the machine loading. The most important examination is that whether the workpiece exceeds its due date. If yes it doesn't make sense to continue the simulation, we will have to start a new run with different conditions.

Using the utilization statistics stored in the summary report, the special reports like schedule in a file, the evaluation expert system can evaluate the schedule, and if it is necessary can suggest a new run of simulation with new simulation conditions.

The system interconnection is perhaps one of the most important question of the implementation. There are several methods connecting simulation and expert systems.

We have some experiences that in this problem only the multitask performance can be efficient. It is especially true in PC environment, since the memory of a PC is very limited. Therefore we should use individual PCs for the simulation and for the expert system, respectively.

The connection between the PCs can be any network system like DECnet. Using DECnet DOS we can define mailboxes in order to change information between the SW modules.

In workstations this problem is smaller, because the multitask and mailbox facility are provided by the system itself.

A common data-representation is desirable in order to minimize interface requirements.

5. Further development, expected results

In this paper, a new approach to build up a knowledge-based simulation system for FMS scheduling has been presented. The architecture shows the interconnected system of expert modules for preparation and evaluation, a simulation scheduler and a schedule advisor.

The precise structured analysis has resulted in a complete functional description of the target system. We were able to develop the software system incrementally. That means, we could divide the whole development into distinct steps and decide which functions should be performed by software modules in each developing steps.

In the first step we implement only the simulation module and the EES in a form of SIMAN and CLIPS programs, the connection is realized simply by file transfer. The functions of the expert modules are performed by the human programmer and the domain (scheduler) expert.

In the following steps we plan to make up more and more human assistance activity by intelligent program modules, mainly via building expert systems.

References

1. Stecke,K.E., Sloberg,J.J., 1981, "Loading and Control Ploicies for a Flexible Manufacturing System", Int., J. Prod. Res., Vol. 19, No. 5, 481-490
2. Kusiak,A., 1985, "The Part Families Problem in Flexible Manufacturing Systems", Annals Opers. Res., 3, 279-300
3. Morton,T.E., Smunt, 1986, "A Planning and Scheduling System for Flexible Manufacturing", FMS:Methods and Studies, North-Holland, 151-164
4. Co,H.C., Biermann,J.S. and Chen,S.K., 1990 "A Methodical Approach to the Flexible Manufacturing System Batching, Loading and Tool Configuration Problems", Int.,J. Prod. Res., Vol. 28, No. 12, 2171-2186
5. Stecke,K.E., Kim,I., 1991, "A Flexible Approach to Part Type Selection in Flexible Flow Systems using Part Mix Ratios", Int., J. Prod. Res., Vol. 29, No. 1, 53-75
6. Blackstone,J.H., Phillips,D.T. and Hogg,C.L., 1982, "A State of the Art Survey of Dispatching rules for Manufacturing Job Shop Performance", Int., J. Prod. Res., Vol. 21, No. 127
7. Sridhar Subramanyam and Ronald G. Askin, 1986, "An Expert Systems Apporach to Scheduling in Flexible Manufacturing Systems", FMS:Methods and Studies, Horth-Holland, 243-256
8. Reynolds,R.F., McMahon,J.A., 1988, FMS Scheduling with An Expert System, FMS, 87-102
9. Shaw,M.J., 1988, "Knowledge-Based Scheduling in Flexible Manufacturing Systems : An Integration of Pattern-Directed Inference and Heuristic Search", Int., J. Prod. Res., Vol. 26, No. 5, 821-844

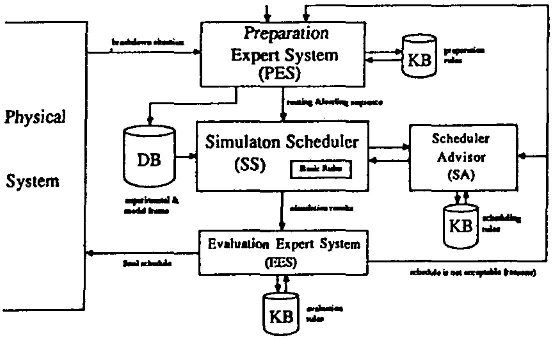


Fig.1. Knowledge Based Scheduling and Simulation System

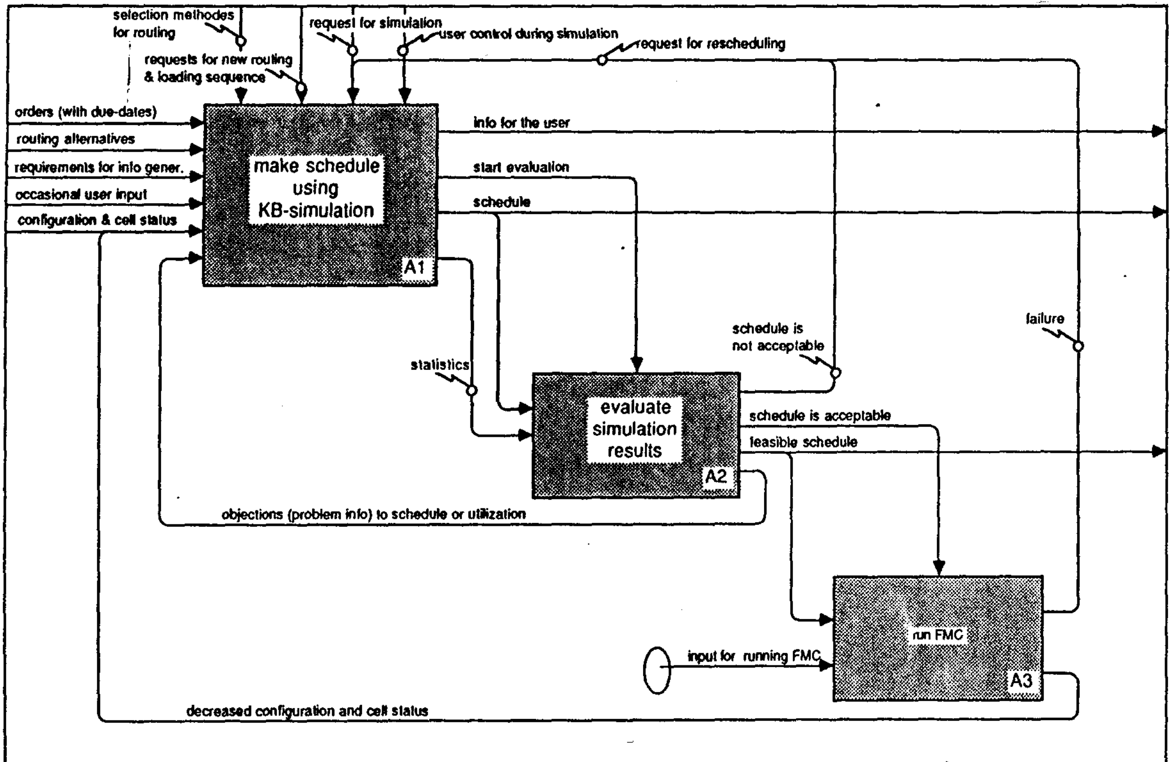


Fig.2. **A0 Main functions of the target system**

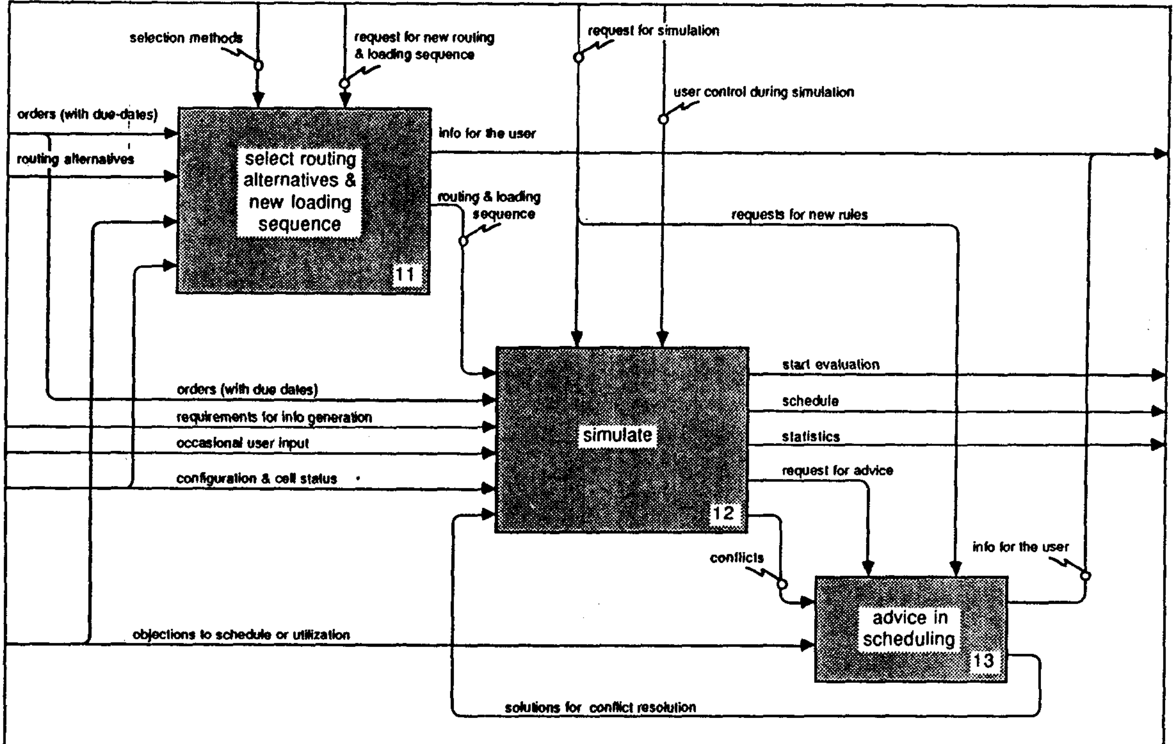


Fig.3. **A1 make schedule using KB-simulation**

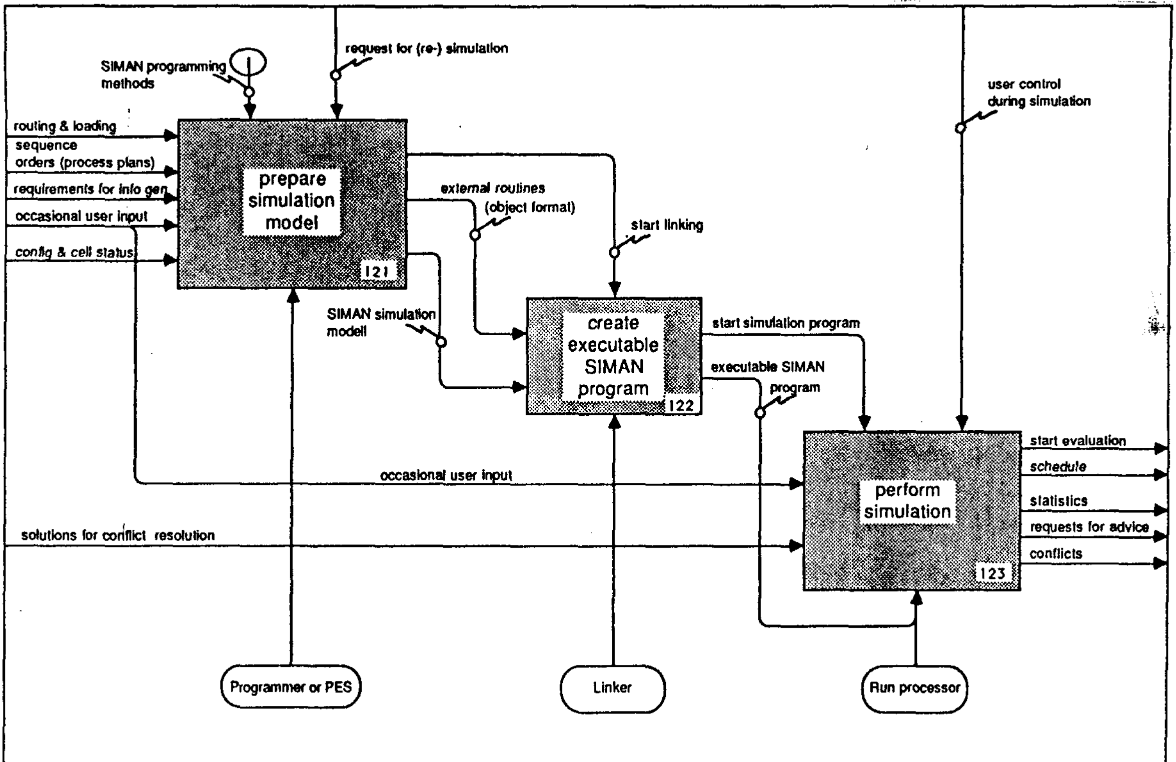
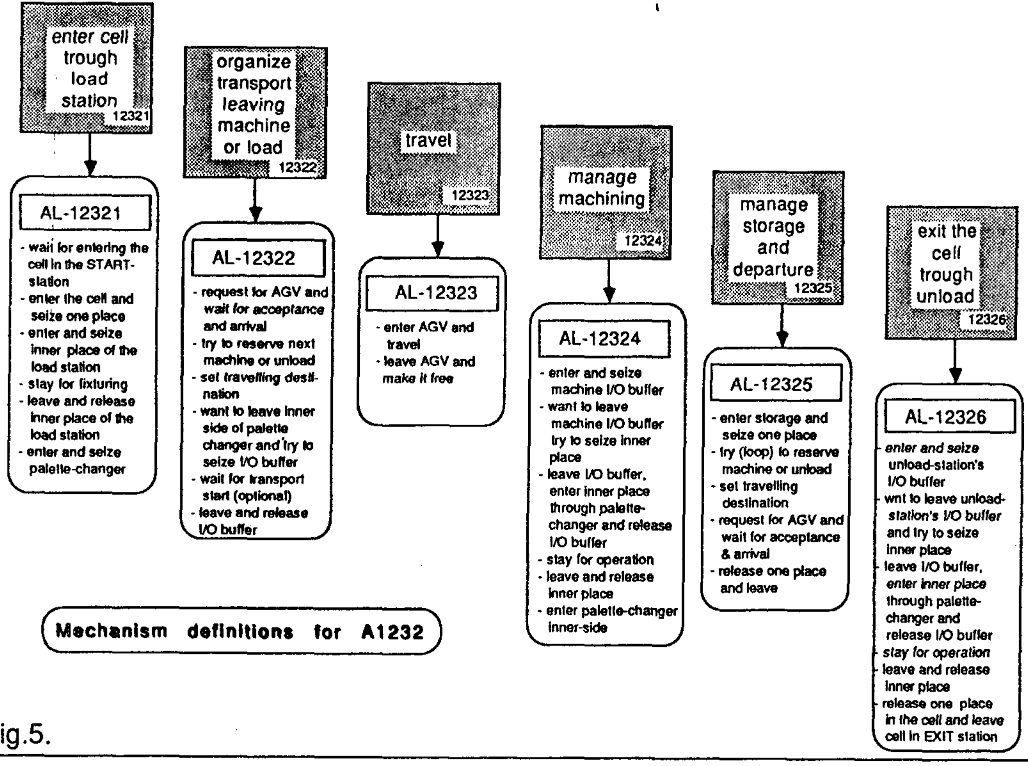


Fig.4. **A12 simulate**



AL-12321

- wait for entering the cell in the START-station
- enter the cell and seize one place
- enter and seize inner place of the load station
- stay for fixturing
- leave and release inner place of the load station
- enter and seize palette-changer

AL-12322

- request for AGV and *wait for acceptance* and arrival
- try to reserve next machine or unload
- set *travelling* destination
- want to leave inner side of palette changer and try to seize I/O buffer
- wait for transport start (optional)
- leave and release I/O buffer

AL-12323

- enter AGV and travel
- leave AGV and *make it free*

AL-12324

- enter and seize machine I/O buffer
- want to leave machine I/O buffer try to seize inner place
- leave I/O buffer, enter inner place through palette-changer and release I/O buffer
- stay for operation
- leave and release inner place
- enter palette-changer inner-side

AL-12325

- enter storage and seize one place
- try (loop) to reserve machine or unload
- set travelling destination
- request for AGV and wait for acceptance & arrival
- release one place and leave

AL-12326

- *enter and seize* unload-station's I/O buffer
- wnt to leave unload-*station's I/O buffer* and try to seize inner place
- leave I/O buffer, *enter inner place* through palette-changer and release I/O buffer
- *stay for operation*
- leave and release inner place
- release one place *in the cell and leave* cell in EXIT station

Mechanism definitions for A1232

Fig.5.