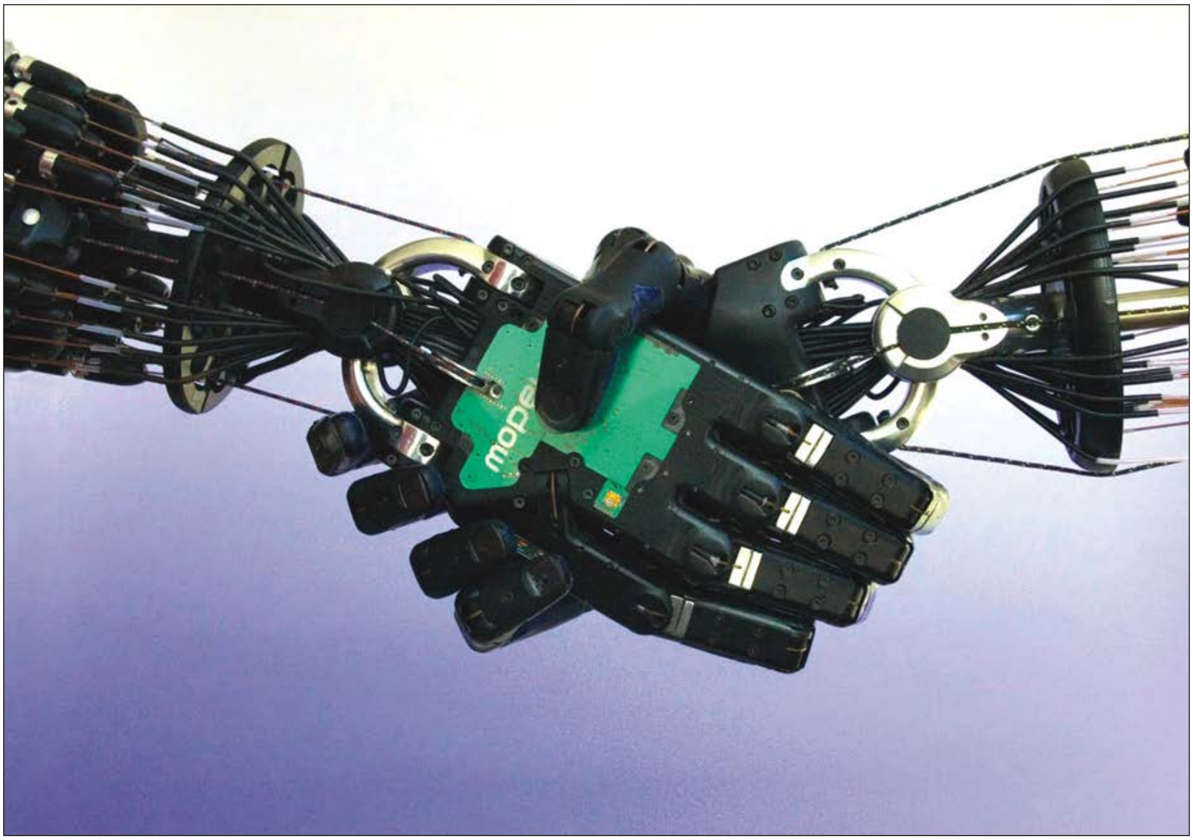

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A Review of Simulation-based Intelligent Decision Support System Architecture for the Adaptive Control of Flexible Manufacturing Systems

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Abstract: The aim of this study is to review the architecture of simulation-based Intelligent Decision Support Systems (IDSS) for real time control of a Flexible Manufacturing System (FMS). The study considers flexibility in operation assignment and scheduling of multi-purpose machining centers, which have different tools with their own efficiency. The study shows that simulation-based IDSS constitutes the framework of adaptive controller supporting the co-ordination and co-operation relations by coupling a real time simulator, a simulation optimizer and an intelligent DSS for implementing dynamic strategies. The intelligent controllers receive online information of the FMS current state and manage different scenarios of control parameters within real-time simulation data exchange. The simulation-based IDSS uses a posteriori adaptive real time machining process monitoring mechanism that also is online control method acting after the event occurs versus such popular reactive control methods. The study presents the adaptive controller's bilateral mechanism for simulation optimization based on appropriate control rules that enhance multi performance criteria simulation optimization efficiency. Application of these adaptive controllers showed that they could be an effective approach for real time control of various flexible manufacturing systems. Present method to review is the relevance and chronological appearance of the simulation-based projects for the controlling of the manufacturing systems.

Key words: Control, simulation, real time, flexibility, rule, IDSS

INTRODUCTION

Manufacturing systems have to incorporate efficient configuration of their facilities and management methods to survive in today's rapidly changing market. Therefore, there is a growing need for manufacturing systems that are both highly productive and flexible. Productivity minimizes manufacturing costs and flexibility helps them to overcome various uncertainties regarding the volume and attributes of the product. Flexible Manufacturing Systems (FMS) are a response to the need for an efficient production system in environments with rapid changes allowing a number of small batches to be gathered into families and manufactured accordingly. The FMS is a manufacturing system with the capability of producing a wide variety of products. In a FMS there are a set of machining centers in which an operation can be performed by any machine in the work center. While a great deal of research works has been conducted on control of production systems in the last decades, only very few researches have considered controlling such a system.

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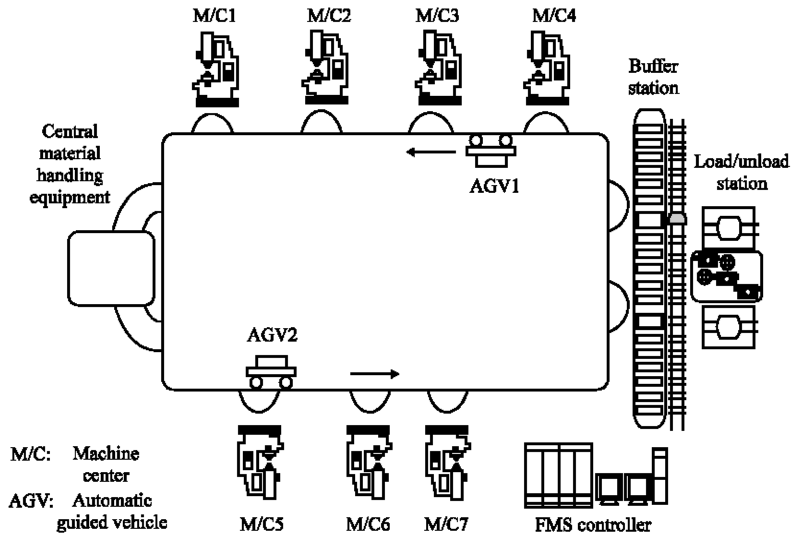

Fig. 1: Generic architecture of FMS (Buzacott and Yao, 1986)

Typically, FMS architecture can be characterized as a set of multi-purpose machine tools connected by a material handling system which is controlled by both computers and human operators as shown in Fig. 1 (Buzacott and Yao, 1986; Dixon, 1992). Any material handling system has a mechanism to transport parts automatically. Some advanced systems also contain automatic tool transportation devices (Shirazi *et al*., 2010). These systems can transfer tools among tool magazines and the central tool storage area while the system is in operation. This advancement in FMS hardware has rendered a major impact on FMS operation (Edghill and Davies, 1985). The FMSs are essentially more flexible than the conventional manufacturing systems, mainly because of utilizing versatile manufacturing lines, redundant and reconfigurable machines, alternate routings and flexibility in operation sequencing (Byrne and Chutima, 1997; Moon, 2006).

Due to different operations on a product and machine requirements to process each step of production, it is so hard to control different events that might happened at different cells to achieve best practice of performance criteria (Tawegoum *et al*., 1994). Regarding these considerations, control of these environments plays an essential role at manufacturing systems.

Manufacturing system control monitors the allocation of machines to perform a set of jobs and achieve appropriate performance criteria. Due to different operations on a product and machine requirements to process each step of production, it is difficult to control different events that might happen at different machining centers and achieve best practice of performance criteria (Brennan, 2007; Gertosio *et al*., 2000). Although in environments with stochastic events operations are assigned to machines, uncertainty does not allow achieving an optimized solution.

Control framework has been studied on FMSs in the literature and there are different methods for selecting the most appropriate control policies at each decision point (Stecke and Kim, 1991; Basnet and Mize, 1994; Tang *et al*., 1995; Ayel, 1995; Seifoddini and Zhang, 1996; Szelke and Monostori, 1999; Guo *et al*., 2006; Van der Zee, 2006; Chan *et al*., 2008). These strategies deal with the allocation of jobs to multi-purpose machining centers, which have to be made in a flexible way. Most of these studies focus on reactive strategies that enable the FMS to better deal with randomness and variability. It means that most of these FMS controllers usually use fixed and offline policies to operate the system. However, these methods do not consider many realistic constraints and dynamic changes such as tool magazine capacity, operative efficiency changes and availability of tools in the part selection and operation assignment problems. These offline methods are mainly categorized into two forms: priori reactive control and the posteriori reactive control methods. The offline methods are applied before the running of system. The control is planned according to the structural information, forecasts, orders, management rules and objectives (Habchi and Berchet, 2003).

Some heuristic methods were developed to solve flexible manufacturing systems problem in recent years (Mahdavi and Mahadevan, 2008; Mahdavi and Zarezadeh, 2009). Other hybrid methodologies based on artificial immune algorithm (Bagheri *et al*., 2010), genetic algorithm (Tanev *et al*., 2004; Zandieh *et al*., 2008; Adeyemo and Otieno, 2009; Mahdavi *et al*., 2009) can be also addressed.

Moreover, there are a lot of heuristic search algorithms for controlling problems in FMS environments. These algorithms have two main constraints:

- They could not consider the machine flexibility and fail to work on multi-purpose machines
- They consider small to medium-sized problems and their application to large-sized problems is computationally intractable

This study reviews embedded robust real time control framework instead of implementing previous ad-hoc controllers. The online method (posteriori control) adapted directly to the system for preventive deviations by controlling occurrence of events.

Improving the performance of an FMS supervised by an effective controller is still a complex task that not only is time consuming but also needs much human expertise in decision making (Douglass, 2003). In order to implement an adaptive controller, decision support systems (DSS) have become an effective method for their adaptability in controlling complex and dynamic operations (Yao *et al*., 2003; Holsapple and Whinston, 2000).

There have been limited investigations on intelligent decision support systems (IDSS) for controlling such systems as a unified approach. There is a need to construct a framework in which a knowledge-based decision analysis will assist the decision process to improve the FMS control parameters. Table 1 shows different IDSS control researches on FMS from 1988 to 2010.

An effective approach for reinforcement of IDSS performance is to develop an embedded simulation model that meets the desired objectives of the system (Guariso *et al*., 1996; Gertosio *et al*., 2000; Fowler and Rose, 2004; Chan and Chan, 2004a, b). Discrete-Event Simulation (DES) is a very powerful tool that can be used to evaluate alternative control policies in the manufacturing system (Schroer and Tseng, 1988; Henneke and Choi, 1988; Drake *et al*., 1995; Chan *et al*., 2002; Chong *et al*., 2003; Brennan and William, 2004; Tavakkoli-Moghaddam and Mehr, 2005; Yang, 2008; Wu and Zeng, 2009).

Although, the procedure of analyzing simulation results could rely on various guidelines and rules, decision-making still requires significant human expertise and computer resources. To efficiently use simulation in the decision process, integration of IDSSs with simulation has been emphasized (Schelasin and Mauer, 1995; Anglani *et al*., 2002; Arnott and Pervan, 2005; Brennan, 2007).

Table 1: Different IDSS control researches on FMS (1988-2010)

Authors and years	Research area
Montazeri *et al.* (1988)	A Modular Simulator for Design, Planning and Control of FMS
Mellichamp *et al.* (1990)	FMS designer: An expert system for flexible manufacturing system design
Muller *et al.* (1990)	A simulation-based work order release mechanism for a flexible manufacturing system
Pierreval (1992)	Expert system for selecting priority rules in flexible manufacturing systems
Tang *et al.* (1993)	A study on decision rules of a scheduling model in an flexible manufacturing system
Kashyap and Khator (1993)	Control rules for tool sharing in flexible manufacturing system
Zimmermann (1994)	A modeling method for flexible manufacturing system based on colored Petri nets
Narayanan *et al.* (1994)	Modeling control decision in manufacturing systems simulation using object
Abdallah (1995)	A knowledge-based simulation model for job shop scheduling
Goyal *et al.* (1995)	Simulation for analysis of scheduling rules for a flexible manufacturing system
Jayaraman and Srivastava (1996)	Expert systems in production and operations management
Pflughoeft *et al.* (1996)	Intelligent DSS for FMS: Design and implementation of a knowledge-based simulator
Wang (1996)	An integrated object-oriented Petri net paradigm for manufacturing control systems
Belz and Mertens (1996)	Combining knowledge-based systems and simulation to solve rescheduling problems
Brennan *et al.* (1997)	Dynamic control architecture for advanced manufacturing system
Chen and Lu (1997)	A Petri-net and ERD based object-oriented design for manufacturing systems control
Sabuncuoglu (1998)	A study of scheduling rules of flexible manufacturing systems
Booth (1998)	Object-oriented modeling for flexible manufacturing systems
Borenstein (1998)	IDSSFLEX: An IDSS for the design and evaluation of flexible manufacturing system
Mak *et al.* (1999)	An object-oriented rule-based framework for the specification of FMS
Tung *et al.* (1999)	Multiple-objective scheduling for the hierarchical control of flexible manufacturing system
Park *et al.* (1999)	A Development of object-oriented simulator for manufacturing execution systems
Klingstam and Gullander (1999)	Overview of simulation tools for computer-aided production engineering,
Berchet and Habchi (2000)	Modelling for simulation of manufacturing system control
Chan *et al.* (2000)	The development of intelligent decision support tools to aid the design of FMS
O'Kane (2000)	A knowledge-based system for reactive scheduling decision-making in FMS
Benjamin *et al.* (2000)	Model-based approach for component simulation development
Son and Wysk (2001)	Automatic simulation model for simulation-based real-time shop floor control
Chen *et al.* (2001)	Knowledge-based support for simulation analysis of manufacturing cells
Anglani *et al.* (2002)	Object-oriented modeling and simulation of FMS: a rule-based procedure
Ozbayrak and Bell (2003)	A knowledge-based support system for the measurement of parts and tools in FSM
Habchi and Berchet (2003)	A model for manufacturing systems simulation with a control dimension
Chan and Chan (2004a, b)	Analysis of dynamic control strategies of an FMS under different scenarios
Oztemel *et al.* (2004)	KB-SCHED: Knowledge based scheduler for complex and dynamic systems
Chtourou *et al.* (2005)	An expert system for manufacturing systems machine selection
Jönsson *et al.* (2005)	A virtual machine concept for real-time simulation of machine tool dynamics
Yalcin and Namballa (2005)	An object-oriented simulation framework for real-time control of automated FMSs
Delen and Pratt (2006)	An integrated and intelligent DSS for manufacturing systems
Suresh and Sridharan (2007)	Simulation modeling of tool sharing and part scheduling in single-stage multi-machine FMS
Malhotra (2008)	Meta-modeling framework to manage meta-model base and modeling knowledge
Iassinovski *et al.* (2008)	SD Builders: A production rules-based tool for on-line simulation, decision making and discrete process control
Liu, *et al.* (2009)	Performance modeling, real-time dispatching and simulation of using timed extended object-oriented Petri nets
Guo *et al.* (2009)	Intelligent production control decision support system for flexible assembly lines
Xing *et al.* (2009)	Multi-objective flexible job shop schedule: Design and evaluation by simulation modeling
Mahdavi *et al.* (2010)	Simulation-based decision support system for controlling stochastic flexible job shop system

Volkner and Werners (2002) and Kadar *et al.* (2004) have developed a simulation-based DSS named to improve the sequencing of business process workflow by evaluating different process alternatives quantitatively. The integrated environment was implemented as a DSS, which uses the simulation language. They have proved that simulation-based approaches are appropriate in supporting decision making with respect to complex dynamic systems with uncertain data.

However, there have been limited investigations on integrating IDSS with the modular simulation languages as a unified approach for controlling manufacturing systems. So, FMS control appears to be an excellent area for applying adaptive IDSS simulation-based controller (Mahdavi *et al*., 2010). These simulation-based DSS represents a theoretical framework for embedding simulation and optimization as well as the processing facilities and offers an effective support to the classical phases of the decision process.

This research focuses on reviewing simulation-based intelligent expert system with dynamic rules contemplating tool and machine flexibility control. For implementing inter-process synchronization in real-time control of FMS, the IDSS receives online results from simulation module and different scenarios of control parameters with simulation replication action.

ADAPTIVE FLEXIBILITY CONTROL ON FMS SHOP FLOOR

Adaptive Control Mechanism

Adaptive supervisory implies selection of an appropriate control policy based on the current state of the workcell. Depending on the degree of flexibility, the system should use a supervisory dynamic controller to reprogram the operation of the shop floor. Regarding dynamic control of manufacturing systems, jobs are dispatched to machining centers using dispatching rules at the specific moment based on the available information. Afterwards, appropriate tool is mounted in machining center according to the tooling strategy (Vieira *et al*., 2003). Because of the flexible characteristics of FMSs, control decisions should be applied as soon as possible based on the real time state of the system. An FMS adaptive controller has to deal with the dynamic environment in which the system operates to seize online machines and tools redundancy capabilities, alternative routing and hazard control remedy.

Figure 2 shows the adaptive flexibility control functions of the FMS shop floor.

The adaptive controller should have the following properties:

Property 1: Capable of specifying FMS configuration parameters particularly about the order requirements, multi-purpose machining centers, tools and transporters.

Property 2: Be able to determine the type of manufacturing execution system in FMS about dispatching rules, tooling strategies and machining rules.

Property 3: Be able to designate and extract FMS performance criteria (e.g., cycle time, tool utilization, local buffers utilization, throughput, tool inventory, etc.) according to the current shop floor status by an embedded core of such controller.

Property 4: Capable of justifying the FMS performance by firing the appropriate rule to manage different scenarios of control parameters, diagnosis of the system problems and resolve them.

Flexibility Control Functions

In flexible manufacturing systems parts are mounted on proper fixtures before the start of machining operations. Then both will mount on special pallets and conveyer transports pallets to machining centers. The pallet should be carried to an idle machining center if the

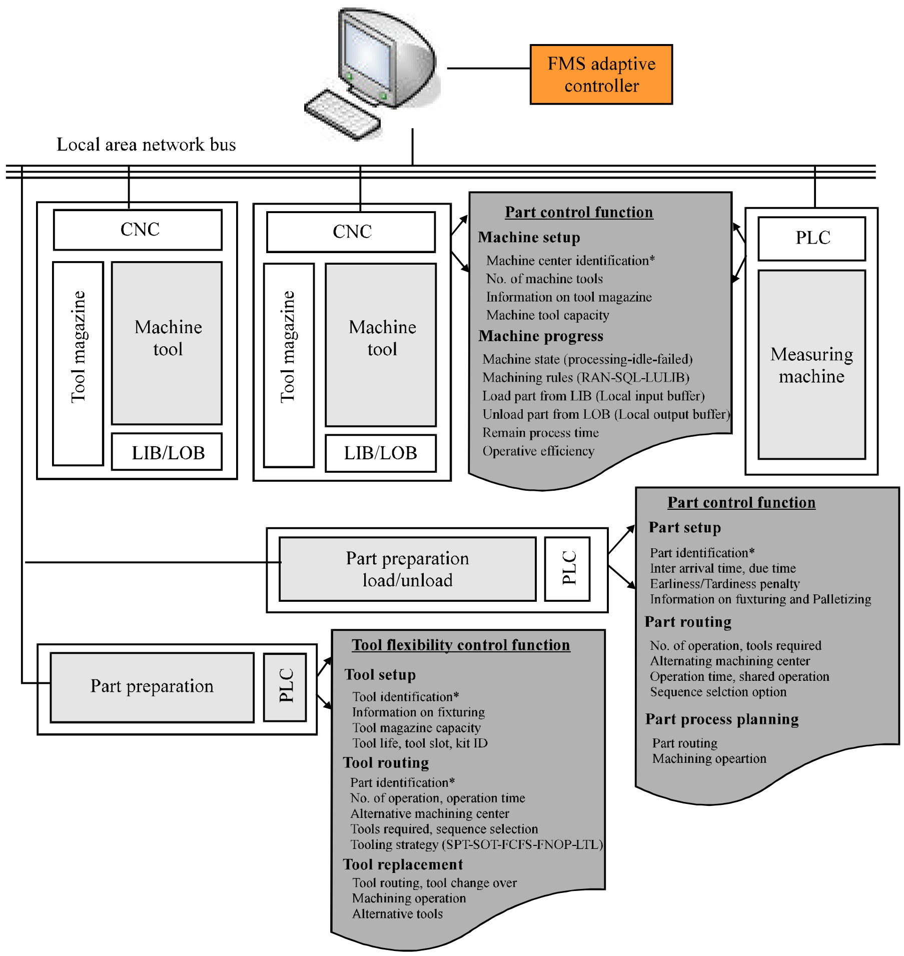

Fig. 2: FMS shop floor flexibility control functions

machining center is busy. The original eight categories of Browne *et al.* (1984) which is one of the most famous topologies for classifying different types of manufacturing flexibility consists of machine, process, product, operation, routing, volume, production and expansion flexibility. Flexibility does not seem to have a universally accepted definition. The most commonly accepted definition of flexibility is the ability to take up different positions or alternatively the ability to adopt a range of states (Slack, 1983). Many different authors have defined many different types of flexibilities in the literature (Barad and Sipper, 1988; Carter, 1986; Kouvelis, 1991; Tomek, 1986; Veeramani *et al.*, 1992; Beach *et al.*, 2000; Wahab, 2005). Here, we consider the flexibility control function as follows:

Machine Flexibility

Browne *et al.* (1984) defined machine flexibility as the ease of change to process a given set of part types. A measure can be obtained by computing the ratio of setup time to processing time. Buzacott (1982) defines machine flexibility as the ability of the system to cope with changes and disturbances at the machines and workstations. Thus this is actually

Table 2: Machining center flexibility control function

Module 1: Machine setup	Module 2: Machining process
Machining center identification*	Machine state (Processing-idle-failed)
No. of machine tools	Load part from LIB (Local input buffer)
Information on tool magazine	Unload part to LOB (Local output buffer)
Machine tool capacity	Load/Unload parts from/to central buffer
	Remain process time
	Operative efficiency
	Machining rules (RAN-SQL-LULIB)

*Machining center identification = Machining center name + No. of machine tools

an indicator of the internal change within the system. Das and Nagendra (1993) define machine flexibility of a machining center as the ability of performing more than one type of processing operation efficiently. Therefore, machine flexibility is measured by the number of operations that a workstation processes and the time needed to switch from one operation to another. Basically, the Table 2 illustrates the information structure of the machining center control function.

As shown in Table 2, modules machine setup and machining process are configured for controlling machining center flexibility. Machine setup module identifies machine tools information. Machining process module controls machine and buffer states using appropriate rules.

Tool Flexibility

Tool flexibility can be defined as getting the right tool, to the right place at the right time (Gray *et al*., 1993; Kouvelis, 1991). The need for tool management strategies originates from the high variety and number of cutting tools that are typically found in automated manufacturing systems. The adoption of appropriate tool management policies that consider alternative cutting tools allows the desired part mix and quantities to be manufactured efficiently while achieving improved system performance (Buyurgan *et al*., 2004). At machine tool level, there are three technical constraints related to tool allocation: tool magazine capacity, tool life and tool size. Due to tool magazine capacity, there is a restriction on the number of tasks (operations) that can be processed in a single tool setup. On the other hand, if tools can be loaded and unloaded while the machine is running, the capacity of the tool magazine can be assumed to be unlimited (Sarin and Chen, 1987; Ventura *et al*., 1990). In this scope, the use of an automated tool delivery system relaxes the tool magazine capacity constraint. On the other hand, it requires additional effort in scheduling and further synchronization of the tool delivery system with the other components in FMS (Rau and Chetty, 1996; MacChiaroli and Riemma, 1996; Hedlund *et al*., 1990).

One of the distinguishing features of an FMS is the tool magazine which holds a large number of tools. In this study, an advanced system containing automatic tool transportation devices has been considered to modify tool magazine constraint. The tool magazine capacity is an influential factor in determining the flexibility of the system. A proper tool management is needed to control processing of parts and enhance the flexibility to manufacture variety of parts. The basic information structure used in the tool flexibility control function is shown in Table 3.

As shown in Table 3, modules tool setup, tool routing and tool replacement are configured for controlling tool flexibility. Tool setup module identifies tool magazine information. Tool routing module controls appropriate routes for executing operation with respect to tool strategies. Tool replacement identifies the alternative tools for executing a same operation.

Table 3: Tool flexibility control function

Module 1: Tool setup	Module 2: Tool routing	Module 3: Tool replacement
Tool identification*	Tool identification	Tool identification
Information on fixturing	Part identification	Tool routing
Tool magazine capacity	No. of operation	Machining operation
Tool life	Alternative machining center	Alternative tools
Tool slot	Tools required	Tool changeover
Kit ID	Operation time	
	Sequence selection option	
	Tooling strategy (SPT-SOT-FCFS-FNOP -LTL)	

*Tool identification = Tool name + No. of tool required

Table 4: Part control function

Module 1: Part setup	Module 2: Part routing	Module 3: Part process planning
Part identification*	Part identification	Part identification
Inter arrival time	No. of operation	Part routing
Earliness/Tardiness penalty	Alternative machining center	Machining operation
Due date	Tools required	
Information on fixturing	Operation time	
Palletizing of part	Sequence selection option	
	Shared operation	

*Part identification = Part name + No. of part required

Table 5: Time routine control function

Module 1: Time initialization	Module 2: Event handler
Clock*	Resource current state
Future Events List (FEL)	Current part-machine-tool sets
Current Events List (CEL)	Trigger event
Marked events	Mark event
	Unmark event
	Update time
	Event advancement routine (CEL,FEL)
	Next event type

*Clock = Current simulation clock + Time advancement routine

It is important to design a tool management control function so that the proper tools are available at the right machine at the desired time for processing of scheduled parts. The tool magazine capacity limits the number of tools mounted on a machine. This reduces the number of parts that can be processed on a machine without reloading the tools.

Part Control Function

The work-order processing and part control system is the system that essentially drives other control systems. The basic information structure used in the part control subsystem is given in Table 4.

As shown in Table 4, modules part setup, part routing and part process planning are configured for controlling part flexibility. Part setup module identifies part's general information. Part routing module controls alternative machining center and tools for executing operation with respect to a predefined sequence. Part process planning module designs an executive plan for part's operations.

This subsystem concerns the determination of a subset of part types from a set of part types for processing. A number of criteria can be used for selecting a set of part types for immediate processing (e.g., due date, limited availability of tools on tool magazine, requirement of tools bye part type, etc.). The real time adaptive control framework is based on affiliating all current events and expected future event to a time tag for process synchronization. Time routine control function considers the state vector of a FMS cell as shown in Table 5.

As shown in Table 5, modules time initialization and event handler are configured for controlling time routine. Time initialization module initializes the simulation clock and FEL, CEL vectors. Event handler module updates FEL, CEL vectors using event advancement routine.

FMS ADAPTIVE CONTROLLER ARCHITECTURE

Simulation-Based Intelligent Decision Support System

The main contributions on simulation-based IDSS for the adaptive real-time control of flexible manufacturing systems can be summarized as follows (Mahdavi *et al*., 2010):

- Simulation-based IDSS constitutes the framework of adaptive controller supporting the co-ordination and co-operation relations by coupling a real time simulator, a simulation optimizer and an intelligent DSS for implementing dynamic strategies
- The simulation-based IDSS uses a posteriori adaptive real time machining process-monitoring mechanism that also is online control method acting after the event occurs versus such popular reactive control method
- The adaptive controller proposes a new bilateral mechanism for simulation optimization based on appropriate control rules that enhance multi performance criteria simulation optimization efficiency
- The expected values of multiple performance criteria are controlled by the proposed system at different level of controllable parameters vector

A combination between simulation and intelligent decision support system as an interactive model is developed for FMS adaptive control and shown in Fig. 3. Figure 3 shows the cooperation between IDSS and the simulator module.

The current configuration parameters of the FMS are read by user interface and are used as the input data to build conceptual model. The simulation model will evaluate the current shop performance, such as actual cycle time, tool and buffer utilization. If the performance target is not achieved, the system will recommend how to modify the simulation model. This process continues until a satisfying and controllable shop floor configuration is reached. Figure 4 shows the detailed relationship between the modules.

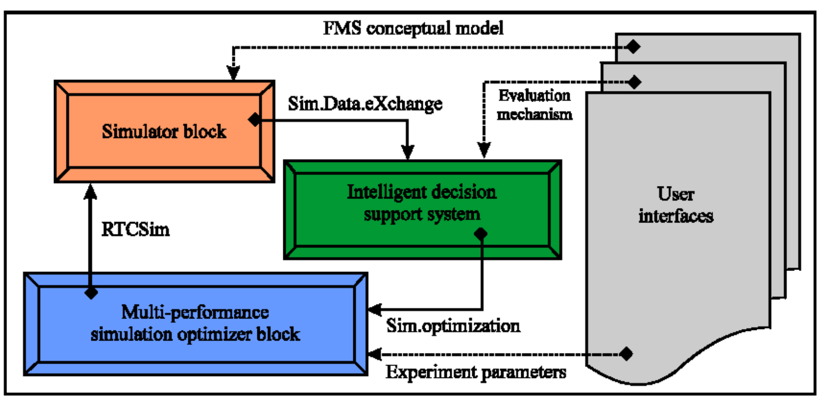

Fig. 3: The structure of simulation-based IDSS for FMS adaptive control

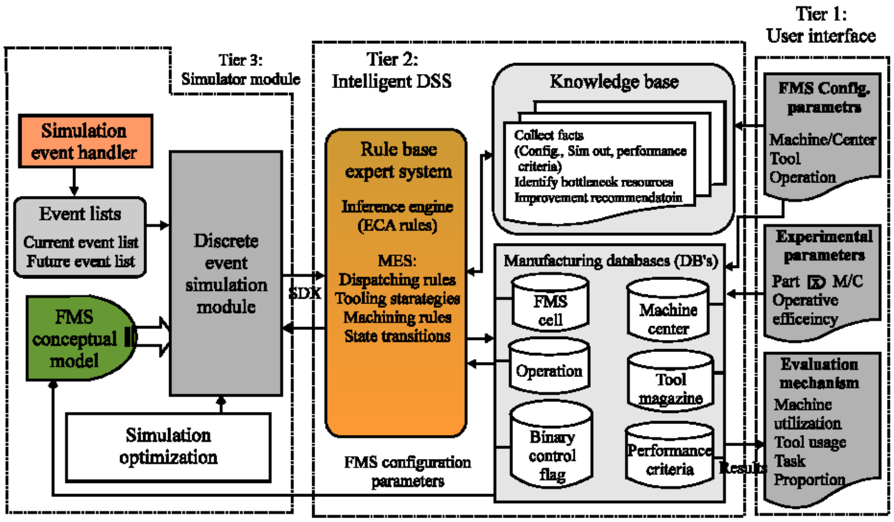

Fig. 4: The structure of simulation-based IDSS for FMS adaptive control (Mahdavi *et al*., 2010)

This project was conducted in a wood manufacturing system in Manzandaran province, Iran among 2008-2010. The system presents details of the architecture, components and functions of a FMS decision-making controller. The controllers consist of a simulator model coordinate rule based IDSS with a real time mechanism. The simulation output data are fed to the knowledge-based system as input data. The rule-based IDSS analyzes output of simulation model to control the real-time status of FMS. Once the IDSS makes recommendations, the simulation model is adjusted accordingly and the process is repeated (Delen and Pratt, 2006). The simulation and IDSS components cooperate with each other until the control goals are achieved. Since the primary objective is to improve the throughput of the shop floor, a simulation analysis assisted by decision process is carried out. The status of the cell, machines, part orders, the availability of operators and system control flags are recorded in separate databases (DBs). Manufacturing execution mechanisms as a production monitoring system uses the information of these DBs. With the help of IDSS, possible improvement points are recognized and the recommendations are provided.

Sequence of jobs is used to control the flow of parts through the system. The first step to estimate the performance criteria is assigning the operations to machines and scheduling the operations on each machine. Simulator module was implemented using the simulation language. The simulation language objects are used to access the information about the FMS to construct a conceptual model of the system. Entity attribute values, variable values and model information can be accessed during the simulation period and hence is an appropriate tool for real time Simulation Data Exchange (SDX). The simulator module consists of the simulation event handler (to handle current event lists and future event lists), the conceptual model (FMS processes that are simulated) and simulation optimization core. The simulation language library could simulate conceptual model of FMS entities using resources, stations, variables, attributes and queues.

The simulation model should be run in execution mode using the function to synchronize simulation logic with an external process of FMS controller system. The simulation clock is set to the real-time clock of the operating FMS system and all other simulation processes are initiated. Configuration of FMS resources and control commands provide static and dynamic information for the simulation module with considering both machine and tool flexibility. It could achieve a good production schedule in the flexible manufacturing environment using the simulation module mentioned above with restraining completion time on machining centers and restriction of other criteria.

It could achieve a good production schedule in the flexible manufacturing environment using the simulation module mentioned above with restraining completion time on machining centers. The simulation model is used for initial analysis of the controllable parameters of the system. Since the system performance criteria are not in the desirable level, analysis of the simulation output is necessary for possible improvement.

Considering the lack of ability to breakthrough manufacturing problems in priori simulation, the controller is capable to run a posteriori simulation and fetch online results. The IDSS also is capable to replicate the simulation. In order to obtain the optimum responses in simulation optimization core, the first step is to explore the region around the initial operating conditions to decide which direction needs to be taken to move (Guo *et al*., 2009). Designing of these experiments depends on the task proportion factor. In order to explore the region around the current operating conditions, simulation replications of the experiments should be done using.

The simulation optimization functions apply a mechanism to move from the initial operating conditions to the vicinity of the operating conditions according to the different levels of actual cycle time, tool usage and buffer usage.

The posteriori adaptive control framework is implemented by combination of the control rules and real time simulator for enforcing dynamic strategies of shop floor control. The simulation model is used for initial analysis of the controllable parameters of the system. Since the system performance criteria are not in the desirable situation, analysis of the simulation output is necessary for possible improvement. To control the external processes of FMS, the simulator module and IDSS are synchronized via simulation data exchange. The IDSS analyzes outputs of simulation model to control the real-time status of FMS after receiving these results. The IDSS then sends appropriate control signals of beginning operation to the corresponding entities when an event is occurred. Proposing the adaptive controller with this structure allows modeling of synchronization mechanism between FMS entities and transmission times for messages exchanged between the IDSS and simulator.

The rules are composed in such a way that in all states the FMS is controlled based on system events. For implementing real time Inter-Process Synchronization (IPS) between simulator and IDSS, Visual Basic® for Applications can be used. Events provided by the simulation language library code execution are returned to IDSS module for firing appropriate rules.

Figure 5 schematically describes the inter-process synchronization between the IDSS and the simulation language modules.

The simulator can trigger the rule-based IDSS to generate the appropriate control policy. The simulator module sends messages to the external rule-based system to indicate simulated results from. The rule-based IDSS interpret these results and sends appropriate action messages back to the simulator and user to indicate the instructions to be done. All of the information regarding the FMS shop floor status such as machining centers, part types and binary control flags are kept in appropriate Data Bases (DB). Exchanging data between the simulator and the DB is done through ActiveX Data Objects (ADO).

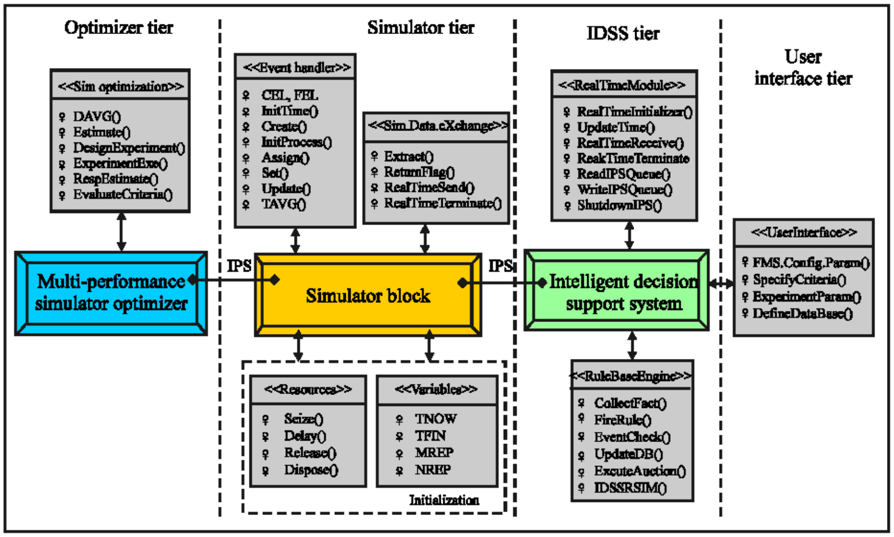

Fig. 5: Real time simulation data exchange via inter-process synchronization

Rule Production for FMS Real Time Simulation-Based Controller

The IDSS collect the facts into appropriate DB, which is then used for inference by simulation outputs in feed forwarding reasoning (Iassinovski *et al*., 2008). The control framework is implemented by integration of the adaptive control rules and real time simulator for enforcing dynamic strategies of FMS shop floor control. In order to strengthen the expert system reasoning, knowledge-elicitation techniques are used for preventing ineffective redundancy at concurrent firing of rules and high degree of parallelism.

This knowledge-based IDSS is aimed at providing a powerful control on different operations of FMS. It acts as a cell manager, which may work alongside the operating cell-oriented part and tool management system. These sections describe the knowledge representation through a set of control rules. Design of IDSS controller focuses on the development of appropriate Event-Condition-Action (ECA) rules for tuning control parameters. These rules are formulated by the techniques of data gathering and knowledge elicitation to construct IDSS. The IDSS is able to obtain feedback results from the on-line system of simulator. This allows the expert system to check the control policy to see whether it is within the desired tolerances when the predictions of FMS properties are correct. These results are very significant and let the expert system to re-simulate if the performance criteria are not desirable.

The rules applied in this study are structured in the following form and consist of three segments: event type, condition and action:

When ‹Event_1, Event_2, Event_3, … ›
If ‹Condition_1, Condition_2, Condition_3, … ›
Then ‹Action_1, Action_2, Action_3, … ›

Event Type

This tag specifies that analysis of condition should be done once the events take place.

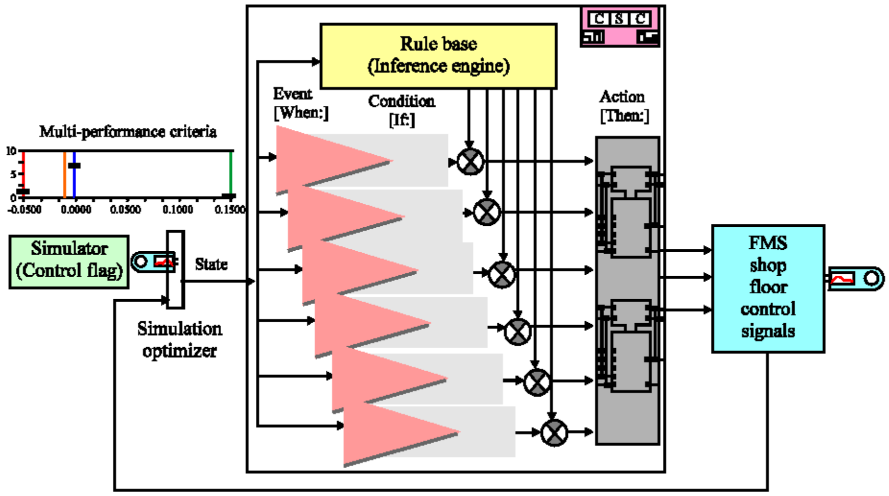

Fig. 6: IDSS real time control rule structure

Condition

This segment of ECA rules specifies a list of conditions. In order to trigger an action rule, all conditions should be satisfied. These conditions refer to a logical assertion of the FMS states extracted by the simulator module.

Action

This segment specifies actions which may consist of a list of operations. Whenever an action rule is triggered by an event, the operations being in its action list will be initiated sequentially. These operations may be contained in different action rules with different combinations.

The operational control should indicate in a precise way the actions to be taken synchronously. So, the $\{\text{Events}\}\times\{\text{Conditions}\} \rightarrow \{\text{Actions}\}$ rule-based system is constructed three main sections as shown in Fig. 6.

[When:] section describes temporal aspects, [If:] section represents the resource and operator status and finally [Then:] segment sends control signals to FMS shop floor at the higher decisional levels. The IDSS is able to obtain feedback results from the on-line system of simulator. This allows the IDSS to check the control policy to see whether it is within the desired tolerances when the predictions of FMS properties are correct. The rules identified for implementing manufacturing execution system consists of dispatching rules, machining rules, tooling strategies and the rules for control of FMS different states transition, bottleneck detection and resolving and assign the operation to non-bottleneck machine

The rule-based system for manufacturing execution system provides the parts sequence list to the multi-purpose machines available and then the operation assignment and task proportions of parts on related machines. The output can be manipulated by changing the rules and strategies entered at the expert system query stage such as the number of machines used, the part-scheduling rule adopted, the part batch size and the manufacturing period.

CONCLUSIONS

This study reviews intelligent decision support system architecture to tackle the production control of a FMS. Development of the knowledge-based system is aimed at integrating an ECA rule-based system and a simulator module to ease the cell adaptive supervisory control. The FMS shop floor data are gathered and stored into the appropriate databases over time. The adaptive control mechanism employs a real time discrete event simulator to predict performance of the given system during the remaining time of planning horizon. The current state of the FMS performance criteria from the simulator is then stored on the appropriate databases. This type of system provides an applicable and efficient framework for real-time control of the shop floor in flexible manufacturing system. The criteria considered to measure performance of the system shows that the approach is effective and efficient in controlling shop floor.

As a result, these systems are suitable for different control frameworks on an existing flexible manufacturing system considering the physical constraints and the production objectives. Furthermore, these systems illustrate the potential of using the intelligent rule-based DSS for adaptive control of modern industrial plants.

Future Trend

Future researches may concentrate on the application of mix type of flexibility in shop floors using simulation-based predictive controllers. Briefly, the future trend of intelligent DSS controllers will experience:

- Fuzzy multi-input multi-output intelligent discrete adaptive controller
- Nonlinear intelligent discrete-time controller
- Intelligent co-simulator for FMS control
- Finite-time control of discrete-time stochastic FMS

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