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Multi-factors Bidding method for Job Dispatching in Hybrid Shop Floor Control System

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ABSTRACT

A shop floor can be considered as an important level to develop a Computer Integrated Manufacturing system (CIMs). The shop floor is a dynamic environment where unexpected events continuously occur, and impose changes to planned activities The shop floor should adopt an appropriate control system that is responsible for scheduling coordination and moving the manufacturing material and information flow. In this paper, the architecture of the hybrid control model identifies three levels: i.e., the shop floor controller (SFC), the cell controller (CC) and the equipment controller (EC). The methodology for developing these controller is to employ an object-oriented approach for static models and IDEF0 for function models for dispatching a job. SFC and CC are coordinated by employing a multi-factors bidding and an adapted Analytic Hierarchy Process(AHP) prove applicability of the suggested method. Test experiment has been conducted by with the shopfloor, consisting of six manufacturing cells.

Keywords : Hybrid shop floor control system, CIM, objet-oriented paradigm, IDEF0, Multi-factors bidding, Adapted AHP

1. Introduction

As product life cycles are reduced, modern manufacturing systems are required to have sufficient responsiveness, and to adapt their behaviors efficiently to a wide range of circumstances. The responses to these demands include progress in the automation of manufacturing systems, such as the use of manufacturing knowledge, shorter programming times, and appropriate control modeling methodology. The efforts to achieve advanced automated factories bring into focus the development of manufacturing systems with high levels of flexibility and intelligence. [1-4]

CIM (Computer Integrated Manufacturing) system has been introduced to complete the advanced manufacturing systems by integrating some parts of the new technologies With all of its merits, the integration resulted in the rigid and hierarchical control architectures whose structural complexity grew rapidly with the size and variety of production system. A hierarchical structure for CIM systems had been designed and implemented at the Automated Manufacturing Research Facility (AMRF), consisting of five levels of control : facility, shop, cell, workstation and equipment levels. Among the control levels, the shop floor control level is provided with ever more versatile production equipment, such as robots, NC machines, AGV, etc., so that is responsible for coordinating the production, supporting jobs on the shop floor and allocating resources to the jobs.

In order to realize shop floor control systems, Liu et al. proposed an object-oriented analysis and design method for the modeling of shop floor control systems. This methodology allows the manufacturing system to be independent, autonomous and distributed, and those achieving an adaptability to the change the manufacturing environment as well.[5]

In order to achieve the best possible manufacturing process, in shop floor control level the alternatives must be evaluated on the basis of a number of the relevant criteria. Ou-Yang suggested a bidding method based on the required production costs only.[6] However, criteria for job dispatching involved in a shop floor are related to multi-factors instead of single factor, such as cost or time. Analytic Hierarchy Process(AHP) is an intuitive and relatively simple method for analyzing such problems.[7] Akturk and Balkose suggested a multi-objective cluster analysis heuristic to deal with these objectives simultaneously.[8] The analytic hierarchy process is employed to determine priority of the objectives in order to unify them. Zhen and Hikaru proposed an extended AHP method for comprehensive evaluation with quantitative and qualitative factors.[9]

In this paper, the hybrid shop floor control system [10] is described, which identifies three levels, the shop floor controller, the cell controller, and the equipment controller. Each control level is modeled by using an object-oriented paradigm and IDEF0 to achieve the static reconfiguration and functional representation, respectively. For dispatching a job, SFC and CC are coordinated by employing a multi-factors bidding and an adapted AHP prove applicability of the suggested method, test experiments has been conducted by with the shop floor, consisting of six manufacturing cells

2. Modeling of hybrid Shop Floor Control System

2.1 Object Modeling of Shop Floor

The Object-Oriented approach is used to describe a method of modeling for the hybrid shop floor control system in which the system is organized as a collection of discrete objects. Each modeled object not only contains both the data and the behavior, but also corresponds to the physical object associated with a shop floor or a manufacturing system. A shop floor or a manufacturing system is considered as a composition of two major parts, that is, the set of physical devices which require control (the controlled objects) and the set of controllers (the controlling objects). This object-oriented approach has effects on the development of the interface between the physical devices and the shop floor control system because it provides a generic interface independent of equipment types.

As shown in Fig.1, an abstract resource model composed of a shop floor is modeled by using UML (Unified Modeling Language) that is one of the object-oriented approach methods. All classes developed in the model are designed to represent the real manufacturing group of objects. They contain aggregating generic objects or machines (robot, NC machines, conveyor, etc.) that can easily be specialized and refined. A shop floor can be viewed as a group of manufacturing cells, such as a machining cell, an AS/RS cell, an inspection cell, a conveyor and sensors. In turn, a machining cell contains lathes, milling machines, robots, and a cell controller. An inventory is released by AS/RS and transferred to robots through a AGV. And several sensors are embedded in the manufacturing system or shop floor to monitor the functioning of machines, a conveyor, and robots.

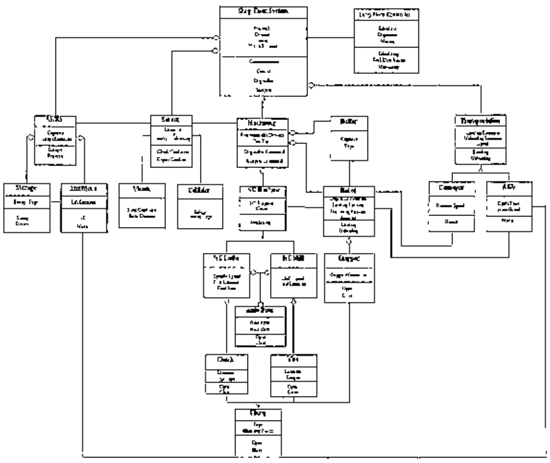

Fig. 1 Object model for hybrid shop floor control system

2.2 Shop floor control model

As shown in Fig.2, the employed hybrid control architecture consists of three levels of controllers : the equipment controller (EC), the cell controller (CC), and the shop floor controller (SFC). For the functional modeling of the control system, IDEF0 method is employed, which consists of a hierarchy of related diagrams.

2.2.1 Shop Floor Controller (SFC)

The SFC is responsible for all the system-level management, coordination and control. It is also the sole communication port with the external systems, i.e., CAD/CAM, CAPP, and MRP. It consists of two modules, i.e. a scheduler and a coordinator that has two sub-modules: a dispatcher and a monitor.

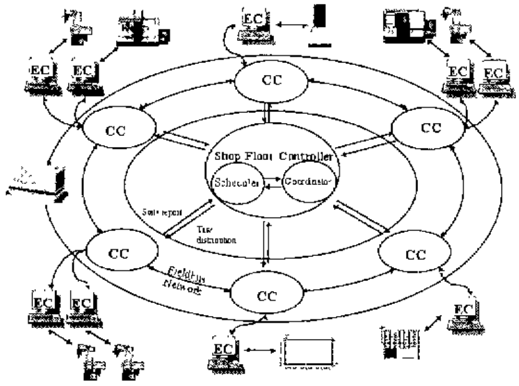

Fig. 2 The proposed control architecture

The scheduler determines the optimal tasks, taking into account the finite capacity of the machine tools and what is to be done by the cell controller. The coordinator manages the set of CC during production, executing the schedule by dispatching work-orders and constantly monitoring CCs.

Each controller in SFCs performs many tasks that can be bundled into two or three groups according to events occurring at different frequencies. In other words, each group may contain a few tasks which can be managed and executed by an appropriate groups are assumed to be planning, scheduling and execution as shown Fig.3.

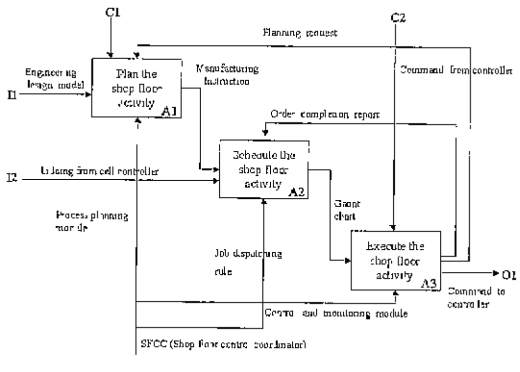

Fig. 3 Function model of Shop Floor Controller (SFC)

The planning module at SFC level receives orders and planning data of related parts of those processes supplied from CAPP system and prepares a set of jobs to be scheduled. The schedule module at shop floor control level takes charge of sequencing and dispatching the multiple parts in order to resolve resource contentions. The executor at shop floor control level interprets incoming messages, detects and corrects errors, and broadcasts newly created messages to CC.

2.2.2 Cell Controller (CC)

The cell controller (CC) corresponds with a small subset of equipment that directly interacts. For instance, it can correspond with an industrial robot and a NC machine for unloading and loading. It deals with commands and information received from the SFC, and is responsible for parts moving between the various equipments and for specifying the processes performed at the equipment.

The functionality of the Cell Controller(CC) is decomposed into three main activities - planning, scheduling and execution - in order to ensure completion of the orders, as shown in Fig.4.

The CC is initiated by a command received from the SFC execution module, and then drives the three functions and communicates with other controllers. The CC's planning module invoked either by the CC's execution module when a new part arrives to the CC or by the CC's scheduling module when replanning is required The CC's scheduling module is invoked when a planning activity on a new part is finished, or when an operation is finished at a machine tool, or when a device becomes idle. Basically, the execution module invokes the scheduling module whenever an event requiring decisions is encountered. Then scheduling module understands its implication, and updates the resource and part status. The event is one of the scheduling problems. For instance, operation sequence problem, part dispatching problem, robot location problem, etc. The scheduling module selects scheduling rules for the problems that are supposed to provide the next action to be taken. The execution module is reading inputs and exchanging information. The execution module receives a set of control and response messages from its own planning and scheduling module, and from other controllers. Being analyzed and understood, the messages are decomposed into the detailed messages that are broadcast to other functions and controllers. Each message carries the set of parameter, which determines the characteristics of the message.

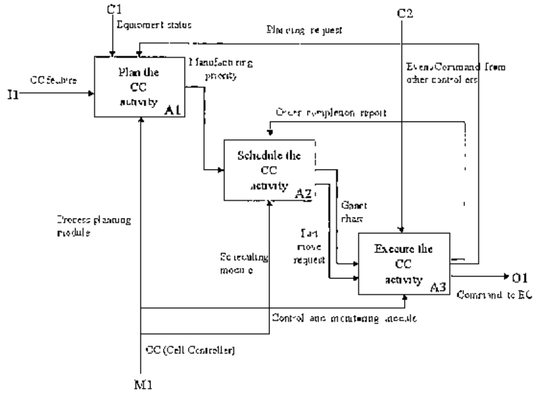

Fig. 4 Function model of Cell Controller (CC)

2.2.3 Equipment Controller (EC)

The Equipment controller (EC) is on the lowest level of the hybrid control architecture. There is one equipment level controller for each piece of equipment in the system. Individual machine also has machine controller that provides physical control for the devices. These include robot controllers, NC controllers, PLC, and motion controllers, in which are usually provided by machine tool vendors. Equipment controllers provide a generic interface, based on equipment type, to other equipment controllers and to a higher level controller, cell controller.

An equipment controller is responsible for converting the processing instruction data into a form directly usable by the specific machine controller and monitors the operation of the machine under control and reports the state of a particular machine to an upper level controller, i.e. cell controller(CC). As shown in Fig.5 the EC also consists of three functions: planning, scheduling, execution.

A major input to the controller is the EC feature that represents assigned features and their precedence relationship. The EC planning module is received the planning request from CC's execution module. Then it determines the detail facts to execute the given operation. They are about tool dispatching, the modification of tool path and machining parameter operation which is considering the equipment status and tool and fixture status from CC's execution module, Then EC's planning module determines the detailed operation sequence and total finishing time. Next it transfers message that needed to operate task to scheduling module. The scheduling module determines the sequence of features and forwards a NC file associated with each feature to the executor. The executor accomplishes the assigned feature by downloading the corresponding NC file to the machine control unit. The execution module also communicates with other controllers by sending and receiving various status messages. The EC's execution module performs similar functions to that of the CC's execution module, except the device monitoring activity. The device monitoring activity must be designed to read analogue signals and generate corresponding digital messages. The execution module may also receive command and status messages from the other controllers.

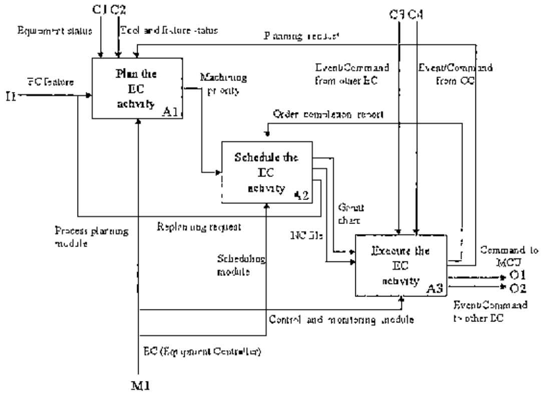

Fig. 5 Function model of Equipment Controller (EC)

3. Multi-factors bidding for job dispatching Method

The SFC is responsible for the process of job dispatching. For a new product, each CC determines the feasibility of fabricating that product by submitting the bidding factors. Using adapted AHP method, the SFC evaluates the bidding factors submitted and assigns an appropriate cell to fabricate the product.

3.1 Multi-factors bidding method

For a mathematical method, to compute the bidding factors in a CC the notations are as follows:

J	part
i	cell
k	machine
l	tool
P_{jik}	processing time of part j on machine k of cell i

d_j due date of part j
T_{ji} the completion time for part j in cell i
T_{jik} the completion time for part j in machine k of cell i
h_j the carrying charge for part j
CB_{ji} the total price for order Q_j in cell i
CI_{ji} inventory cost for part j in cell i
CP_{ji} processing cost for part j in cell i
CP_{jik} the process cost for part j in machine k of cell i
Q_j quantity of part j in an order
MU_{ji} machine utilization for Order Q_j in cell i
PM_{ji} machine j price in cell i
TR_{ikl} tool life remained of tool l at Machine k in cell i
TTR_{ji} total tool life remained for Order Q_j in cell i
TC_{ikl} tool cost of Machine k in cell i
TTC_{ji} total tool cost for Order Q_j in cell i
QL_{ji} quality of part j produced in cell i
t_{ij} transportation time from cell i to cell j.

The model for computing the bidding factors of a job can be described as:

$$CB_{ji} = CI_{ji} + CP_{ji} \quad (1)$$

$$MU_{ji} = \sum_{k=1}^{m} PM_{ik} \quad (2)$$

$$TTR_{ji} = \sum_{k=1}^{m} \sum^{l} TR_{ikl} \quad (3)$$

$$TTC_{ji} = \sum_{k=1}^{m} \sum^{l} TC_{ikl} \quad (4)$$

where :

$$CI_{ji} = (d_j - T_{ji}) \times h_j \times Q_j \times (1 - y) \quad (5)$$

$$CP_{ji} = \sum_{k=1}^{m} CP_{jik} \times P_{jik} \times Q_i \quad (6)$$

$$T_{jik} = T_{jik-1} + P_{jik} \quad (7)$$

$$T_{ji} = \mathrm{Max}|T_{jik}| \quad (8)$$

$$y = 0 \ \text{ if } d_j \geq T_{ji} \ \text{ otherwise } y=1 \quad (9)$$

The production cost needed for a product is composed of the processing cost and the inventory cost of the evaluated order (Eq.(1)). The processing cost is the product of the machine cost per unit time, the required processing time for each component and the quantity of the components, (Eq.(5)). The inventory cost is the product of the difference between the actual finishing time and the due date, the unit storage cost, and the quantity of the components in an order (Eq.(6)). In these equations, the final finishing time T_{ji} is the completion time of the final operation(Eq.(7) and (8)). Machine utilization is determined based on capital investment of cells, that is the sum of the machine prices in a cell (Eq.(2)). Considering tools required for the order, each cell controller calculates the total tool life remained(Eq.(3)) and the total tool cost (Eq.(4)). And the predicted quality of parts to be produced is determined statistically and represented as a rejected rate of parts. For example, value 0.1 denotes 10% of rejected rate .

3.2 Adapted Analytic Hierarchy Process (AHP)

The job dispatching method used by the proposed hybrid control framework includes two steps. For a new order, each CC will evaluate its contents such as the required quantity and quality, and then submit bidding factors including the machine utilization, the tool remained life, the tool cost, the predicted quality, and the production cost As shown in Fig.6, the SFC applies the adapted AHP algorithm to solve the multi-criteria decision problem, and determine on a suitable cell to proceed the order.

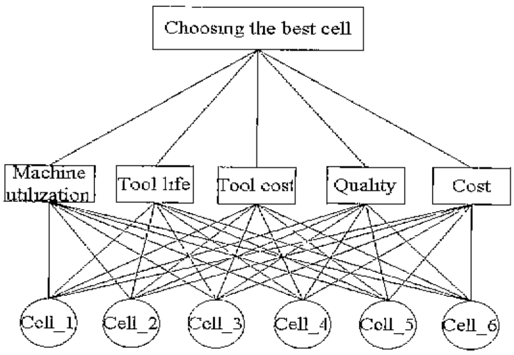

Fig. 6 AHP of the proposed model

Typically, AHP can be represented as three parts : decomposition, comparative judgment, and synthesis.[8] The decomposition is carried out based on the affected attributes, and can be in turn further decomposed into sub-attributes. The attributes considered here are the proposed factors, involved in the manufacturing performance to achieve the dispatching goal. A comparison matrix is set up to carry out pairwise comparisons of the relative importance of factors. Every elements of a comparison matrix shows the relative contribution of the i^{th} activity as compared to the j^{th} activity, i.e $a_{ij} = w_i/w_j$, $1 \le i \le n$, $1 \le j \le n$, where w_i, $i = 1,2,\ldots,n$, represents the weight of factor i. The scale for judgment is represented as important intensity, for example, intensities 1 and 3 denote equal importance and moderate importance, respectively. The values of the w_i/w_j are just estimated, not obtained from precise calculation.

In this paper, CC deals with objective values for quantitative factors, such as cost and time, so that SFC converts the evaluation of quantitative factors into AHP model. According to relevant data on the quantitative factors, relative weights on each quantitative criterion should be calculated. In the case of some factors, such as total cost and quality, the smaller value of them illustrates the better weight. So that, the normalized reciprocal of the weights (NRW) is employed for the evaluation.

Finally, the priorities are synthesized by multiplying local priorities by the global priority of corresponding criterion in above level, and adding them for each factor in a level according to the affected criteria.

4. Case study

For a case experiment, a shop floor consisting of 6 machining cells is modeled under QUEST, as shown in Fig.7. The machines, a NC lathe, a NC milling, and a robot, arranged in each cell are capable of performing one or more families of parts.

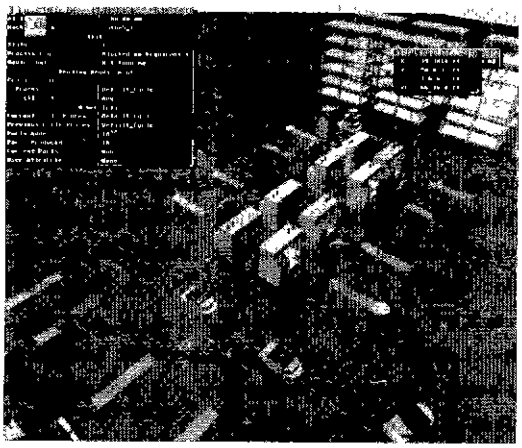

Fig. 7 Modeling of a Shop floor

Table 1 Information and order of the parts to be considered

	Part design	Process	Quantity	Due
Part 1		Milling	5	25
Part 2		Milling +Turning	5	20
Part3		Turning	5	27

Table 1 shows information about products to be ordered by SFC, including the quantity and due date. Each product requires the specific process that is manipulated by a lathe or a milling, or both. Part 2 is announced as a new order and bid by SFC and CC, respectively.

In the SFC, the comparison matrix (Table 2) for the quantitative factors is obtained form the selected answer sheet of questionnaire decided by a manager. The weight vector [0.2877 0.0714 0.0456 0.1405 0.4548] is calculated from the normalized eigenvector.

Table 3 shows the capability of each cell to complete the given order. Each machine belonged to a cell requires the setup time, the production time, the unit time cost, and the completion time for the part 2 As the result of calculation based on the equations, from Eq(1) to Eq(9), values of six quantitative factors are obtained as shown in Table 4, and submit to SFC for evaluation. The ratios on quantitative factors are obtained by applying normalized reciprocal of weights (n.r.w) and shown in Table 4. These values also represent the priorities on factors, that is the evaluation matrix

Table 2 Relative Importances

	MU	TR	TC	Quality	Total Cost
MU	1	5	7	5	1/3
TR	1/5	1	3	1/5	1/6
TC	1/7	1/3	1	1/4	1/5
Quality	1/5	5	4	1	1/6
Total Cost	3	6	5	6	1

Table 3 Production information about the part 2

	Cell1		Cell2		Cell3		Cell4		Cell5		Cell6	
Machine	**M1**	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**	**M8**	**M9**	**M10**	**M11**	**M12**
ST, MT	18	12	15	25	15	12	15	10	14	18	15	15
UTC	25	18	30	10	30	30	26	25	32	18	10	30
FT	117		152		99		277		202		129	

Table 4 Weights of ratios criteria

	Tool cost		Quality		Total cost		Machine Utilization		Tool life	
	Value	**n.r.w**	**Value**	**n.r.w**	**Value**	**n.r.w**	**Value**	**n.w**	**Value**	**n.w**
Cell 1	29	0.286	0.05	0.091	3340	0.171	5.500	0.108	510	0.204
Cell 2	50	0.169	0.08	0.045	3506	0.180	7.500	0.147	391	0.157
Cell 3	65	0.130	0.01	0.364	2562	0.132	3,000	0.059	883	0.354
Cell 4	110	0.075	0.03	0.136	3200	0.164	4,000	0.078	250	0.100
Cell 5	83	0.125	0.02	0.091	3861	0.198	10.000	0.196	118	0.040
Cell 6	48	0.216	0.03	0.136	3008	0.154	21,000	0.412	345	0.138

Finally, the priority vector, [0.149 0.150 0.159 0.127 0.168 0.227], is calculated from multiplying the evaluation matrix with the weight vector (Eq.(10)). The final rank of cells is : cell6 -> cell5 -> cell3 -> cell2 -> cell1 -> cell5. That is, cell 6 is selected as a best ideal choice, in case of considering all 5 factors.

$$\begin{pmatrix} 0.108 & 0.204 & 0.286 & 0.091 & 0.171 \\ 0.147 & 0.157 & 0.169 & 0.045 & 0.180 \\ 0.059 & 0.354 & 0.130 & 0.364 & 0.132 \\ 0.078 & 0.100 & 0.075 & 0.136 & 0.164 \\ 0.196 & 0.040 & 0.125 & 0.091 & 0.198 \\ 0.412 & 0.138 & 0.216 & 0.136 & 0.154 \end{pmatrix} \times \begin{pmatrix} 0.2877 \\ 0.0714 \\ 0.0456 \\ 0.1405 \\ 0.4548 \end{pmatrix} = \begin{pmatrix} 0.149 \\ 0.150 \\ 0.159 \\ 0.127 \\ 0.168 \\ 0.227 \end{pmatrix} \tag{10}$$

5. Conclusion

In this paper, a hybrid control system for a shop floor or manufacturing systems has been investigated and modeled by using object-oriented paradigm and IDEF0. As a modeling technique, UML (Unified Modeling Language) is employed and provides reusability, extensibility and modification of the resulting software design. The hybrid shop floor control system developed consists of three levels of controllers : the Shop Floor, the Cell, and the Equipment controllers. With benefits of an object-oriented approach the shop floor control system is designed to adapt to an unstable environment and will become independent, distributed, cooperative system and an efficient system. The paper suggests a structured method to capture and model the manufacturing messages and data using IDEF0 function approaches. The IDEF0 function model contains the necessary function requirements and their input -- output relationships of a complex system. A job dispatching approach in terms of a bidding and AHP concept is proposed under a hybrid control framework and shows great potential in dealing with those real-time problems involved in factory automation

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