A Dynamic Decision-Making System for Manufacturing Control

S Nahavandi[1], H Abachi[2] and M Abdollahian[3]

[1] Department of Engineering and Technology, Deakin University, Australia
[2]Department of Electrical & Computer Systems Eng, Monash University, Melbourne, Australia
[3]Department of Statistics and Operations Research, RMIT University, Melbourne, Australia

ABSTRACT: *This paper addresses the problems involved in the decision making process for the control of manufacturing systems. A dynamic auction based decision-making system is developed for the control of activities at the factory and cell level for an experimental manufacturing system. The developed system utilises a hybrid control architecture, taking the advantages offered by both hierarchical and heterarchical control structures. The results from this research proves that such a system has greater fault tolerance against unforeseen events and also can provide buffer management.*

Keywords: Hybrid control system, distributed decision-making, negotiation

INTRODUCTION

The centralised architecture was the first attempt at providing effective manufacturing control and generally involves the implementation of a centralised computer that acts as a manager and monitors the state of all processes in the factory. Veeramani (1993) and Duffie (1994) point out that the major problem with the centralised approach is the fact that failure of the centralised database can cripple the system. It is possible to design redundancy in the event of this failure, however, the centralised database would struggle in its ability to handle effectively all the database transactions in the system - thus "in all but the smallest organisations, performance and cost considerations will dictate distribution and function of data".

THE MODIFIED HIERARCHIAL STRUCTURE

With the pure hierarchical form there was a major disadvantage - at the subordinate level there was no autonomy, meaning that if a "break in the chain of command" occurred anywhere from the top of the structure to the bottom then the whole system would fail. The chain of command and the slave/master relationship is maintained with the Modified Hierarchial architecture but the degree of autonomy of the slaves is increased. When the first operation is carried out on the job at the first cell, enough information is passed to it by the SCS (Shop Control System) so that it can arrange for the next operation at the second cell. This allows the CCS (Cell Control System) the ability to supervise the operation and frees up the SCS to carry out more important tasks.

THE HETERARCHIAL FORM

To overcome the limitations of the previous two architectures Dilts (1991). proposed a new system - the Heterarchial architecture. The Heterarchial form is a distributed type of architecture where the control of the overall system is done in a distributed and opportunistic fashion. Many researchers have found that there are a number of limitations associated with hierarchical architecture, one of the major problems being increased complexity as the system expands, and modifiability problems. The core of this problem is in the inflexibility of the strict command protocol and master-slave relationships and because complicated command chains exist between modules.

With the Heterarchial form no Master/Slave relationships exist as inter-cell negotiation protocols such as the Contract Net Protocol Shaw (1985, 1988); Smith (1980, 1978) are used to distribute processing tasks and decision-making between the cells in the manufacturing

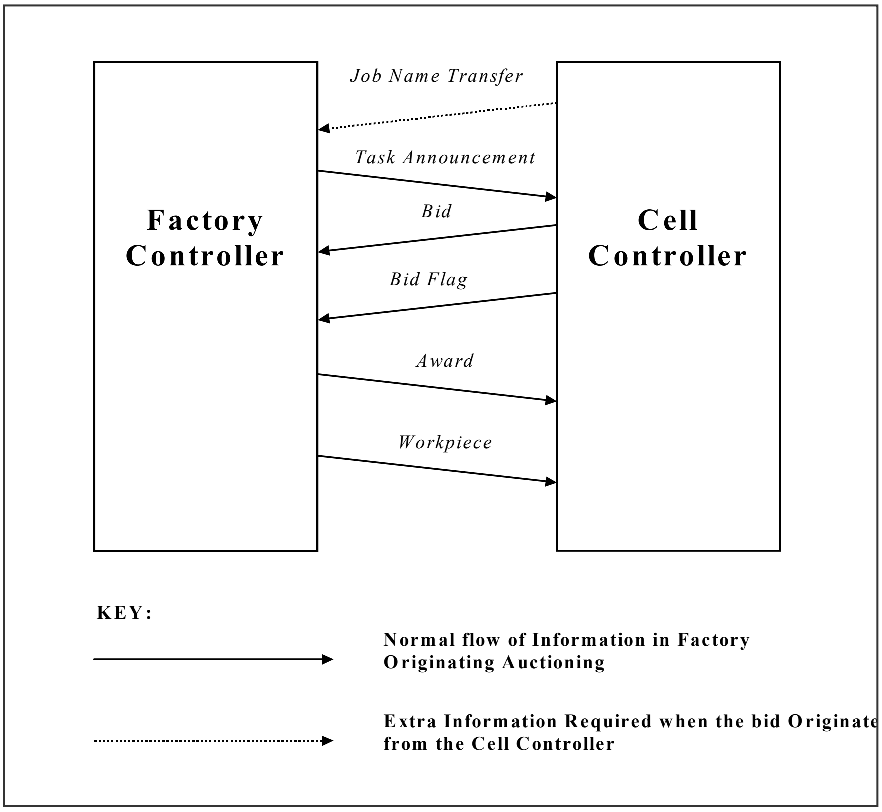

Figure 1 - The Bidding System

system. Global information is eliminated or minimised in this architecture which means a copy of all system required data is held and updated in each cell, this fact tends to aid in the designation and implementation of a fault tolerant system. A negotiation protocol is used between CCS's to decide where the operation required to be undertaken is best carried out, thus giving any CCS the capability of refusing to carry out an operation. The design of the system is such that each CCS's required software is the same giving an implicitly modular system, each module within each CCS being able to be customised to suit the requirements of the system - this allows for reduced software complexity and implicit fault tolerance. However, still there was one problem: that no negotiation took place between factory controller and the cell controllers. Hence a Hybrid architecture was introduced.

THE HYBRID ARCHITECTURE

In the Hybrid structure the negotiation exists not only between the Cell Controllers but also between the Cell Controllers and the Supervisor. The Hybrid architecture was designed to make use of many of the features of modern management philosophies - in particular the ideas of teamwork, management utilising worker expertise as well as other philosophies such as Goldratt's (1984, 1990) "Theory of Constraints" and JIT manufacturing.

The Hybrid architecture also incorporates the ideas of modularity and the loose coupling that exists between them and has been designed to promote a high level of flexibility.

The Hybrid architecture implements a distributed control / decision-making system. A distributed decision-making system gives the following advantages:

- Good Reliability because of the graceful degradation of the schedular in the event of failure.
- Upward Extensibility - the control structure remains the same when new cells are added with minimal increase in network traffic.
- Scheduling is performed in parallel therefore the bottleneck produced by the global schedular is eliminated.
- Cost Effectiveness -processing requirements are less, therefore it is unnecessary to buy more expensive controllers and computer equipment.

JOB ALLOCATION BASED ON DISTRIBUTED DECISION MAKING

The general model of the Hybrid control system is used for the allocation of tasks. When a job is new (no tasks have been carried out) and is ready to be scheduled for the processing of it's first task, the Factory Controller opens the job's file, extracts the relevant data from it and then disperses it to all active cells in the factory. The cells calculate a bid that is dependent on a given performance criteria (ie: Earliest Finishing Time) and also negotiate with other cell and finally these bids are submitted to the Factory Controller for analysis. The Factory Controller algorithm then makes a decision on the most appropriate cell to carry out the task and awards the task accordingly. This developed bidding algorithm (Fig. 1) in this research is based on the Contract Net Protocol.

EXPERIMENTAL RESULTS

Fifteen jobs were randomly queued in the Factory Controller jobs pending queue three consecutive times to give a total of 45 jobs. The start times and dates were set the same for all jobs to ensure effective queue build up in the system, in this way a definitive conclusion could be drawn. All transit times between cells were treated as equal. During the run all activities were recorded at each Cell and Factory Controller including average queue lengths, mean time between completion, task start times, finish times as well as a number of other variables.

After running the system and recording the results, a graph of the loading across the various NC Milling cells within the Hybrid system was obtained as shown in Figure 2. The results demonstrate how the loading on each device in the various cells in the system is balanced. As a queue grows at a given device the other queues at the other devices become more competitive due to the use of the Earliest Finishing Time heuristic and negotiations between the cell and the factory controller, hence decisions are made in an effective distributed manner. This type of balancing will achieve throughput within the system providing other aspects such as buffers are managed satisfactorily as outlined by Goldratt.

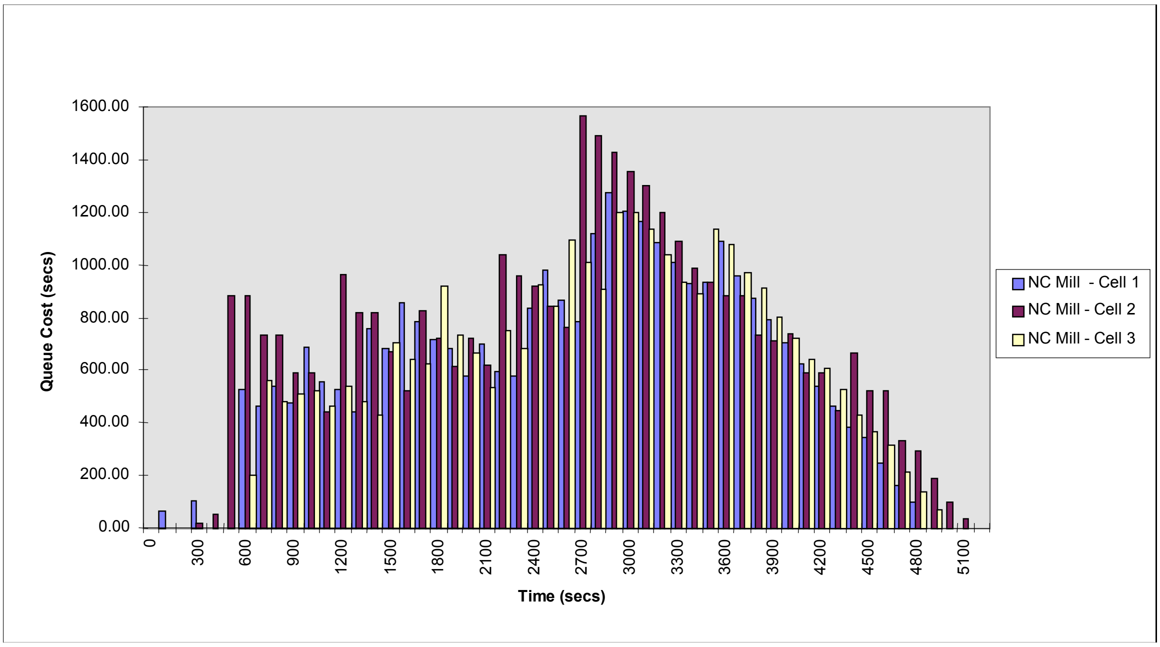

Figure 2 - Queue cost verses time

BUFFER MANAGEMENT

The Hybrid control system is able to incorporate the use of variable buffer sizes to control the volume of work in any one queue. This idea limits the volume of work that exists in an in-going queue for a given manufacturing device and is generally used as an implementation of a given management strategy. Such a system is useful in the following ways:

- To approximate J.I.T manufacturing where this philosophy is required to be implemented - this would be carried out by setting the queue buffer to the time required to process the largest existing task.
- To execute a program of buffer management for the various manufacturing devices within the system thereby increasing throughput and lowering inventory costs within the manufacturing environment.
- To implement any other management strategy that involves controlling the volumes of work allowed in the various queues.

In the second experiment all the ingoing queue buffer sizes were set at 30,000 seconds to ensure that the queue sizes were allowed to build naturally without any constraint. In the Buffer Management test the ingoing queue buffer sizes for the NC Milling Machine on Cell 1 was set at 400 seconds, the buffer for the NC Milling Machine on Cell 2 was set as 30,000 seconds and the buffer for the NC Milling Machine on Cell 3 was set at 800 seconds.

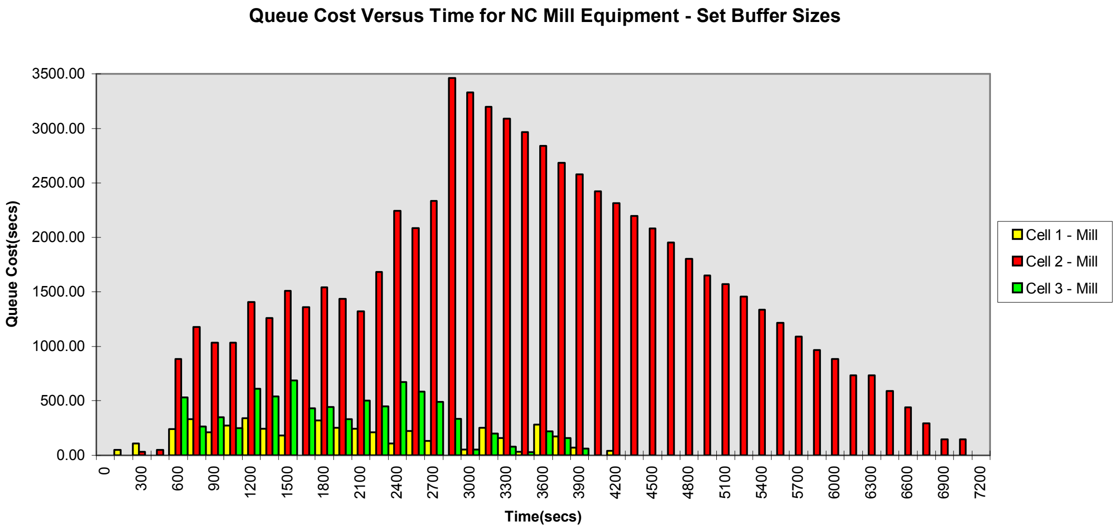

Figure 3 - Queuecost Versus Time for the NC Mill in each Cell - Variable Buffer Sizes

As can be seen in Figure 3, the NC Mill on Cell 2 which has the unrestricted ingoing queue buffer takes on the majority of the workload, whereas the NC Mills on Cells 1 and 3 have queue costs which are not able to exceed the buffer sizes of 400 and 800 seconds respectively.

The total milling time required to complete all milling tasks was 7050 seconds as opposed to 5116 seconds in Experiment 1 (Fig. 2), as the load was balanced over all common processes using the bidding algorithm in that test. Experiment 1 however, was carried out under the assumption that all NC mills over all three cells had the same ability to carry out the job, in reality this may not be the case as different NC Mills may have more horsepower or rigidity / capability for instance, and as such are able to carry out the work at a faster rate. In order to solve this problem, processing, setup and load/unload times could be allowed for in job descriptions to allow for a wide range of machinery of a given type in the one environment. This approach however would be very difficult and rather simplistic, a better approach would be to look at the bottlenecks in the system over a long period of time and vary the in-queue buffers limit to suit.

Experiment 2 (Fig. 3) demonstrated that each NC Milling Machine in-going queue in each cell is restricted so that its size is not allowed to exceed the buffer stated for that machine. At scheduling time a check is made by the Bid Formulation Application in each cell to ensure that the proposed task cost added to an otherwise eligible processes in-going queue cost does not exceed that process buffer limit. If the case arises whereby it does exceed the buffer limit the process is not able to submit a bid for the task.

CONCLUSIONS

A real-time distributed system for the allocation of tasks belonging to various jobs to different cells via negotiation and distributed decision-making has been achieved. This algorithm was based on the concept of the hybrid control system philosophy whereby the advantages of two dissimilar control architectures were combined. The developed system has the potential for being used as a method of identifying the system's bottleneck and then running in real-time and using the knowledge from the simulation to provide even better decisions for real control operations.

REFERENCES

Dilts, DM, Boyd N.P. and Whorms H.H , The Evolution Of Control Architectures for Automated Manufacturing Systems, *Journal of Manufacturing Systems,* Vol 10, #1, pp. 79-93, 1991.

Duffie, N.A. and Prabhu, V.V., "Real-time distributed scheduling of heterarchical manufacturing systems," *Journal of Manufacturing Systems*, Vol. 13, No. 2, pp. 94-107, 1994.

Goldratt , EM, *The Goal - A Process of Ongoing Improvement*, 1984.

Goldratt, EM, *Sifting Information Out of the Data Ocean - The Haystack Syndrome*, 1990.

Shaw, M. and Wiegand, G., "Intelligent Information Processing in FMS," *The FMS magazine*, July, pp. 137-140, 1988.

Shaw, MJ and Whinston, AB , "Task bidding and distributed planning in flexible manufacturing" *Proceedings of the Second Conference on Artificial Intelligence Applications*, pp. 184-189, 1985.

Smith, Reid G , "The Contract Net Protocol: High - Level Communication and Control in a Distributed Problem Solver", *IEEE Transactions on Computers*, Vol C-29, #12, Dec 1980.

Smith, RG & Davis, R , "Applications of the Contract Net Framework: Distributed Sensing" *Distributed Sensor Nets: Proceedings of a workshop held at Carnegie Mellon University*, pp.12-20, 1978.

Veeramani, D, Bhargava, B & Barash, M.M "Information system architecture for heterarchial control of large FMSs", *Computer Integrated Manufacturing Systems* ,Vol 6, #2, pp 76-90, May 1993.