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THE ROLE OF SIMULATION IN OPERATIONAL PLANNING AND CONTROL OF FLEXIBLE MACHINING CELLS

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ABSTRACT

The use of simulation as a solution to the operational planning and control problems of flexible machining cells is now well established. This paper describes the role of simulation models as: a decision support tool, a scheduler and as an aid to develop appropriate control procedures. To illustrate the ideas presented, a novel framework for the simultaneous management and control of parts, fixtures and cutting tools is outlined which is termed multi-flow control. Three simulation models have been designed and implemented to carry out specific tasks within this framework. These models and their respective functionality are also described in this paper.

1 INTRODUCTION

Simulation models have been used extensively for the purpose of design and analysis of Flexible Machining Cells (FMC) (Mertines and Wieneke-Toutaoui 1991). There has been a number of benefits reported in the use of simulation as a design tool (Tempelmeier 1992). These reported benefits include :-

- rapid development of cell designs resulting in reduction of design cost.
- selection of an optimum design among a number initial configurations.
- the concept of 'getting it right first time' to reduce the initial cost of machining cells.

The successful use of simulation as a design tool has encouraged researchers to investigate into possible ways and methods of using these models for planning, scheduling and control (Stecke 1988). More recently, the area of real-time control of manufacturing cells using simulation models has been the subject of a number of research projects (Manivannan and Banks 1991).

Planning, scheduling and control of production systems is a problem of well known complexity. Among the various manufacturing activities, these problems have been the areas with the largest proportion of research and development projects in recent years. This is due to the significant financial incentives for manufacturing companies to constantly improve their manufacturing practices (Grant and Clapp 1988).

This paper describes how the flexibility offered by simulation models can be utilised to improve efficiency and productivity of FMC. The initial part of the paper identifies some of the FMC operational problems in the areas of production strategy selection, scheduling, and cell control. The latter part of the paper describes a novel framework for the simultaneous scheduling and control, of parts, fixtures and cutting tools, termed multi-flow control, to highlight the effective use of simulation in solving the operational problems of a FMC.

2 OPERATIONAL PLANNING AND CONTROL OF FMC

The need for an efficient production management and control system has further increased with the introduction of the flexible machining facilities. In these highly automated systems a number of CNC machine tools are closely linked via work and tool handling facilities, operating under the supervisory control of a computerised cell controller. A typical representation of such a cell is illustrated in Figure 1.

An FMC presents several operating problems that were not encountered in conventional manufacturing systems because of the tightly controlled environment in which they operate (Gupta *et al.* 1993). These operational problems, together with how simulation models are used to solve them, are discussed in the following sections.

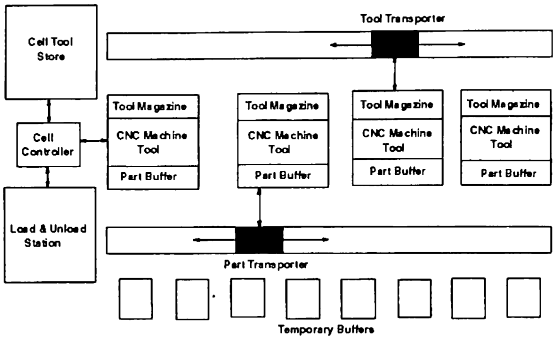

Figure 1 : A Block Diagram Representation of a Flexible Machining Cell

2.1 Simulation Based Planning and Scheduling

The daily operation of a FMC involves the process of a manufacturing plan, by converting a list of jobs to finished/machined parts. There are a number of tasks involved in generation of daily manufacturing plans such as batching (lot sizing) of total orders into manageable partitions, routing parts through machining cells, producing a dispatching list for the load and unload stations, and sequencing the operations within jobs.

The scheduling task is one part of the manufacturing planning and control process. Scheduling is required whenever a set of resources in the manufacturing system must be shared to make a variety of different products during the same time period. The objective of manufacturing scheduling is the allocation of machines and other resources to jobs, or operations within jobs, and the subsequent time-phasing of these jobs on individual machines.

The scheduling policies, constraints and requirements vary significantly between different manufacturing applications. As a result, the majority of schedulers developed are designed to suit a particular application such as discrete part manufacture, the process industry, assembly of PC boards, etc.

Simulation has been traditionally utilised in the area of scheduling as the means of validating the robustness of a generated schedule before it is released to the manufacturing system. Simulation models, by introducing variability with the use of statistical distributions and random numbers, have had the capability to predict bottlenecks, queuing problems, over utilisation of resources, etc.

More recently, the flexibility of some of the more established simulation languages have been used to develop models that act as a scheduler (Kachitvichyanukul 1991) and generate the work list sequence. The flexibility of simulation allows the modelling of an application with various levels of detail and tailoring schedulers for very complex scenarios. Typical examples are where part operation routing is particularly complicated in a multi-cellular environment or for applications in the process industry where time constraints are very restricted.

2.2 Simulation as Decision Support Tool

Planning and scheduling of flexible machining cells is a very demanding task involving significant decision making based on a number of manufacturing parameters and variables, some of which are illustrated in Figure 2.

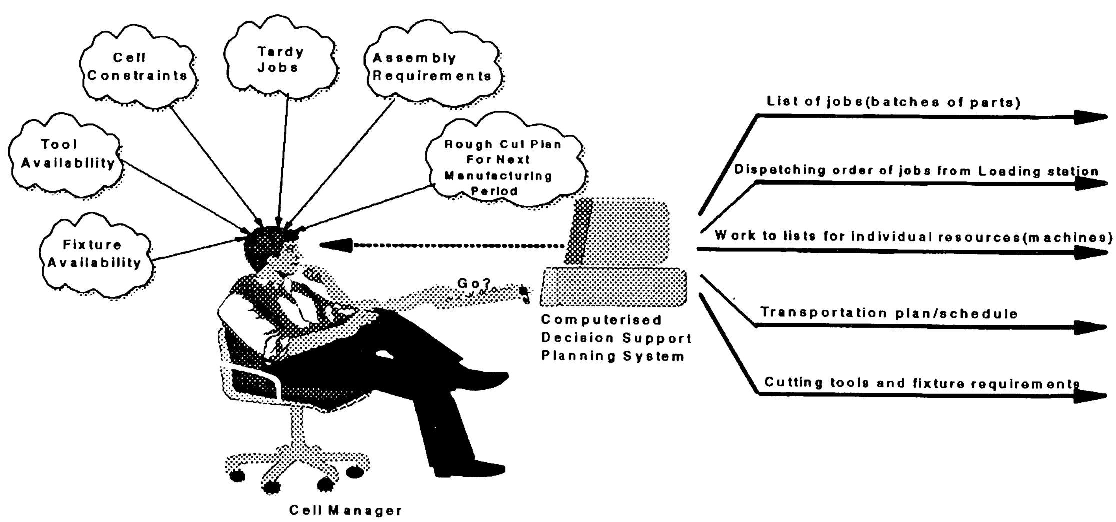

Figure 2 : Planning for the Next Manufacturing Period

A large number of conflicting constraints and manufacturing goals such as meeting due dates, minimising inventory and operation costs, maximising the utilisation of resources and achieving a balanced work load across the resources make the planning task a very complex decision problem. In applications with large numbers of jobs, a wide variety of part types, cutting tools and fixture types, 4-8 CNC machines and very tight due dates; the effect of some of these decisions are vital, but not easily realised. For these complexities and the unpredictable nature of production systems, it has been virtually impossible to develop a fully automated planning, scheduling and control system. This highlights the important role of decision makers and the effect of their decisions.

In addition, there is an ever increasing number of production strategies being introduced to minimise the throughput time and production costs, to maximise the use of resources, and to achieve higher efficiency and productivity. Therefore, the decision maker in charge of operational planning should have the facilities available to test and analyse alternative plans based on various strategies and decision scenarios to obtain confidence that the proposed plan is executable.

Simulation models have been used widely as decision support tools to provide answers for the 'what if' queries. These models enable users to realise the effect of a set of decisions on the system under evaluation. Furthermore, they allow the assessment of the performance under a set of different operational strategies and the selection of the most appropriate ones for a particular application.

2.3 Simulation in Control of FMC

The control function within a FMC is the implementation of a specific production schedule, continuously monitoring the state of the system and the progress of the schedule. This has to be able to take steps to overcome problems introduced by changes in the system status (e.g. machine breakdowns) or interrupts to the schedule(e.g. shortage of raw material and tools). The problem of schedule adherence has been the subject of many research projects with various solutions been suggested (Cheng and Gupta 1989).

One of these solutions is the real-time control of manufacturing systems. With real-time control there is a need for a detailed model of the manufacturing system which has been integrated via a computer network to the physical resources on the shop floor. This model receives information on system status through shop floor data collection facilities and issues appropriate corrective instructions to overcome any possible problems (Smith *et al.* 1994). Knowledge based models and simulation models have been used to set-up the real-time control systems. The success of such a system relies very much on the design of the information structure and the quality of information being exchanged between the control system and the shop floor.

Developing the most suitable recovery procedures for operational changes and interrupts requires a significant number of experiments with various sets of constraints and alternative decision scenarios. Simulation is the most effective tool in such situations.

3 MULTI-FLOW CONTROL FRAMEWORK

Multi-Flow Control (MFC) has become the in-house research terminology for the simultaneous scheduling and control of the parts, fixtures and cutting tools within flexible batch machining facilities. MFC aims to generate knowledge and generic techniques/solutions to harmonise the interactions between the three principal flows by short term control and planning of these flows.

Traditionally, manufacturing control systems have always been concerned with the flow of workpieces through production systems and the importance of the effective management of cutting tools and fixtures has been neglected. The cost of cutting tools is a significant component both in the initial capital investment and operational costs of machining facilities. A number of researchers have addressed the general tool management problem (Gray *et al.* 1993). However, none of the research work has identified a structure to provide an adequate basis for short term scheduling and control of tool flow at the machining cell level i.e. identification of the precise time and a workstation where a collection of tools(referred to as a toolkit) is required

Fixtures have a greater role in the daily operation of FMC than their traditional use in the jobshop environment (Grippo *et al.* 1988). For example the utilisation of unmanned machines requires workpieces to be rigidly secured on a work holding devices. Furthermore at times, with latest CNC machine tools capable of machining complex curved surfaces, the workpiece needs to be accurately positioned with respect to machining surfaces. As a result, a number of special design fixtures have been developed which can be used with a limited number of part types. Therefore, effective management of fixtures within FMC play a vital role on the overall performance of such systems. However, the published research on the use of fixtures has mostly focused on the design of fixtures with little emphasis given to the management of fixture flow within FMC.

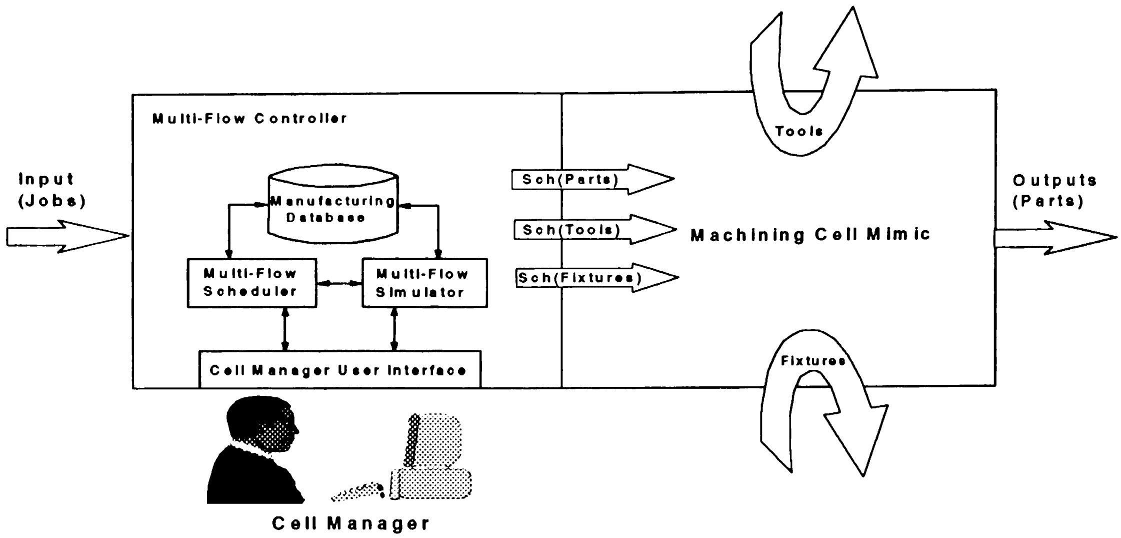

Figure 3 : Overview of Multi-Flow Control Framework

To overcome these problems, a unique structure of software modules, termed the multi-flow controller, has been designed and implemented to regulate the flow of parts, fixtures and cutting tools in a flexible machining environment. These modules are integrated around a manufacturing database. The multi-flow control framework does not aim to automate the control procedure but to act as an 'advisory system' to the person responsible for decision making. This decision maker is referred to as the 'Cell Manager'. The MFC assumes that a rough cut forward planning projection in the form of a job list is offered to the scheduler (via a MRP or equivalent). This joblist is initially handled by the cell manager which will recommend strategies for the provision of parts, fixtures and cutting tools. The strategies are offered to a multi-flow scheduler which in turn generates a short term schedule for the three principal flows. The proposed schedules are then, down loaded to a simulation model which provides output to the cell manager. This gives the cell manger insight into the potential performance of the cell and allows him to make valued judgements on whether the schedules should be down loaded for implementation.

An overview of the multi-flow control framework is shown in Figure 3. The role of simulation models used within these framework are described in more detail below.

3.1 Multi-Flow Scheduler

As a part of the MFC prototype software, a novel scheduler is required to generate schedules not only for jobs to be processed in a machining cell but also for the cutting tools and fixtures required by those jobs.

Research issues involved in the design and implementation of such a scheduler is described elsewhere (Rahimifard and Newman 1995). One of the principal issues involved, is the selection of a scheduling approach to develop the scheduler. A simulation-based approach was identified to be the most flexible and powerful technique for the development of this scheduler.

As a result, a simulation based multi-flow scheduler has been developed that simultaneously generates short term schedules for the three principal flows. A commercial simulation based scheduling software, termed PREACTOR (The CIMulation Centre 1994) has been used as the basis to develop the multi-flow scheduler. The primary inputs to this scheduler being an unsequenced list of jobs for a specified manufacturing horizon and the machining cell status at the start of this horizon and the primary outputs are three individual and synchronised schedules for the control of the principal flows.

3.2 Multi-Flow Simulator

A multi-flow simulation model is designed and implemented as a part of the MFC, to model the part, fixture and cutting tool flows around a machining cell. The commercial simulation software ARENA (Systems Modeling 1994), has been utilised to construct this simulation model. The multi-flow simulator is designed to act as a flexible decision support system which can be used in many ways. It can simply execute schedules generated by the multi-flow scheduler on a deterministic mode, to produce manufacturing performance measures (e.g. resource utilisation, queue/buffer sizes) and act as a window through which consequences of the decisions made during the planning and scheduling stages can be realised. Alternatively, the multi-flow simulator can be used to measure the effect of some of the constraints such as transportation or temporary buffer storage capacity which might not have been considered in the first stage of manufacturing planning.

3.3 Machining Cell Mimic

It is obvious that the research ideas behind the solutions of short term control of the three flows need to be tested and validated, before it can be widely accepted and adopted. Originally, it was envisaged that an actual machining installation would be used to carry out a number of experiments. However, it became clear that the access to such an installation with appropriate configuration, that challenged the research ideas will not be possible. Therefore, an experimental simulation model, termed the machining cell mimic (MCM) which represents a specific cell configuration, is utilised to validate the MFC research ideas. A number of defined manufacturing disturbances(machine breakdowns, shortage of parts and cutting tools) are also modelled.

The primary inputs to the MCM are a set of approved schedules for the three flows generated by the MFC prototype software and the machining cell status. The primary outputs from the MCM are reports on the progress of jobs, resources status and delays that are caused by the introduction of the manufacturing disturbances. These outputs provide the initial machining cell status to be used for the planning of the next manufacturing period.

4 CONCLUDING REMARKS

Simulation has seen a significant use in the design of flexible machining installations. This paper highlights a range of operational problems experienced with these types of systems and provides a further use for exploiting simulation in the operational planning and control of such a facilities to overcome these problems. Furthermore it has identified how simulation models can be used within a novel framework for the control of the flows of parts, fixtures and cutting tools within FMC. This multi-flow control framework harmonises the interactions between these three principal flows by enabling the preparation of fixturing and cutting tool requirements prior to the start of the production period.

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