TOOL FLOW MANAGEMENT

IN BATCH MANUFACTURING SYSTEMS

FOR CYLINDRICAL COMPONENTS

by

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A Doctoral Thesis
submitted in partial fulfilment of the requirements
for the award of

Doctor of Philosophy

of the Loughborough University of Technology

Department of Manufacturing Engineering

March 1989

DECLARATION

No part of the work described in this thesis has been submitted in support of an application for any other degree or qualification of this or any other University, or the C.N.A.A. or other institute of learning.

To My Parents for Their Love and Support

ACKNOWLEDGEMENTS

My grateful thanks are made to my supervisor Professor R. Bell for his direction, support, and interest in this research; Dr. R. B. R. De Souza, for his help and collaborative efforts and input to this project and whose research into tooling systems for prismatic parts manufacturing runs in close parallel to the work described in this thesis. My gratitude to my colleagues in the FMS Research Group, Alvey Programme, ISS Group, and the machine tool laboratory for some interesting discussions; Mrs. J. Booth and Mrs. D. Donnellon for their adminstrative support.

I am indebted to Normalair Garrett Ltd. (NGL), particularly Mr. R. Freeman, the Manufacturing Systems Manager, and the Superintendent of the Turbine Cell of NGL, for providing the data. I also thank Mr. W. B. Trick of TRAUB AG for sending the relevant materials, and TRAUB Ltd. for permitting the use of data from TRAUB publications.

I also thank the following collaborating companies for their participation: APV Baker, British Aerospace, Cross International, GEC FAST, Lucas Industries, Rolls Royec, Matrix-Churchill, and Istel.

My thanks to Mr. J. T. W. Smith for his professional help in taking the photographs; to all my friends who helped me in the preparation of this thesis.

I wish to express my gratitude to the government of the People's Republic of China and to the British Council for financing me during this project.

SYNOPSIS

The objective of the research is to study the design of and operating strategies for advanced tool flow systems in highly automated turning systems. A prototype workstation has been built to aid this process. The thesis consists of three main parts. In the first part the current flexible manufacturing technology is reviewed with emphasis laid on tool flow and production scheduling problems. The 'State-of-the-Art' turning systems are studied, to highlight the requirement of the computer modelling of tool flow systems.

In the second part, the design of a computer model using fast modelling algorithms is reported. The model design has concentrated on the tool flow system performance forecasting and improving. Attention has been given to the full representation of highly automatic features evident in turning systems.

A number of contemporary production scheduling rules have been incorporated into the computer model structure, with the objectives of providing a frontend to the tool flow model, and to examine the tool flow problems interactively with the production scheduling rules.

The user-interface of the model employs conversational type screens for tool flow network specification and data handling, which enhances its user friendliness greatly. An effective, fast, and easy to handle data base management system for tool, part, machine data entries has been built up to facilitate the model performance.

The third part of the thesis is concerned with the validation and application of the model with industry supplied data to examine system performance, and to evaluate alternative strategies. Conclusions drawn from this research and the recommendations for further work are finally indicated.

TABLE OF CONTENTS

CHAPTER 1 INTRODUCTION

A Flexible Manufacturing Systems (FMS) can be defined as a group of CNC machine tools which are interconnected by automated material handling and tool flow systems, and supported by other auxiliary equipment. The whole system is under the control of a computer or a computer system which is capable of dynamic production scheduling, and part and tool routing.

CNC lathes especially highly automated turning centres have been widely accepted by industry in batch manufacturing systems. Installations are evident in which both standalone work stations and multi-machine turning cells can be found accompanied with workpiece and tool handling systems automated or otherwise. The main subject of this thesis is to study the flow of tools within batch manufacturing systems for cylindrical part manufacture.

Cutting tools are of crucial importance to an FMS. On one hand, they constitute a considerable percentage of the whole system investment, as an FMS may employ thousands of cutting tools. On the other hand, the efficient operating of a manufacturing system and its flexibility relies largely on the availability of tools. A tool management system assures that the correct tool is present at the right place, at an appropriate time, with the necessary information. It is essential that tool life be monitored, and tool exchanges forecasted accurately so as to maintain a proper level of tool inventory.

FMSs are high capital intensive systems and their introduction should be carefully justified. The interaction of different areas of an FMS makes it complicated to plan and operate such that any decision making must examine the whole system instead of individual elements. Computer modelling of such a system is necessary, as the experimentation with hardware is prohibitively expensive and alterations are difficult to implement.

The thesis commences, Chapter 2, with an extensive literature survey of flexible manufacturing concepts, its future trends and machining installations; the tool flow and production scheduling for such advanced manufacturing systems; and the modelling and scheduling techniques implemented for system design and evaluation. The developments in turning automation, discussed in Chapter 3, range from chuck jaw /

gripper exchanging, workpiece handling, to workpiece gauging, tool probing and exchanging. The installation examples of highly automated turning centres and the integration of such systems into batch manufacturing cells is also discussed. Live tooling facilities have increased CNC lathe capability significantly by incorporating secondary operations. The application of live tooling, and their accommodating and handling has been discussed in Chapter 4. It is then followed by the discussion of modular tool design, tool exchanging systems, and the tool presetting and preparation, in chapter 5.

The level of complexity in turning automation and its associated tool flow management requires a framework for the analysis, selection, and evaluation of a suitable solution. A computer model has been built to aid this process. In Chapter 6 the basic modelling concept is presented. The algorithmic approach to tackle the tool flow complexity in terms of a large body of individual tool, part, and machine data, and order information has been discussed in the chapter. A structured representation of turning systems from individual machine primary tool storage to cell level secondary tool storage and central tool store organisation is presented in Chapter 7, which forms a generic tool flow configuration in terms hierarchy of tool storage, transportation, and exchange. The tool management framework is discussed in the chapter, which includes system configuration specification, the tool management strategy selection in the high level, and the operating strategies selection in the lower level.

Chapter 8 presents tooling and operating activity flow in the individual machine together with the associated logic flow and the algorithmic representation of the activities. It is followed by the report of a comprehensive case study using published industrial data to examine a highly automated turning centre.

The integration of individual CNC lathes into a turning cell and the modelling of cell level tool and part flow is presented in Chapter 10 in the form of logic flow and algorithms. Chapter 11 discusses the modelling of central tool store activities which includes the planning of tool assembly and presetting, tool issue, assignment, returned tool disposal, and the tool component requirement.

Heuristic dispatching production scheduling rules have been implemented for different system operating environments, which enables the studying of turning systems in a more balanced manner with regards to tool and part flow, see Chapter 12.

A case study of a currently operating CNC turning cell was carried out, with the data supplied by an industrial collaborator. The turning cell is first studied subjected to the alternative operating strategies. The case study is then extended to examine alternative system designs and different levels of system automation. This process and the modelling results are presented in Chapter 13.

The discussion of the user-interface of the comprehensive software is presented in Appendix IB. The detailed illustrations of relevant materials of the case studies are presented in Appendix IA and II.

The research project has been carried out with the close collaboration of several British companies supported by the ACME/SERC, and is strongly influenced by the collaborator. It is intended to make a more substantial understanding of tool flow problems and the unique feature of turning automation. As a result of the project, a prototype software package has been made available for industrial use.

Close collaboration has been maintained with a number of parallel research programs of the department during this project, especially the project on tool flow management for prismatic part manufacturing and the LUT FMS Emulator, which are in themselves subjects of complementary theses. These have been discussed and cross referred throughout the thesis.

CHAPTER 2 LITERATURE SURVEY

2.1 INTRODUCTION

The scope of this literature survey is to give a review of the main topics of FMS related to the area of the project.

The concept and planning of an FMS and its application fields are presented first. Currently operating systems have been reviewed with emphasis given to installation examples for the flexible manufacture of rotational parts, with tool flow network automated or otherwise. A cross-section of computer modelling and simulation tools for FMS design and evaluation has been given with particular emphasis being laid on the review of tool management modelling. Production scheduling problems have been discussed.

2.2 FMS CONCEPTS

The concept of the FMS has been rapidly developed and evolved from NC machines over the last 20 years [42].

The 1950s saw the introduction of Numerical Control (NC)machines. In 1960s NC technology reached a stage when they became reasonably reliable and productive, this along with the progress of computer industry led to the introduction of Computer Numerical Control (CNC) machines and Direct Numerical Control (DNC) systems. The first DNC system emerged in Japan, by the 1960s and in 1973, the first DNC was seen in Europe in Hungary. [250] [82].

A DNC system consists of a few or large number of NC machines which are integrated and operated by instructions received from the control computer. With the development of tool, and workpiece handling systems, and the development of electronic industry, the first NC machining centre operating unmannedly was introduced in 1975, and this is believed to be the first major step towards FMS [250].

During the last 10 years the development of manufacturing industry has been dominated by FMS. Sutton, G. P.[282] forecasted that the FMS market was likely to be the only major segment of machine tools (except industrial robots) and FMS market should grow between 20% to 30% per year.

During the development of Flexible Manufacturing, the flexible machining system has received more attention and has more installations than any other types (Such as welding and assembly). Flexible machining systems will be the main topic through out the thesis.

A functional layout of a flexible machining system is shown in Fig. 2.1. An FMS consists of a group of machine tools and/or production equipment interconnected by an automated material/tool handling system and all under the control of the computer [258]. Fig. 2.2 shows the typical elements of an FMS. Workpieces and tools are transferred by automatic handling equipment within the FMS. Workpieces are usually loaded onto pallets and transported to the machining queue. Production schedules are issued dynamically by the control computer. Tools are preset in the central tool store and distributed to the respective Flexible Machining Cell (FMC) or CNC machines. The data base management system records the information about tools, parts, machines, fixtures, etc.

An FMS processes workpieces of different kinds simultaneously and randomly. The uniqueness of FMS lies in the random processing capability and bring together of the system elements (e.g work stations, material handling, etc.) to function as an integrated automatic system [77].

The flexibility of an FMS is constrainted by various sorts of limitations imposed on it. [103]. An absolute flexibility could be achieved, but the production will be uneconomical, and the system could be of prohibitive price.

A number of FMS definitions representing different angle of view have been given by different researchers [42]. Some emphasise the automated workpiece of tool flow feature [61, 63], some emphasise its random process capability [226]. An FMS may be defined as a 'computer-controlled configuration of semi-dependent workstations and a material handling system designed to efficiently manufacture more than one part type at low to medium volumes' [64].

Ranky defined an FMS as a system dealing with high level distributed data processing and automated material flow and storage system [250]. This definition emphases on the information processing and automation side of the system.

Sutton [282] specified an FMS as a system that allows random machining of a limited variety of related parts at costs that are substantially below what traditional method can achieve.

An FMS of very large size is difficult to control and its initial investment is extremely high. There is a trend to design the FMS as an integration of Flexible Manufacturing Cells (FMC). Each FMC can be viewed as a intelligent subsystem which can be run unmanned [134]. A host computer and a system level material and tool handling network will link the FMCs together. This makes the FMS easy to control and feasibly to build up modularly [38, 20].

Fig. 2.3 presents a typical FMC where a small number of CNC machine tools are linked together, and the whole production process and material flow are controlled by a cell control computer. The control computer is of PC type and can be linked to the system computer via the LAN (Local Area Network) [107].

The multi-cell design with each cell being relatively simple is evident in industrial installations, which can be classified into two structure categories: parallel and flow line type multi-cells [3, 38]. The parallel cell approach, Fig. 2.5, aims to achieve Just-In-Time [243] production by producing all the components needed for assembly simultaneously. A comprehensive example of this type of design structure is the Yamazaki Worcester plant [211, 130, 129].

The flow-line, fig. 2.4, multi-cell design almost mimics a flexible transfer line. The holset multi-cell FMS [12, 307, 128] and AIMS of Rolls-Royce [260, 13, 47, 48] are strong evidences of this type.

The future factory will be developing towards the Computer Integrated Manufacturing (CIM) which involves planning and linking a variety of operating and management systems together to perform as a whole team [116, 255].

The concept of Computer Integrated Manufacture is shown in Fig.2.6 [94]. CIM is concerned with providing computer assistance, control and high level integrated automation at all levels of the company. CIM covers the following activities [251]:

(1). Analysis the market requirement, develops the product strategies and the concepts of FMSs.

(2). Component design and process planning.

(3). Production scheduling and factory control.

(4). Analysis feed back of certain selected parameters to improve the performance and the company's ability.

CIM concentrates on information processing. The information within a company can be categoried as strategic, tactical and operational ones, fig. 2.7. The strategic information which concerns a company's long run production strategies is relatively static but vague. The tactical information of a company usually needs to be updated in a month or a couple of weeks. It is reasonably accurate and predictable. In the operational level, all the information required for the manufacturing area should be generated. The information should be accurate and needs to be refined continually by taking the information fed back from the machining areas.

Kanban system has been initiated by Japanese industries to keep tracks of orders and the components of each order [243]. CIM systems can be built up by integrating all processes including marking, finance, design, scheduling, stock control, MRP (Material Requirement Planning) [279] and CAD/CAM. The CIM system concept is built on the core of a distributed management information system, often known as a Distributed Data Base Management System. [251, 252, 317, 206].

2.3 FMS ACQUISITION, DESIGN, PLANNING, AND APPLICATIONS

Each FMS is user specified. Whether it is applicable depends on the part types to be machined, their batch sizes and mix, and many other constraints. FMSs are far too complex and expensive to be built by the builder itself. At any stage of the development the involvement of the user is essential.

When an FMS is being planned, initially decisions must be made on the following problems:

(1). The product range problem;

(2). The process planning problem: tools and operation allocation;

(3). Machine capacity problem;

(4). The transport problem;

(5). The fixturing problem;

(6). The pallet problem.

The whole process of planning starts with identification of the problem and comparison of a variety of alternative solutions [42].This results the most appropriate way of dealing with the problems such as the most suitable system configuration and the right operating strategies for the system selected. Through-out the whole process, simulations and modelling by computers will be necessary.

The steps required to implement an FMS are recommended as fig. 2.8. Once a decision has been taken to install an FMS, the next step would be to choose the part types that would give the most profit by using such a system, after that, alternations of the system configuration and layout will be compared to select the most suitable one for the proposed production requirement. [64].

This whole process requires the extensive involvement of both the supplier and the user, fig. 2.9. [302, 229].

A realistic method recommended for estimating the capacity required to complete all jobs by their due date was to load jobs according to the infinite capacity planning principle [87].

Before the operation of a FMS, the following problems have to be solved to set up the system:

(1). Part type selection for the upcoming production period.

(2). Machine grouping - partition the machines of similar types into groups so that each machine of a group can perform the same operations.

(3). Production ratio problem - determine the part type mix ratios so that high system utilisation can be achieved.

(4). Resource allocation - allocate the pallets and fixtures required for production.

(5). Load cutting tools for operation. [275].

The selection of part types and the determination of production mixture can be carried out in a sequential way or in a constraint-directed approach. The former sequentially selects an item with the highest estimated probability of eventual success into the part group. This method considers the important factors such as potential utilisation of machines, the due date of a part type, the degree of sharing tools and the tool store capacity. Alternatively, the part group to be processed simultaneously and continuously can be formed under the constraints of tool magazine capacity, due dates of each part type, total processing time of each tool. [115]. Kusiak has built a mathematical model for grouping parts and fixtures in an FMS [136].

A flexible part type selection and production ratio forming were suggested as when the production requirement for some part types have been finished or some production orders have changed, the new part types can be introduced if this input can help make the system more highly utilised. [275].

The criteria to evaluate a flexible manufacturing system varies, to name some typical ones: system productivity and reliability, the capability of self diagnostic and flexibility, W.I.P., product lead time, and system economics, etc. [318]. Different users may put different priorities to those criteria;

FMSs, as mentioned before, are very capital intensive. Therefore it would be wise to develop such a system modularly and step by step, this is particularly true for smaller companies. Sheppard [270] suggested a three level approach for FMS implementation. In level 1, which is the machining cell level, the priority is to provide the capability to integrate the machines via automated material handling techniques and the potential to run the cell unmanned. The second level is fully flexible manufacturing systems of 2 to 7 CNC machines. The major priority now is to provide sophisticate system control and management software to facilitate the schedules of parts, tools, fixtures, pallets, etc. and system monitoring and diagnostic package. The level 3 will be to build up a fairly large customised flexible manufacturing project.

The most crucial philosophy, to design and implement an FMS, is to partition the system both Hardware and Software, into modular functional units. By this way, not only can development of the modules proceed in parallel, but also it is easy to take new developments of the system layout concept into account so as to prevent the system out of date, as a flexible machining system features a long lead time between design until full production. The modular design concept is also fundamental to resilience against failure. One example of modular system design is the pilot FMS SCAMP by 600 Group. [312].

A well planned FMS should have the following features: the system control software such as production scheduling, part programming, tool and workpiece flow managing, should have a development facility to incorporate the new requirement that may rise. Both the electronic and mechanical hardware should be modular so that new parts of same family can be accommodated with little change made to the manufacturing system.

Kusiak [132, 134, 135] classified FMSs into 5 categories:

(1). Flexible Manufacturing Module (FMM), Which is a unmanned workstation built around an CNC machine [82].

(2). Flexible Manufacturing Cell (FMC) which consists of several FMMs.

(3). Flexible Manufacturing Group (FMG) which is a collection of FMCs and FMMs.

(4). Flexible Production System (FPS) which is a integration of FMGs for fabrication, machining and assembly.

(5). Flexible Manufacturing Line (FML) which is a set of dedicated machine tools.

Fig 2.10 shows one way of the justification of different manufacturing systems. Traditional job shops consisting of individual machines have high level of manning and a large part variety. Dedicated transfer lines have been used for mass production with limited component variety. Its application can be seen largely in automative industries. Unmanned workstation based on a single CNC machine tool offers flexibility and component variety. CNC lathes have been used largely in this form. An FMC consisting of a group of CNC machines can be either a intelligent stand alone manufacturing system or a building block for an FMS [7].

Flexible Transfer Lines (FTL) have found their position in high volume and reasonable high variety production [299, 129]. Cross has developed Flexible Transfer Lines to meet the high production requirements of the automative industry. One shortcoming of traditional transfer line is its synchronous nature which allows the part transfer only at the end of the slowest workstation cycle. Seeing this, Cross offers FTLs with non- synchronous transfer system which has the ability to queue and rapidly exchange pallets at the end of each individual machine cycle. Although a FTL could work in a one-off mode in an emergency situation, Cross pointed out that a physical minimum batch size for an flexible transfer line will be 40. In one of its FTL, 78 component variants can be processed at a rate of 800 per hour [6].

2.4 FMS INSTALLATION EXAMPLES

A full review of the current FMS installations over the world and its trends of development is given by a United Nations publication [83]. The FMS systems are so numerous that it is impossible to list all of them in this thesis. Some of the typical and successful installation examples are reviewed as follows:

The FMS of HOLSET Engineering Co., Hudderfield, has been designed to produce shaft and turbine wheel assemblies for diesel engine turbo-chargers. The system consists of 7 autonomous flexible machining cells. Each cell includes up to 4 machine tools, served by a gantry robot. Transportation between cells are carried out by 3 Scissors-lift AGVs, fig. 2.11.The system is of flexible transfer line type. It works in a similar manner to that of a transfer line. Alternative routings need only be considered when there are machine breakdowns or preventive maintenance is to carried out. The assembly starts off as a forged shaft and a cast wheel. A few operations are performed on each of them (shaft and wheel) before they are welded together and further operation carried. It will undergo some 32 successive operations, mainly being turning and grinding, but also friction welding and heat treatment.

Each cell is controlled by the local area controller. The controller is a Hackler and Koch model which incorporates two levels of control. The low level programmable Logic Controller is used to monitor the safety equipment, and the movement of AGV. The high level Micro Computer handles the production control, program selection and AGV task assignment. The seven local area controllers are linked up to the host computer through a Local Area Network (LAN).

The system produces 50 different component types for 5 frame sizes of turbo charger at a rate of 800 parts/day. [12, 307, 128].

AIMS (Advanced Integrated Manufacturing System) is a flexible manufacturing system formally opened at Rolls-Royce Plc. Derby, in January 1986. AIMS is an integrated grouping of versatile machine and processing cells that can manufacture a wide range of different disc components under the control of a host computer system. It comprises of 27 cells, each of them is in effect a mini-factory. 12 of 38 machine tools adopted are CNC machines. (Fig. 2. 12). The FMS is designed for a family of 35 part types. The parts are compressor wheels and turbine discs for RB211 family engines. A typical component would be subject to rim turning, profile turning, milling, drilling, broaching, post broaching turning, profile chamfering, grinding, magnetic crack detection, and Ultro-sonic cleaning.

The AIMS manufacturing strategies are: (1). Parts should be organised into family groups and production divided into cells; (2). Standardisation and rationalisation of tools, fixtures, operation sequences, and reduce the set up time. Actually the cutting tools has been reduced from 2000 to 100 standard tool sets; (3). Incorporating the in-cycle inspection; (4). Integrating all manufacturing processes.

The prime objectives of the project are to reduce the Work In Progress and to build up a economic one-off type manufacturing system.The complete facility is under the control of an IBM 8100 series linked to Rolls-Royce's main frame computer. Two DEC PDP 11/44 mini computers control work-flow, part handling, and tool kitting.

The new machining technology involves a number of special 4- axis CNC turning centres which could turn both sides of a disc simultaneously. Quick change 'cassette' tooling are introduced. Work is delivered to the cells by 8 Rolatruc AGVs in fully made-up kit form, with everything needed: raw or partly machined workpieces, fixtures, and a set of cutting tools. [260, 13, 47, 48].

A substantial example of the application of turning systems in the highly mechanised configurations is the Yamazaki Minokamo factory. The plant consists of Box Line, Frame Line, Spindle Line, and Flange Line, etc. Cylindrical components are grouped into 2 families. The long slender components are machined in the Spindle Line. The Flange Line is for the components with low ratio of length to diameter.

The Flange Line consists of seven Slant Turn 40N Mill Centres and three machining centres. Workpieces are delivered to a station at the end of the line. In the Spindle Line, there are 5 Slant Turn 40N ATC Mill Centres, one VQC-20/40 Vertical machining centre, and 2 CNC grinders.

For these two lines, CNC lathes are equipped with live tooling facilities, thus, operations normally performed on a small machining centres can be carried out on the lathes, reducing handling and setting up time.For the Flange and Spindle lines workpieces are transported on universal disc-shape pallets carrying 6-10 workpieces. The AGVs bring loaded pallets from the setting up area to pallet station of each line. In either of the two lines, there is a rail guided vehicle transferring pallets between the pallet station and the workpiece table of each machine. Yamazaki's FLEX robots are mounted on each CNC lathe to load/unload workpieces.

A unique tool exchanging principle for the Box and Frame lines has been implemented where the whole magazine is exchanged. Each machining centre has a 40-tool drum type magazine. And the magazines are detachable, normally there is one on the machine in use, and another one on a horizontal slide that extends along the side of the machine. Two drum magazines can be carried at the same time by the trolley transferring between the machine and the tool room where tools are changed manually. By doing this, huge variety of tools are transferred and exchanged into machines automatically.

There is a main aisle in the plant for the distribution of workpiece across the plant, with spurs running logitudinally to various areas.The Minokamo plant produces 120 CNC lathes and machining centres per month. [104, 212].

Yamazaki opened a highly automated flexible factory at Worcester U.K. in 1987. The plant employs 180 people and it outputs 100 CNC machines per month. There are good reasons that it can be viewed as a further development of the Yamazaki Minokamo plant.

The plant is designed in multi-cell manner. (Fig. 2.13). The flexible machining is carried out in 3 cells. The large prismatic line produces large parts such as machine beds. It consists of 3 Mazak YMS 40Q machining centres with 80 tool-magazine. 36 pallets holding workpieces are transported automatically by automated rail guided carts.

The small prismatic part line consists of 7 Mazak H25N Horizontal machining centres with 80 tool-magazine. Components for the gear-box etc. are transferred by 2 automatic stacker cranes.The rotational parts line is of particular interest as it uses turning systems with 'Live Tooling' to carry out conventional secondary operations rather than employing small machining centres. It comprises 3 Mazak ST40 ATC MillCentre lathes, each with a 80 tool magazine. The CNC lathes are fed by Mazak robots from 60 pallets of stacked components. The 40N ATC Millcentre tool turret features 2 tool positions, one for live tools and the other for stationary turning tools. The chain type tool magazine can store both rotational and conventional turning tools. The turning centres also offer the capacity of storing up to 15 sets of chuck jaws.

The tool distribution highway carries tools on an overhead monorail using random access order to replace tools directly into all machining centres and turning centres and to return worn tools.

Machined parts, purchased goods and assembled units are held in an automatic ware house and distributed to the assembly areas using 2 AGVs. Another two AGVs serve the raw materials and machined parts among the machining lines, painting area and the material centre. The main asile separate the machining and assembly areas of the factory.

The whole plant has been controlled by a highly advanced CIM system. An central IBM S/38 for total production and scheduling information control is linked to 3 DEC Micro VAX FMS CPUs which control the on-line systems. The complete CIM ensures that manufacture requirement are fulfilled in an optimum time, with minimised inventory. [211, 15, 130, 14, 128, 44].

2.5 TOOL MANAGEMENT IN FMS

2.5.1 Tool Management System Concept

The introduction of CNC machines and the trend towards smaller batches flexible automatic manufacturing has made the tool management an increasingly important issue [45, 27]. CNC machines and flexible auxiliary equipment are a very expensive investment, which results their high cost per working hour. High machine loading is generally required to keep the manufacturing system cost effective. This calls for the availability of suitable cutting tools. The manufacturing system flexibility implies the following sides:

Machine flexibility - Universal CNC machines for large variety of components;

Route flexibility - A dynamic routing;

Product flexibility - Machining a variety of products in random order;

Design flexibility - Easy for design changing [40, 138].

All the aspects mentioned above rely more or less on tool availability and tooling system flexibility. Unmanned or less man power machining requires automatic tool flow and bigger tool storage capacity both on individual CNC lathe and the turning cell. What's more, the cutting tools for CNC machines are relatively expensive, this, together with the bigger tool requirement results in the investment for tooling system a fairly high percentage among the whole system cost.

The development of cutting tool design has resulted in CNC lathe efficiency. On the one hand, new cutting tool materials which permits higher metal removing capacity and the indexable tool tips result a shorter economic tool life, which has shortened processing time. On the other hand, modular tool design ease the tool storage and handling greatly. The use of quick change tooling on CNC lathes has greatly reduced batch set-up time and the machine time lost when changing worn tools [58, 59].

A comprehensive tool management system ensures that the correct tool is presented at the right place in an appropriate time with the necessary information while keeping a lower tool inventory.

The primary goal of a tool management system is to strike a balance between minimising tooling costs through proper design and inventory levels while maximizing revenue producing output. [96]. The problems that are faced with tool management systems are usually not so much the technological ones but rather analytical and managerial ones such as when and what tools required, where and how to best organise preparation of tools and their information [280].

The management of tooling has to meet six basic requirements:

(1). Machine based tool storage;

(2). The ability to complete tool exchanging;

(3). Tool identification;

(4). Tooling selection and preparation;

(5). Tool distribution;

(6). Tooling standardization. [127].

The tool distribution usually has dominated tool management systems. A lot of research and developments have been carried out in currently running systems.

Brohan suggested to build a tool management system for a whole machining shop or each section, centred around a tool file controlled by a tool file editor (Fig. 2.14). The tool file must be accessible by all departments concerned with cutting tools, e.g process planner, NC programmer, tool storage and purchasing, and the machine tool operator etc. By maintaining such a data file and the file editor updating information for each individual tool, the tool management can be carried out precisely and tool requirement can be forecasted with certainty.

An efficient tool management system will feature the following key elements:

Advanced preparation of tools off-line and away from the machine;

Tool control and identification - A control system keeps tracks of all tools, and memory chip can be implemented to each tool to record down all the tooling information;

Tool requirement planning and tool rationalisation - Its simplest form is to model tool list for each job, with sister tools according to the batch size. By sharing tools between batches, tool requirement can be reduced;

Tool file for process planning and performance data feed back. [45, 46].

A live tool data base management system is essential. It should provide all the relevant documentation controlling the tooling and its uses, its cutting conditions, and components used on identity. It is the core for tool pre-setting, tool monitoring, automated tool supply and tool changing. [259].

A large number of cutting tools are usually required by a manufacturing system. A distributed data processing system employing computer networks, shared data bases, known as distributed data management, is essential necessary not only for an efficient tool management but also for the manufacturing system as whole. Tool data flow concerns all the FMS managing process, right from the process plan and NC program generation to the process control system, stock control, tool assembly and maintenance.

A tool data base management system should have the following features: (1). Flexible operation interface; (2). Compatibility: (3). Real time communication and updating; (4). Logical integrity and practical modularity; (5). Capable of performing distributed processes [253].

The information describing a cutting tool can be classified into four categories [43, 253, 254, 255]:

(1). Real time data (Dynamic data): Tool position, tool life left, preset dimensional parameters, etc.;

(2). Storage data: Physical appearance of the data in the data base. It represents the view of the tool data to the data base administrator and indicates where and how the data is actually maintained;

(3). Static data: Usually a description of the tool type. It represents the data that do not change over a relatively long period of time, e.g. size of tool holder, tool materials etc.;

(4). Programmatic data: Those data that concern the part programmer and process planner.

These four categories of information describes a physical tool and corresponds to 4 level of tool management, fig. 2.15 [254]. Level 1 contains the real time data and represents a physical tool. Level 2 is of interest to a part programmer and describes a tool type. Level 3 and level 4 are for the central tool store controlling and used for tool assembly and disposal. A universal tool data structure was proposed by Eversheim [89].

2.5.2 Tool Management System Structure and Strategies

Ber and Falkenburg outlined the tool management system as a range of integrated functions including tool monitoring, tool transportation, inventory management and purchasing. The tool file monitoring is carried out at each work station. Tool transport system delivers cutting tools following a predetermined tool changing schedule. In certain circumstances, the alternative route for tool transferring should be available. In the tool crib, tools are inspected, preset, and disposed or refurbished according to a predetermined tool refurbishment criteria. The tool requirement generation and tool inventory control is also one of the main function of the tool crib [40].

Bill and Hankis described the tool management system by recognising its major components [41, 101]: Tool room support, Tool allocation, Tool distribution, Faulty detection and Tool data flow.

Four tool allocation strategies were suggested and examined:

Bulk Exchange - Provide a copy of each tool needed for each job visiting the machine;

Sharing tools in a frozen production window - Sharing common tooling between the workpieces in a frozen schedule, tool matrix are serviced at the end of the production period;

Tool migration at the completion of a workpiece type - As workpiece types are completed, some tools can be removed, the removal of those tool permits the loading of new tools for the following workpieces. This concept allows sharing of tolls between the production windows;

Resident Tools - The tools of high usage will be loaded to the magazines of the machines in the same group, and migration of tools will be carried out within the remaining pockets. This gives the flexibility to the processing capacity of machines in the group. Simulations were carried out to examine the tooling strategies on a specified FMS.

Similar tool allocation Strategies were suggested by Tomek et al [289, 290]:

Batch of parts, group of tools;

Several part batches, one group of tools: Based on group technology, a mix of parts is chosen and are served by a common tool storage;

Common tool inventory shared by a group of machines: A group of identical machines is addressed. The most often required tools resident in all matrixes, individual tools are transported between tool room and machines, and among machines in the same group automatically on request. The latter is examined by a simulation module on 3 FMS installations for prismatic parts.

Other tooling strategies have been suggested and implemented by Atket [33], MAST [25], Cuppan [74].

Comau has developed a tool management philosophy of classifying cutting tool priorities [43]:

(1). Active part-program tools.

(2). Active part-program sister tools.

(3). Tools for next part-program.

(4). Sister tools for next part-program.

(5). Any other tools not covered by the first four classes.

To gain high availability of tools at low expenditure on time and costs concerns two fields, i.e tool circulation in the machining system and tool disposition of central tool store. When organising the tool circulation, the following aspects should be considered:

(1). System structure: Tools can either be stored centralized which implies high expenditure on transport; or each machine can have its own tool stock, which in turn results in a large number of tools required. Machines can be supported with tools related with actual production requirement (high expenditure on per-setting, transport, and setting up) or each machine can be loaded with a tool set-up for a relatively long machining period, and is complemented only if a tool is worn.

(2). Capacity of primary tool storage, tool transporter and staff availability etc.

(3). The capability of the system to incorporate the predictable events such as machine break down or tool premature failure.

Two methods can be implemented for the tool disposition in central tool store, viz. tool disposition according to the demands of manufacturing orders; and tool disposition based on the tool consumption in previous production periods. The former requires large effort to determine those demands but guarantees the maximum system flexibility and tool availability. The latter depends the experiences and usually causes a large tool stock if tool availability is to be ascertained. [292].

2.5.3 Tool Management Implementations

Three hierarchical level of tool management were outlined by Happersberger, i.e. machine oriented tool logistics, manufacturing oriented and plant oriented tool logistics. [23]. The tool management of FERRARI Automobili S.P.A [57] features a historical file which records each tool included in the FMS, with its assumed life and position in the system. The simulation module will establish the average quantity of tools required for a given production plan. A tool wear plan file contains the list per tool type to be prepared to the quantities quoted in the production time. Tools are assembled, preset and inspected in the tool room. The tool management program keeps on updating tool status and position, and provides all the technological tool data to the machines concerned. Machines will feed back the information including tool entrance, position change, tool exit and rejection to the central computer to update the tool file. (Fig. 2.16). The whole tool management system is built around the tool room control.

Lamb Co., Warren, Mich has implemented a Machine Information Centre (MIC) as a stand alone production control system. It includes a video screen with colour display and application software. When integrated into a manufacturing systems it will gather 'real time' data on all machine features, monitor the machine processing and tell an operator when to carry out tool exchange and display a list of tools which must be changed. [308].

JCB claimed that it has the most complete computerised tool management system installed. The tool management at machine and system level has been computerised to be integrated to the tool pre-setting area. Tool issue list to each machine is generated according to the work-to-list. What's more, the tool and tool component reorder is done directly through the computer link to the suppliers. [123].

The Nagoya plant (FAST) of Takoka Electric consists of 6 machining centres and 4 Mazak NC lathes. It has been designed for 24 hours of unmanned operation. The total tool management system and flexible material handling reduces set-up time dramatically. [21].

Heller has built up a PC based DNC system for tool management. On-line simulation technique was employed for tool requirement and exchange forecasting on individual machines [152].

2.6 Modelling and Simulating of FMS

The FMSs are very sophisticated manufacturing systems. Operation of such a system involves complex activities and decision making. The experiments on hardware of it would be impossible. Some kinds of computer aided modelling are prerequisite both in the system designing stage and to improve the performance of a existing system installation. simulation models are also widely used to gain experiences before system instalment and forming the foundation of the production control software.There are many different kinds of decisions to be made, hence there are many different ways to model the same system, depending on emphasis given to different aspects.

The key idea of modelling or simulating a system is to build up a model. The models which are assumed by each technique may differ in type, assumptions and system details. The essential features of any model are its ability to be manipulated and the time scale reduction. Although it is impossible to experiment a real system, a model may be used experimentally to predict a system behaviour for particular situation. When the computers are used, the modelling can be run much faster than the real system works. When modelling a FMS, it may be desirable to build up a mathematical model, as it can be solved by a existing mathematical method and gives a direct indication to the system performance. This requires the fact that the structure of a system is identical to some standard mathematical structure. However there are circumstances where a mathematical model cannot be found without over-simplifying the real system or the mathematical model itself is impossible to be solved in the current stage. In both cases models which represent the internal working principle of a system, as well as the inputs and outputs, known as simulation models are required. [145].

Models can be classified into the following categories according to their application and modelling approaches [56, 124, 302, 281]:

(1). Physical models, also called emulators, make use of hardware devices which are sufficiently similar to the real system in their characteristics.

(2). 'Continuous simulation' models. These are usually built on an analogue computer. Packages examples are DYNAMO, CSMP.

(3). Discrete simulation models. These models consider time and other variables to be discrete. A simulation model takes the data used by the real system and through step by step duplication of changes that data would undergo as the real system operated, and transform it into output measures.

(4). Computer Modelling. The models consist of modules representing the real system blocks. They are written in high level language.

(5). Analytical models represents quantities and relationships as mathematical variables and expressions. The computer application in this area is mainly to solve the mathematical problem. Linear programming and Queuing theories are commonly used for building up such kind of models. [145, 273].

A classification of different modelling method and its application was done by Wang et. al. [302, 303].

The two main steps in designing and implementing an FMS are the general pre-study and dimensioning of the system; and detailed exploring the system. The first phase requires a great number of trials and iterations with different data and parameters, with an aim to optimise the main criteria and with a scarce level of details. The second one requires very detailed modelling and treats usually great quantities of data.The mathematical model are generally for the first step, based on 'average' criteria, but gives a main indication of what the system may perform, and offers the advantage of being quick for both execution time and the data input. Although some simple simulation models can be adopted for the first step evaluation, most of the simulation models are of high detail, and precision, but they are heavy both in time and memory occupation and difficult to be configured. [295]. One of the shortcoming simulation language is its difficulty to handle large body of data. The modelling tool flow in individual tool level requires a powerful data handling mechanism which is not available in the current simulation languages [237].

There are cases where a high degree of accuracy is required for modelling special aspects of the hardware configuration, or some module(s) of a machining system requires more attention than the other parts. The computer modelling can be tailored to suit this requirement. These models usually consist modules written in high level language, e.g. FORTRAN, PASCAL, which can be built up to represent the desired hardware configuration. These models have the advantage of being able to deal with large amount of data for a specific aspect(s) of a machining system, quicker in processing and require a lower computer resource than a high level simulation model. The principles of its logical construction are easy to grasp due to to its modular design.

Kusiak has given a review of most of the modelling tools and techniques applicable forsolving FMS problems [135].

2.6.1 Analytical Models

Mathematical models are generally adopted in the analytical stage. They have the major advantage of fast response, allowing rapid evaluation of different options in early stage of a project. The solutions to the models implemented are usually existing, so, less computation and programming effort are required. Their main disadvantages are the limited level of output provided, and the original system has been too simplified, consequently relatively lower level of accuracy. A lot of cases can be found where it is difficult to say which parameter(s) is required to be optimised. Mathematical models ignore the effects of the machine and buffer storage capacity, thus they can not model the blocking problem. However mathematical models are still valuable tools to give a general indication. [225].

The queuing network theory has been used as the basis for many analytical models. These types of model can in general provide approximate indications of the adequacy of practical systems, which may be sufficient as a preliminary solution. e.g CAN/Q, G.M.S and MVA models.

CAN/Q (Computer Analysis of Networks of Queues) model is restricted by the following hypotheses:

- The activity time are distributed according to an exponential distribution;
- Each station has a infinite storage capacity (i.e there are no blockage). [30].

MVA (Mean Value Analysis) is an alternative Queuing Network model providing steady state mean performance measures. It can model more detail features (e.g Multiple part classes) than CAN/Q model without loss of efficiency. But still, some of its assumptions make the model unrealistic for most installations [302].

Some machining systems can be represented mathematically as Linear or Non-linear Integer Programs. The Mathemtical Programming concerns mainly the optimal collection of limited resource to complete activities subject to a set of constraints. The weakness of this approach is its inability to capture dynamic features of the machining system.

The Petri Nets theory permits a dynamic, deterministic model of machining system. Timed Petri Nets, in conjunction with certain modelling conventions appears to be quite useful modelling tools. Activities requiring many resources (e.g Machine tools, transporters, load/unload robot, cutting tools etc.) can be modelled. It can also be implemented to model activities with time durations (e.g processing times, transportation times, set- up times, etc.). However the Petri Nets theory is still inefficient to incorporate detailed system features such as finite buffer storage size, and dynamic part routing. [302].

Maimon et al have built a mathematical model considering uncertainties such as facility unavailability or quality variance of raw materials for workload balancing [21]. Kimemia developed a mathematical model for the optimal part routing adopting a network flow optimisation approach. [97].A closed queue computer model for facility planning and layout of FMSs were built by Co et al [68].

Mathematical models have been built to examine production scheduling problems by Grunwald et al [98], O'Grady and Menon [231, 232], Pourbabai [241, 242], Radharamanan [247], Ramaw [249], Stecke [277, 278], and Whitney et al [310].

2.6.2 Simulation Models

Simulation model can be used in detailed system exploring stage, or in the analytical stage. There are simple simulation models written in simulation language which are very efficient in use of computation time, and form a base of the development of detailed models. It is however, unlikely that a model of this type would be built, unless, it is envisaged that a detailed type model would be required at a later stage.The development of simulation technique and its application has been studied by Carrie [56], Rathmill [256], Griffin [97], Alting et al [5], Newman [229] and Wang [302].

Emulation models are the ultimate development of the simulation concept. They provide a detailed insight into the complete system, to such a extent that they can be used as the foundation for the control software of the finished installation. It is usually used for the fine-tuning of a system layout, and for the comparison of alternative production control strategies. As one would expect, large data handling, long computation time, and heavy computer equipment e.g mainframe or minicomputers, are normally required for a emulation model. [225, 97].

Simulation languages can be classified into different categories according to their simulation approaches to the real system:

(1). Discrete-event, three phase system [62]. This is sometimes known as British approach. The 3 phases are: Phase 1, Time increment to reach the next future event; Phase 2, Scans through all the activities in progress, terminating those due to finish; Phase 3, Starts those events due to start.
The language examples are E.C.S.L, SEE-WHY, SIMON.

(2). Discrete-event, two phase systems. This is usually referred to as American approach. It is very similar to the 3-phase system, except that phase 2 and phase 3 are combined. Consequently, the processing is more efficient and quicker, but it does require significant preliminary analysis of the system. The well known languages are G.P.S.S, SLAM II, etc.

(3). Continuous systems.These languages use a process type description of the activities. e.g SIMULA. [225, 145, 273].

ECSL (Extended Control and Simulation Language) models requires a detailed activity-queue diagram to form the basis of the programming of the simulation. [145, 62, 56]. SLAM, marketed by Pristsker and associates is a general purpose simulator based on a system of queues and activities. It uses a high-level graphic language by which the creation of units (parts or information), the waiting of resources, activities and the distribution of units can easily be represented. SLAM is especially suitable for describing physical flows. It is widely accepted as a general purpose simulator to model and simulate production systems. [30, 63]. The SIMULA has been developed for UNIVAC by Dahl and Nygaard. The basic syntax of SIMULA is the same as ALGOL, but new concepts have been included that make it easier to be used for simulation. The main feature of it is the ability to define a set of processes that operate in parallel and that through a routine of timing, called sequencing set, synchronised themselves on the system according to the physical activities that they represent. [295].A simulation model was built by Mojka using SIMULA [226].

PETRI uses simple networks of graphical primitives to model a system. It is better suited for representing operations. The advantage of PETRI is its small number of symbols:

- Places, corresponding to a notion of state;
- Transition,representing the passage from one state to another;
- Arcs, linking places and transitions. [30].

SIMAN language was developed by Pegden. It is a FORTRAN based language designed to run on mini computers as well as on large computers. A SIMAN model framework is built up of two basic components, i.e. the model itself and the experimental framework. It may be constructed to model discrete, continuous, and discrete-continuous systems [80, 236].

The GPSS/PC was specially created for IBM/PC compatibles. It requires that a block diagram of the production process is established first. Then the flow chart is assembled to represent the sequential relationship of the process and GPSS code can be written to communicate the flowchart to the computer. The GPSS/PC computer program can perform the simulation in monte-carlo fashion. [90].

General purpose simulation languages and packages are easy for implementation in the start but great program modifications are required to simulate a particular machining system. A lot of different dedicated simulation packages have been developed either by the system designer or by users, or by a software company, for a particular FMS installation or for a particular type of FMSs. Such a package requires a remarkable development time and specialist skills. [295].

Specialised simulators are implemented to certain types of production units or to a particular machining system. Renault Automation has developed a specialized simulator for material handling system called SAME/AGVS (Simulation Applied to Manufacturing Engineering for Automated Guided Vehicle Systems). The software allows the sketching a transport network and describing its technical characteristics. The control rules can also be specified as an input. SAME/AGVS allows the visualization of the behaviour of the material handling system. [30, 225].

Ferrari Automobili S.P.A, Italy [57] has incorporated a simulation module into its FMS software. The input to the simulation module includes the follows:

- Data related to the processing equipment allows the definition of plant structure in terms of machines;
- Part information, allows the definition of what is necessary for working each part;
- Pallet configuration;
- Handling topology.

It gives the outputs after a significant running:

- Total processing time;

- Workload pattern for each machine;
- List of tools to be inserted on each machine and total tool requirement;
- Average number of parts waiting for a machine;
- The required fixtures, etc.

Perera has examined the application and drawbacks of SIMAN and MAST and developed a data handling facility to be linked to a simulation model so that large amount of data concerning individual tools can be handled [236, 237].

The simulation model construction and implementation was studied by Abdin [2]. A event driven language Q-GERT was used to build a simulation model to test a number of production control rules for a FMS. [2]. A modular simulation system, MUSIK, was built by IPA and has been implemented to study a number of FMS installations. [304]. The five significant ACME/SERC founded simulation projects running currently have been reviewed by Waterlow [308].

A comprehensive simulation model was developed and implemented by Carrie et al to evaluate a 6 machine FMS producing heavy prismatic parts for mineral equipment in a Scottish engineering company. [52, 54, 55].

The most significant development in simulation is the graphical animation which displays movements of entities of the simulated system [239]. Two types of animating facilities are evident:

- Graphical post-processor which reads the output file resulted form the simulation program and animates the entity movements;
- Concurrent animating.

The current trend is to display the animation concurrently with the simulation, so that the simulation and thus the animating process can be interrupted for user specification and to observe the consequence, e.g. SEE-WHY, HOCUS.

Hurrion [116] and Griffin [97] discussed the link of OR models interactively to animated visual display facilities - known as 'Visual Interactive Modelling'. GRAFSIM of SEIMENS [193, 194] offers the animation facility for representing work and part flow. The colour icon system was developed for programming interface. It is possible to be used for on-line scheduling. CINEMA graphics can be used as a post-processor to SIMAN model building for work and tool flow animation. It can also be linked to FORTRAN, PASCAL, or C language models [150].

The LUT suit of FMS design aids features a full range of simulation and modelling tools. The evaluation model provides rapid appraisal of system performance using average measures based on queuing theory. An emulation model generates detailed dynamic statistics. Specific patterns are emulated using animation, under system constraints and with defined operating rules. The emulation modules are processed in parallel. [39, 271]. Although in their early stages, the emulation model is under expansion to include the tool flow [223] and for multi-cell modelling [3]. A knowledge based model has been finished offering different modelling levels form analytical modelling through detailed part flow simulation, to the modelling of limited tool flow features interactively with part flow [302, 303]. A detailed tool flow model for prismatic part modelling has been finished and is under expanding to include multi-cell features and fixture flow. [37, 77]. All of the above mentioned research project has been carried out in collaborative interaction with this research work and are subjects of complementary theses.

2.6.3 Specific Tool Flow Models

Tool storage, transfer and control requires careful analysis and planning for each individual case in order to meet user- specific requirements. It is precisely in this area that many as yet unexpected productivity reserves exist [91]. The tool flow management presents a real challenge to the FMS designer in choosing the right level of automation and tooling system configuration to suit the needs of the FMS [125].

A mixed integer linear programming formulation has been formed for part grouping and tool allocation. It can examine the tool change-overs between part groups, when and how often a tool change over is done, and the assignment of tools and operations to various machines. However, the model ignores the precedence constraints and the sister tooling consideration. And it assumes that tool change over is done simultaneously. [248]. A mathematical model was built by Chakravrty for grouping parts with tool requirement similarity under the constraints of machining times, palleting availablity and tool requirement capacity. [61]. Rabinovich constructed a mathematical model to study the preparing and issuing of complete tool sets for a shift work. [246]. A formulation has been established by Kordysh [131] to decide the time of automatic change of tools from magazines. Optimal initial tool arrangement has been studied for machining centres by Crookall and Jamil [71, 72, 73] using simulation model, and by Vlasenkov using a mathematical model [298].

Crite et al [70] have developed a detailed simulation model called PathSim using SLAM to analyse the performance of an automatic tool handling system. PathSim allows the use of addressable type material handling devices for both the tool and part movement subsystems. PathSim concentrates on the study of the operating parameters particularly the use of different tool cart control algorithms.

Two simulation programs have been written at Cranfield to study the tool exchange mechanisms of machining centres [122]. The Toolsim1 model is a single machine model with a choice of four modes of tool exchange being incorporated. Toolsim2 is an extension of Toolsim1 to allow secondary tool exchange mechanisms to be modelled. The two models require the specification of tool change requirement for each part as the input. Further extensions are made to the models by Hong [112] and Papagiorcopuls [234].

Hankis [101] has developed a simulation program to gauge the interface of the machine tool magazine with the spindle utilisation. This has been implemented at Cincinatti Milacron.

El-Maraghy [86] has developed a general purpose simulator called FMS-SIM as well as an all encompassing simulation package called TOOLSIM for designing and evaluating automated tooling systems. The package is written in FORTRAN and produces statistical reports on utilisations, average length of queues and parts processed.

The MAST system of Citroen Industries' examines the continuous, periodical, or the combination of the two, tool replenishment strategies. [25].

Carrie and Perera have built a simulation model which incorporates a expanded data base management system to overcome the shortcoming of the simulation language. The model was built to examine a Scottish installed FMS, which is capable of simulate tool storage, exchange, and transferring [55]. The following operation strategies were examined under the tool magazine capacity constraints:

- The part selection for immediate processing;
- The part releasing strategy;
- The part routing strategy;
- Operation assignment strategy.

The FMS examined features high tool variety due to different part types. The initial tool assignment strategy were evaluated considering the oversize tools. Both tool and part dominated systems were examined with the aim of reducing tool exchange [236, 54].

A three level modelling approach was adopted by Seliger [267]. A mathematical analytical model has been built to roughly estimate the FMS performance. A building-block-oriented simulation model MOSYS can then be implemented for evaluating the dynamic behaviours of those FMS concepts selected by the mathematical model. For specific task of designing FMS with integrated tool flow a parameterised simulation model TOSYS has been developed to examine the tool transportation performance. The constraints of the TOSYS is that it can not examine the tool flow system on individual tool level, thus only a hypothetic number of tool exchange can be evaluated.

Hannam [104] developed a software called CADETS aimed at providing the designer with an interactive means of creating features which are related through the software to the tooling available to machine them. This computer assisted control of tooling thus tackles two aspects: control of tooling specified at the production planning stage and the control of tooling effectively specified by designers when they create geometry.

Carmo Silva studied the tool requirements and tooling strategies at a lower aggregated level. [49]. Choi [66] has carried out a preliminary study on turning automation and the tool management system for cylindrical part manufacturing. Tool flow problems have also been studied by El-Gomayel et al [85], Mamalis et al [139], Brohan [45, 46], and Polstore [27].

A complementary model to that described in this thesis but for highly automated batch manufacturing systems for prismatic parts has been developed by De Souza [77, 37]. Two other parallel research programmes also consider tool flow at a lower level than that described in this thesis. A knowledge based model has been developed to consider both part and tool flow integration [302, 303]. This model considers tool flow at two levels. At the first level an infinite PTS capacity is assumed and no secondary tool store is present and hence no tool transfer or tool sharing is considered. At the second level the user is presented with an option either to manually input tools into the PTS or to generate and assign kits from an STS. The implementation of tool flow in the Emulator for part flow is under development [223].

2.7 PRODUCTION SCHEDULING IN FMS

Production scheduling concerns the sequence and assignment of particular job to processing resources. It was first encountered in conventional manufacturing systems [35, 69]. The production scheduling problem those systems has been tackled for single processor [34, 217, 311], parallel processing systems [95, 241], flow shops [31, 99, 6], and job shops [65, 76, 115, 231, 264, 313].

The part spectrum for an FMS features high variety and low batch size. Therefore the decisions of when a part should be loaded to which resource are complicated and should be made frequently. FMS scheduling not only presents all the difficulties associated with job shop scheduling, but also has a higher degree of complexity due to the tool and fixture flow, material handling, etc. [81].

The scheduling on FMS can best be tackled in a multi-level, dynamic method: First, in a overall planning level, production requirement and machining system information can be taken from the CIM controller. The FMS loading plan can be worked out for a short-period of time allowing appropriate part mixture selection, lot-sizing and balancing. In the second level, which is the system operation level, the whole system and FMCs can be scheduled dynamically, incorporating the real time production requirement based on the system loading plan. [228, 250, 268].

Chan divided production scheduling into three levels, viz. part releasing, machine loading, and operation sequencing [62]. A similar approach was adopted by Chang [63].

2.7.1 FMS Loading Algorithms

The loading problem can be specified as selecting a subset of jobs, and assigning their operations to the appropriate machines in the planning period under certain manufacturing constraints. The objectives of FMS loading varies, but the primary ones are system workload balancing and minimising job tardiness. When feasible, consecutive operations should be performed on the same machine to minimise the part movements. If the tool magazine capacity permits, operations should be assigned to more than one machine to increase the part routing flexibility in real time. [53].

Some of the often recognised objectives of FMS loading are:

(1). Balance the workload on each machine.

(2). Minimise the total processing time by rationalise the tool -machine efficiency.

(3). Minimise the number of movements of parts between machines.

(4). Pool the operations with common tool requirements.

(5). Unbalance the workload per machine for a system of groups of pooled machines of unequal sizes.

Some of these objectives can be achieved by one FMS loading procedure. However, some of them may conflict in certain circumstances. [67, 274].

A heuristic loading algorithm was developed by Shanker et al, which is attempted to balance the workload. By giving the overdue job a highest priority and let it be the loaded as soon as possible, this algorithm can be extended to achieve a good workload both for system balancing and minimising job tardiness. [268]. The job sequencing on the allocated machines can be solved dynamically by implementing dispatching rules.

Efforts have been taken by Chung to incorporate multiple and conflicting objectives in one model. A heuristic algorithm was proposed which focuses on balancing the workload on machines. But it takes into consideration the rationalisation of part, tool, and machine combination, therefore the processing time is minimised. The heuristic algorithm that balances the workloads is
stated as follows:

Step 1, arbitrarily select a machine;

Step 2, For all candidate operations requiring the machine, load the operation which requires the shortest operation time to the machine.Tie-breaker: the operation with more required tools in the tool magazine of the machine will have a higher priority;

Step 3, Repeat steps 1, 2 for all machines;

Step 4, Select the machine which has a lowest workload;

Go to Step 2;

Step 5, Stop if all parts have been loaded. [67].

A heuristic loading policy was proposed by Erschler et al [87] in order to minimise the part flow conflicts. The main basis of the procedure is to search for a sequence on the 'bottle-neck' machine which allows to schedule the parts on the other machines. This leads to a global solution that makes easy the flow of parts by limiting the waiting times in the buffers. This procedure can be used only in the case when all parts visit the critical machine.

2.7.2 FMS Scheduling Algorithms

The efficient scheduling of FMS is complex. Most of the work done on the scheduling of FMS has relied on the investigating the effect of different heuristic dispatching rules. Various mathematical models have been developed, but very often they are either based on a over-simplified system, or too difficult to be implemented on the real systems. When the effect of tool availability of the system is also considered, it increase the complexity of the scheduling even further. [280].

The control and operation of FMS concerns the following aspects:

- Part selection and product mix forming according to the system capacity;
- Part families will be allocated to machines with required tools under the constraints of tool magazine capacity and the limitation of pallets and fixtures. The objective of part allocation will be to maximise the tool sharing by parts and part sharing by tools.
- In the operational level, part movements will be scheduled inside the FMS.

A simple dispatching rule consisting of two steps was adopted by Chakravarty [60]: In Step 1, whenever a machine becomes free, the available list of parts waiting to be processed by tools available on the machine will be created. In Step 2, a determination is made as to which of parts from the available list has the highest percentage remaining processing time and that part is dispatched to the free machine.

A mathematical model was developed by Sarin and Chen [261] to determine the routings of the parts through the machines and to allocate appropriate cutting tools to each machine to achieve minimum overall machining cost. The assignment of operations and tools will be constrained by machine availability, sufficient tool life, and magazine capacity. Each operation is assigned to only one machine. The machining cost of an operation is assumed to depend upon the tool machine combination that processes it. The linear integer programming model developed assigns every operation of the parts and required tools to machines. Once the decision is made, the tools will stay with the assigned machines for the planning period. Thus the model cannot incorporate the tool flow effects.

A production scheduling framework together with heuristic scheduling algorithms has been developed by Kusiak [134, 135, 136], involving parts, tools, fixtures, pallets, and material handling elements. A mathematical model were developed by Afentakis for scheduling FMS operations to maximise throughput and minimise lead-time [4]. Shaw [269] developed a pattern-driven non-linear planning system for FMS scheduling. A queuing network model has been built by Seidmann to schedule the FMS under the constraint of limited buffer capacity [263].

Iwata, et al have examined tooling within FMS from the view of production scheduling and have developed a programme to simulate this. The model allows the determination of schedules of machining and transporting parts, and of transferring cutting tools simultaneously, so as to minimise the makespan of production. [117, 118, 119, 120].

A simulation model was developed by Denzle et al to evaluate the scheduling decisions for a dedicated FMS. The scheduling decisions were made in three levels: part loading, part launching and part routing. The part loading decision can be made either based on order file or based on system status, or the combination of them can be used. The part launching rule implemented was: Send the loaded pallet to that part's first machining operation as soon as possible. The part routing rule implemented was: When the previous operation has been finished, send the part as soon as a cart is available to the machine that can perform the next operation which has the least workload. Part waiting in the machine buffer will be machined in a first come first served sequence. [78].

A simulation based approach for FMS scheduling was presented by Doulgeri et al. The simulation of the system activities and the scheduling decision making are carried out in two separate modules. At each decision point, the information of system status and part detail is copied from the dynamic recording files. For each idle machine, a set of parts whose next operation can be performed on the machine will be formed. The suitable part from the choice set will be chosen according to the heuristic dispatching rules. The whole procedure will be repeated until all parts have been finished and a non-delay production schedule will be produced. [81].

A production scheduling rule for a job shop type FMS was developed by Abdin. The objectives of the algorithm were to obtain high machine utilisation, high production rate, minimum makespan and W-I-P, in both regular working conditions and when the system is subject to random occurrence of breakdowns. The problem was solved by a discrete event simulation using SLAM II. The scheduling decision is taken in two levels, viz. machine slection and part sequencing on the selected machine, and transporter scheduling. The dispatching rule at a machine is: priority jobs are sequenced on the base of the SPT. [1].

Simulation experiments were carried out by Carrie et al on a particular prismatic FMS consisting of 5 CNC horizontal machining centre and one special horizontal machining centre with a facing head on which back facing operations are processed. Among the 5 CNC machining centres, 2 are for rough operations, another 2 for semi-finishing, and one for finishing operations. Several part launching sequence rules were examined for the system, viz.

(1). Random order;

(2). Decreasing order of work content;

(3). Increasing order of work content;

(4). Decreasing order of work content when the content is greater than medium value and then increasing order;

(5). Increasing and then decreasing order of work content (The medium of work content as turning point);

(6). Alternating: The part with greatest work content followed by a part with least work content, then next pair and so on;

(7). Part launch sequence for minimising tool changes - Similarity between each pair of parts on each machine is calculated as the ratio of tools common to both parts to the total number of tools used by either part;

(8). Dynamic priority decision making -- Select parts from queues within the model so as to minimise the required tool change dynamically. [50, 51, 52, 54, 55].

A simulation model was built by Stecke [278] to examine a number of priority scheduling rules. Yamamoto and Nof studied the dynamic scheduling and the incorporating of machine breakdown in an FMS [316]. The application of simulation models for on-line production scheduling was also studied by Perera and Carrie [238]. A new technique for production scheduling is the OPT (Optimum Production Technology). It gives a complete prioritised schedule for each job of the bottleneck process. [98, 111].

The MOSES of NEL [179] facilitates graphically bar type display of work-schedule and the consequence of altering the position of a particular job.

The production control of Ferrari Automobili, S.P.A. [57] is built around 5 software modules:

(1). Routing Management Module - Determines the choice of which pallets to be allocated on the available machine. A pallet is selected depending on its priority;

(2). Sequence Management Module - Sequence the transfer of pallets from one unit to another;

(3). Display Module - Enables the monitoring of the production and the state of resources;

(4). 'Operator' Module - Guides the load/unload station operations;

(5). Resources Determination Module - It is activated during the production stage. It schedules and allocates tools, fixtures, and unfinished parts.

Fig. 2.18 Shows the production control and scheduling of a company [262]. By planning prior to the machining period, a machine load plan is established so as to achieve uniform utilisation of machines and of their pertinent tools for a specific planning period. The results obtained will become the basis for sequence controlling of the manufacturing facility. The master computer will distribute the manufacturing orders to different machining stations.

A new strategy of manufacturing control were realised by VUOSO, Czechoslovakia [290]. Groups of working stations instead of individual machines are addressed. For every group of work stations, a job queue is formed, and the selection of the most suitable job from the waiting queue is based on the following criteria:

- Workpiece priority (Special cases, where workpiece must go through the system as fast as possible).
- Minimum tool transportation action for machining operation on a given machine. (Best case is when all needed tools are present in the machine based tool store).
- Effort to complete the present part. (That is in a case when a part is machined in two or more set-ups).

Cluster analysis can be used to group components into families on the base of similarity in terms of machines or tools required.

The cluster analysis technique can be implemented in 3 phases. Phase 1, The similarity measure between each pair of components will be calculated; Phase 2, Similarity coefficient matrix will be formed in which all pairs of components are related by their common properties; Phase 3, Operate the cluster analysis. In the hierarchical process of clustering, two most similar components are clustered into a group, and the same process will be repeated until all objectives have been grouped into the cluster containing all components.The process and results of clustering can be represented by the use of the dendograms which is a graphical description of the hierarchical clustering process. [283].

Knight and Spurgean have applied cluster analysis technique to schedule production on the similarity of tooling required. By clustering the complete solution dendogram, turret tool set-ups can be formed. Each comprehensive set-up allows a variety of components to be produced without a tool change. By dedicate the most predominant tooling to positions on the turret and clustering parts on the remaining positions, a large number of components can be machined with a minimum number of tool changes. [126].

A heuristic two level scheduling algorithm was developed by Kusiak, A. for a generalised system consisting of a Flexible Machining System and a Flexible Assembly System. In the aggregate level, the whole system can be viewed as a 2 machine flow-shop, comprising of the machining system and the assembly system, where the Johnson's rule or any other flow shop scheduling rules can be used. In the detailed level, each assembled product and single part will be given a priority index according to their positions in the aggregated schedule and the level in the assembly procedures. A job schedulability status will be defined reflecting the precedence constraints, pallet/fixture status, tool constraints, material handling system constraints, and if the batch is ready for scheduling, the job with highest priority will be processed providing its schedulability status allows it to be scheduled. [133].

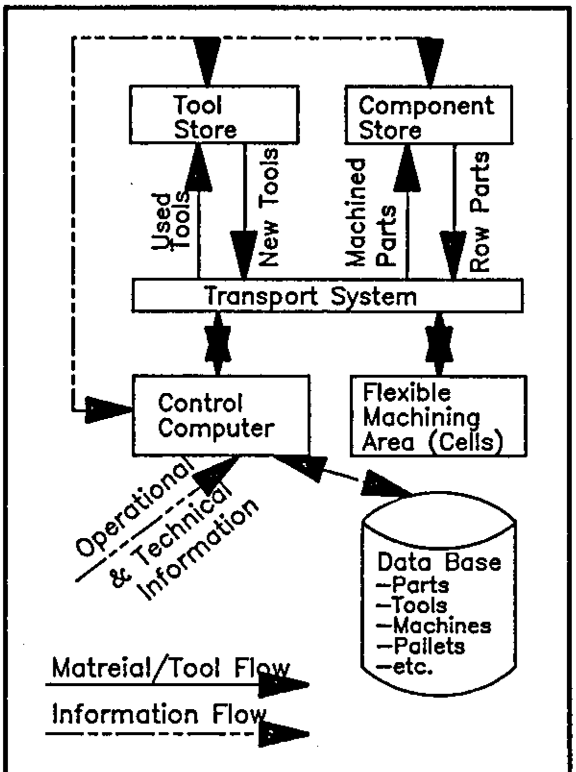
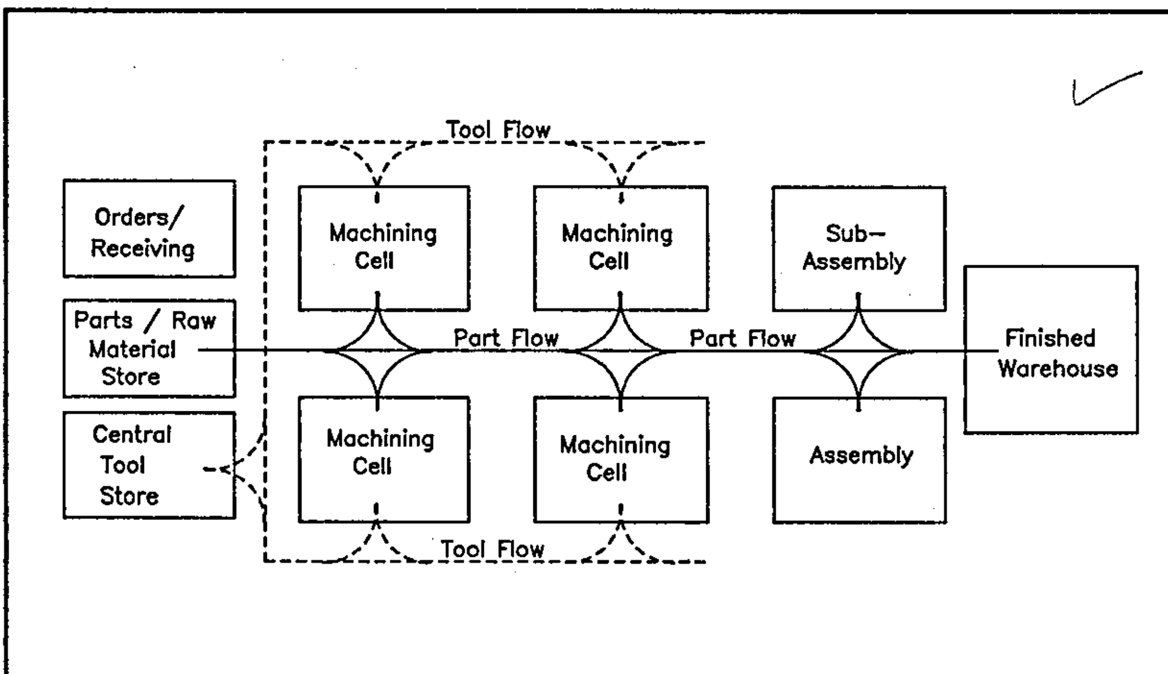


Fig. 2.1 FMS Functional Layout

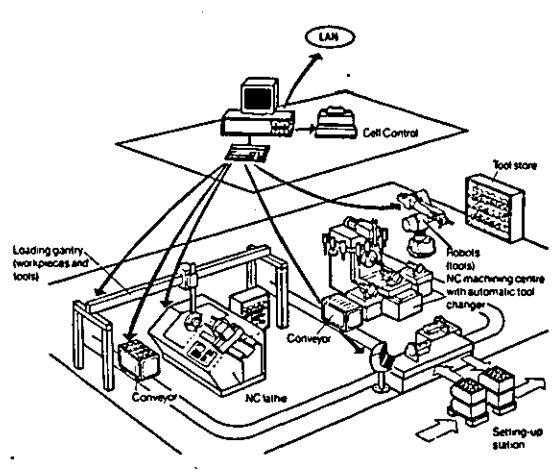
LUT–FMS RESEARCH GROUP



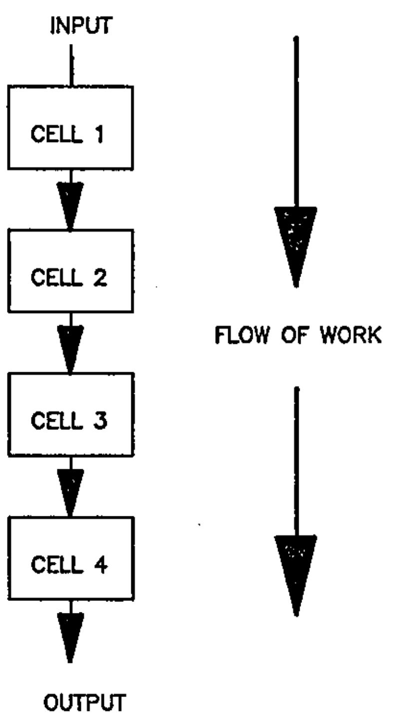
[Ref. 229]

Fig. 2.2 TYPICAL ELEMENTS OF A MANUFACTURING AREA

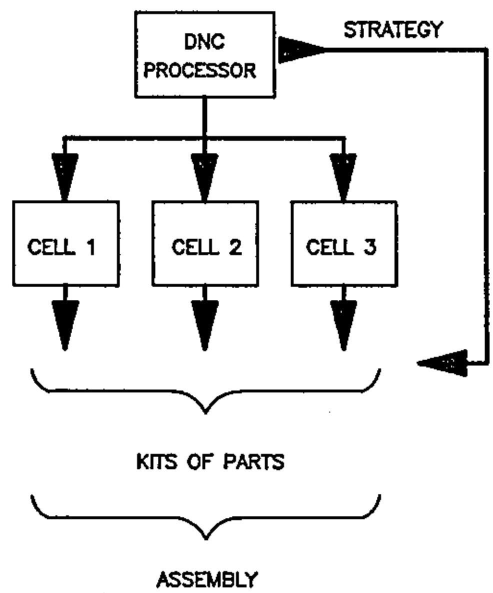
LUT – FMS Research Group



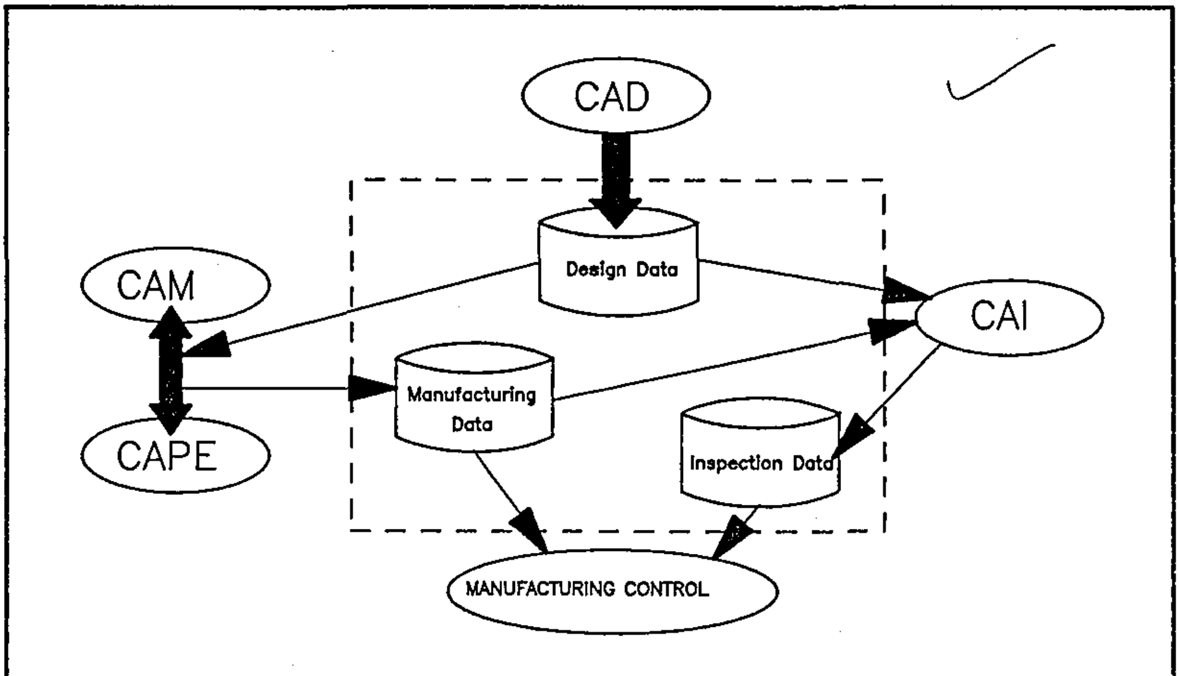
[Ref. 106] | Fig. 2.3 A Typical Flexible Manufacturing Cell | LUT – FMS Research Group



[Ref. 3] | Fig. 2.4 'FLOWLINE' MULTI-CELL | LUT–FMS RESEARCH GROUP



[Ref. 3] | Fig. 2.5 PARALLEL MULTI-CELL | LUT–FMS RESEARCH GROUP



[Ref. 94]

Fig. 2.6 A COMPANY VIEW OF COMPUTER INTEGRATED MANUFACTURING

LUT – FMS Research Group

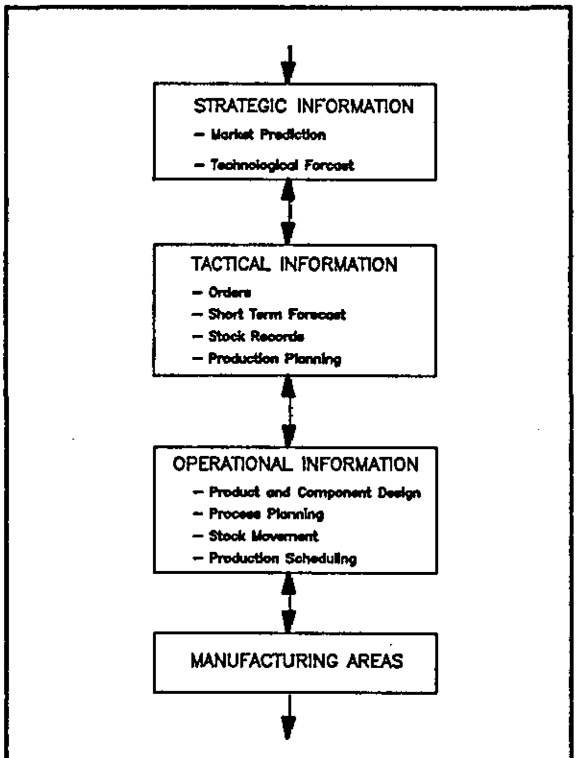


Fig. 2.7 CIM Information Categories

LUT–FMS RESEARCH GROUP

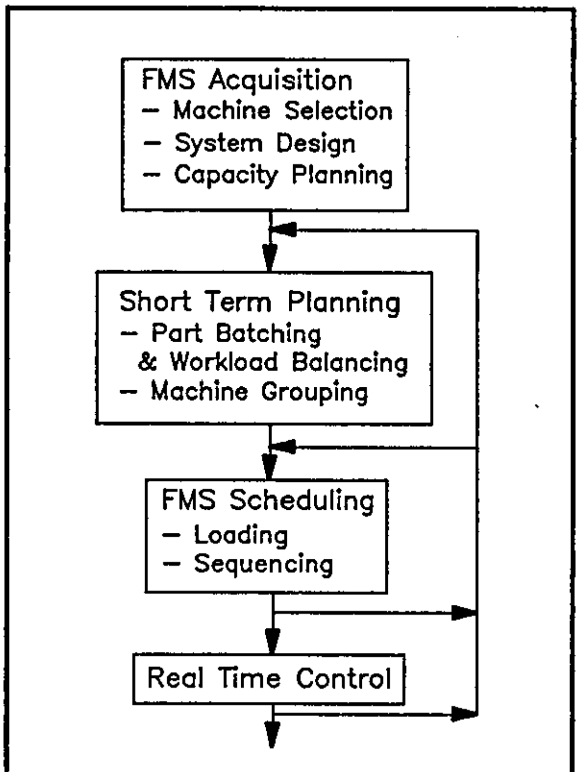


Fig. 2.8
FMS Acquisition
& Operation

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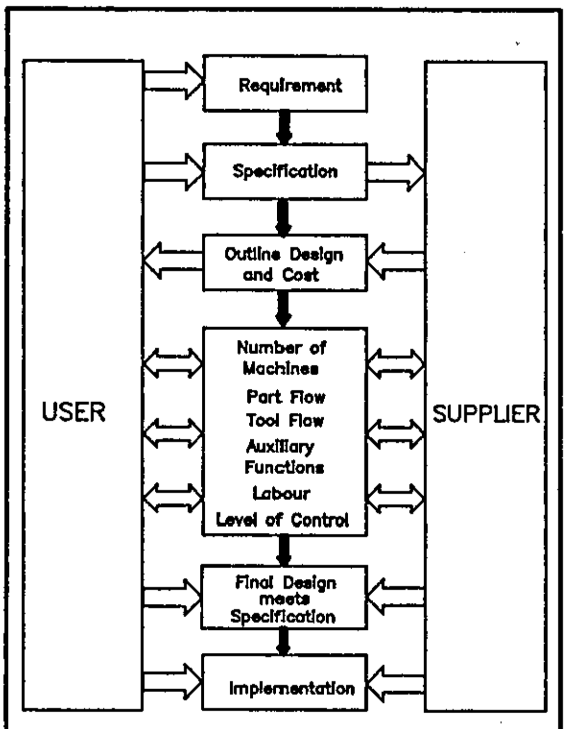

[Ref. 229]

Fig. 2.9 USER/SUPPLIER
INTERACTION IN
MANUFACTURING DESIGN

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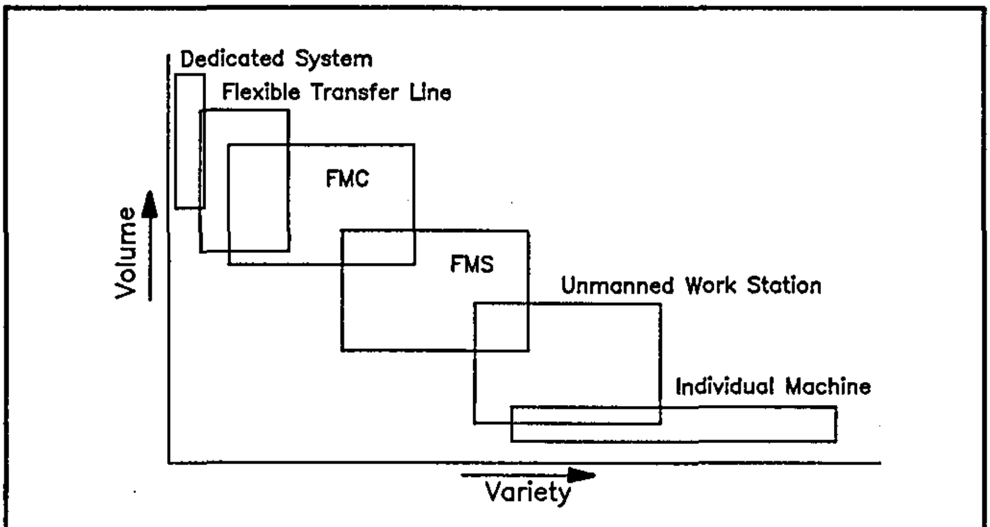
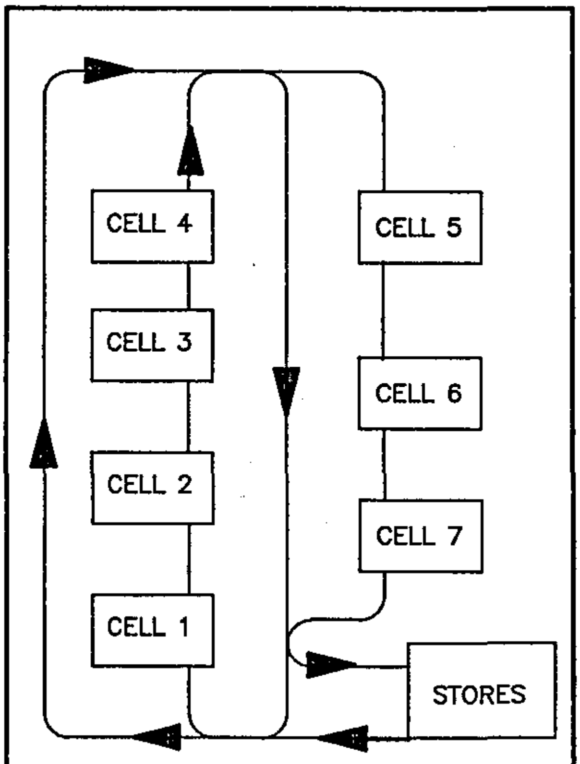
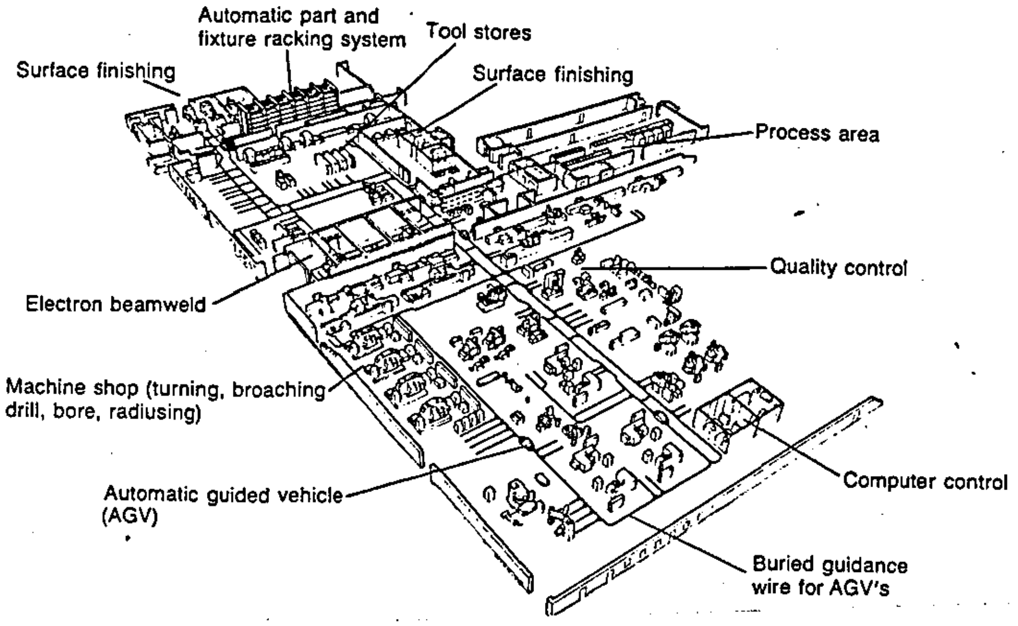


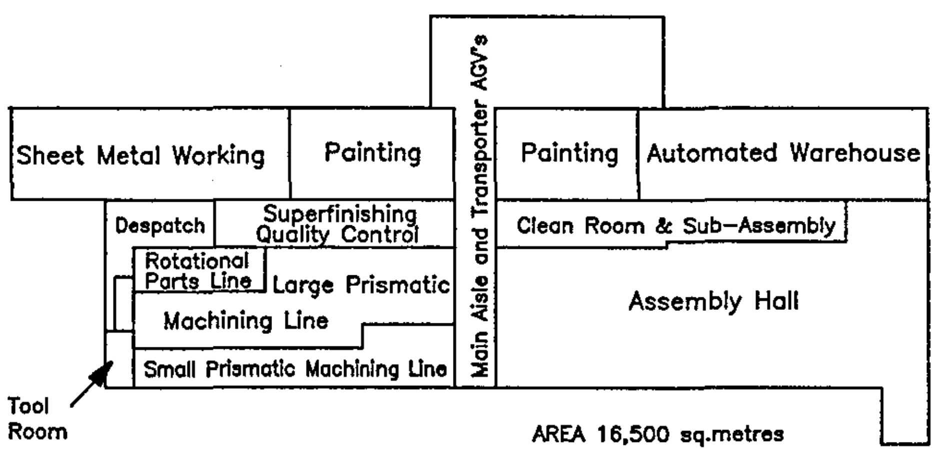
	Fig. 2.10 Comparison of Manufacturing Systems	LUT – FMS Research Group



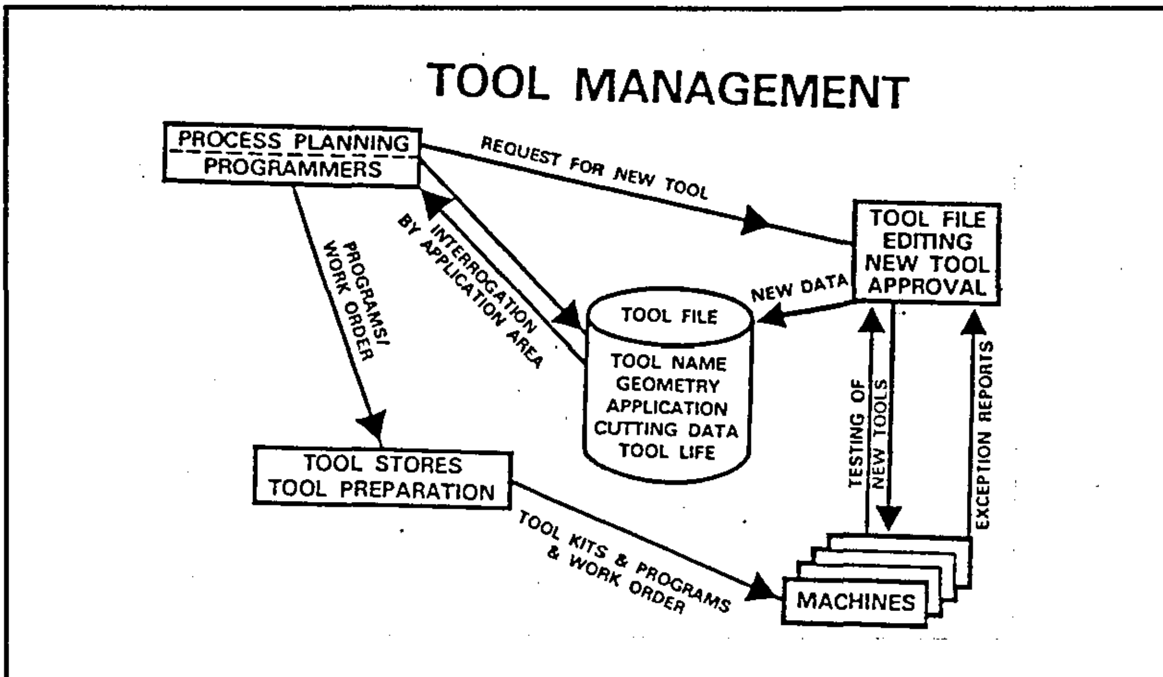
[Ref. 128]	Fig. 2.11 HOLSET MULTI-CELL FMS	LUT-FMS RESEARCH GROUP



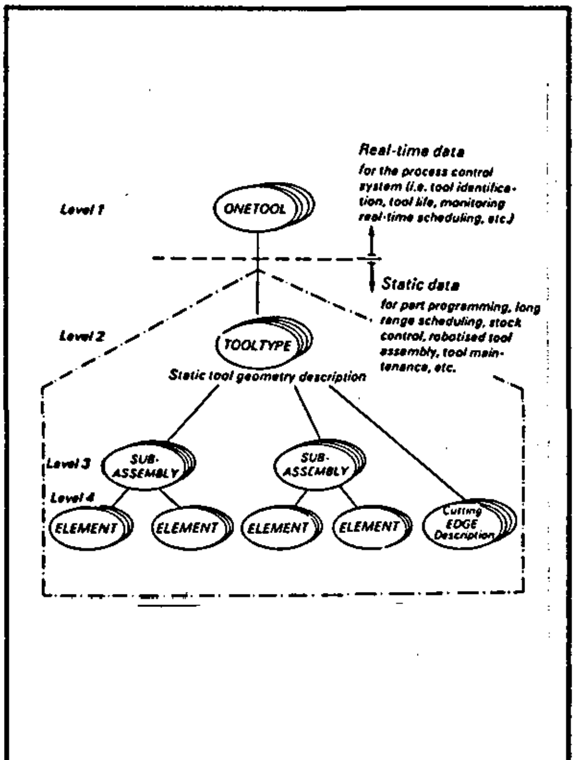
[Ref. 47]	Fig. 2.12 AIMS Layout	LUT – FMS Research Group



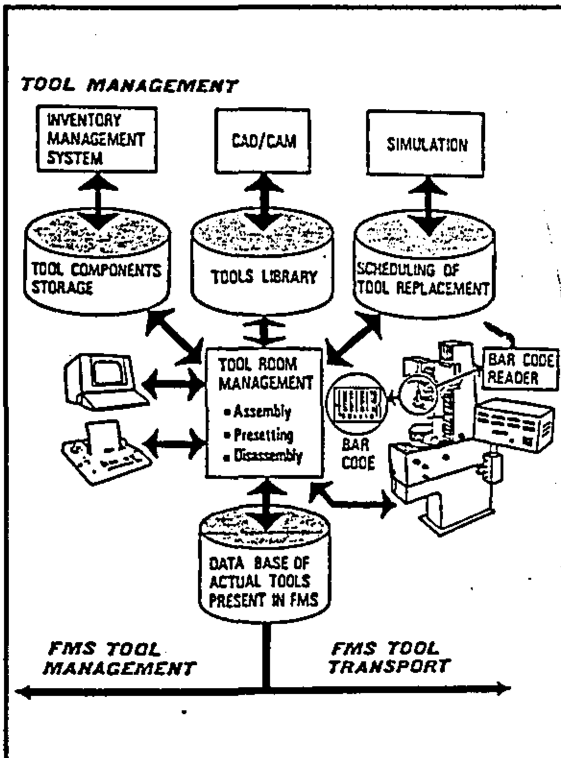
[Ref. 130]	Fig. 2.13 Yamazaki Worcester Installation	LUT – FMS Research Group



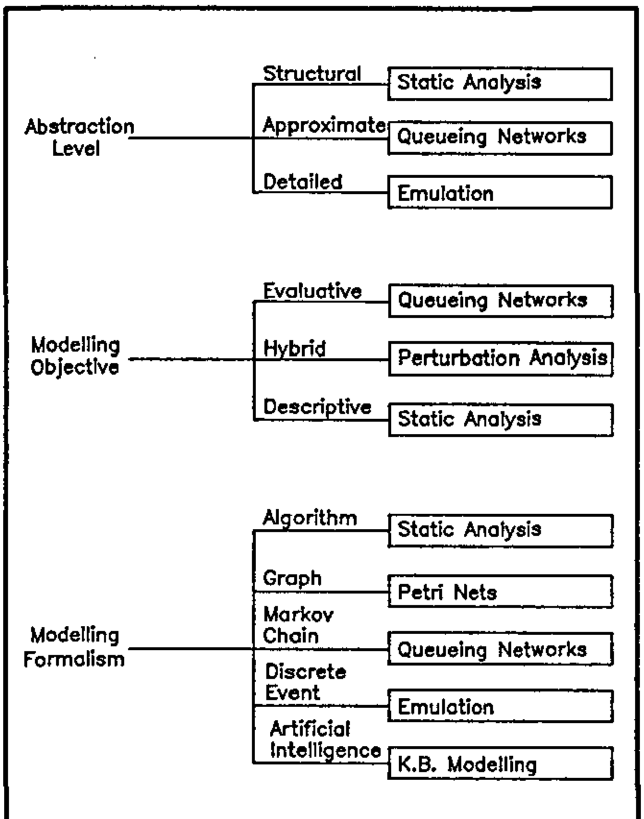
[Ref. 45] | Fig. 2.14 Tool Management Concept | LUT – FMS Research Group



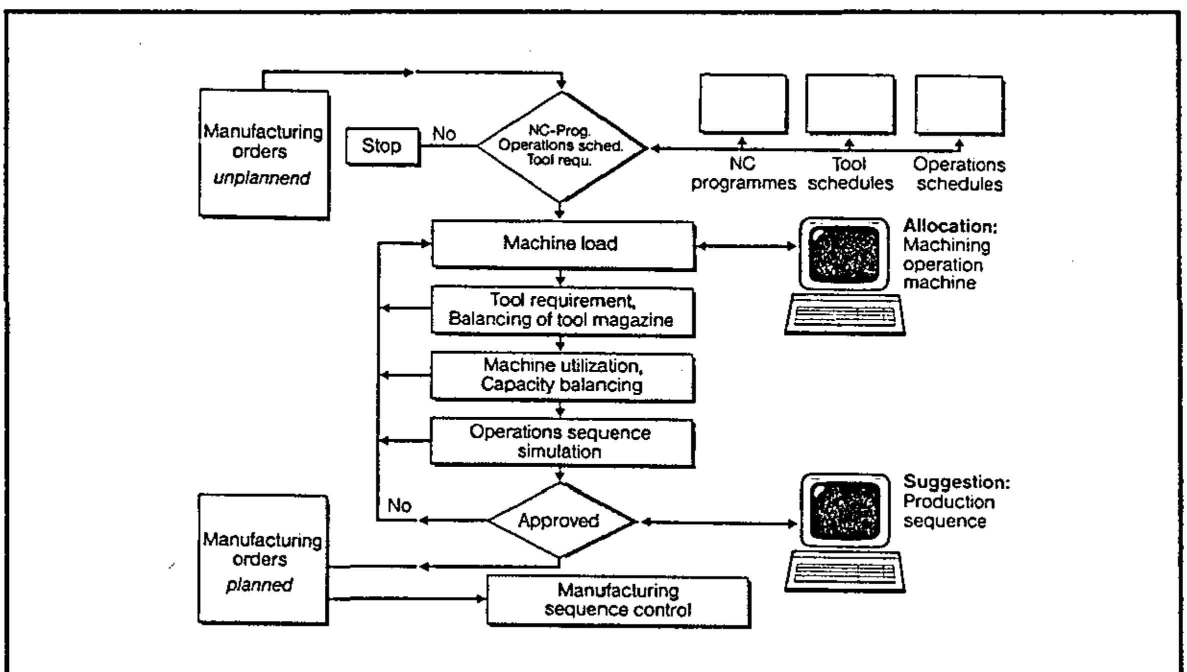
[Ref. 254] | Fig. 2.15 Tool Data Structure | LUT–FMS RESEARCH GROUP



[Ref. 57] | Fig. 2.16 A Tool Management Configuration | LUT–FMS RESEARCH GROUP



[Ref. 302]	*Fig. 2.17 Classification of Modelling Methods*	**LUT-FMS Research Group**



[Ref. 262]	Fig. 2.18 Production Control System – A Company Approach	LUT – FMS Research Group

CHAPTER 3 DEVELOPMENTS OF TURNING SYSTEMS

3.1 INTRODUCTION

The use of turning machines in flexible machining does not lay emphasis so much on the automation of tool and workpiece flow as in the case of machining centres. Instead, the single machine has been highly automated equipped with tool and workpiece handling facilities and incorporated with complete machining capability. Highly automated stand-alone turning centres have been widely accepted for flexible machining. However, there are substantial examples where CNC lathes have been integrated into flexible machining systems.

Highly automated turning requires the following system features to achieve maximum output and minimum downtime: (1). Tool and workpiece holding; (2). Tool presetting and component inspection; (3). Automatic machine loading and component transportation; (4). System monitoring; (5). System control and management information flow. [58, 106, 286].

In this chapter, the current state of turning system design and utilisation is discussed in order to establish the nature of flexible turning and its tool flow requirements.

3.2 OVERVIEW OF TURNING AUTOMATION DEVELOPMENTS

The major developments around CNC lathes are summarised in fig. 3.1. There is a clear distinction between a CNC lathe in its basic form and a highly automated turning system. A turning system will typically have workpiece handling facilities; tool flow will be provided to give magazine support to tool turrets; Contact probes will be implemented for the in-process workpiece gauging and cutting tool measuring , and a CNC controller will carry out the automatic compensation; To make a universal turning system, C- axis control and power driven system in the tool turret have been provided, when live tooling is employed, to enable complete machining including secondary operation, e.g milling, off-centre drilling etc., in one set-up. Workpiece loading/unloading between the spindle and the workpiece pallet eliminates operator involvement. Automatic chuck or chuck jaw changing and gripper exchanging will increase the system flexibility in terms of workpiece handling ability and the best clamping effect can be achieved. The implementation of twin turrets CNC lathes increases the productivity even further. [141, 142,182, 148, 202, 158, 151].

The modular design concept of CNC turning centres has features of a proven range of extensive options enable the machine to be customised to specific individual requirements using standard 'Building Block' modules. Economy in both purchase and production are thereby ensured. (Fig. 3.2). [203].

A company approach to build such a highly automated turning system is shown in fig. 3.3. [92, 201, 301].

The progress in CNC control and electronics technology has allowed the production of highly automated and yet mechanically simpler lathes. Transistor feed drives and thyristor controlled spindle drives eliminate the need for complex transmission systems. The use of servo drives has greatly simplified the turret driving mechanisms. [286].

The slant bed design has enabled removed metal to fall through the machine rather than to build up around the workpiece as it would on a conventional lathe. (Fig. 3.4) [213]. This structure design prevents the scratching of the finished surface by the chips and increases the machining accuracy, as the accumulation of hot machined chips can thermally distort the lathe bed and affect turning accuracy.

Twin turrets 4-axis CNC lathe has reduced the cycle time significantly by allowing a variety of turning processes to be carried out simultaneously. In the case of long bar turning, the use of two tools positioned in both sides of the workpiece can reduce the effect of cutting force in X-axis direction, and thus increases the turning accuracy. (Fig. 3.5) [19, 79, 153, 214].

System monitoring is indispensable to ensure an improved machining quality and reliable operations for a unmanned turning system. Vision systems can be used to make sure that a right component is presented for automatic workpiece handling devices. Tool breakage needs to be detected. Machine overloading and cutting force monitoring have also become popular functions. [105, 182].

Tool turrets have been used as a fundamental tool storage facility. A turret can typically have 6, 8, 10, 12 up to 18 or even more tool positions. But a turret with more than 18 positions is likely to be arranged in two layers. Only two positions have been designed for Mazak 40N ATC Mill Centre (Fig. 3.6). It is claimed that this unique design has totally eliminated tool interface problems. [215]. Yamazaki has also made an optional turret on its Quick Turn CNC lathe. Based on the standard turret, two block-tool holders have been mounted on each position, offering maximum 24 tools. The large tool storage for permanent-set tools can meet the requirements of a wide variety of workpieces or longer period of unattended operation [217].

To prevent system failure, and to deal with situations when faults do happen, integrated diagnostic software and hardware is a must. Traub GmbH has developed a three stage diagnostic concept:

First stage: The interactive online process monitoring is designed for the operator to permit the rapid location and rectification of operation faults and peripheral disruption; Second stage: Extended integrated diagnostic is provided. An additional diagnostic software pack is implemented in the control unit, the test program and the related results are displayed on the screen. This method enables faulty sub-assemblies to be located; Third stage: A full external diagnosis at the manufacturer's works enables faulty controls to be connected to a test computer. Individual elements can be tested and faults are located. [205].

3.3 AUTOMATIC CHUCK/JAW CHANGING AND GRIPPER EXCHANGING

The Automatic chuck/Jaw Changing (ACJC) and Gripper exchanging are important developments to handle a variety of workpiece types with medium to small batch sizes. These features guarantee the achievement of the 4best workpiece clamping effect on a workpiece spectrum.

Flexible turning systems impose the following requirements of work-clamping devices.

(1). Automatic clamping;

(2). Controllable clamping force;

(3). Flexibility to clamp a wide diameter range;

(4). The ability to hold first and second operation work . [127].

The first two requirements have been satisfied by the development of CNC lathes. However, the better operational characteristics cannot be attained over a wide diameter range of workpieces, and vice versa. [19, 32, 142].

Practical automatic chuck jaw changing systems differ on the construction of chuck itself and the jaw changing operation (Fig. 3.7). The fundamental difference is whether top jaws or master jaws are to be changed.

For the top jaw change type, three jaws can be changed simultaneously, thus reduces the jaw change cycle time. This kind of jaw change is easy to handle, no special devices are required. Usually, a workpiece handling device (robot) can be adopted. The chuck jaw changing system can be equipped even after the machine tool installation. Fig. 3.8 shows an example of an automatic three top jaw simultaneous change system. It consists of the chuck, jaws, magazine, and jaw changing robot or loader. [182]. Sequential master jaw change type requires a special jaw changing device. Jaws are changed sequentially, so, longer changing cycle time is generally required. But large number of jaw sets can be stored, relatively easier than in the three-jaw simultaneously change type.

The automatic chuck jaw changing system of Yamazaki Slant Turn 40N ATC Mill Centre features a high speed and accurate repeatability. The chuck jaw magazine has a capacity of 15 sets of chuck jaws and the adjacent jaw-set replacing takes only 45 sec.

Traub has equipped its FHS2 with up to 6 sets of gripper jaws for the gantry type workpiece exchanger to facilitate both external and internal gripper respectively [198, 201].

3.4 WORKPIECE HANDLING AND INSPECTION

The primary objective of the development of turning systems has been to satisfy the need of the processing requirement with shorter machining times and shorter change-over times. As cylindrical components feature short cutting time the loading/unloading of workpiece and tool exchanging has come to constitute an higher percentage of total processing time than the prismatic parts. Thus significant gain can be achieved by automatic workpiece handling and part inspection both in terms of set-up time reduction and manning requirement saving.

The flexible machining system requires the workpiece handling equipment to be simplified in resetting operations, freely programmable of movements and shorter change-over time requirement. Adequate handling capacity should be available so as not to limit the assortment of parts. [230].

Overhead gantries, fig. 3.9 have been widely used for automatic workpiece loading and tool exchanging in an flexible turning installation. The modular designed gantries incorporate intelligence, the main carriage, insert arms, gripper and associated pallet equipment. The whole gantry is under the CNC control which gives much greater flexibility [140, 141, 142, 180]. Multi-axis intelligent robots have also been used to service one or more machines, gauging stations and conveyors in its standard form. [176, 286].

SMT machine company has developed a Computerised Part Changing (CPC) system as its major step towards limited manpower production, fig. 3.10 [197].

An automated part changer should have the following features:

(1). Logically integrated with and physically separated form the CNC lathe. It should be under the same control system as the lathe, but installed separately from the machine to avoid vibration;

(2). Flexibility incorporating all the movement required and being able to handle a wide range of part geometry;

(3). Shorter part changing time and higher system reliability. [195].

The integration of workpiece load/unload system to the CNC turning centres has highly increased the system automation as it needs only supervision rather than continued support of a skilled operator (Fig. 3.11). [181]. This kind of unmanned workstation has also lent itself to system integration to form a fully automated flexible machining systems.

Bar turning lathes have presented extra workpiece handling problems besides automated loading/unloading as has the chuck type workpiece turning. The spindle speeds which machines could actually achieve were limited by power chucking equipment for bar feeds. There are two types of bar guide system available: The oil-filled bar guide tube; and the roller systems with pliable rollers. The later provides the possibility of loading bars from the side of bar magazine and lends itself for further automation. A functional sequence of bar loading magazine of this principle is shown in fig. 3.12: a). Storage; b). Separation and injection; c). Pock-up and feed-out; d). Guiding; e). Introduction for parting off; f). Follow-up feed; g). Ejection residue.

Roller bar guiding system can be further classified into two types with or without telescopic pusher for bar feeding. The roller guide system with telescopic pusher normally results higher system rigidity and hence higher spindle speeds can be achieved. [204, 210].

The increasing demands for better product quality and the rising trend towards automation cells call for an efficient workpiece inspection system. The inspection process can be classified into two types: External post process gauging; and internal in process gauging. The first one requires additional mechanisms and possibly a control system of its own, and a special means for data feed back. Since the data obtained are about the last finished component, it is normally one workpiece later in reaction for theCNC controller to incorporate the measured results. However, as the measuring process is carried out of the machining area and dedicated devices adopted, it generally results a higher accuracy.

The second type - in-process gauging features being easy to implement and quick in response. The gauging probe is mounted in the tool turret. It is brought to touch the workpiece in the measuring operation. Probes can be stored in tool magazines and handled in the same way as the normal cutting tools. The in-process gauging does feature a relatively low precision, and the machine is kept idle during the measuring cycle. [142].

A in-process workpiece gauging system consists of three components: gauging probe, gauging parameter, and measured data processing. The gauging program are usually standard subroutines and are stored in the CNC control unit. [265].

KV tooling system has been designed to accept the Renishaw LP probe system for in-process workpiece gauging, fig. 3.13. The LP2 is a three dimension, touch trigger probe system. The connection between the rotating turret and the machine tool carriage can be made with inductive modules as shown in the figuration. [165, 185].

Typical examples of in process workpiece measurement is shown in fig. 3.14. [216].

3.5 TOOL GAUGING AND SYSTEM SUPERVISION

Tool gauging probes have been installed in CNC lathes to measure the tool offset either when the tool is first entering the turret or after a certain period of tool usage [142, 185].

Fig. 3.15 shows a fully automated supervision system of a CNC lathe. The machine controller will programme a maximum limit of cutting time and record the accumulated tool life usage for each tool, if a predetermined tool life utilisation has reached, it will automatically have a sister tool from the tool turret to be engaged; Cutting force can be monitored during the turning cycle to make sure that a cutting tool is in good working condition; The electronic measuring equipment is connected to the CNC controller, and will carry out both in process and post process automatic gauging. It allows visual display of the workpiece shape, and allows automatic compensation of tool wear and tool offset. The component clamping control units provide improved safety to ensure that the workpiece is correctly clamped. [18, 196, 315, 142].

The 'Tool Eye' of Yamazaki has automated the tool setting (Fig. 3.16). After a tool is exchanged into the turret, it will be brought into contact with the probe, and tool tip is measured. All essential tool dimension data are recorded in the CNC memory. The need to perform a trial cut, measure the diameter, and data editing is completely eliminated. The tool wear compensation facility will automatically monitor the tool wear and transmit data to the CNC controller for automatic compensation. If any tool breakage is found, a spare sister tool will be automatically selected or the operation will be suspended. [215].

Kennametal International offers MP4 and MP6 probes for tool setting on the lathes (Fig. 3.17). The probe is mounted on the head stock, thus the thermal influence due to the movement of tool setter is eliminated. Tools are brought to contact the probe in X and Z axis, measured dimension parameters are passed to the CNC control unit and will be processed there. [165].

Tool wear can also be judged through gauging the workpiece finished. If the tolerance (or surface finish) reached a certain level, a tool is set to be worn, and will be replaced by its sister tool.

Tool probing has been widely equipped in CNC lathes of various manufacturers, e.g Dainichi [146], Heyligenstaedt [148], Nakamura [177, 178], Mori Seiki [176].

3.6 SINGLE MACHINE INSTALLATION EXAMPLES - Primary Tool Storage

A substantial number of highly automatic turning systems can be seen in operation as a result of the state of the art technology being integrated within system development.

The Warner and Swasey has built up a highly automated single machine turning cell around a WSC-8E7 CNC lathe. The whole system was built up by a modular approach. It includes sophisticated functions such as automatic workpiece handling, automatic gauging, visual part identification, process monitoring and quick chuck jaw change. The Sandvik Block Tooling System has been implemented for automatic tool exchanging. A special double arm changer is used for tool changing (Fig. 3.18). [187].

The Flexible Compact System for turning, drilling and milling features a integration of 2 HEINEMANN CNC lathes. Both machines are serviced by the gantry portal robot with workpieces and tools. Hertel FTS tools are stored in 2 magazines offering a total capacity of 120 tool pockets. The disc type turrets have 12 tool positions with up to 6 positions for live tools. Tools are automatically gauged in the machine by a touch type probe to detect tool wear, tool breakage, and to verify the tool geometry. The touch-sensitive probe head for workpiece measurement is handled by the automatic tool changer like any other tools. When dimensions are measured, the nominal and actual dimensions are compared, and any offset of the tool is compensated for by the CNC controller (Fig. 3.19). [157].

Fig. 3.20 shows a fully automated flexible turning cell with possibility to be integrated to a flexible machining system by automatic material transportation network. Workpieces are stored in pallets. Both tool exchange unit and component handling gripper are installed on the same gantry. Hertel FTS 72-station tool magazine has been implemented to back up the two turrets for a longer period of unattendant production. The system is built up around the EMAG MSC22 Twin-spindle CNC lathes. Post-process component gauging system has also been integrated into the cell layout. [58].

A highly automated turning cell - NF250, DNC - was developed by Pittler. Both workpieces and tools are automated handled by a portal-mounted robot. Workpieces of chuck type are stored in separate pallets from the shaft type workpieces. Block Tooling

System is adopted, but tools are also stored in pallets rather than in a BTS tool magazine as in the normal cases. Probes for workpiece gauging have been used and handled as normal Block tools (Fig. 3.21). [187].

A bar turning cell is shown in Fig. 3.22. The bar magazine has a capacity of 100 bars of 3.7 meter long. Bars are loaded to the stock tube automatically. Machined parts are collected into baskets by the component catcher. The baskets are transferred on the powered conveyer system. Sandvik BTS tooling system has been used for tool exchanging. The tool magazine has a capacity of 120 tools. A gantry is installed for ATC. The signal to indicate the tool changing can be obtained in different ways: a). After a predetermined cutting time for a tool; b). When a new part program is selected; c). When the cutting force of a tool is in excess of the predetermined limit.

A tool is set after it has been changed into the turret by a touch trigger probe mounted on the head stock, and measured data will be stored in tool offset file in the CNC unit for use when the tool is required.

A turret mounted Renishaw probe can be used to touch the various features on the component which are required to be measured. [285].

Other highly automated turning system examples of different suppliers are Traub [202, 198, 200, 201], Index [159], Heyligenstaedt [153], Heid [151, 26], Boeheringer [140], SMT [18, 197, 315].

3.7 CELLULAR INSTALLATION EXAMPLES
- Secondary Tool Storage

Substantial evidence can be found that CNC turning machines have been integrated into flexible manufacturing cells. These can be highly automated cells with automatic tool and workpiece flow or a series of manually operated CNC turning centres. Quite often the manually supported turning cells can be found in batch manufacturing systems, where each machine is highly automated. But the part flow inside the manufacturing cell will be in the form of a part pallet transferred by operators. The tool flow to the machine will also be the manual operation [197, 153, 141, 142, 151].

Perkins Engines of Peterborough has invested £6 million on its balancer units section. The new facility has rotary transfer machines, CNC lathes and grinders, gear hobbing, deburring and shaving units plus semi-automatic assembly machines. The whole production line operates on a 2-shift basis. Two similar balance weights are produced in high volume.

The 4-machine turning cell are highly automated. It consists of 4 TI Herbert Churchill CTC4 CNC lathes, each with a gantry type overhead parts loader/unloader. A twin-strand parts conveyer links the cell to the outside. Work handling is fully automated, and operator intervention is restricted to tool changing. (Fig. 3.23)

Operation sequences are identical for the two component types. (Fig. 3.24). The first machine carries all the rough turning on one side, and the second and third machine rough turn the remainder side of all components. The fourth machine does the finish turning.

Perkins opted principally for tool changing on a 'No. of Cuts' per tool, because it claims that the monitoring through a specific parameter - e.g. cutting force - is not sensitive or consistent enough. Sandvik Block Tooling has been implemented on each CNC lathe. Every tool turret carries a duplicate set of tooling and the CNC program automatically shifts between tool sets on the cycle count basis.

An FMC produces limited number of simpler component types (in this case two) in high volume calls for a cell controller with limited flexibility. The software engineering cost is therefore modest. In the Perkins turning cell, an Allen Bradley data highway has been adopted to transfer production and processing information to the central controller. [31].

Hitachi-Seiki has installed three FMCs in its FMS plant. Two of which are made up of machining centres for manufacturing box-type components for machine tools. The third line consists of 3 CNC lathes and a horizontal machining centre. (Fig. 3.25).

The machining line was designed for 460 different gears. The high production variety calls for a complicated controlling software. The cell is run by a computer which chooses the part programs, workpieces and tools for a particular batches. Workpieces are transferred by a belt conveyer, each machine has a industrial robot to lift off the workpieces and place it in the machine chuck or fixture.

Sandvik Block Tooling has been adopted for the tool supplying to the CNC lathes. A drum type Block Tool Magazine Holder has been installed at one end of the manufacturing line. It holds 24 racks each with 5 cutting units. The lathe turrets haves six external and six internal tool positions and tool exchanging into turrets has been carried out by a tool exchanger moving along a gantry over the 3 lathes. [321, 187].

A diesel engine manufacturer Lister- Petter ltd. sited at Durley, UK, a Hawker Siddeley company, has developed a significant FMS known as FMS2. The FMS comprises 6 CNC four-axis lathe, flexible conveyer system and gauging equipment, and all under the control of an integrated computer network. Parts are scheduled by the analysis of bar size and specification and also the tooling condition of the individual machine to minimise tooling set up time. However the latest start date for a batch dominates other scheduling rules.

The FMS was designed for producing over 160 different small turned parts and commenced production at the end of 1986. The bars are 3m in length and range between 8-55 mm in diameter. The finished components could be up to 200 mm. in length. One of the main purpose of this system was to minimise the number of separate operations [11].

UEF Garringtons has implemented a just in time FMS for die and forging tools. The system features a very high variety and very low batch size due to the characteristics of the production requirement -- No more than three may ever be needed at one time, with the frequency of repeat batches varying from once a month to once a year.

The system incorporates 3 lathes, a five-axis mill centre, a co-ordinate measuring machine, in line electric-discharge machines (EDMS) and AGV transporting system. All except the EDMs are under the control of a DEC PDP 11/84 supervisory computer. Operators have to carry out loading/unloading and set-up tasks both at the stores/set-up area and at each machine. The supervisory computer will issue instructions to operators and provide Direct Numerical Control to both the AGV system and CNC machines. The DEC computer will schedule the product taking into account due date, machine up time, tool changes and chuck changes. [8].

The 600 Group has built up a flexible machining cell known as SCAMP (Six-hundred group Computer Aided Manufacturing Project) at the Colchester Lathe site in Essex. The project was supported by the British Government. It was proposed in 1978 and was operational by the end of 1982. It operated for the first and second years as a showpiece of FMS technology. Since then it has reverted to normal production. The cell consists of four CNC lathes, a gear chamfering machine, a gear shaping machine, a cylindrical grinding machine and a hobbing machine. Eight Fanuc robots are employed to carry out load/unload operation and the whole system is served by a part pallet conveyer on which 150 individually coded pallets can be accommodated (Fig. 3.26).

The system control computers download programs to the machine tools and robots, as well as schedule work through the system, and providing operators information on VDUs.

The scheduling of work is done by the supervisory computers according to priorities determined by the operators. It is a computerised Gant Chart system. Operators key in data about workloads and use the VDU display to see the effects of their decision. Thus operators can alter the display until they get the best possible workload and schedule to suit their production target.

Sandvik Block Tooling System has been implemented on two of the CNC lathes. On the other two CNC lathes, further powered turret has been adapted to facilitatesecondary operations.

As soon as a machine tool has completed a component batch, the computer indicates to the operator that a new tooling set up is required and sends down the part program for the machine and associated robot. The operator then re-tools the machine for new component according to the displayed instruction on the VDU before authorising the machining process to commence. [10, 110, 312, 314]. A flexible turning cell consisting of three CNC lathe with automated tool and workpiece flow has been installed at SNECA factory in Corbeil, France, and has completed its test in Feb. 1988. The turning cell produces mechanical parts for aircraft engines in batches varying from 5 to 12 in size. The production rate is about 240 parts/month. [267].

The integration of CNC turning centres into turning cell can be seen in major plant installations: FAST of Takoka Electric [21], Yamazaki Minokamo spindle line and flange line [104, 212], Yamazaki Worcester rotation part line [14, 15, 129, 130, 211], Fanuc motor factory [103, 105], shaft line of Mitsubishi [22].

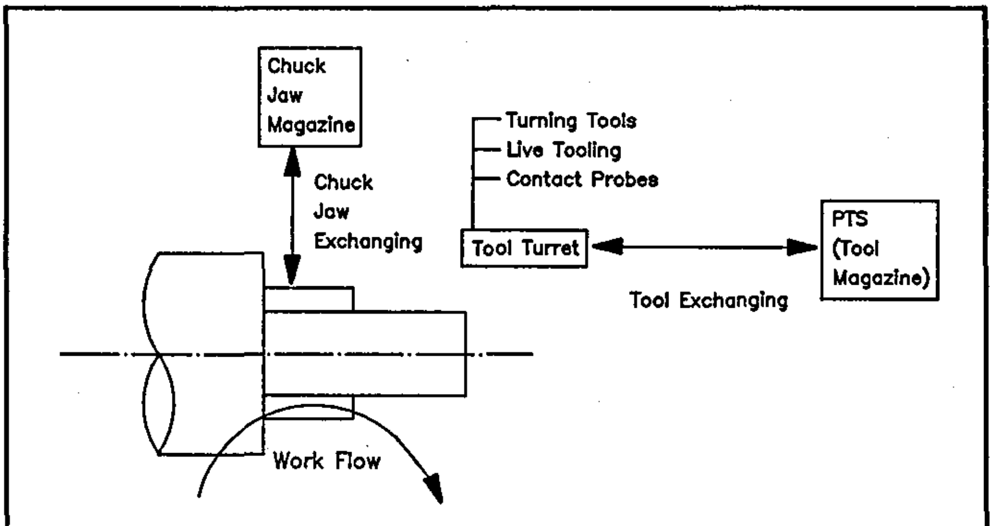
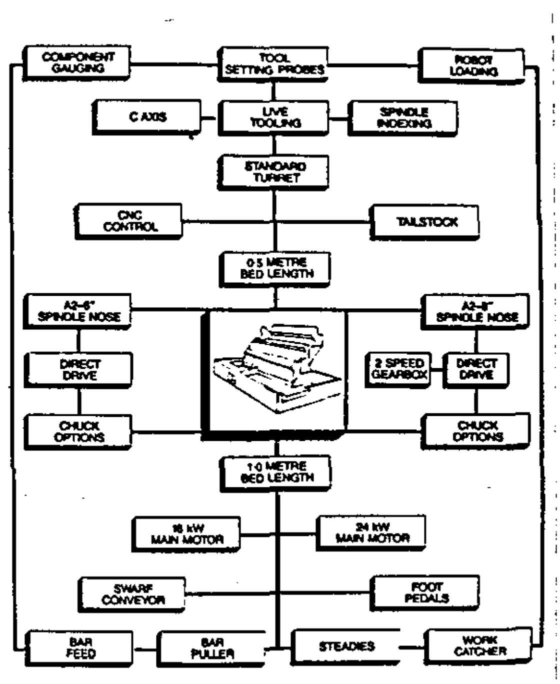
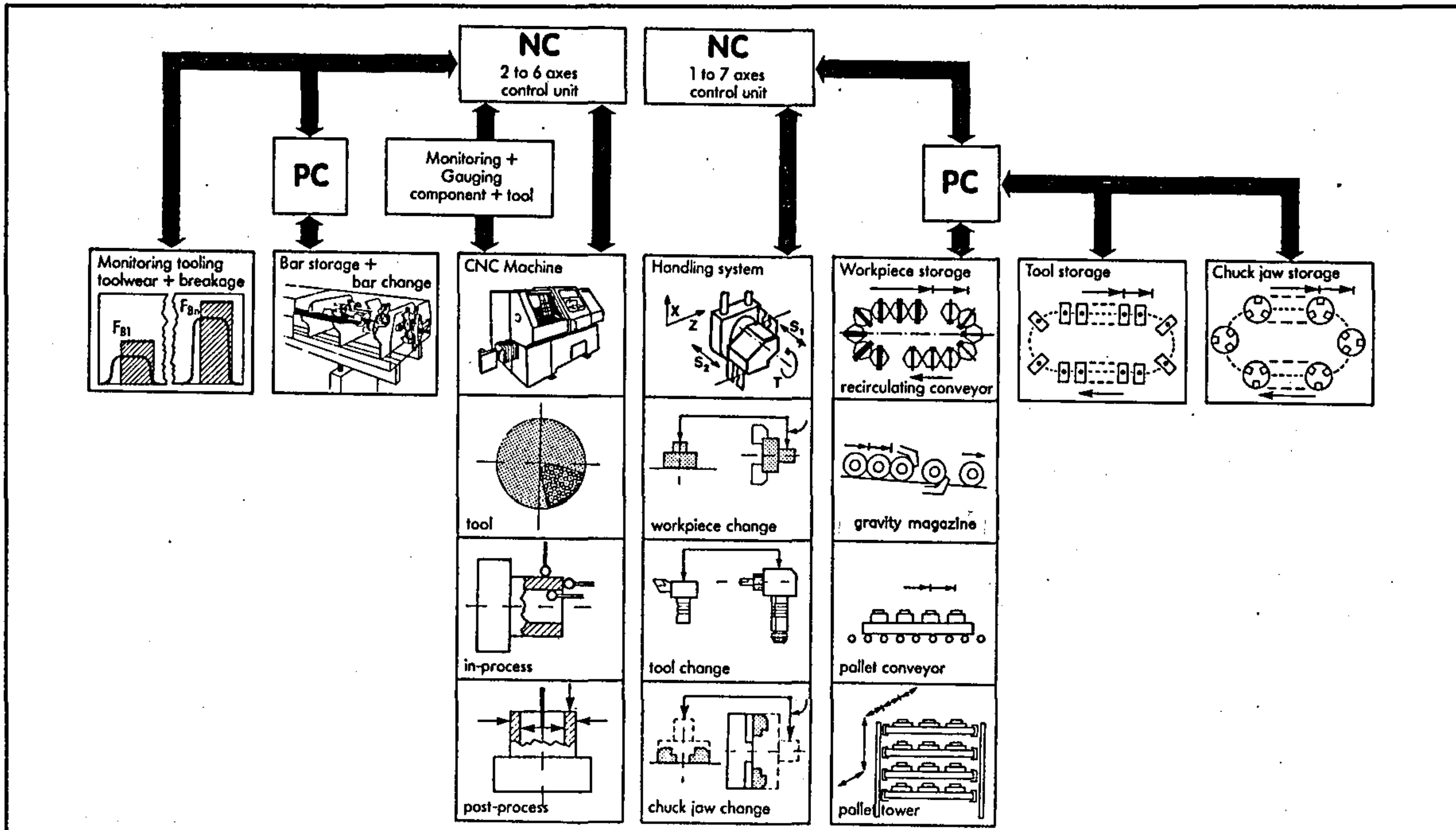


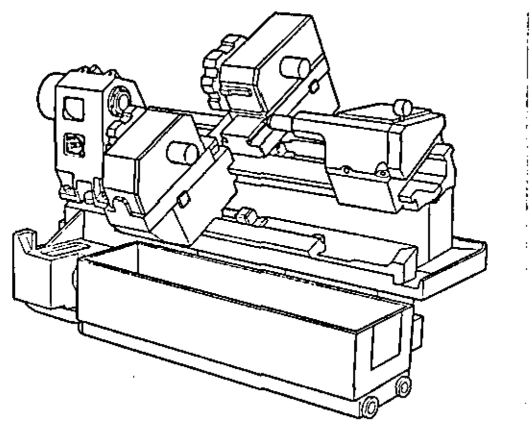
	Fig. 3.1 Development of Turning Automation	LUT – FMS Research Group



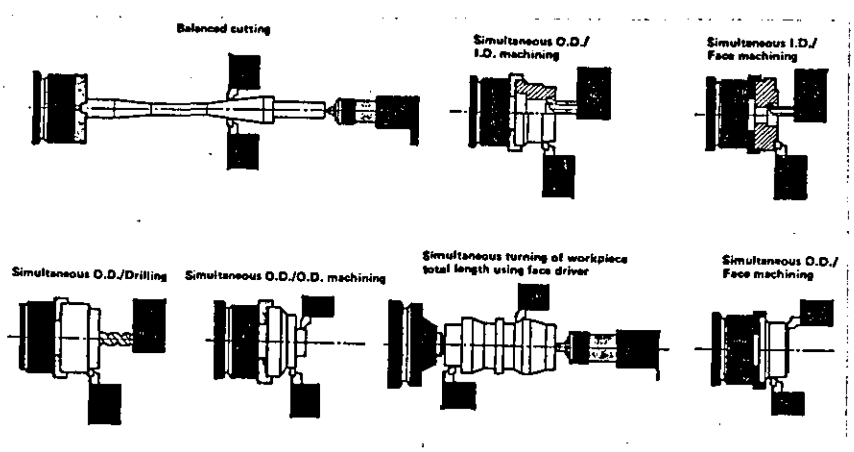
[Ref. 173]	Fig. 3.2 Modular CNC Lathe Design	LUT–FMS RESEARCH GROUP



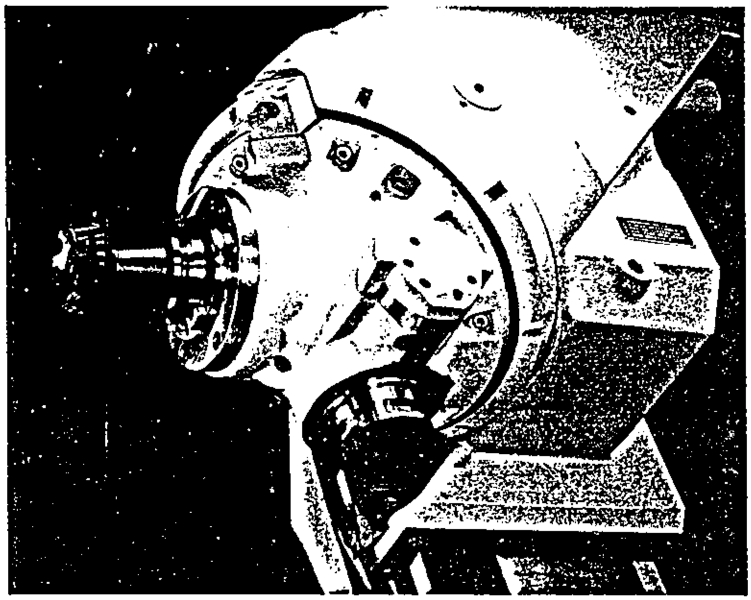
[Ref. 198]	Fig. 3.3 Full Range of Turning Automation Features	LUT — FMS Research Group

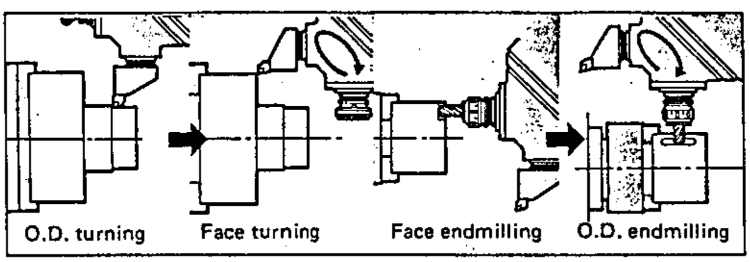


[Ref. 213]	Fig. 3.4 Slant Bed Design	LUT – FMS Research Group

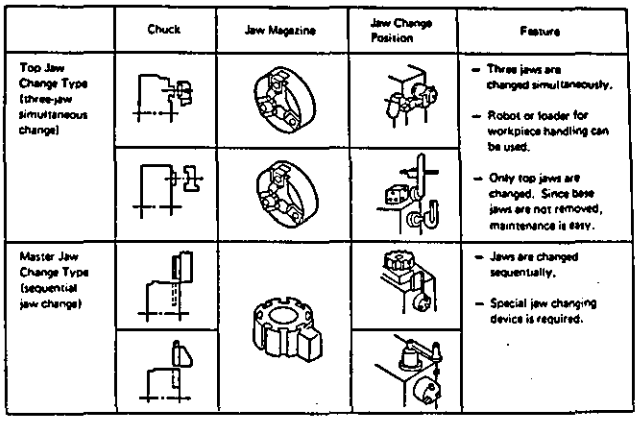


[Ref. 214]	Fig. 3.5 4–Axis Simultaneous Turning	LUT – FMS Research Group



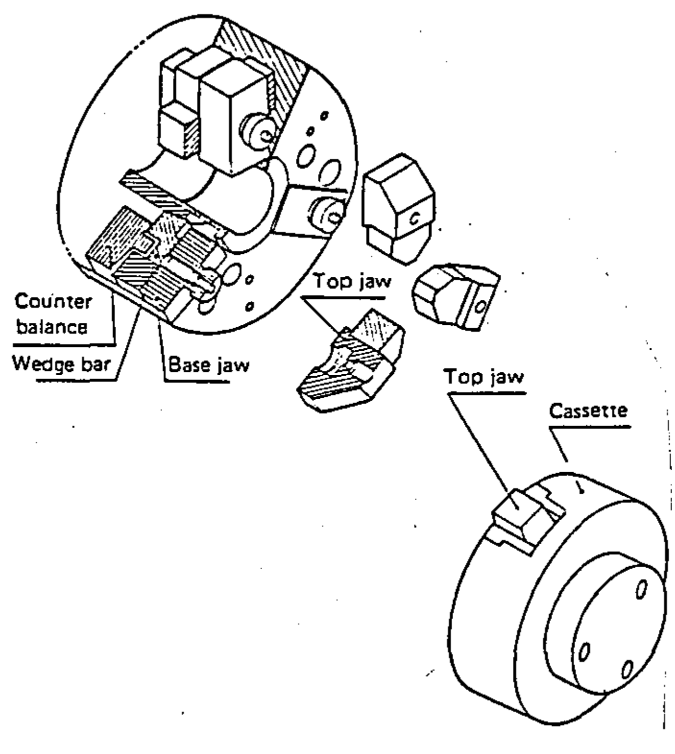


[Ref. 215]	Fig. 3.6 Slant Turn 40N Two-position Turret	LUT-FMS RESEARCH GROUP

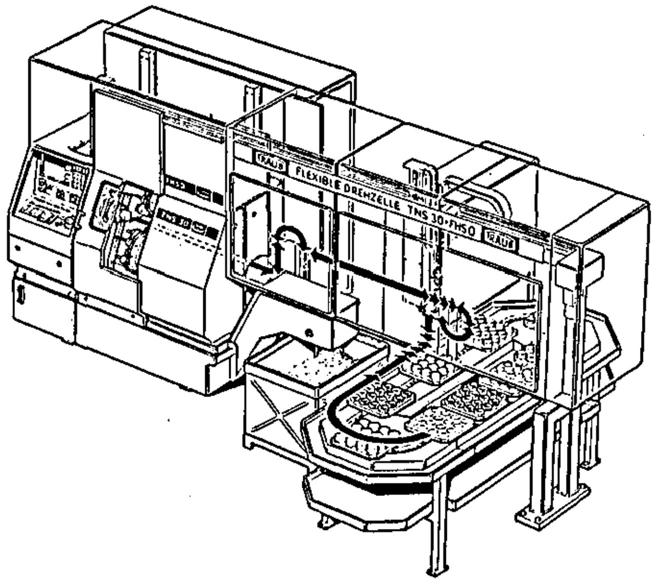


	Chuck	Jaw Magazine	Jaw Change Position	Feature
Top Jaw Change Type (three-jaw simultaneous change)				- Three jaws are changed simultaneously. - Robot or loader for workpiece handling can be used. - Only top jaws are changed. Since base jaws are not removed, maintenance is easy.
Master Jaw Change Type (sequential jaw change)				- Jaws are changed sequentially. - Special jaw changing device is required.

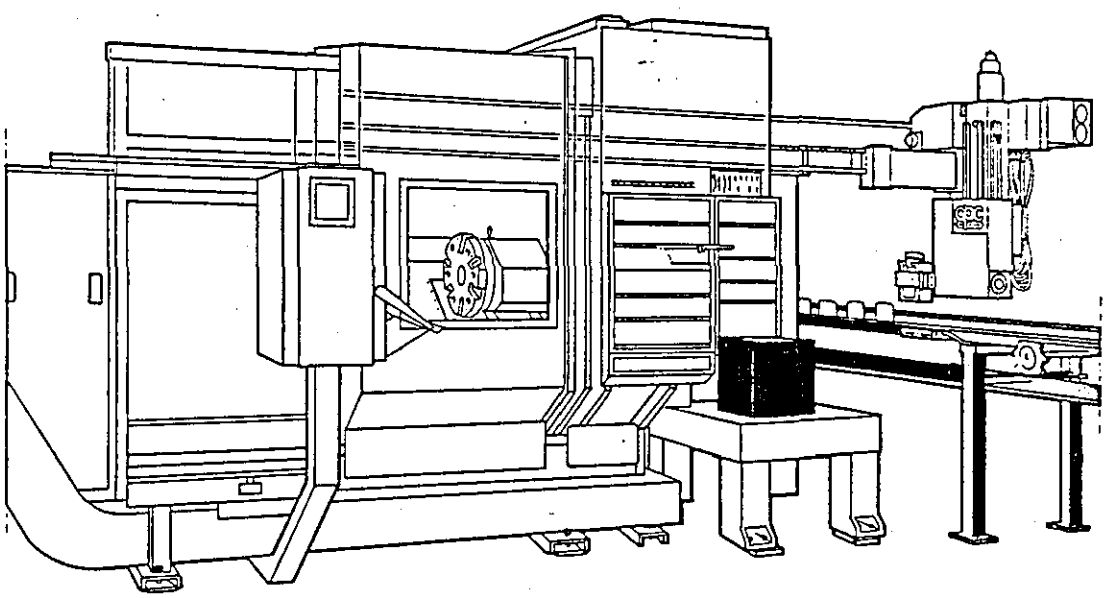
[Ref. 182]	Fig. 3.7 Comparison of Auto. Chuck/Jaw Changing	LUT – FMS Research Group



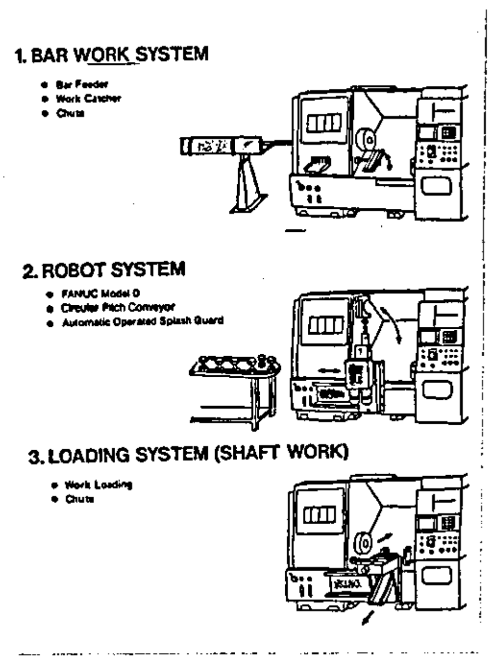
[Ref. 182]	Fig. 3.8 3–jaw Changer and Jaw Change Cassette	LUT–FMS RESEARCH GROUP



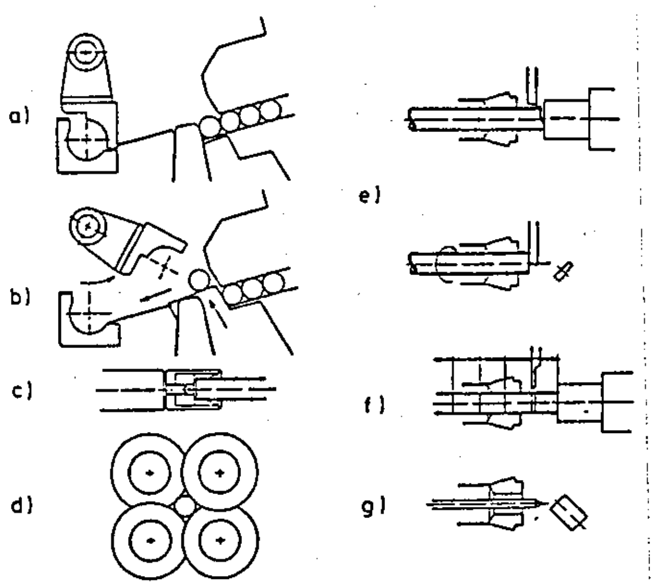
[Ref. 201]	Fig. 3.9 TNS 30 + FHSO	LUT – FMS Research Group



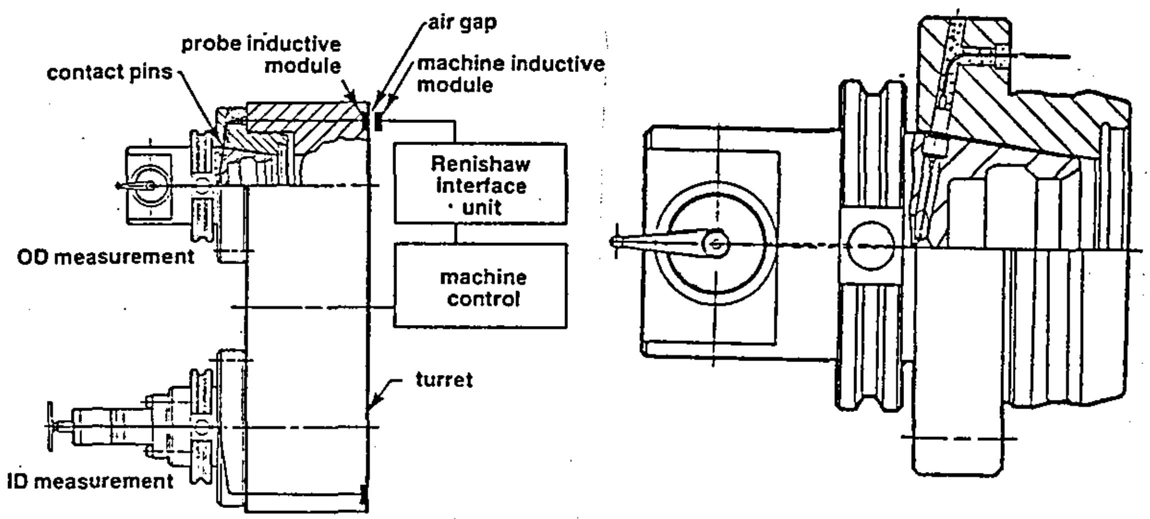
[Ref. 195]	Fig. 3.10 Overhead Gantry Type Workpiece Handling System	LUT – FMS Research Group



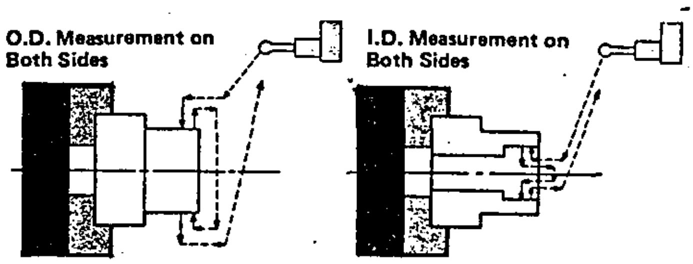
[Ref. 181] Fig. 3.11 Workpiece Handling Systems LUT–FMS RESEARCH GROUP



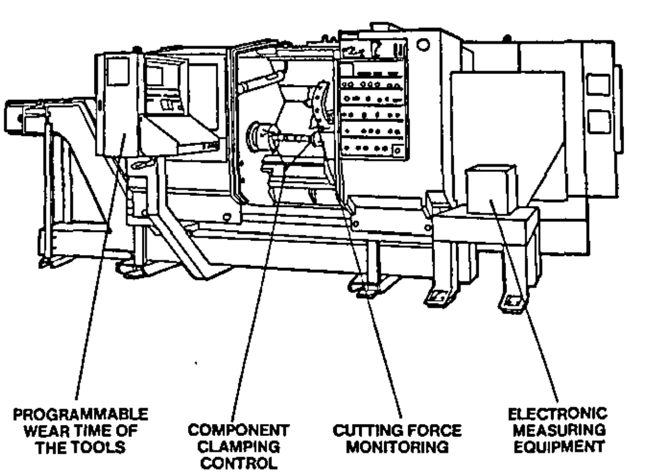
[Ref. 204] Fig. 3.12 A Typical Bar Loading System LUT – FMS Research Group



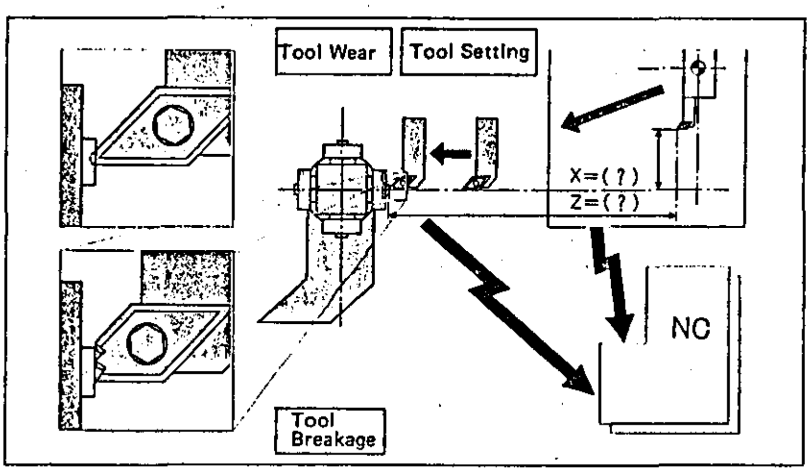
[Ref. 165]	Fig. 3.13 KV Probe Adaptors	LUT – FMS Research Group



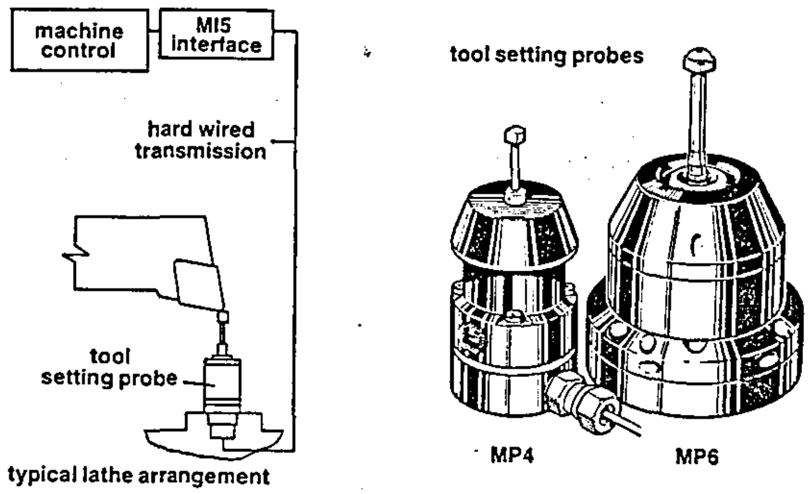
[Ref. 216]	Fig. 3.14 In–process Workpiece Gauging	LUT – FMS Research Group



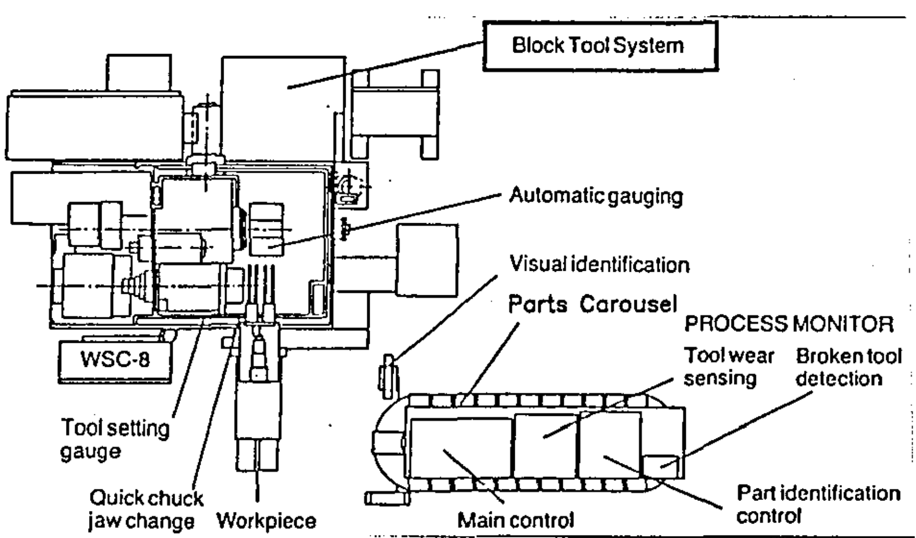
[Ref. 196]	Fig. 3.15 Advanced CNC Turning Centre Concept	LUT – FMS Research Group



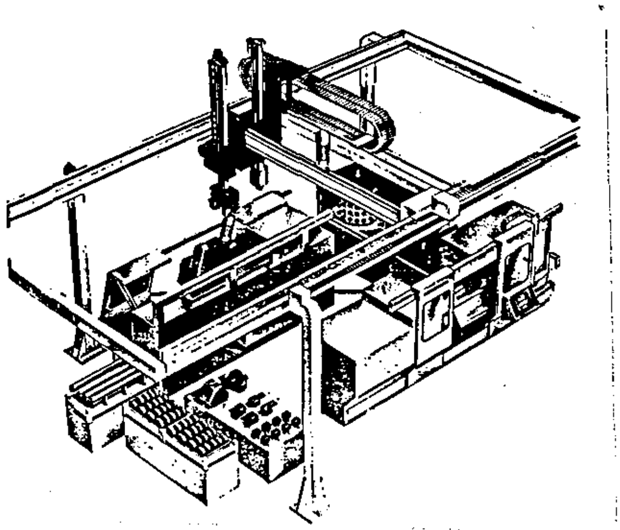
[Ref. 215]	Fig. 3.16 Tool Setting and Measuring	LUT – FMS Research Group



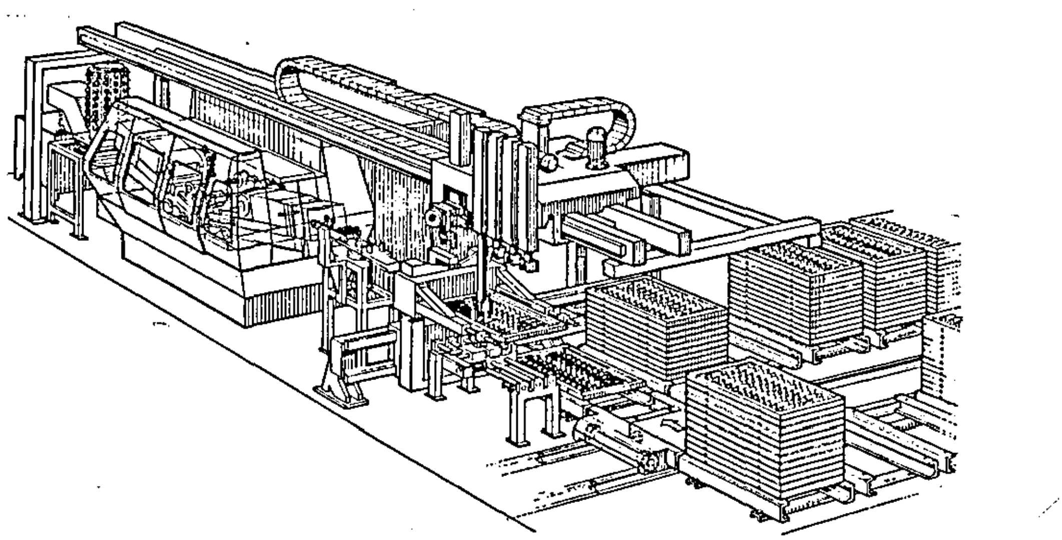
[Ref. 165]	Fig. 3.17 KV in–machine Tool Setting System	LUT – FMS Research Group



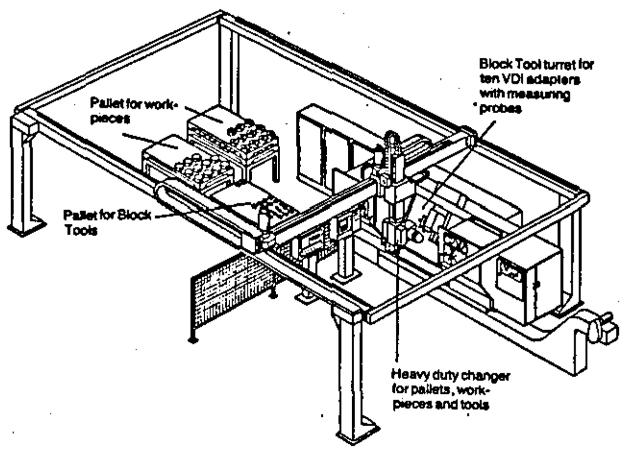
[Ref. 187]	Fig. 3.18 WSC–8E7 Turning Cell	LUT – FMS Research Group



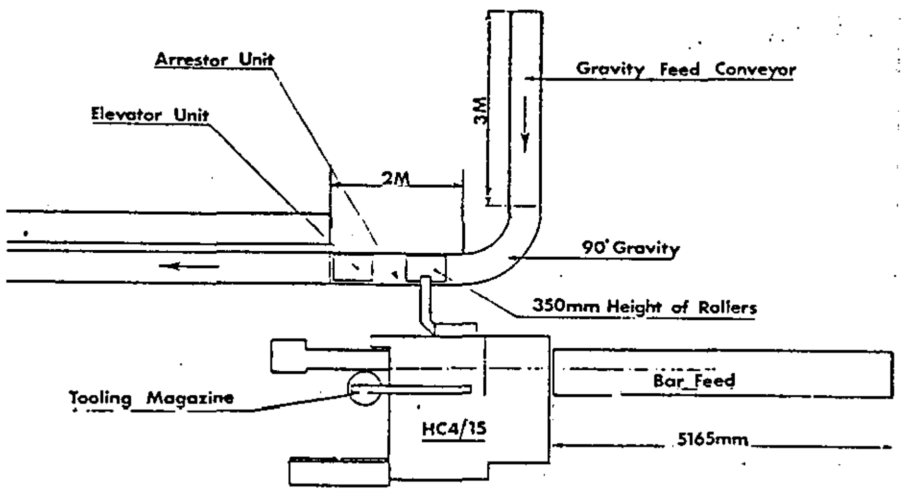
[Ref. 157]	Fig. 3.19 A Flexible Turning Cell	LUT - FMS Research Group



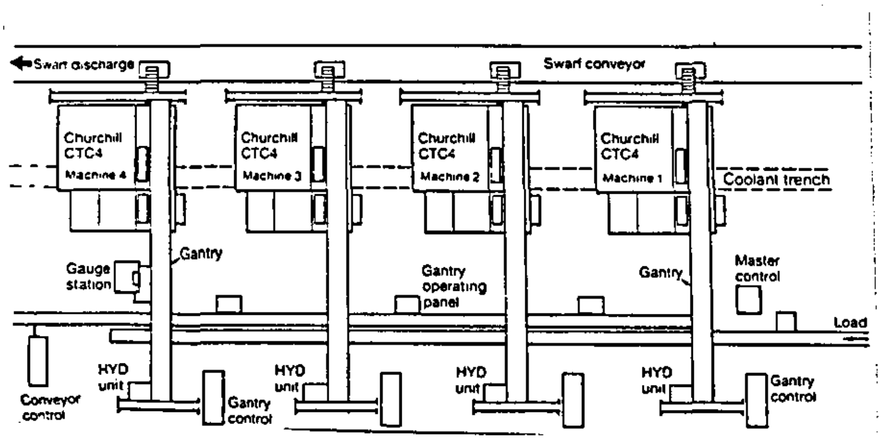
[Ref. 58]	Fig. 3.20 Msc 22 Flexible Turning Cell	LUT - FMS Research Group



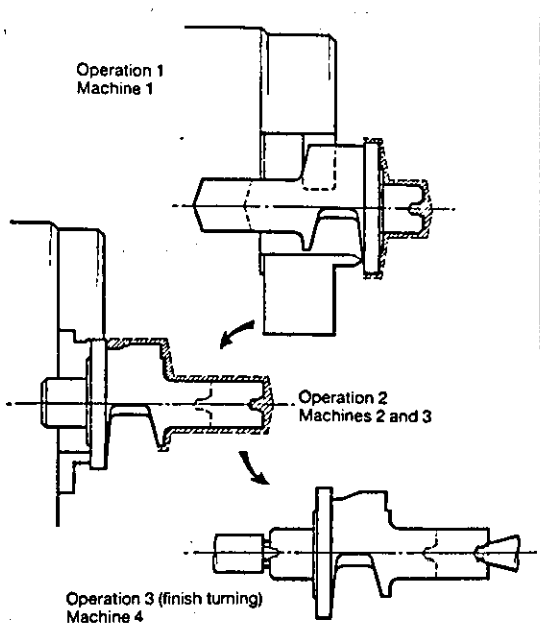
[Ref. 187]	Fig. 3.21 NF 250 DNC Turning Cell	LUT – FMS Research Group



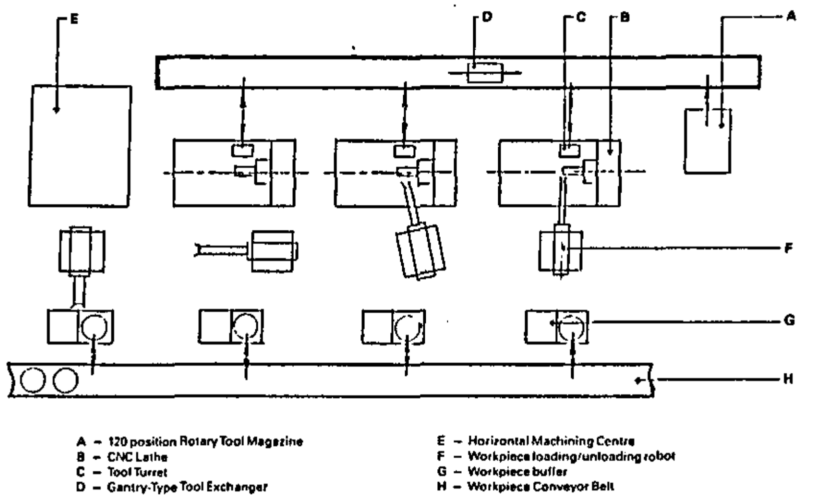
[Ref. 285]	Fig. 3.22 A Fully Automated Bar Machine	LUT – FMS Research Group



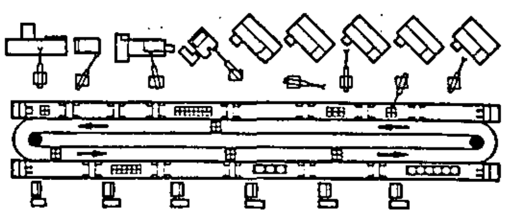
[ref. 31]	Fig. 3.23 Perkins Turning Cell	LUT – FMS Research Group



[Ref. 31]	Fig. 3.24 Balancer Unit Operation Sequence	LUT–FMS RESEARCH GROUP



[Ref. 321]	Fig. 3.25 Hitachi Seiki Turning Cell	LUT – FMS Research Group



[Ref. 7]	Fig. 3.26 SCAMP FMS	LUT – FMS Research Group

CHAPTER 4 LIVE TOOLING AND SECONDARY OPERATION

4.1 INTRODUCTION

The live tooling facility is a significant development of CNC lathes. Secondary operation work on turning centres usually makes the use of a small machining centre in the machining system unnecessary. The time needed for drilling and milling etc. following the turning operation is often so short, that reloading work onto a machining centre is uneconomical. Machining in more than one set-up generally results a greater loss in accuracy accuracy relative to complete machining in a single set-up. What's more, the workpieces requiring secondary operations can be difficult to be fixtured onto a machining centre, which means a large effort in jig design and higher system investment. [203].

A investigation of various users of secondary operation CNC turning centres showed that all claimed 'the machines' main benefit lies in the ability to produce work completely at one set-up, to give short delivery times, reduced work in progress, improved work accuracy, and to avoid the need for multi-stage, first-off inspection.'. [222, 300, 92].

In this chapter the secondary operation applications, the incorporating of secondary operation capability into CNC turning centre design, and the storage and exchange of live tooling are discussed.

4.2 TYPICAL SECONDARY OPERATIONS

The accommodation of live tooling in the tool turret has offered secondary operation capabilities covering cross milling, drilling, tapping, pitch circle diameter drilling and keyway slotting applications, fig 4.1. Angled live tool heads perform operations such as cross drilling and milling at angles other than 90 to the centre line [146, 147, 148, 210].

Churchill Two Series has a unique feature of Rear End machining. It consists of six-station secondary operation turret, behind the head stock, the rotary part-off arm, and turret mounted chuck which can operate in synchronisation with the main spindle for support when parting-off. The turret mounted chuck incorporated with the secondary operation turret can carry out operations on the parted-off end/chucking end and eliminate the second set-up, when such machining operations are required. [172].

Secondary operations can be classified into the following types: [203, 210, 92, 301].

(1). Drilling, tapping: Drilled and tapped holes can be made parallel to X or Z axis. Operations obliquely to the two main axes can be done by either a angled live tool or by adding an extra indexing control to the tool turret. (Fig. 4.2).

(2). Milling with end-milling cutter: Grooves can be cut parallel to the X-axis, on faces, and outside the X-Z plane. (Fig. 4.2). [218].

(3). Milling with saw blades or side milling cutters. Slots can be cut either by straight slotting or plunge milling using saw blades. By clamping two saw blades in tandem, particular economy can be achieved.

(4). Pick-up spindle for machining of the parting-off side. Pick up spindles can either be mounted in the turret like a live tool holder, and being driven like a rotating tool; or special tailstock can be equipped with a sub-spindle chuck. (Fig. 4.3). [219].

(5). Synchronous drive for thread milling and polygon turning. Due to the precise synchronisation of the workpiece and the live tool, it is possible to produce flats on the workpieces. When very small threads are being machined, the maximum contouring speed limits the spindle rotational speed. As a result, the workpiece cutting speed is often to low to chase a clean thread with the usual undercut against a shoulder. With the synchronisation of the spindle and thread miller, it is possible to achieve the resultant optimum cutting speed.

4.3 TURNING CENTRE DESIGN AND LIVE TOOLING DRIVE MECHANISM

The CNC turning centre for second operation must be especially designed to suit the unique requirements demanded by live tools. An additional control - C-axis control must be put for the spindle position control. In some cases a control axis for turret indexing must be added to carry out secondary operations at a angle other than 90 to the centre line [154, 175, 177, 178].

The position control of the spindle can either be achieved by an indexing gear and peg at the rear end of the spindle, or by means of a third servo system (C-axis). [19, 286].

High pressure, high capacity coolant pumps are required. There are two types of live tool driving systems available: With tool shanks of big diameters (Normally >= 40 mm),the driving force for rotating tools can pass through the shank without the stability of the tool holder being affected. When thinner tool shanks are adopted, or when high rotating power is required, external driving motors are usually added to the tool turret. The external driving type has the advantage of that the shank of the holder is not weakened and permits a considerably greater torque transimmision. [203].

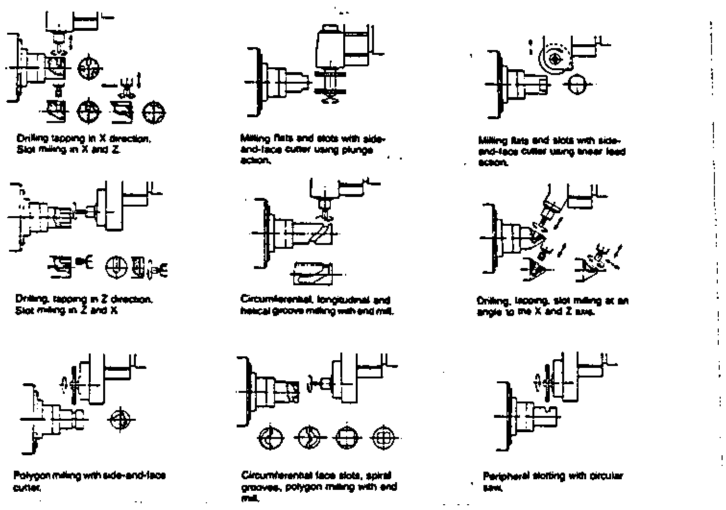
When high cutting torque are required for secondary operations, a tool driving motor is often equipped to the turret. e.g 7.5 KW tool driving motor has been installed on the turret of Churchill Three Series CNC turning centre. (Fig. 4.4). [173].

A typical live tool driving mechanism through the main power supply system is shown in Fig. 4.5. [157, 159].

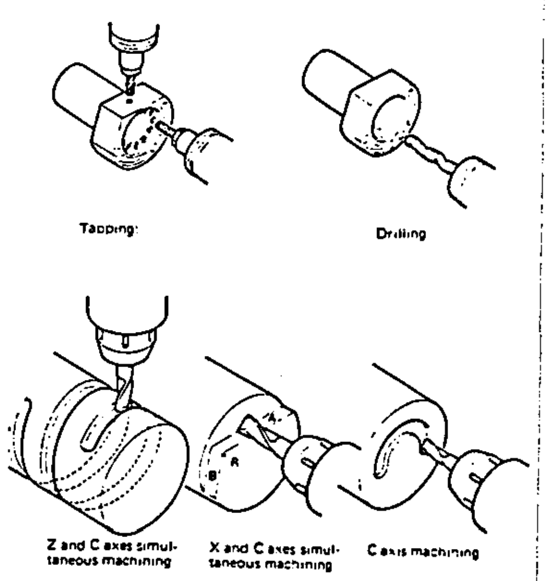
4.4 LIVE TOOLING EXCHANGING AND TOOL FLOW

Live tool exchanging to the tool turret can either be operated manually or automatically. But the problem has been made much more complicated than that of CNC lathes for normal turning operations. Live tooling will normally be allocated in a number of specified positions of a turret. Some special designed live tools can not be handled in the same way as for normal tools.

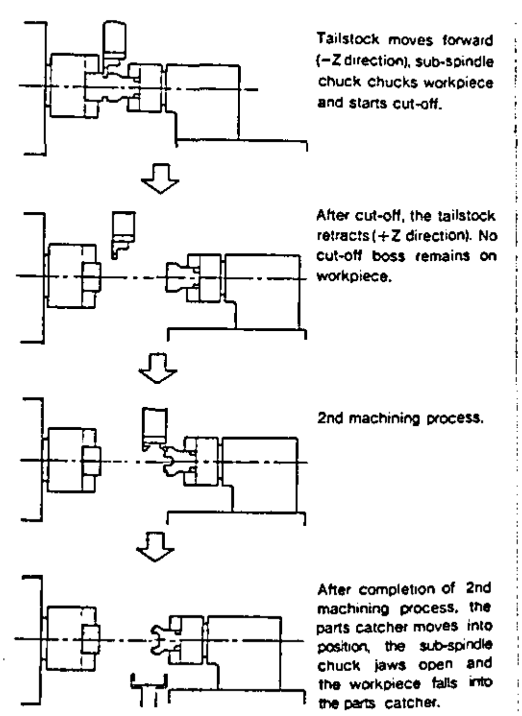
Special efforts have been taken to handle live tools automatically. To facilitate secondary operation, Sandvik has offered disc type tool magazines to store BTS rotating tools. The disc is randomly accessible, and can store live tools and normal turning cutters in any mix of varieties. The magazine is a compact unit which can be easily integrated into most CNC turning machines. (Fig. 4.6). Tool handling system and a typical exchanging operation process are shown Fig. 4.7 and Fig. 4.8. [190, 191]. Chain type magazines have been widely used for storing live tooling and turning tools in any mix [18, 199, 201, 202, 215, 315].



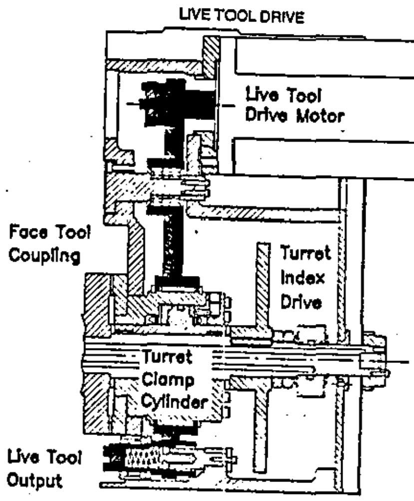
[Ref. 173] | Fig. 4.1 Typical Secondary Operations | LUT – FMS Research Group



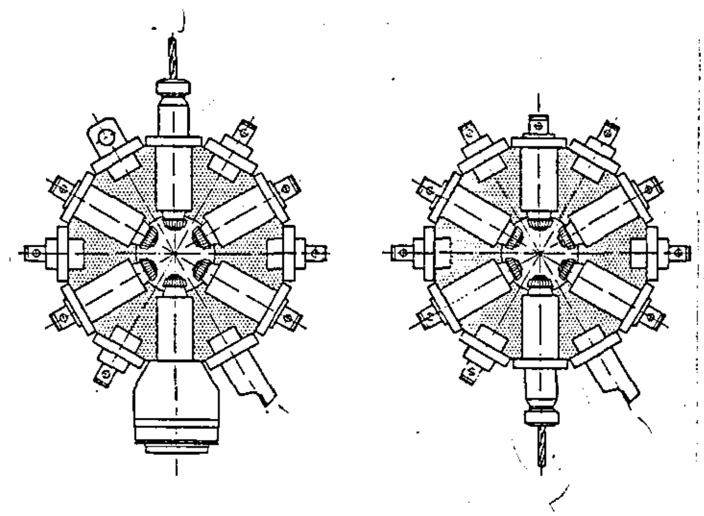
[Ref. 118] | Fig. 4.2 Secondary Operations | LUT–FMS RESEARCH GROUP



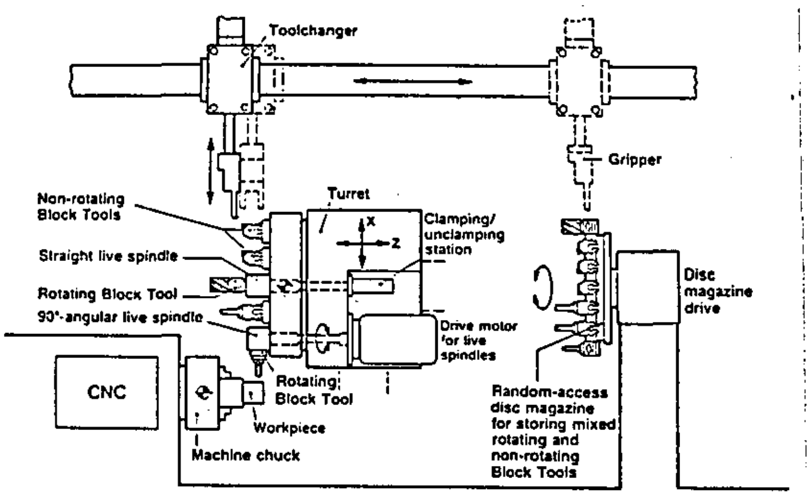
[Ref. 119] | Fig. 4.3 Tailstock Mounted Pick up Spindle | LUT–FMS RESEARCH GROUP



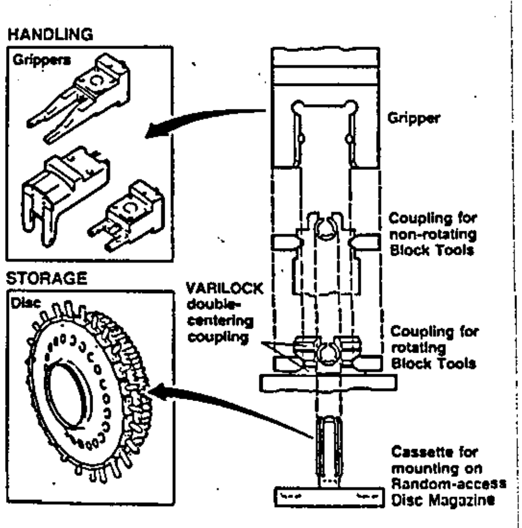
[Ref. 173]	Fig. 4.4 Live Tooling Driving System	LUT–FMS RESEARCH GROUP



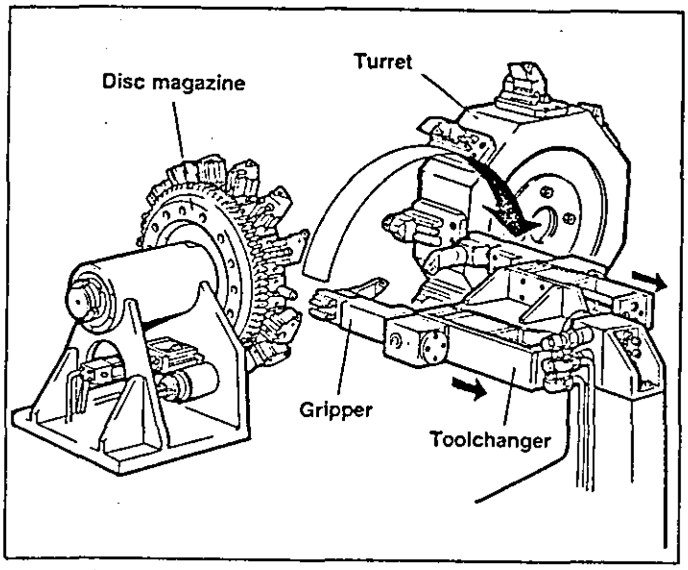
[Ref. 158]	Fig. 4.5 Live Tooling Arrangement in the Turret	LUT – FMS Research Group



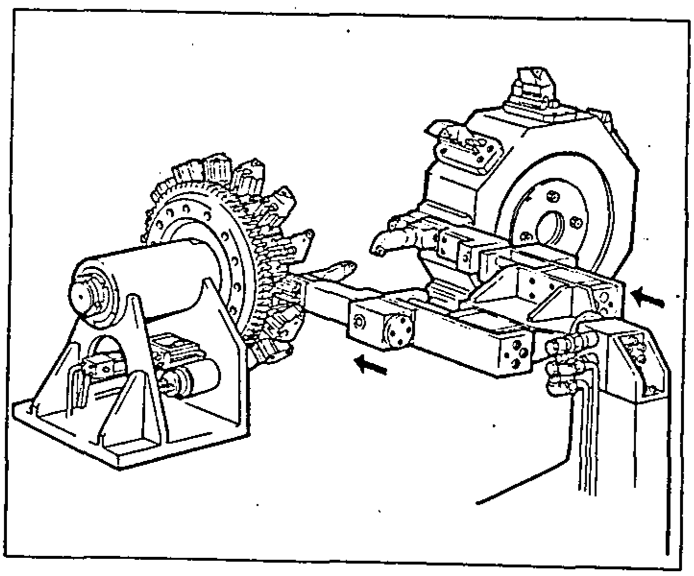
[Ref. 191]	Fig. 4.6 Advanced Integrated Tooling Concept	LUT – FMS Research Group



[Ref. 191]	Fig. 4.7 Handling System for Live & Conventional Tools	LUT–FMS RESEARCH GROUP



Toolchanger removes tool from disc magazine and turret and rotates through 180°.



Simultaneously replacing new tool in turret and used tool in disc magazine.

[Ref. 190]	Fig. 4.8 Tool Exchange Sequence – An Example	LUT–FMS RESEARCH GROUP

CHAPTER 5 TOOLING SYSTEMS FOR FLEXIBLE TURNING SYSTEMS - 'STATE OF THE ART'

5.1 INTRODUCTION

Significant progress has been made in the areas of cutting tool design, and the flow, storage and provision of cutting tools. New tool materials and tool design features have permitted higher cutting speeds. Modular tool concepts have enhanced tool standardisation and tool availability. Tool magazines have been integrated within CNC lathe designs. Automatic tool exchange between the magazine and the turret has reduced machine idle time and eliminated manual involvement.

Central tool store functionality has allowed for total system tool flow management and provided a quick response to the production requirement. Advanced tool presetting devices and tool coding systems have removed tool preparation from the machining area, and facilitated the information flow in the manufacturing system for automated tool flow management.

In this chapter, new tooling design technologies with respect to modular tool concept have been discussed. Discussions on tool exchanging systems and central tool store functions have been presented.

5.2 MODULAR TOOL DESIGN

The development of flexible turning systems requires tooling systems of high flexibility to respond to complicated machining conditions. Considerations should be given to the tool with regards to strength and accuracy. Their constructions should be highly reliable so that they will have durability under various conditions. In addition to the cutting tool material development and indexable inserts, modular tooling system is another important feature of cutting tool design and implementation for FMSs. [233].

The use of modular tooling systems has increased the storage capacity of magazines and the availability of tools. It enhances the standardisation of tooling system design, and facilitates the central tool store tool component storage and assembly.

5.2.1 Sandvik - Block Tooling System

Block Tool System (BTS) is a result of a long period of development of Sandvik Coromant. The project started in 1975 and the BTS was first shown in 1980. Since then it has been developed to cover various turning tool requirements (Fig. 5.1) and helps turn a modern lathe into an unmanned turning centre. [188].

BTS features high stability, repeatability, and easy for clamping. With its high repetitive accuracy of coupling, measuring cut can be eliminated in most of the turning operations. [59].By implementing BTS to a CNC lathe, automatic tool exchange can be carried quickly and easily with high reliability. The BTS tool dimensions are basically corresponding to conventional tool holders. The extensive range of cutting and clamping units is complemented by a whole set up of tool magazines, grippers, probes, and tool monitors. Fig. 5.2 shows how the BTS can be integrated into a CNC lathe installation. [187, 188].

The rotating magazine holder provides tool storage capacities from 60 to 240 cutting units (Fig. 5.3). Each rack holds up to 10 cutting units of same type and can only be accessed from the top of a rack. [189].

BTS features a unique coupling and clamping unit. The turret tool clamping can have an option of being manually, semi- automatically, and automatically operated. The manual clamping device (Fig. 5.4) is designed for easy operation. It requires short clamping stroke and low tightening torque.The automatically clamping units (Fig. 5.5) are compact and reliable, with the drawbar spring produces a positive clamping force, even if the machine power fails. The release of cutting units is done by actuating a piston through a independent closed circuit of hydraulic system. [188].

BTS also offers a disc type random access tool magazine design for rotating tools to be stored mixed with normal turning units.

5.2.2 Hertel - Flexible Tooling System

The Hertel Flexible Tooling System (FTS) offers a great variety of cutting tools including live tooling (Fig. 5.6). It has a unique feature of being used on machining centres as well as on turning systems. [154, 156].

FTS is based on Hirth coupling which gives both a high level of accuracy and excellent torque transmission (Fig. 5.7). The clamping/releasing of cutting heads is carried out by a drawbar actuating the collet. This design features high safety and is easy to be automated. The automatic tool change is achieved by a torque motor which takes the hydraulic supply from the machine tool main power system. [58].

The FTS is easy to be integrated into a CNC lathe installation (Fig. 5.8). Hertel produces standard drum type magazine of 60 and 120 tool pockets. A twin shuttle type magazine of 120 tool positions (2 * 60-station magazines) is also available which allows one magazine to be serviced for the next part family while the other one is being used for present processing. FTS magazine is fully random accessible, offering a greater flexibility. [58, 155].

5.2.3 Krupp Widia - Widax Multiflex and Rotaflex Tool System

Multiflex and Rotaflex tool system were developed to permit manual or, fully automatic tool changing. The whole system automation components includes cutting heads and tool holders; tool locking mechanism; tool exchange gripper and magazine; tool gauging and monitoring facilities; and workpiece gauging system.The Multiflex tool system was designed for turning tools and Rotaflex was designed for live tooling and tools for machining centres.

The tool locking is actuated by a hydraulic motor through the drawbar. The center-piece of the Widax tool system is its coupling mechanism. It features a cylindrical shank with a plane contact surface, which can be manufactured simply and accurately. The connection between the cutting head and the holder guarantees a positive engagement which results a high accuracy and rigidity (Fig. 5.9).

Automatic tool exchange between tool turret and magazines is carried out by a exchange gripper (Fig. 5.10). Tool magazines have capacities generally between 24 to 120 positions. Live tools have been included as well as internal and external turning tools. [137, 166, 284, 167].

4.2.4 Kennametal - KV Tooling System

KV tooling system features a stub-length, tapered shank, which is compact and rigid. It can be used with a wide variety of turning tools (Fig. 5.11). The self-centring characteristics of the tapered shanks make it easy for tool changing. Through-the- tool coolant is provided on all KV turning tools. KV tooling system has a variety of locking system designs to suit the requirements of different automation levels.

There are two clamping system designs for automatic tool change, viz. Ball Lock Turret Unit Assembly (TUA) and VDI Clamping Units (Fig. 5.12). For the TUA, clamping force is generated by the spring washers, releasing is activated by a hydraulic cylinder pushing the drawbar. In the VDI Clamping Units, locking/unlocking is done by rotating the torque nut with a hydraulic or electrically operated torque motor. The automatic clamping units will generate a positive clamping force even though the main machine power fails. [165].

KV tooling system is designed to remove the tool gauging and set-up to the central tool store, thus to reduce the machine idle time due to the tool changing and set-up.

5.3 TOOL EXCHANGING SYSTEMS

Tool turrets have been used as the basic tool handling device through out the history of the NC lathe. With the development of automation technology and the CNC lathe itself, the Automatic Tool Changing (ATC) into the tool turret is introduced to expand the machine based tool storage capacity for the following reasons:

(1). Worn tool replacement. Tool life of a turning tool is quite short, a large number of tools are required to carried out a longer period unmanned operation;

(2). Tool exchange due the changing of part type;

(3). Secondary operation on a CNC turning centre features a big variety of live tools required. A tool magazine is necessary for handling drilling, milling, tapping, and end milling tools. [182, 142, 18, 315].

In some installations turrets are automatically changed as whole stores. The workpiece loading gantry accommodates the carriage used for changing the turret. This tool changing method provided considerably shorter changing times per tool than the individual tool exchange.

TI Machine Tools has developed a turning centre around its Churchill HC 4/15. The Block Tooling System has been adopted. The magazine can store up to 120 tools. tools requiring critical dimensions can be datumed using Renishaw touch trigger probes mounted on the headstock. tool change can be automatically initiated from a signal derived by monitoring component count, tool cut time, or main motor power consumption. Two in-process probes are used for component measuring. (Fig. 5.13). [174, 187].

INDEX GSC 65 Twin turrets CNC turning centre has been installed with two gantry type robots. One is dedicated for automatic workpiece handling, the other one is for automatic tool changing. The unique feature of the system is that two tool magazines have been equipped to back up the tool turrets. (Fig. 5.14). [158, 159].

Yamazaki has designed chain type magazines for its Slant Turn 40N ATC. The standard 30-tool magazine has 15 pockets for turning tools and other 15 for live tools, however, any combination of the arrangement would be possible. (Fig. 5.15). Optional magazines of 60, 80 tools are also available to facilitate a even bigger tool storage capacity. (Fig. 5.16). [215].

The magazine support to tool turret is becoming a common feature of turning centre design by different manufacturers: e.g the Traub machines which feature chain type tool magazines for live tooling and turning tools alike [202, 92, 301]; SMT [18, 315], HEID [153, 26], etc. The State-of-the-Art tooling systems for cylindrical part batch manufacturing has been studied by Zhang and Bell [324].

5.4 CENTRAL TOOL STORE FUNCTIONS AND TOOL PRESETTING

The Central Tool Store (CTS) is one of the important area to be considered for automated tool control [108]. A comprehensive CTS management system will enable a machining system to increase productivity, reduce tool inventory costs and machine down time while giving shop floor management the important aid to monitor the activity and relationship of tooling to the actual production of parts.

The key issues associated with CTS are: 1). Inventory control of tool assembly components; 2). Inventory control of tool component assembly instructions; 3). Inventory control of tools; 4). Maintenance of the tool data; 5). Initiation of tool assembly build up; 6). Determining and disposal of the tool assemblies returned from the machines. [101].

The objectives of the control system for tool cribs include the following:

(1). Reduce the machine waiting time for tools;

(2). Prevent tool shortage;

(3). Know the tool location and tooling condition;

(4). Identify obsolete and overstocked tools;

(5). Monitoring. [240].

The tool preparation and servicing is carried out in the CTS. Three tool service priority levels were envisaged by Knight [127].

Level 1: Tools for the next schedule of workpieces or a tool has reached its planned life. This level would have the lowest priority. It is the main function of the CTS.

Level 2: The non-previously advised tool requirements caused by machine failure or change of schedule.

Level 3: Tool preparation for emergency such as tool premature failure. This level will have the highest priority.

A Micro based software system was developed by ISIS Informatics Limited to carry out automatic tool store management. It is centred on a tool data base management system with a variety of interface to ease tool inventory management. It makes the quantity of the tooling and their locations be known. It will also issue instructions to the tool store keeper of what to do with a returned tool. (Fig. 5.17). [163, 164].

Devlieg Microbore has developed a comprehensive central tool store management system. The system is based on a IBM personal computer. It is divided into several main sections:

(1). Tool data sheet which displays graphical representations of tools as well as part lists or assembly sheets. Tools can be created graphically by calling existing components from the data base. Dimensional data will be input. The tool assembly can be broken down into its components to aid the operator in the actual tool assembly;

(2). Set up sheet has been designed to entail all information required to use the tool. It will be sent out with tools to the machine;

(3). Data management allows the access to the data base;

(4). On line mode. The tool management system has the capability to retrieve and send data between the Devlieg tool pre-setting system.

The description of tools, tool components, crib contents, tool numbers and dimensions can be displayed on a CRT screen in the tool crib area. [96, 149].

The tool room of Ferrar Automobili, Italy [57] is the heart of its tool management. The main operations includes:

(1). Tool assembly - A list of tools to be assembled with its assembly components is displayed. The tool assembly file is updated after the completion of each tool assembly. Bar code is written to the tool by a bar coding device.
(2). Tool presetting - Tools to preset and the information about the parameters for presetting are presented. The measured value is automatically received.
(3). Tools returned are inspected, and bar codes are updated following a instruction.

The primary goal of a presetting system within a tool management system is to provide properly set tooling and tooling information to machine tools to promote maximum machine up time.The tool presetting information flow in a manufacturing system can adopt one of the following fashions, viz. integrated tool presetting system and bar coding system, fig. 5.18. The former features a integrated data base which stores the tool information such as tool and cutter code, planned tool life and life consumption, tool off-set, and tool position and status [43]. The preset tool information will be entered into the the data base automatically through the tool presetting terminal and downloaded to the machine CNC controller when the tool enters the machine [201].

The evolution in the field of electronic optics has made the bar coding possible. In compared with the old system of mechanical encoding, bar codes can store a large amount of information in a limited space without having to add mechanical plates to the tool. It also has a high reliability in data recording and easy for reading/writing.

The presetting process includes setting, pre-machine inspection and measurement, tool labelling, and dimension information transmission. The pre-machining inspection controls the quality of the cutting edges of tools, the condition and the quality of the ground surfaces on the shanks or mounting surfaces of the tool. Tool dimension parameters are then set/or measured. Tooling is then labelled with the necessary information and grouped, transported to machines. [96].

A typical tool presetting machine is shown in Fig. 5.19. In most of the cases, tool offset values measured require no further correction in the machine before tools are automatically loaded into the tool turret. [192].

Kennametal tool presetting system is based on a two co-ordinate measuring machine (Fig. 5.20). Tools will be inserted to the adapter, and their images will be displayed on the screen. A micro-computer based controller electronic system ensures rapid and accurate measurement and data processing, with necessary interface. [165].

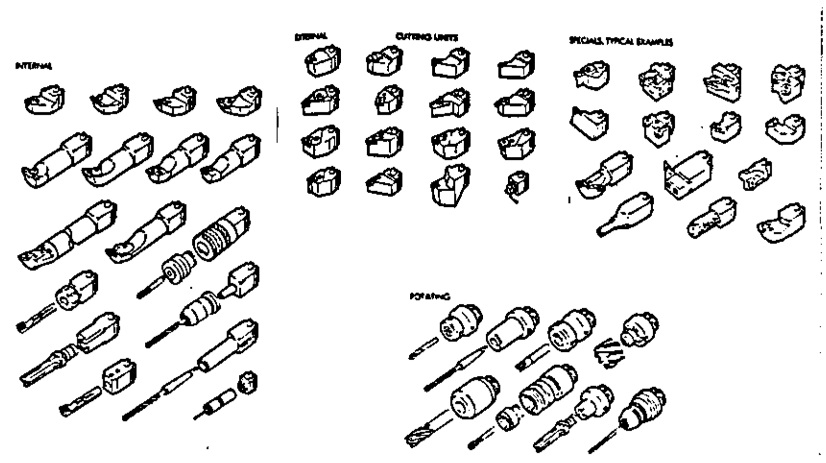
Sandvik Coromant has developed a coding system for BTS cutting units using read/write EEPROM data carrier. (Fig.5.21). The pre- measured tool dimensions and its identification is stored in the magnetic chip. When a tool is called by a machine, its recorded data can be automatically downloaded into the machine CNC unit before tool changing. [192].

5.3 TOOLING SYSTEMS OF MACHINING CENTRES

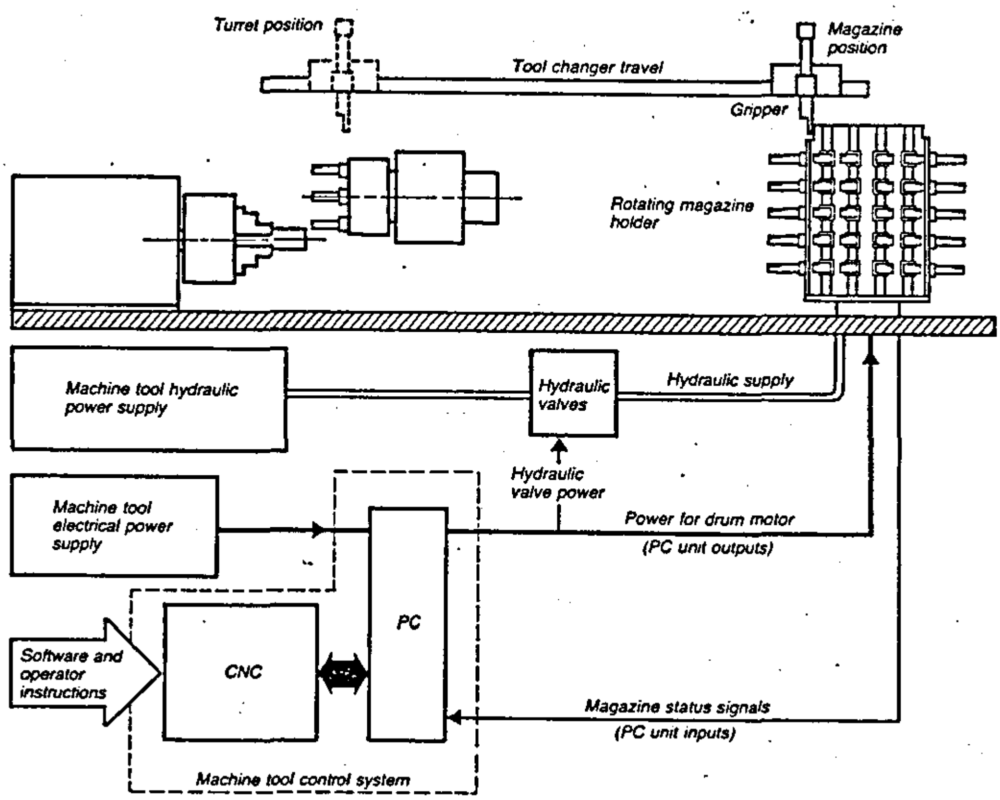
Machining centres have been integrated widely into the highly automated FMS design. Automatic tool changing was one on the first problems to be solved in the machining centre design [17, 144, 168, 287]. The tool flow in a flexible manufacturing system for prismatic parts has been evolved form the expensive hardware solution as in Yamazaki Minakamo which employing a whole drum type magazine exchange [104, 213], to the sophisticated software management solution as in Yamazaki Worcester where a tool exchange highway was built to transfer single tools promptly to destinations [14, 15, 129, 130, 211].

There is a clear trend that a complex intelligent tool management module being integrated into the machine tool controller. Werner's machining centre design allows a set of tools to be exchanged quickly for each job exchange. The chain type magazine has been divided into a variably overlapping storage and changing areas as well as fixed areas for standard and worn tools. Tools are replaced in the respective areas after their use in the spindle. The provision of the respective areas by movement of the magazine takes place parallel to machining time.

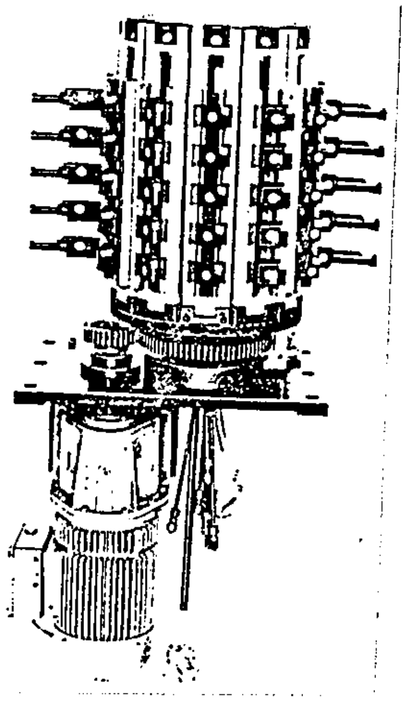
The tool flow to a machining centre of Okuma features a transported magazine on a AGV to supply tools to machine equipped magazine [183].



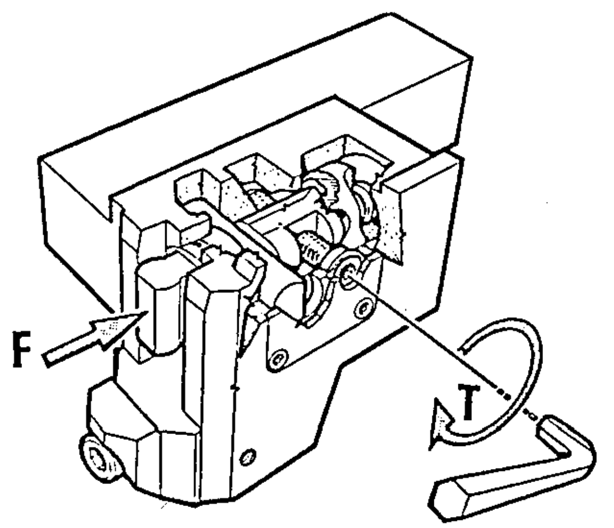
[Ref. 188]	Fig. 5.1 BTS Tool Spectrum	LUT – FMS Research Group



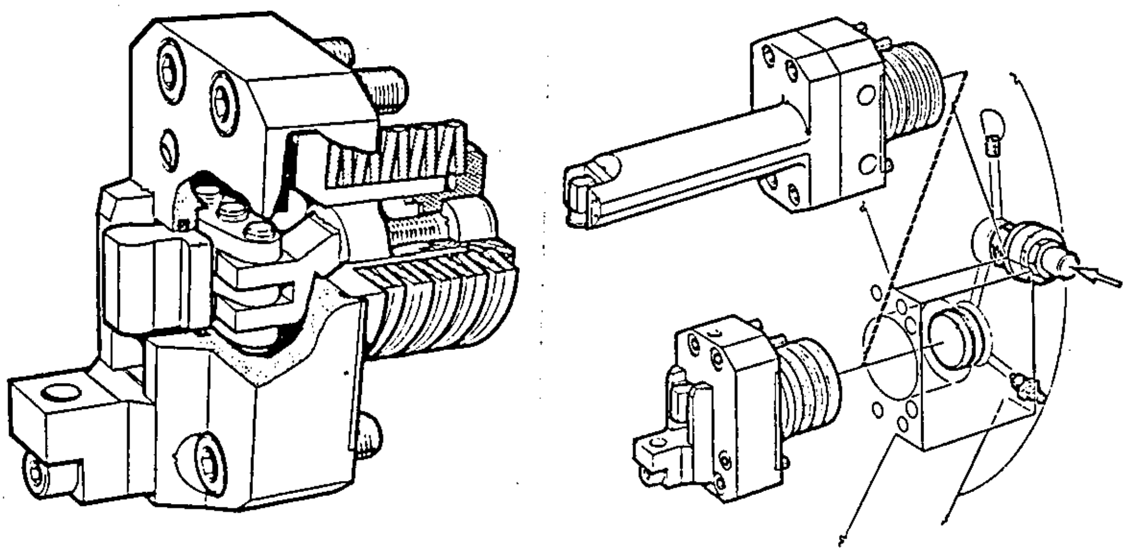
[Ref. 187]	Fig. 5.2 Integration of BTS into CNC Lathe Design	LUT – FMS Research Group



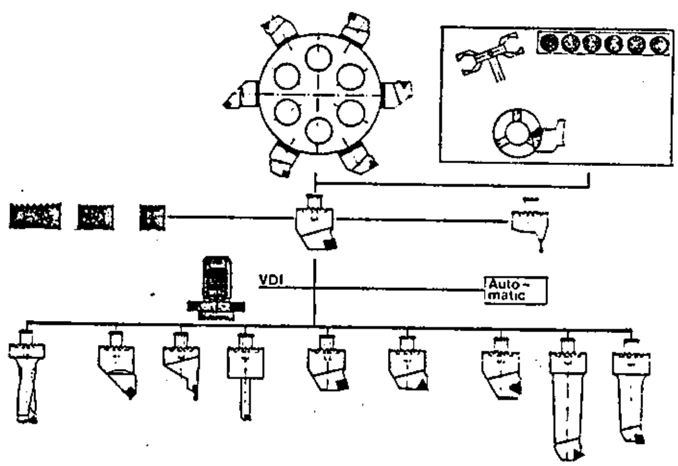
[Ref. 189]	Fig. 5.3 BTS Tool Magazine	LUT–FMS RESEARCH GROUP



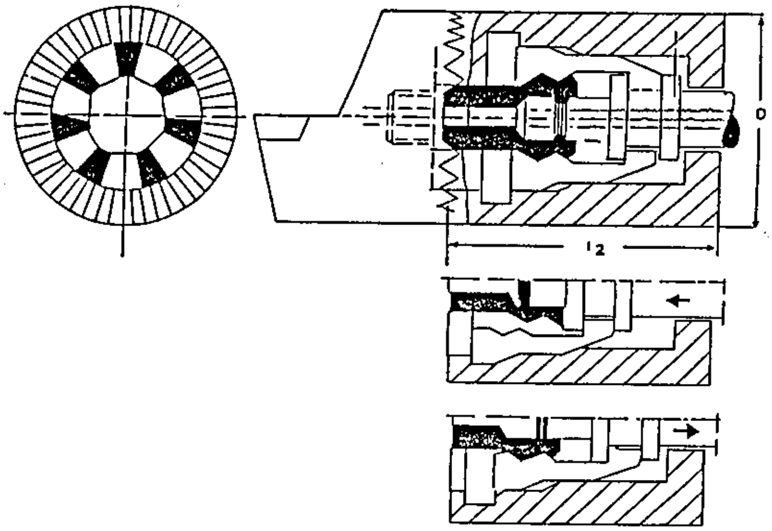
[Ref. 188]	Fig. 5.4 BTS Manual Clamping Unit	LUT – FMS Research Group



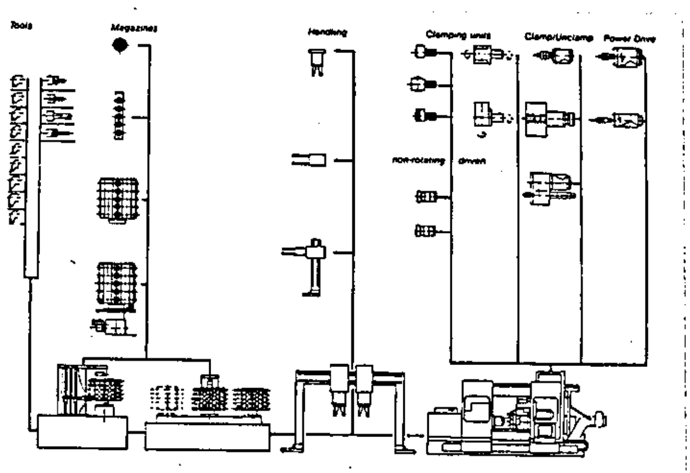
[Ref. 188]	Fig. 5.5 BTS Auto. Clamp & Release Unit	LUT – FMS Research Group



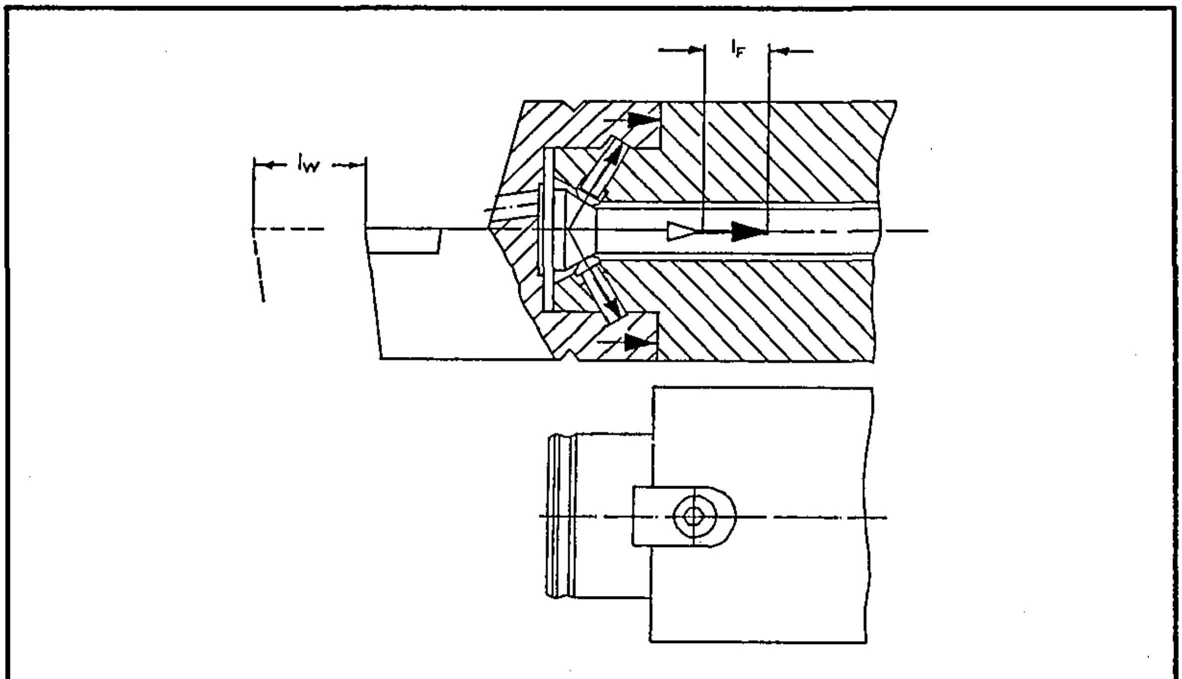
[Ref. 156]	Fig. 5.6 Flexible Tooling System	LUT – FMS Research Group



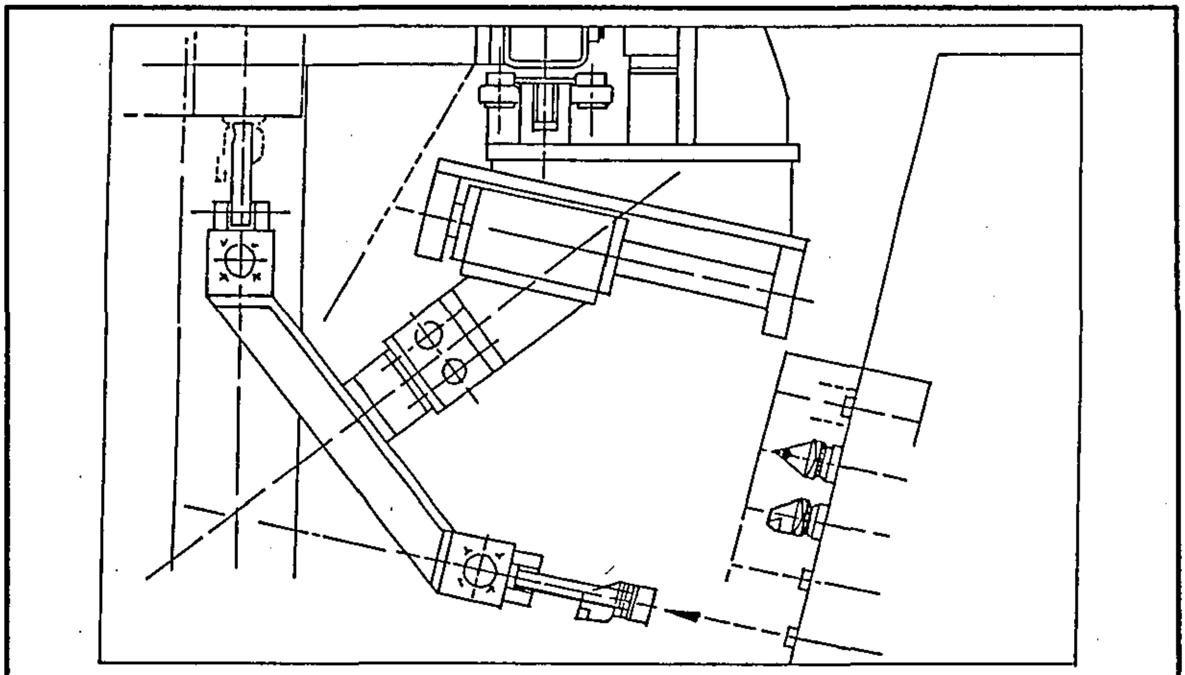
[Ref. 58]	Fig. 5.7 FTS Clamping Mechanism	LUT – FMS Research Group



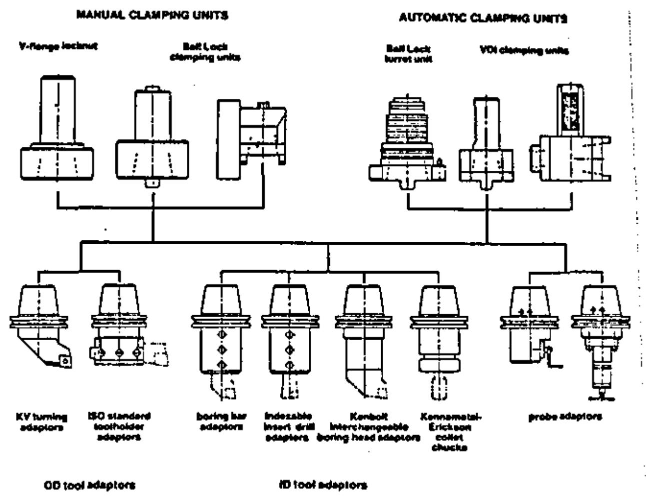
[Ref. 155]	Fig. 5.8 FTS Automation Components	LUT – FMS Research Group



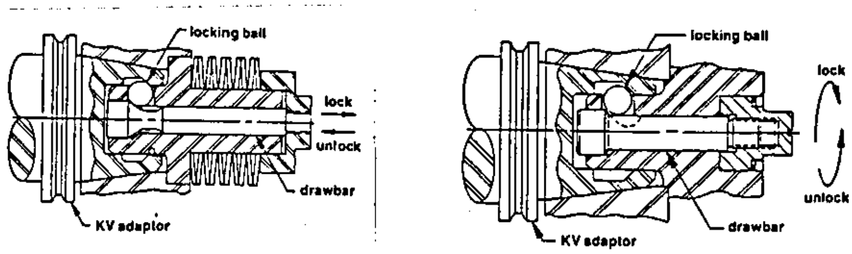
[Ref. 284] | Fig. 5.9 Multiflex Coupling & Locking System | LUT – FMS Research Group



[Ref. 166] | Fig. 5.10 Multiflex Tool Exchanger | LUT – FMS Research Group



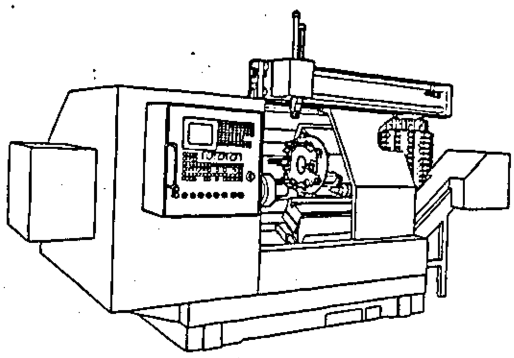
[Ref. 165]	Fig. 5.11 KV Tooling System	LUT – FMS Research Group



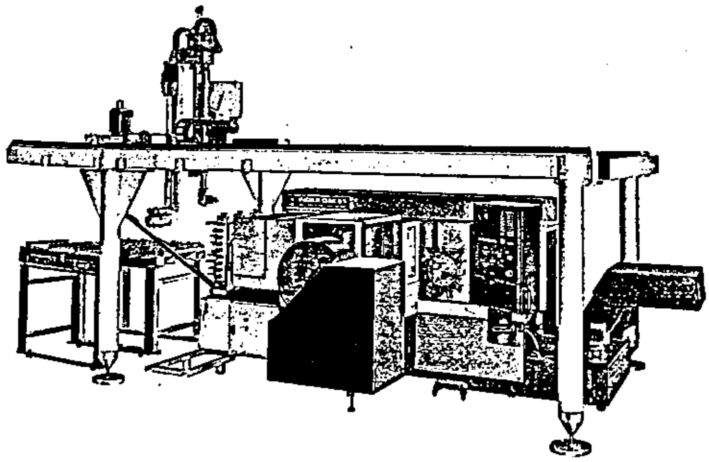
Ball Lock Turret Unit Assembly (TUA)

VDI Clamping Units

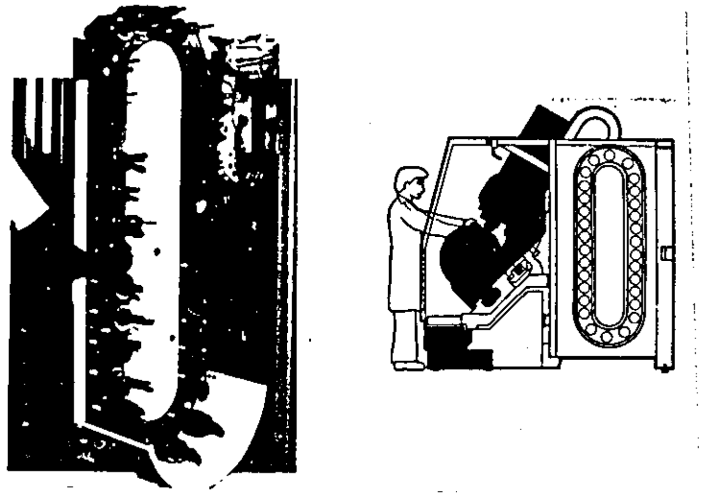
[Ref. 165]	Fig. 5.12 KV Auto. Tool Change System	LUT – FMS Research Group



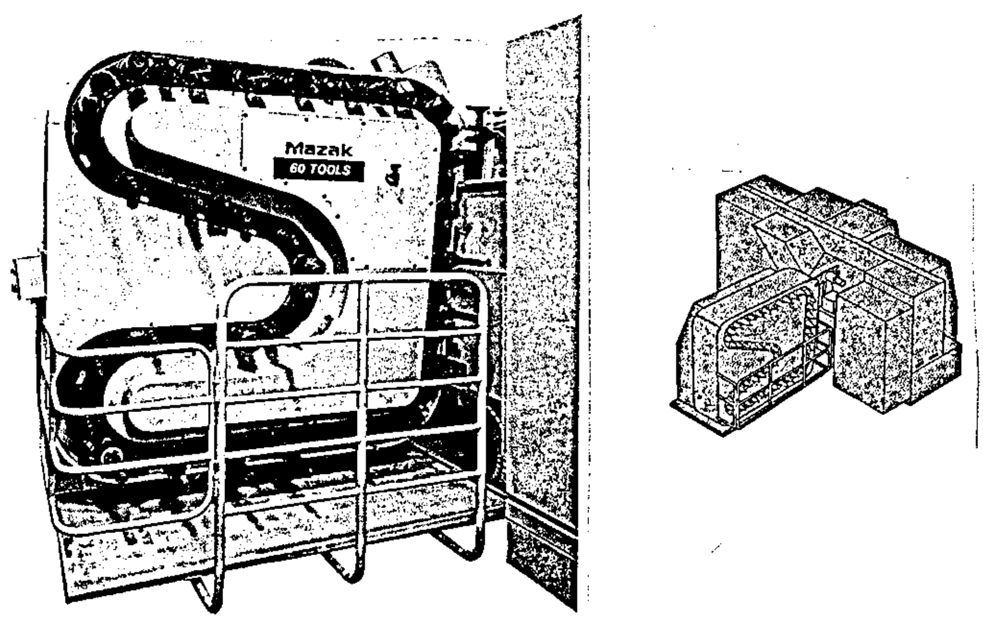
[Ref. 187]	Fig. 5.13 Churchill HC 4/15	LUT – FMS Research Group



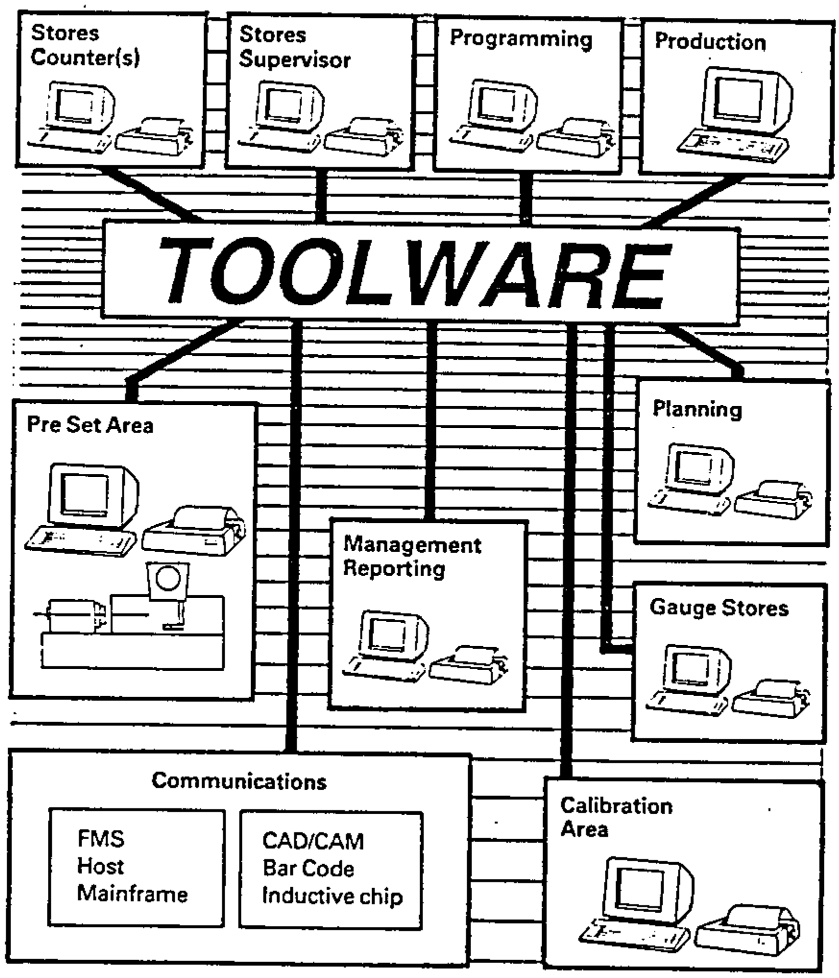
[Ref. 158]	Fig. 5.14 INDEX GSC 65	LUT – FMS Research Group



[Ref. 215]	Fig. 5.15 Slant Turn 30–tool Magazine	LUT – FMS Research Group



[Ref. 215]	Fig. 5.16 Slant Turn 60–tool Magazine	LUT – FMS Research Group



[Ref. 163]	Fig. 5.17 ISIS Tool Inventory Control System	LUT-FMS RESEARCH GROUP

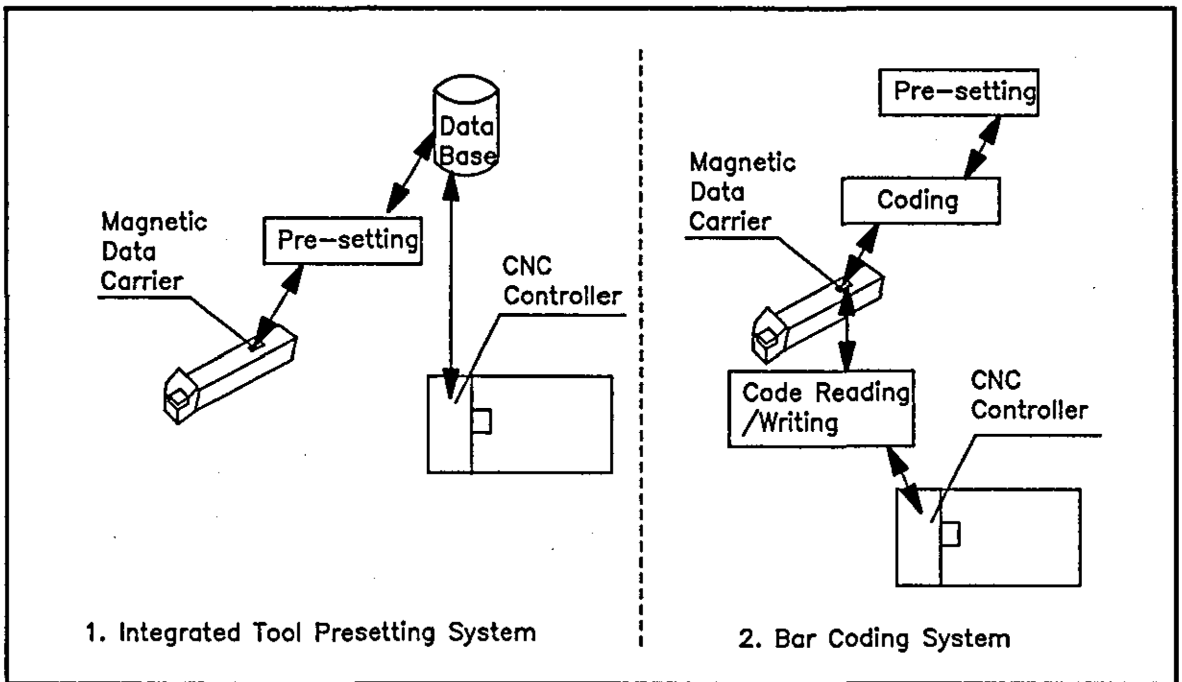
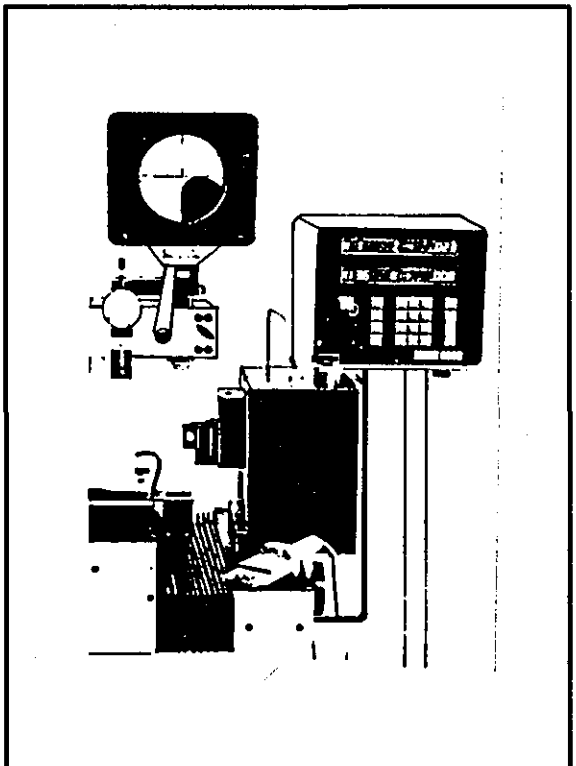
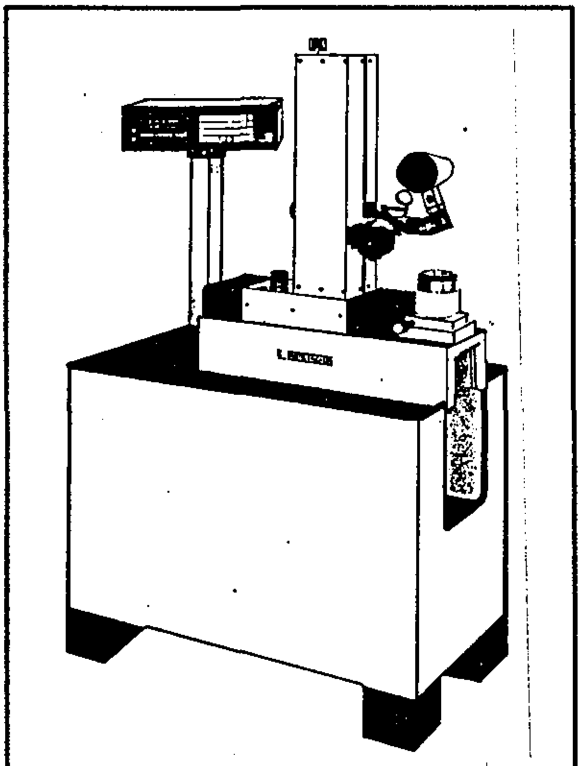


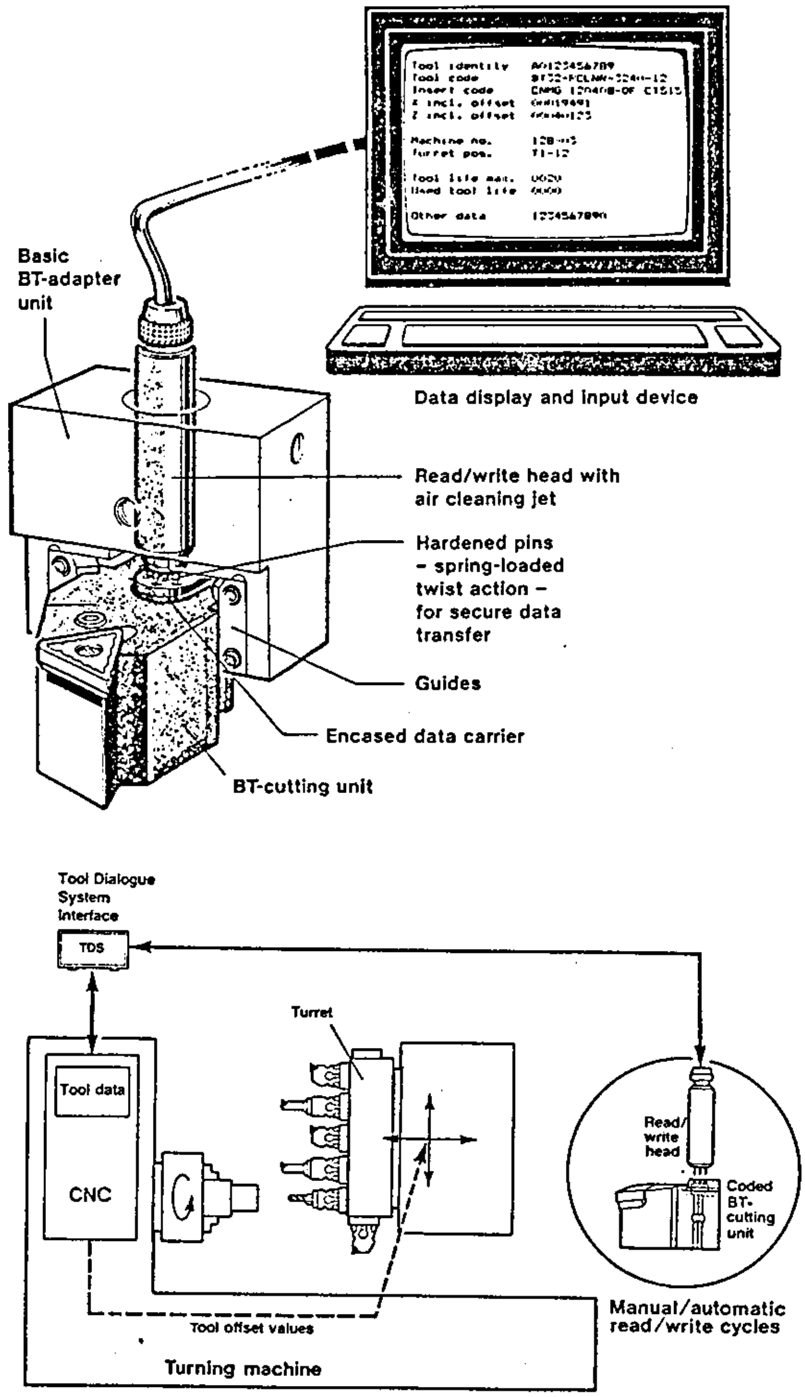
Fig. 5.18
Tool Pre–setting & Data Storage
LUT – FMS Research Group



[Ref. 192] Fig. 5.19
BTS Tool Presetting System
LUT–FMS RESEARCH GROUP



[Ref. 165] Fig. 5.20
KV Tool Presetting System
LUT–FMS RESEARCH GROUP



[Ref. 192]	Fig. 5.21 BTS Tool Coding System	LUT–FMS RESEARCH GROUP

CHAPTER 6 COMPUTER MODELLING APPROACH

6.1 INTRODUCTION

In this chapter, the scope of the research is presented. The reader is introduced to the algorithmic modelling approach to different level of turning automation and the comprehensive model (Turning Model) built. The Turning Model is then compared with the prismatic part tool flow model to highlight the unique feature of cylindrical part manufacturing.

6.2 RESEARCH TASK

The research covers the study and modelling of highly automated batch manufacturing systems for cylindrical components, with emphasis on the tool flow problem. A comprehensive computer model has been built to aid this process. The objective of the model building is such that it should be capable of representing advanced turning systems, evaluating different tool flow system design and operation, and forecasting system performance. The operating pattern of turning systems should be able to be predicted by the Turning Model. This work includes several major subsets of research and software writing as follows:

(1). Turning automation study and computer model (Turning Model) building for highly automated turning systems. The work is targeted at the design and operation of tool flow systems for flexible turning ranging from highly automated turning centres to multi-machine cells with varying design of automation.

(2) Build a framework for fast and effective tool flow system design and evaluation. Design and implement effective algorithms for computer building.

(3). Evaluate alternative tooling strategies for a specified tool flow system and explore the nature of tool flow problem in turning systems.

(4). Incorporate a production scheduling facility so as to provide a sequenced production requirement file for the tool flow model as well as to examine the tool flow problem interactively with the production scheduling algorithms. See the following sections for production scheduling module and refer to Chapter 12 for algorithm descriptions.

(5). Write and implement a data base management system to ease the input and handling of cutting tool, workpiece, and turning centre data for running the model. The principle of design and the implementation of the data base management system has been described in Appendix 1B.

(6). A major feature of the Turning Model is its user friendly interface, so that it can be handled easily with reduced communication effort. The Turning Model is of CNC machine MDI menu driven type. A conversational type screen interface has been developed and implemented for all the modules of the computer model (Ref. to Appendix 1B).

(7). Provide a prototype modelling software suitable for industrial uses.

(8). Algorithmic approach has been implemented for manning pattern prediction, which may be regular or irregular. See Chapter 9 for its implementation.

(9). Case studies based on industrial data have been carried out both for a single machine highly automated turning system (Chapter 9) to examine turning automation features in details, and a multi-machine turning cell to evaluate different design and operating strategies (Chapter 13).

6.3 THE ALGORITHMIC MODELLING APPROACH

The algorithms deal with scheduling and timing of the chain of events and form the basis for the modelling of tool flow systems.

Algorithmic approach has been adopted for model building, which incorporates the following features: Firstly, it requires very short computer running time. A typical CNC turning cell of 5 machines can be modelled of 3 shift work with a run time of average 15 minutes on a enhanced IBM/AT workstation. With the software being implemented on a powerful SUN 386i, the run time is expected to be reduced even further. Thus once the data base has been set-up, a rich number of runs can be carried out to examine different system configuration and operating strategies; Secondly, it is possible to focus on the detailed modelling on particular activities; Thirdly, the time related system operating pattern can be obtained with reasonable confidence.

The Turning Model writing has been emphasised on tool allocation and flow. The modelling work has concentrated on the following aspects: the forecasting of tool requirements and warning of tool exchanging; reducing delay due to tool unavailability and improving reliability of tool information; reducing tool exchange effort and tool inventory level through a well organised tool flow control. (Fig. 6.1).

The Tool Flow Model which is the main stream model of the Turning Model set will give a substantial understanding and solutions to the tool flow problem - not only to the technological ones of how to store, transport, and handle tools, [41, 101, 122, 245], but also to analytical and managerial problemssuch as when and where the tools will be required, and how to best organise the tool flow [96, 149, 240, 163, 164].

Different tool arrangements [71, 72, 73], assignments [41, 101, 126], and storage strategies [126, 280, 290] have been implemented in the Tool Flow Model (Ref. to Chapter 8).

Further algorithms have been developed for scheduling the event chain of machining, part and tool transportation and exchanging, and the manning involvement for turning system operating. For the formulation of algorithms, several different kinds of activities and their associated time intervals should be specified: the set- up, part loading/unloading between spindle and part pallet/magazine, tool exchanging time between turret and magazine, magazine and turret index time, chuck jaw and gripper exchange time, tool and part exchange time to and from a machine. Some of the above activities can be carried out while the machine is in processing, e.g. tool picking up from the magazine and transferring to the waiting position for tool exchanging with turret, and tool returning from turret to be replaced to magazine. Some of the activities should be done when machine is not in operation, e.g. set-up, part loading/unloading to/from spindle, chuck jaw changing, and tool turret indexing. Some of the activities may be carried out either when the machine is in operating or is being set-up according to the system design, e.g. tool magazine set-up or change over, pallet exchange or part magazine set-up.

The model will not tackle the detailed part palletization, storage, etc., inside the turning cell. [42, 229, 244]. The workpiece flow in the turning system modelled will be relegated to the processing according to a scheduled work-list.

The Turning Model will not be constrained to a particular installations [280, 290, 289, 291, 320]. It is based on the generalised tool flow network (Ref. to Chapter 7). The algorithms permit rapid configuration and reconfiguration of a selected level of tool flow automation.

The use of this algorithmic approach provides a powerful tool to design, control and operating tooling systems in a particular manner. General purpose discrete event simulation and analytical models have not been used as the large body of data concerning tooling and tool flow activities are required to be recorded, manipulated and output. The model works on definite time related data other than the normal statistical based outputs obtained form simulation. This approach, unlike simulation, is not strictly time synchronised based on next event or minimum time incremental. Instead, the time increment is determined by major activities when a individual machine is due to be interactive with cell level work and tool flow. Back trace timing algorithms have been used to get the time related outputs. This simplified approach allows the user to focus on particular areas of concern, as well as provides time related outputs with respect to work and tool flow, manning requirement patterns which can be employed for predicting purpose. Once subject to interpretation combined with user's experience, the time related outputs can act as the base for adjusting work flow and manning schedule so as to achieve certain pattern.

Detailed emulation [229] of the whole machining system was not chosen, which reduces the complexity of the model but calls for the manipulation of large body of data with specific concern at high speed, and simplifies the model set-up requirement put to a user. However, a detailed emulation model of part and tool flow is under development by a parallel research project which is a subject of a complement thesis [223]. The output of which is expected to be able to examine the nature of dual flow, and to fine tune tool and part flow interactively in a complicated system. The Turning Model should represent the turning automation as having been reviewed in the previous chapters in details and can be used to examine the unique features of tool flow incorporating turning tools and live tooling for cylindrical component manufacture.

The primary objective of the algorithmic approach is to generate tooling requirements by scheduling and sequencing the activities of machining and transportation and exchange of parts and tools efficiently and economically according to specified decision rules and strategies in order to evaluate the relative merits of these particular operating strategies or to evaluate alternative tool flow network designs.

6.4 TURNING MODEL OVERVIEW

An overview of the model configuration is shown in Fig. 6.2. The configuration consists of a number of modules embedded within the user interface viz. the data input module, the work flow scheduler and a output module. these modules provide inputs necessary to drive the modelling algorithms which were discussed previously. A data collection facility retrieves the outputs from the modelling and organises the results into categories in a way which is meaningful and easy to interpret.

6.4.1 The User Interface

The user interface is based a on menu driven conversational structure which is closely related to the operation of a tool flow network for a specified level of automation. The interface is based on a software design now commonly found in machine controllers which employ automatic programming functions. The essence of this conversational language is the ability to prompt and assist the user by leading him through the required steps by asking the questions in the correct sequence and indicating the correct key to press. The user is asked to specify the manufacturing system parameters to describe the configuration, the machines, the transporters, the tool stores and the tool handling system. The user input is supported by an interactive database which contains information on machines, tools, parts, and configurations. This data base allows the user to retrieve or query data within the data files or alternatively, to input the data interactively through the user interface. As will be discussed in the next section, part flow will be scheduled according to heuristic priority dispatching rules which can be selected in the input process, or a pre-scheduled work-to-list will be accepted.

Considerable detail involving complex relationships between the system elements has been built into the tool flow model through the use of rules and strategies. The intention of this detail is to reproduce as accurately as possible, the real operating tasks to be performed within the turning system, see Chapter 8, 10, 11.

The model has the ability to record considerable amounts of user specific data on the operation of turning systems, tool and tool flow systems. Once subjected to a comprehensive analysis, those outputs can be employed to improve the overall tool flow system performance. The model can be subjected to a multi-run, thus a particular tool flow system can be modelled for several periods, and a comprehensive tool inventory and requirement can be interrogated to permit the determination of the tool handling capacities.

The model essentially tests out the acceptability of lathe solutions and offers a facility for the tuning the system performance. By varying emphasis on the rules and strategies the model could be forced to behave in a particular manner so as to allow the user to improve or design the overall performance and operation subject to his own experience. The results obtained from the model, see Fig. 6.3, typically include tool transfer schedules, through times, tooling requirement, tool life analysis, transient capacities, tool exchange forecasts, manning patterns, and finally the utilisations. The model is implemented on a state-of-the-art SUN 386i workstation which offers the very latest in 'multi-window' technology. This not only permits several models to be run simultaneously, but also allows the user to view and edit inputs and outputs side by side. This computing facility enhances computing power significantly and permits a large number of data entities to be considered.

6.4.2 Production Scheduling Module

Some basic loading and scheduling functions complement the tool management package to provide a balanced prototype modelling facility.

Part flow can be introduced either by inputting a pre-scheduled work-to-list, or through the built-in production schduling rules. The former requires a work-to-list to be specified in sequence in the input process. Besides the possibility of acceptting a user specified schedule, it offers the flexibility to be linked to other production schedulers, e.g the EMULATOR [229] of the parallel research project.

When chosen to use the built in production scheduler, the specified production requirement is assigned to individual machines through the workload assignment module followed by either External or Internal scheduling algorithms according to the user specification, viz.

a). External algorithms: schedule parts according to order and part characteristics, e.g Earliest Due Date (EDD), Shortest Processing Time (SPT), [35, 69, 78], etc.

b). Internal algorithms: schedule parts according to tool requirements and tool exchange effort [280, 289, 290, 291, 320].

A Computer Assisted ClusterAnalysis (CACA) module has been developed in the group by DeSouza[77] which can supply a short range schedule to the Turning Model. The CACA module analyses the operations of each machine in a group to find tool families of parts which can be machined one after the other using the same tooling. Operation of such a manufacturing system is designed according to the concept of tool family scheduling. This strategy provides each machine with the flexibility to produce any individual part that is included in the tool cluster set. The tooling configuration of any primary tool store is thus managed on the basis of cluster sets rather than individual tools.

6.5 COMPARISON OF THE TURNING MODEL WITH TOOL FLOW MODEL FOR PRISMATIC PARTS

A comprehensive tool flow model has been built in the research group by De Souza, which is the subject of a complementary thesis [77]. This section is to give a brief comparison of the Turning Model with the prismatic tool flow model. Attention is focused on two areas: different features of the flexible machining systems for prismatic parts and for cylindrical parts; and the different areas that the two models tackled.

Processing of prismatic parts features long operation time, longer tool life, and very small batch size. A machining centre is not so complicated as a highly automated turning centre with respect to tool and part flow. But the integration of machining centres into cells and multi-cell installations is highly advanced.

The fixture flow, part palletization, and the storage of palletised parts in the cell level and machining centre buffer level requires careful modelling. Whereas for cylindrical parts, a number of items can be stored in a pallet and a number of pallets can be stacked beside a turning centre.

Most cylindrical components feature relatively shorter cycle times. It is more common to see batches of large size (up to 50 or even more). Turning systems usually operate on supervised mode but not fully automated. Single turning centres have been highly automated, and equipped with automatic part loading/unloading robots [181, 195, 230, 286], Automatic chuck Jaw Changing (AJC) [182, 215] and gripper exchanging, and Automatic Tool Changing (ATC). (Ref. to Chapter 3, 4). Power driven mechanism and C-axis has been added to give a CNC lathe secondary operation capability which eliminates the requirement of second operation set-up. Tool flow problem is more complicated with the introduction of live tooling (Ref. to Chapter 5).

The turning tool life is commonly monitored on the basis of engagement time, or number of cuts [30, 291, 230]. Tool lives are shorter, the tool exchange cycle time is relatively longer compared with machining centres, which increases the part cycle time. Tool magazines can be of very big size [58, 189, 155] to fulfill the tool requirement for long period of unmanned operation. Thus an even larger body of data entities are required to be handled by the Turning Model in terms of tool inventory, and operation spectrum for a modèlling period of the same length.

These unique features, each of which is a subject of algorithmic representation, have been incorporated into the model design (see Chapter 8).

With regard to the model structure, the following differences can be drawn: The Turning Model has incorporated a production scheduling facility to provide a balanced design aid. It is planned that the scheduling module can be employed to provide scheduled work lists for the tool flow model for prismatic parts.

The Computer Aided Cluster Analysis (CACA) module for tool and part clustering has been developed as part of prismatic tool flow model. It can also provide a short range schedule for the Turning Model.

Algorithms for manning pattern prediction have been incorporated in the Turning Model, since the manually supported turning cells are widely used.

The prismatic tool flow model is not so centred on individual machines as the Turning Model is. Instead a multi-cell structure is adopted, which can incorporate the Turning Model for hybrid facility modelling, see next next section.

6.5 MODELLING OF HYBRID FACILITIES

The Turning Model can be incorporated into the tool flow models for prismatic parts manufacture [77] to model a mix of facilities where machining centres and turning centres are present in hybrid cells or a cylindrical part cell is in parallel with a prismatic part cell. In such cases the turning centrés will be represented in a simplified artificial machining centre form in the prismatic tool flow model for long time system performance prediction followed by detailed Turning Model or prismatic part modelling to evaluate the system operation in details and CNC lathe acceptability and to fine tune the turning facility performance.

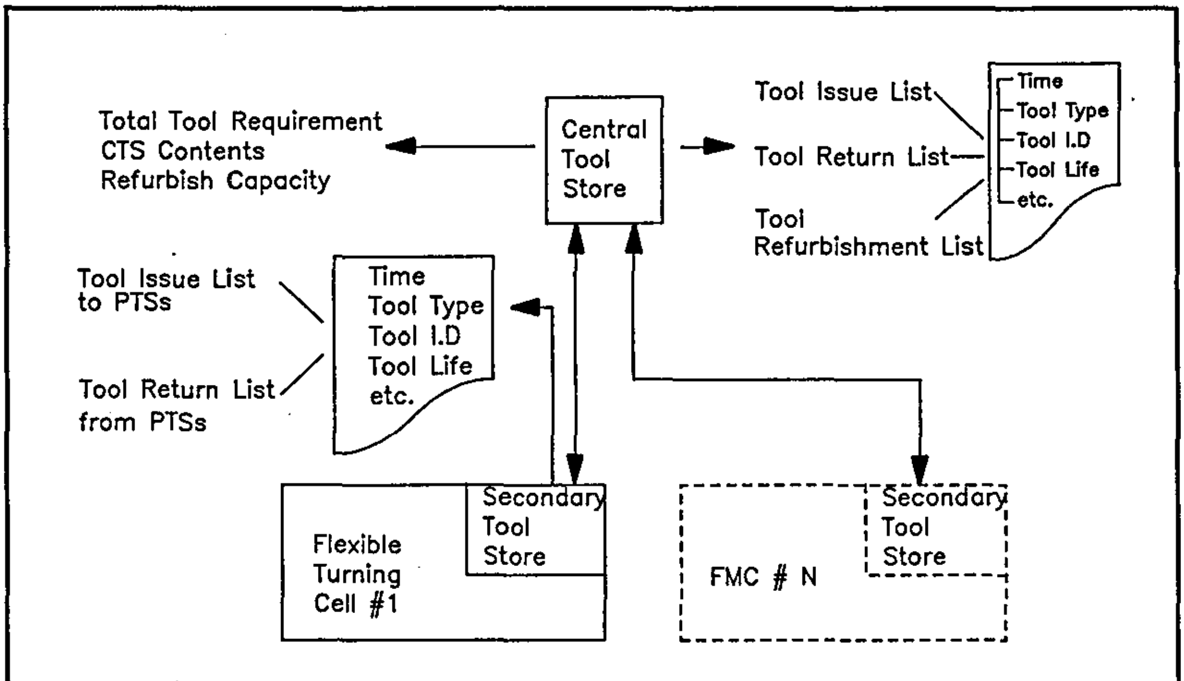


Fig. 6.1
Tool Management Requirement

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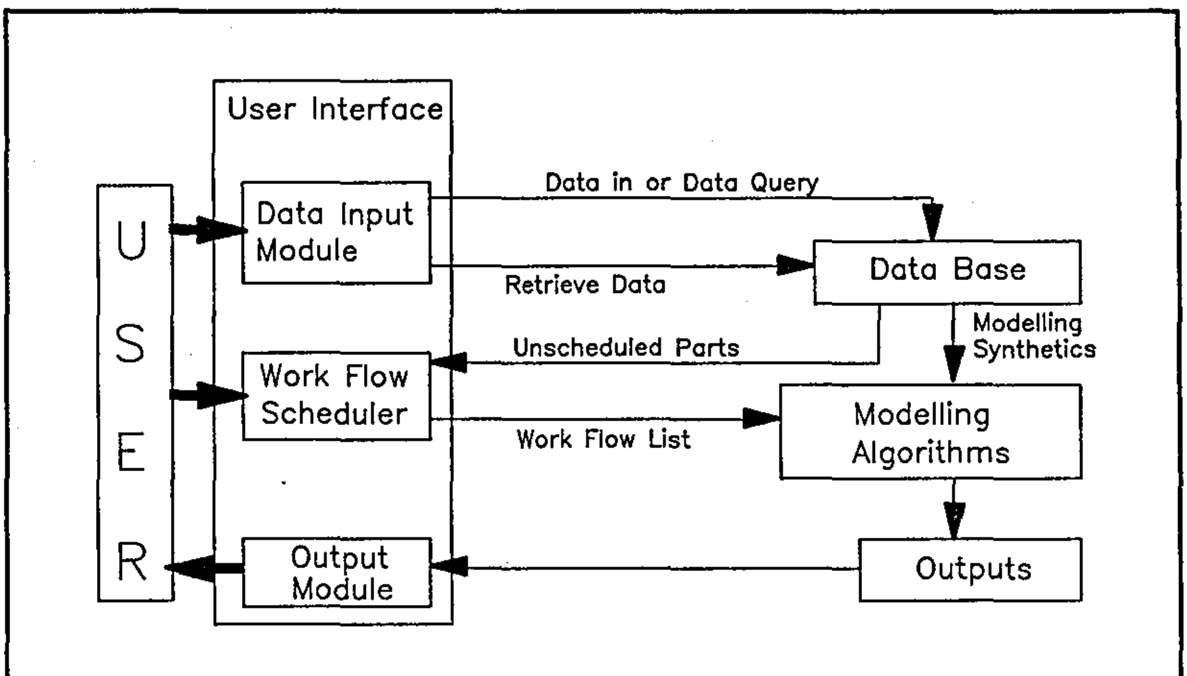

Fig. 6.2
Overview of Turning Model

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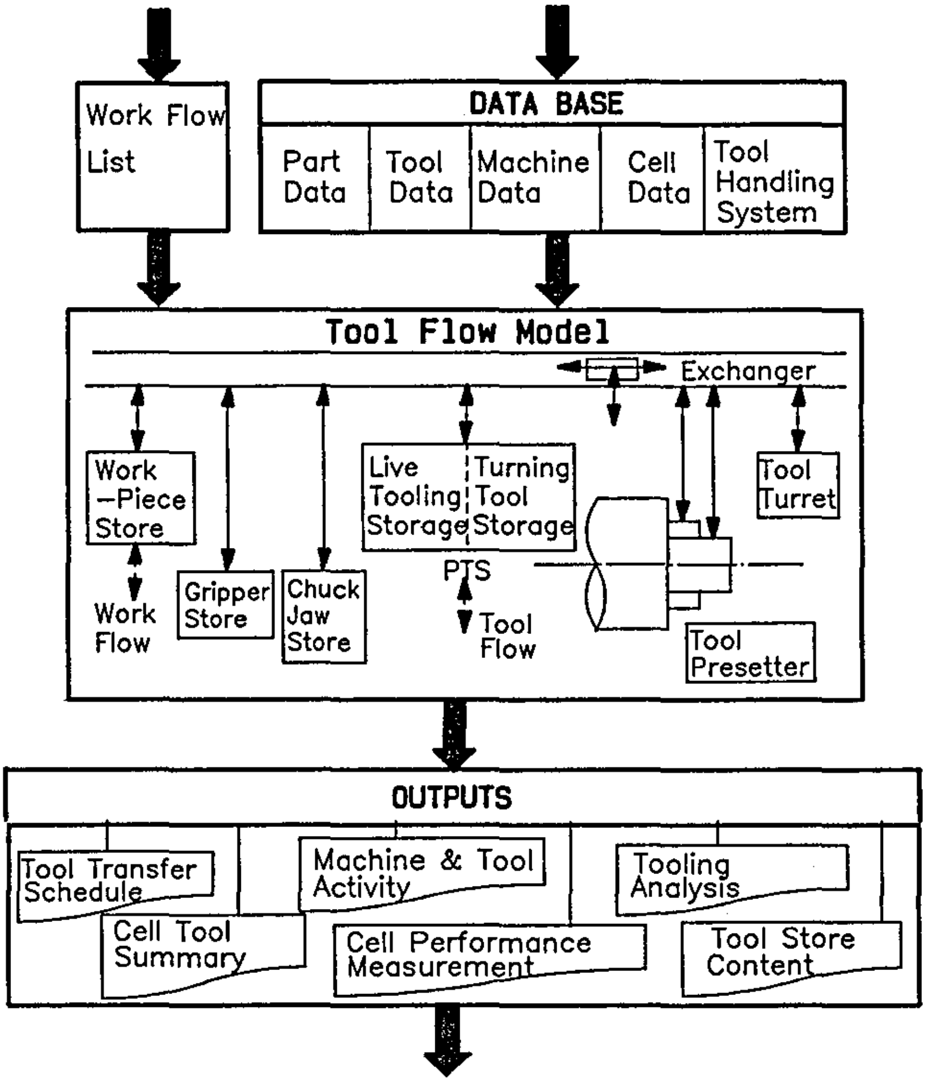

Fig. 6.3

Turning System Tool Flow Model

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CHAPTER 7 TOOL FLOW SYSTEM CONFIGURATION AND TOOL MANAGEMENT FRAMEWORK

7.1 INTRODUCTION

The Turning Model handles highly automated machining cells for cylindrical parts with a great detail of tool flow. The part flow side has been concentrated on the scheduling of part movement inside turning cells. The two interactive aspects are linked up by tool flow management strategies.

A structured approach for generic representation of tool flow configurations is presented in this chapter, in terms of hierarchical tool storage, issue, and transportation, based on the survey of current tooling systems in the previous chapters. This generic representation, together with its associated tooling strategies, provides the basis for the algorithmic computer model building, see the later chapters. A framework for tool flow system design and operating strategy evaluation is presented, which employs the built computer aid - Turning Model.

7.2 TOOL FLOW SYSTEM CONFIGURATION

The tool flow network defined makes use of a tool transportation system inter-linking a hierarchy of tool stores where tool exchanges take place (Fig. 7.1, 7.2). (Ref. to Chapter 2, 3, 4, 5).

The network has been defined hierarchically in 3 levels: the central tool storage and tool issue, turning cell level, and single turning centre level. It has been recognised to consist of the following essential elements: [14, 129, 122, 291, 320, 244, 93].

1). Central tool storage.
2). Factory level tool transportation and distribution.
3). Cell secondary tool storage and control.
4). Cell level tool transportation.
5). Individual machine based tool storage and tool exchanging.

7.3 CENTRAL TOOL STORE

The Turning Model deals with the Central Tool Store (CTS) activities in full detail which involves the following aspects (Fig. 7.3): tool preparing, issue and returned tool disposal. New tools are prepared according to the production requirement and distributed to the turning cell; Tools returned from the turning cell are assessed, refurbished and disposed. Reusable and refurbished tools will re-enter the circulation. [40, 41, 57, 101].

Tools are refurbished according to the specific criteria [93]. Live tooling will be re-ground. Turning tools with indexable inserts will be reconditioned with a fresh tip present. Tools (both live tooling and turning tools) that are not required will be disassembled so that the tool parts can be used for the assembling of other tools.

Tools will be assembled and preset in CTS according to the production schedule (Ref. to Chapter 11), and issued to respective individual machines [59].

The outputs of the Turning Model with respect to the CTS will include the requirement of tool assembly, preset, and disposal; tool issue list and the total tool component requirement for the production period which can be employed for the forecasting of tool components inventory and purchasing for the planning period. [41, 46, 77].

7.4 CELL SECONDARY TOOL STORAGE

A turning cell consists of one or a number of CNC turning centres [10, 186, 312]. (Fig. 7.4). (Ref. to Chapter 3).The tool flow activities modelled in the cell level include the tool supply, exchange and transportation between the cell Secondary Tool Store (STS) and individual turning centres.The cell Secondary Tool Store (STS) supplies tools to all the machines inside the turning cell [100, 122]. A STS is used for either one of the following two modes: 1). as a transient tool buffer linking an FMC to the CTS; 2). or, as a major tool store with big capacity to hold all the tools required by the turning cell for a planned production period.

Tools are stored in numbered positions in the STS. [157, 187, 321, 322]. STS capacity has to be specified as number of tools that it can handle. STS capacity in the industrial installations features a big range. A STS of a small turning cell usually has the capacity between 120 up to 240 [157, 187, 321]. As far as the software is concerned, there is no limit for the maximum STS capacity that can be modelled.

A cell tool transporter of user specified capacity links the STS (if any) to respective turning centres. It transfers tools from the cell's STS to a machine's primary tool store at specified stages of machine's schedules. [84, 126].

Turning cells are more likely to be less mechanised compared with machining centres, where highly automated turning centres work independently rather than highly mechanically integrated. Or, although the machines are integrated in terms of workpiece flow, the tool flow inside the cell still features operator intervention for tool exchanging [8, 10, 11, 31, 104]. To represent this situation, the tool transportation in the cell level can be either automated [15, 211], or manually [309].

The system transportation network links the system central tool store to respective cells' STSs. New tools are transferred from the CTS to the respective STS, worn tools, if any, are loaded into the transporter and returned to the CTS. [14, 15, 129, 130, 211].

It is assumed that the same time interval is required for the tool transporter to travel from the STS to any machines in the turning cell. No inter-machine tool exchange is allowed [77].

7.5 TURNING CELL CLASSIFICATION

Three types of multi-machine turning cells have been classified:

(1). Manually Supported Turning Cell, fig. 7.5: work flow to the cell is carried out automatically through the factory level workpiece flow system. Workpiece loading/unloading between each machine spindle and part pallet is done automatically, e.g by a machine equipped industrial robot [176, 286], or gantry type workpiece exchanger [140, 141, 142, 180].

The manning involvement includes tool/magazine exchange to the machine, and workpiece pallet exchanging between the machine workpiece buffer and the cell buffer; The industrial installations fallen into this category are: Traub [92, 201], SMT [153, 197], etc.

(2). Manually Operated Turning Cell, fig. 7.6: each machine requires a operator for pallet exchanging, tool/magazine exchange, during the set-up period of a batch, and workpiece loading/unloading during the processing of a batch. The NGL CNC turning cell presented in Chapter 13 is a typical example of this type of installation.

(3). Highly Automated Turning Cell, fig. 7.7: the tool/magazine exchange, part pallet exchange, and workpiece loading/unloading are all performed automatically, e.g. Fanuc Motor Factory [105, 107], Yamazaki Rotational Line [15, 44, 211], FAST of Takoka [21].

7.6 TURNING CENTRE

7.6.1 Basic Features

Individual CNC lathes feature machine based tool storage for normal turning operations under the supervision of operators for part handling, etc. (Fig. 7.8).

Two types of machine based tool storage configurations have been recognised:
(1). Turning centres with single or double tool turrets [203, 213, 214, 215, 286]. The Tool Flow Model can handle tool turrets of up to 16 (or even more) positions. Tooling features such as modular tool design [156, 188, 284] can be modelled. The tool turret(s) is defined as the basic tool store.

(2). The tool turret backed up with the tool magazine. Such a magazine which supplies tools to the tool turret of one machine is defined as the Primary Tool Store (PTS). Tool magazine capacities usually range from 30 to 150. [58, 156, 157, 165, 166, 187, 188, 215]. The maximum PTS capacity limit has been set to 240 tool positions [188, 189].

Bar turning CNC lathe can be modelled. The extra features of a bar machine are its bar storage magazine and bar guide system. Two type of bar guide systems has been recognised: 1). Oil-filled bar guide tube; 2). Roller systems with pliable rollers. [204, 285].

7.6.2 Highly Automated Turning Centre Features

In addition to the basic features mentioned above, it is intended to model turning centres with the following advanced features (Fig. 7.9):

(1). Automated chuck jaw changing, and gripper exchanging [127, 215]. The selection of a set of chuck jaw is according to the component diameter range that it can handle. The number of chuck jaw sets implemented in practice range from 3, 6, up to 15 [182, 215, 300]. The maximum sets of chucks has been set to 15.

The handling of automatic gripper exchanging in the computer model works in the same principle as the automated chuck jaw changing, with each set of grippers being specified with the minimum and maximum workpiece diameter that it can accommodate.

(2). Automatic tool gauging [165, 196, 215]. The process of the tool presetting and tool wear compensation by head-stock mounted tool probes can be modelled. The tool gauging time is regarded as part of set-up time.

(3). In process workpiece measurement, the storage and exchange of contact probes have been incorporated into the Tool Flow Model design. The probe storage and exchange is modelled in the same way as cutting tools, but with very long tool life. Particular turret positions can be specified to accept probes. [165, 216, 265, 285].

(4). The storage and exchanging of both turning tools and live tooling. Turret positions with power driven mechanism have to be specified to accommodate live tooling. [157, 173, 203, 286].

The following PTS features have been incorporated into the Turning Model design:

(1). Tool magazines for turning tools only. [188, 189].

(2). Tool magazines which can store both turning tools and live tooling. [58, 106, 190, 191, 215].

(3). A tool magazine for turning tools plus a tool magazine for live tooling.

The PTS (if any) of a turning centre is linked to the cell's secondary tool store by the cell tool transportation mechanism.

Tool spectrum includes the normal turning tools, live tooling [190, 191], and turret mounted contact probes for workpiece measurement [165, 216, 265, 285]. Turning tools are further classified into external and internal operation tools.

7.7 TOOL MANAGEMENT FRAMEWORK

The essential role of tool management is the timely scheduling of tools to satisfy a short to medium term manufacturing task. A framework for tool management is shown in fig. 7.10. The first phase is to specify the manufacturing system configuration and its associated level of tool and part flow automation appropriate for the manufacturing requirement. As will be seen in the case study of Chapter 14 the turning centre automation features bear the direct and the most significant relationship with respect to number of machines required, tool issue requirement and tool inventory, and manning pattern for tool and part flow.

The second phase involves the definition of tooling strategies which includes the specification of tool management strategy in the high level and tool storage and issue strategies in the lower, operational level. The tooling strategy selection in different level influences each other, see below sections. The determination of the turning system configuration and tool management strategy often dictates a certain choice of tool storage and issue strategies which interact amongst themselves.

The third phase will be the implementation of the modelling technique to test out the tool flow system installation or a new proposed system design, and to provide an appropriate tool flow management solution for a turning system to fulfill a certain production requirement.

There are several factors involved when considering the form of tool management system to implement or to replace in a flexible machining installation. These are total tool inventory, tool requirements, the transfer network, the tool flow solution, the production volume, the part mix and last but not least, the cost.

The total tool inventory is by far the most important factor, as it is the substantial reduction of this inventory that most tool management systems seek to achieve. The efficiency of a tool management system is often judged against the number of captive tools versus the cost of holding and maintaining this tool inventory. In the case of turning systems the number of captive tools at cell and machining level is the major factor in determining the total tool inventory and the cost of the solution.

While the presence of live tooling requires careful planning and design of tool flow and handling at individual machine level, the cost of live tooling inventory may only show in the central tool store with regards to tool component requirement and tool preparing effort, see Chapter 11.

The transport function at cell level is also a major feature of any tool management systems. The pattern of supply and return of tools is of particular importance. A number of solutions exist resulting in either irregular, periodic or regular patterns of supply and manning. The solutions, some of which are cheap but clever, and others which are expensive in hardware often reflect the level of software control inherent in the system [211, 301].

7.8 HIGH LEVEL TOOL MANAGEMENT STRATEGIES

The tool flow system can be operated under one of the two types of tool management strategies: viz. tool oriented and workpiece-oriented tool management [77, 292].

(1). Tool oriented system a 'fixed cluster' of tools is used for the whole production period. A worn or broken tool will be substituted by its sister tool, but no new tool type will be introduced during the production period. [245, 291,320].

Groups of tools can be formed to produce certain types of parts. The control of tool flow will be addressed to tool groups rather than individual tools. This gives the flexibility to the turning centre to produce any individual part within the tool group, as long as the tool group is present. The actual control of tool flow has been greatly simplified and it offers greater system reliability. But this strategy does require complicated software for tool group forming. Large tool requirement may result due to the duplication of tools between tool groups. [169, 170, 171].

A statistical method - Cluster Analysis can be employed to cluster the tool groups [77, 126, 283, 293]. A Computer Assisted Cluster Analysis (CACA) software has been written in the research group by De Souza to form tool and part families for tool oriented systems [77], which is implemented in the Turning Model when required.

(2). Workpiece oriented tool management: It requires supplying of tools according to the requirement of each part operations [47, 48, 280]. Tools are scheduled to a machine according to its work-schedule. Tool sharing can be achieved but complicated software is required in terms of tool issue, transportation, setting-up, etc. [292].

It has been decided to model turning systems under the workpiece oriented strategies (unless specified as tool oriented) as this is the case when complicated tool flow management is required.

7.9 TOOL STORAGE STRATEGIES

Tool storage strategies are determined by the turning system configuration and individual turning centre design. It bears direct relationship with tool issue strategy as will be discussed in next section. Tool storage strategies fall in either of the two categories:

(1). Decentralised: individual machine based stores (the turret and magazine) hold most/all of the tools for a production period. [43, 101, 259].

(2). Centralised: Cell secondary tool store or central tool store holds most of the tools required by the whole turning cell. [41, 101, 290, 291, 320].

The decentralised tool storage strategy may result in large tool inventory of the cell and requires large tool magazine capacity. But it puts less requirement on tool transportation inside the turning cell once the tool magazine has been filled up.

The tool transporter may be a gantry robot which transfers a single tool at a time, or tool exchange device which handles a package of tools.

The centralised tool storage strategy requires a large cell level secondary tool store capacity (STS), tool saving may be achieved by permitting tool sharing across individual machines, but only at the expense of extensive tool exchange effort between the STS and individual machine magazines. This strategy requires a tool transporter with bigger capacity, high movement speed, or more than one transporters for the FMC, otherwise, the tool transportation may become the bottleneck of production.

Cylindrical component manufacturing features shorter part cycle time, shorter tool life, and big tool variety (including live tooling), larger batch size (around 50), which results in larger tool requirement. Tool transporters may be used extensively both for new tool type exchanging and for worn tool replacement.

7.10 TOOL ISSUE STRATEGIES

Tool issue deals with allocating and distribution of tools to operations on respective turning centres. The selection of tool issue strategy reflects the form of tool management required. The solutions adopted range from kitting through to the issue of single tools. The selection of tool issue solution bears a direct relationship to the pattern of supply and return of tools within a cell and thus on the selection of the tool management strategy in the high level and the selection of tool storage strategy mentioned above.

The selection of an appropriate tool issue strategy is dependent upon a number of parameters other than the tool management category, see fig. 7.11. The interaction and specification of these parameters will suggest a suitable tool issue strategy. The selection of machine, local tool storage (whether tool magazine, tool turret, or block tooling system) and local tool store capacity is a primary factor in determining the method of tool issue. The part mix, complexity of machining and the certainty of visits of specified parts to specified machines, are secondary features. The local part buffer, number of operations per part and the operation or tool usage times would also almost certainly dictate the method of tool issue as would the tool flow network, whether automated or otherwise. Last but by no means the least as an influencing factor, is cost which bears a direct relationship with all the other factors.

Following the specification of turning system configuration and tool management and storage strategies, tool issue strategies fall in one of the two categories:

(1). Tool issue for next production period;

(2). Tool issue for next batch.

7.10.1 Tool Issue for Next Production Period

This category of strategies recognises common tooling between workpieces or several part batches in the same production period [25, 33, 41, 74, 101]. Tools which are so identified are not duplicated in the machine based tool stores (magazine and turret) for each part type. It thus has a tendency to lessen the total tool inventory. The tool magazine is serviced only once at the beginning of a production period which may consist of a number of batches or a number of pallets of a same batch if the batch size is large. The constraints of this strategy category is the tool magazine capacity. Two types of magazine service strategies are evident:

(1). Complete magazine exchange;

(2). Partial magazine service.

7.10.1.1 Complete Magazine Exchange

Before the start of next production period, a tool magazine newly filled with tools for next period will be exchanged with the tool magazine for the previous period.This is a common practice where the whole magazine, especially block type magazine, can be exchanged [95, 188, 189].

This strategy recognises the tool sharing between part operation of the same period, but ignores the possible tool sharing between successive production periods. It facilitates tool flow automatio since tool exchange to a machine can be done in a short time provided that the preset tools have been filled in a tool magazine and ready for exchange when required. The strategy is more suitable for larger batch manufacturing which is a unique feature of turning manufacturing [103, 105] and calls for unmanned processing.

7.10.1.2 Partially Serviced Tool Magazine

At the end of a production period, only worn tools will be removed form the tool magazine, and new tools required for next period will be loaded. It recognises tool sharing both among batches of the same production period and between the successive periods. The strategy suits the manufacturing of a variety of batches of smaller size. In such a case, large variety of tools will be required with each tool being used for a shorter time period thus it can be used for next period. The strategy is a feasible solution for tool flow when the tool magazine can be serviced during the machine is in operation, otherwise long time delay will be likely due to tool exchange. A number of manufacturers have offered such turning centres suiting this tool issue strategy to facilitate low batch size / big variety of workpiece manufacturing [14, 77, 101].

7.10.2 Tool Issue for Next Batch - continuously Replenishment

Migration of tools at the completion of a workpiece type permits tools to be provided, replenished, and re-circulated to machines continuously as required by work flow and not periodically at the end of a fixed number of batches or pallets as in the tool issue for next period strategies. In this category of tool issue strategies the production period is not affected by the tool magazine capacity. As a batch is completed several tools may become candidates for removal from the machine. This removal permits to loading of tools required for other workpieces. This category of strategies allows the ability to respond to unexpected situations which may arise during the production. However, the decision logic concerning the set of tools to leave the machine based tool stores and new tool issue list becomes more sophisticated which can only be determined by modelling. A number of tool issue strategies of the category have been incorporated in the turning model design:

(1). Tool Kitting;

(2). Differential Tool Kitting;

(3). Single Tools.

7.10.2.1 Tool Kitting

Tools are issued in kit for each batch visiting each machine. When the present batch is still in processing, the tools for the next batch will be kitted. The tool kit will be transported to the machine before the finish of the present one, and will be exchanged with the used tool kit. This strategy guarantees maximum tool availability, and tool transporters will be called only once for each batch, if the transporter capacity is sufficient to handle the largest tool kit. [46, 101, 289, 290, 294]. The strategy may be justified when a chain type magazine (or tool pallet) which has a limited number of tool positions but can handle the mixture of turning and live tooling, is implemented.

7.10.2.2 Differential Tool Kitting

Tools are issued in kit for each batch, but common tools can be shared between tool kits in the same machine. Tool transporter will transfer the tools that are not available in the tool magazine and the tool turret to the machine for the next batch. This strategy goes one step further than the tool kitting concept. Tool requirement can be reduced, because of the sharing of tools between part types. But the tool flow model software has to decide which tools should leave and which tools should be retained in the machine after the completion of a batch. [46, 101, 289, 290, 291, 320].

7.10.2.3 Single Tools

Tools are issued to a machine individually when a tool requirements arise. Tools can be shared in the machine by all the part types. This strategy requires a relatively simple software, but the tool tansportation system may be kept busy for assigning tools. It is only feasible when most of the tools are available in the the machine based tool stores [77]. This is true when a turning centre has been equipped with large capacity tool magazine, which can hold the tools required for a shift or even longer operation [182, 188, 189].

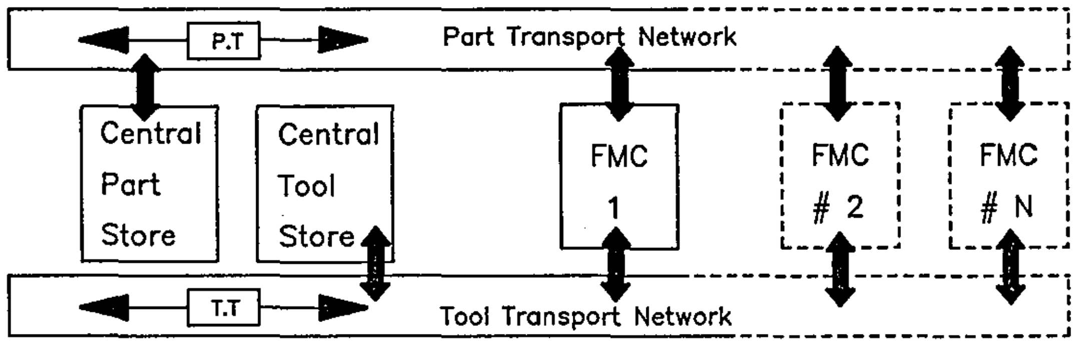

Fig. 7.1 TOTAL PLANT
TOOL AND WORKPIECE FLOW

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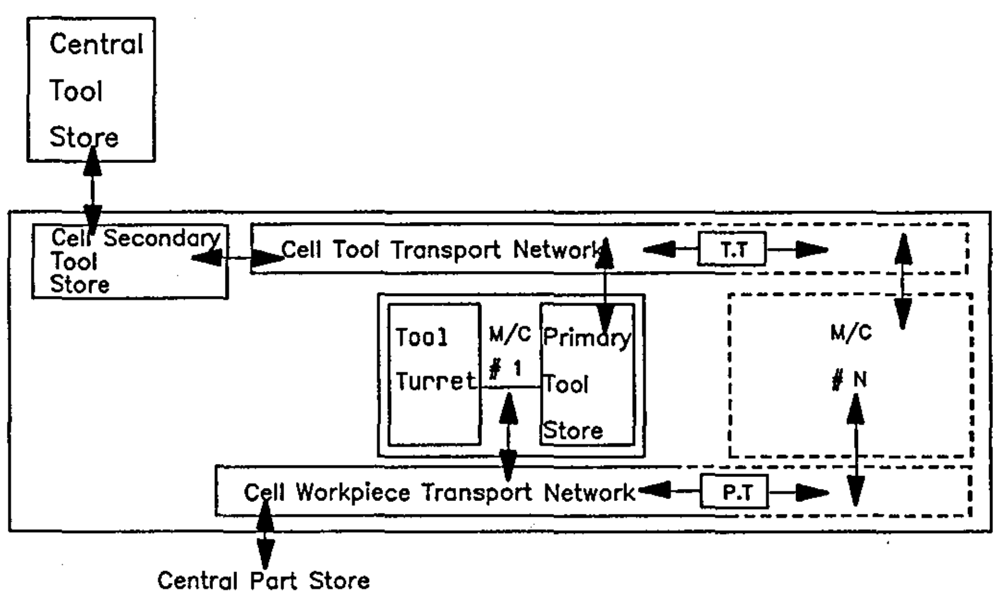

Fig. 7.2
Cell Level Tool And Part Flow

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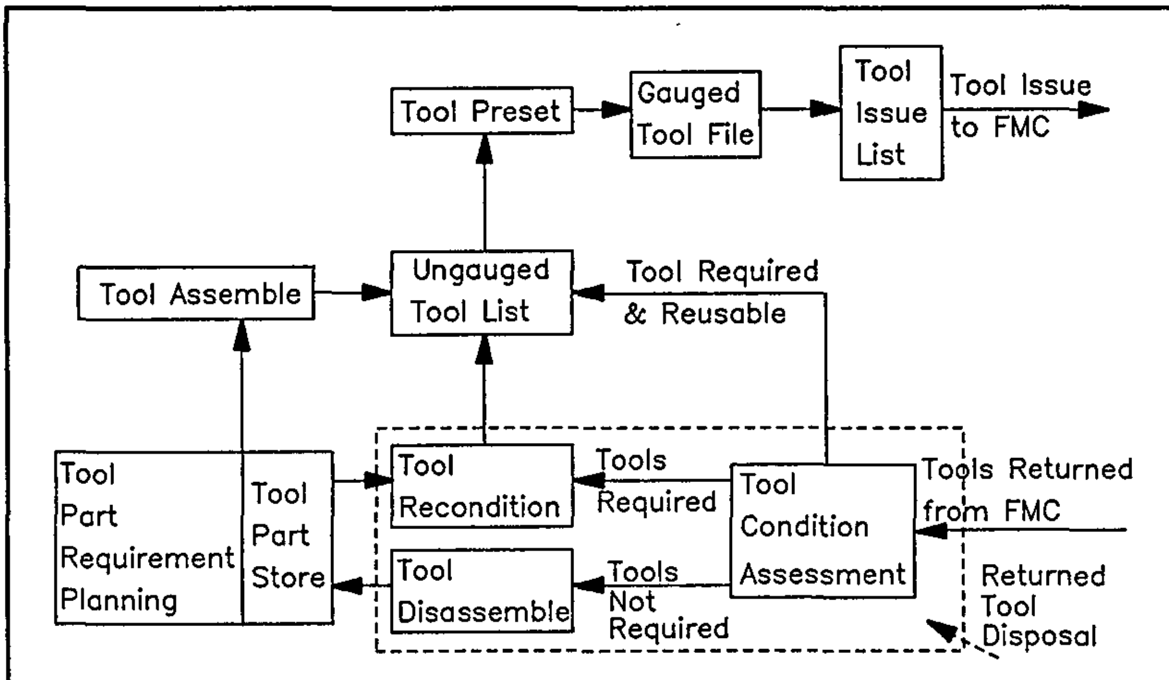

Fig. 7.3
Central Tool Store (CTS) Organisation

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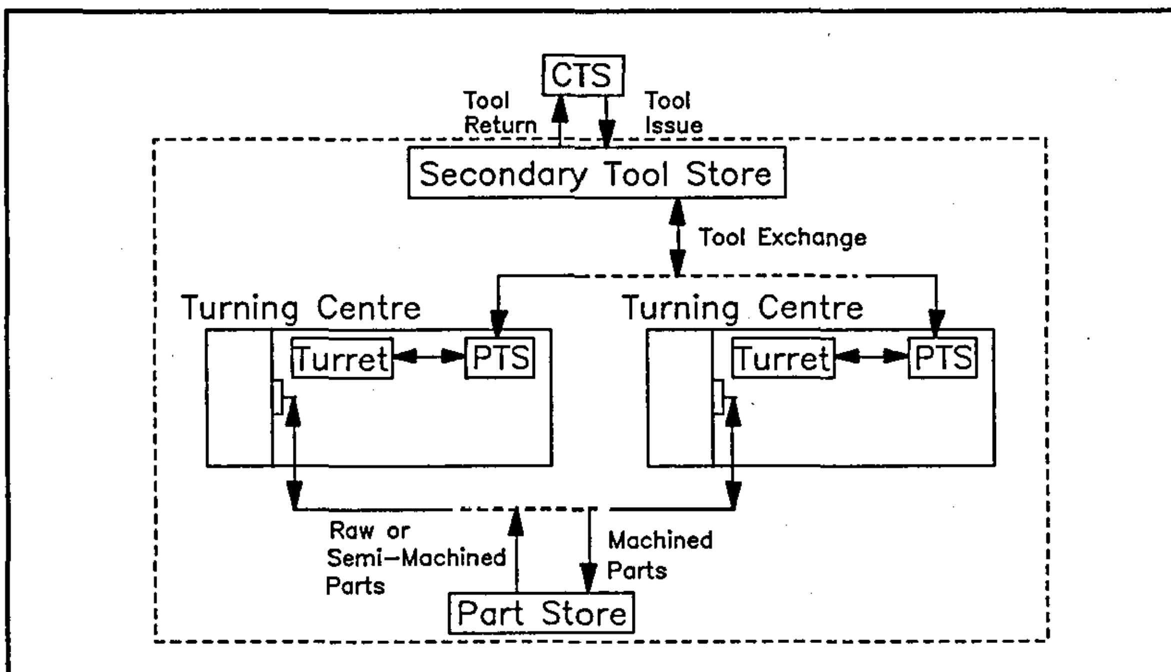

Fig. 7.4
Turning Cell Configuration

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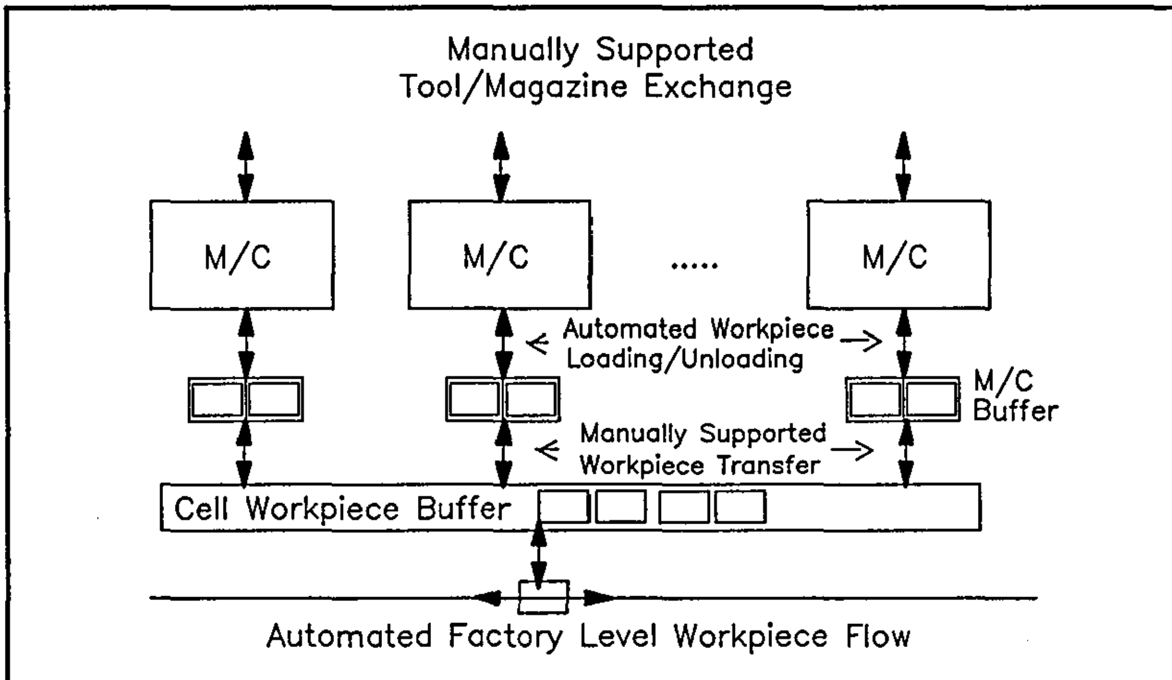

Fig. 7.5
Concept of Manually Supported Turning Cell

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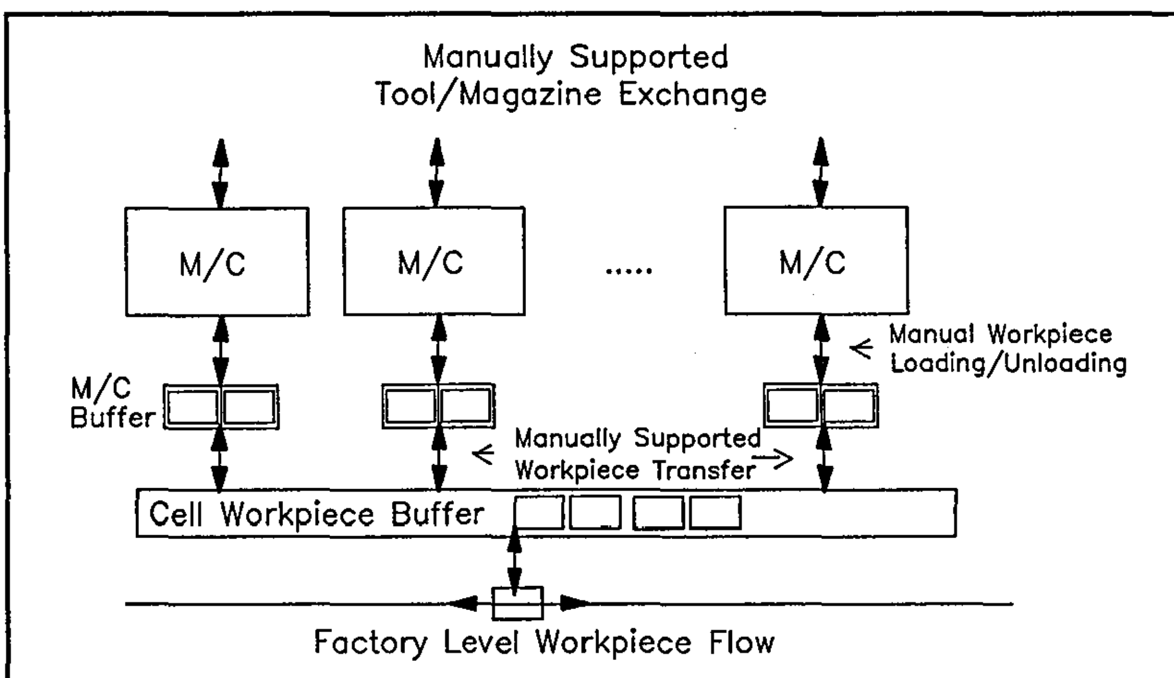

Fig. 7.6
Concept of Manually Operated Turning Cell

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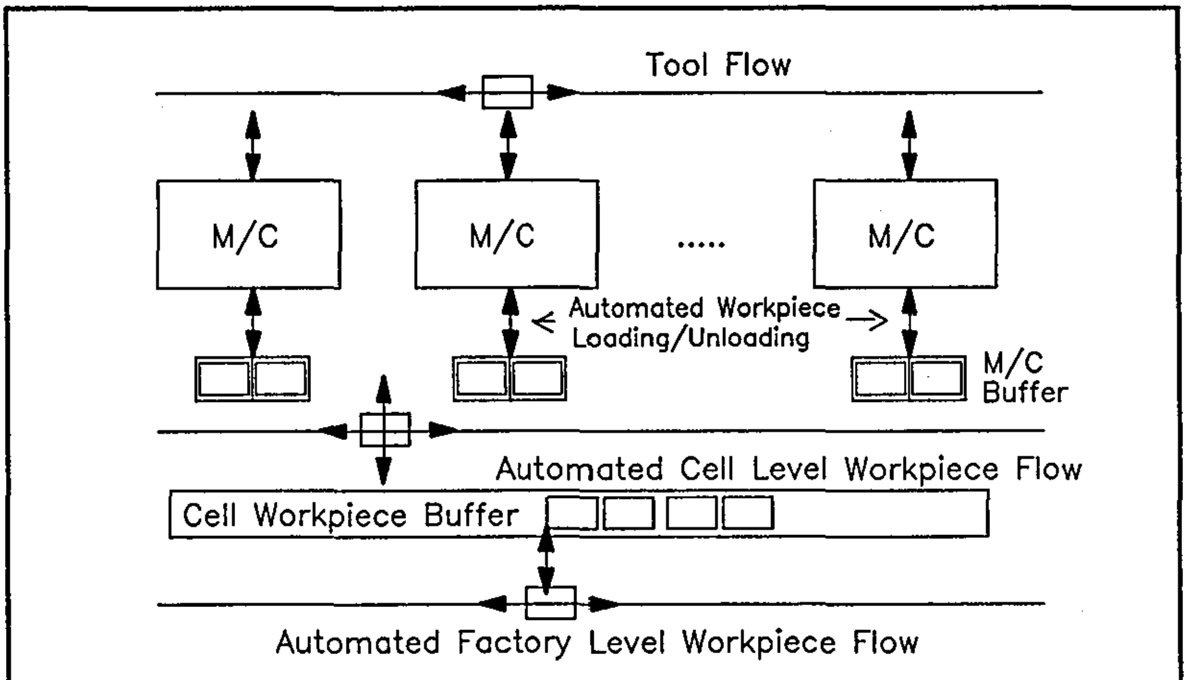

Fig. 7.7
Concept of Highly Automated Turning Cell

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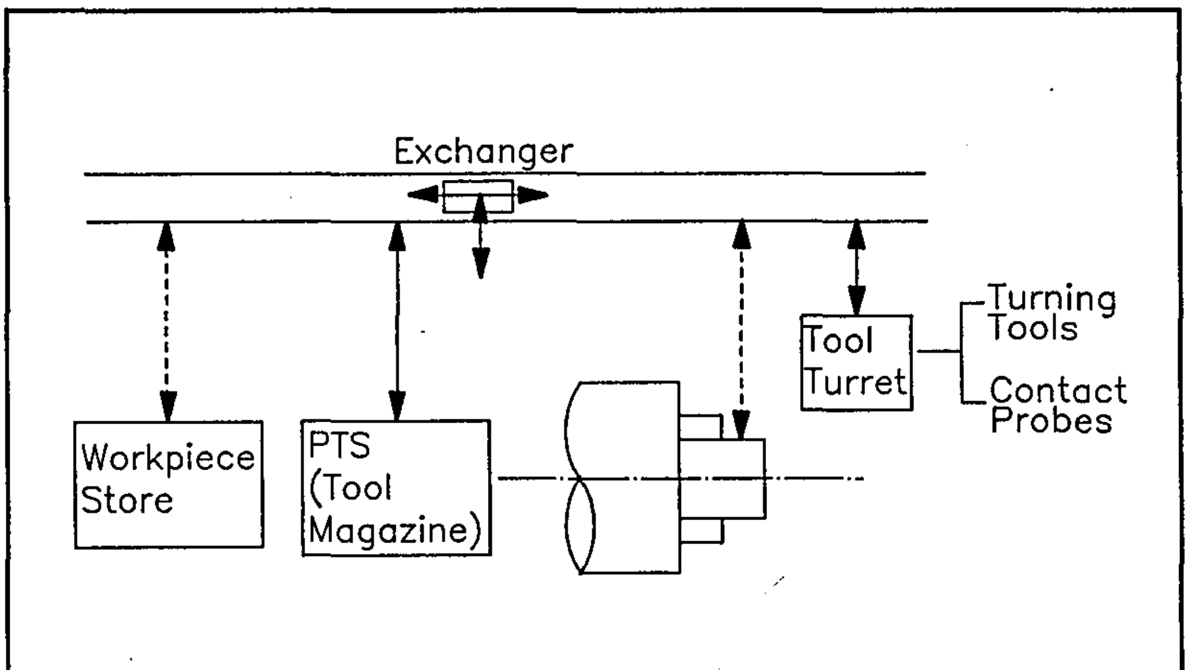

Fig. 7.8
Turning Centre Configuration
Basic Features

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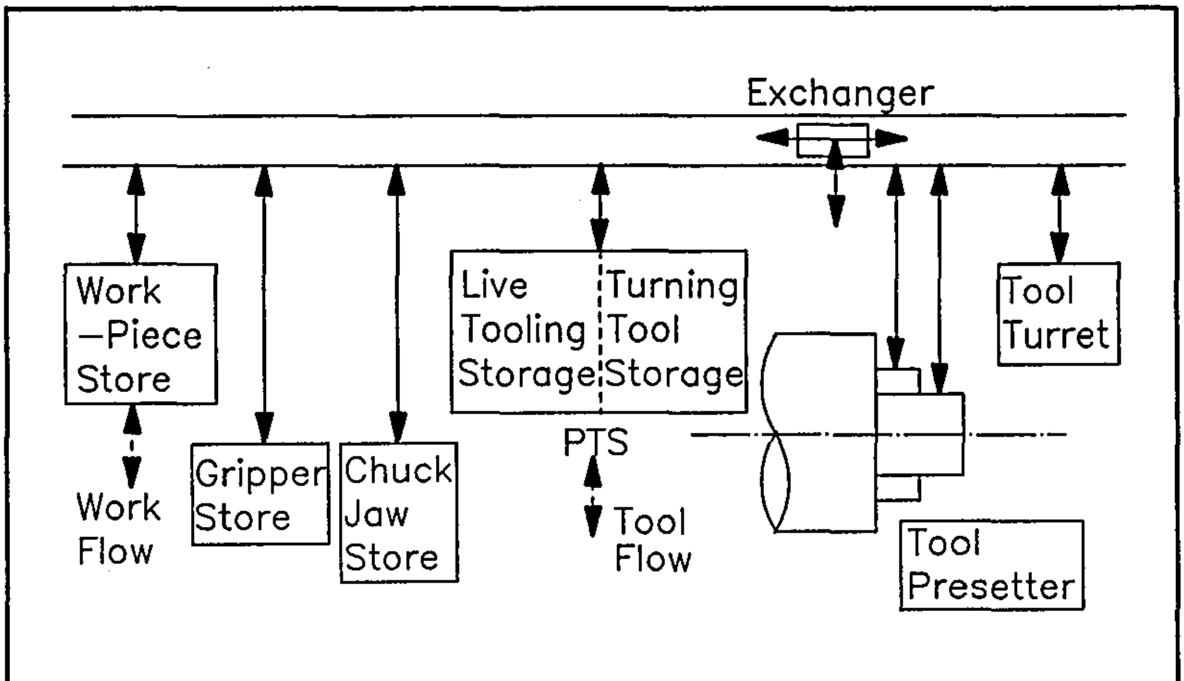

Fig. 7.9
Turning Centre Configuration
Highly Automated Features

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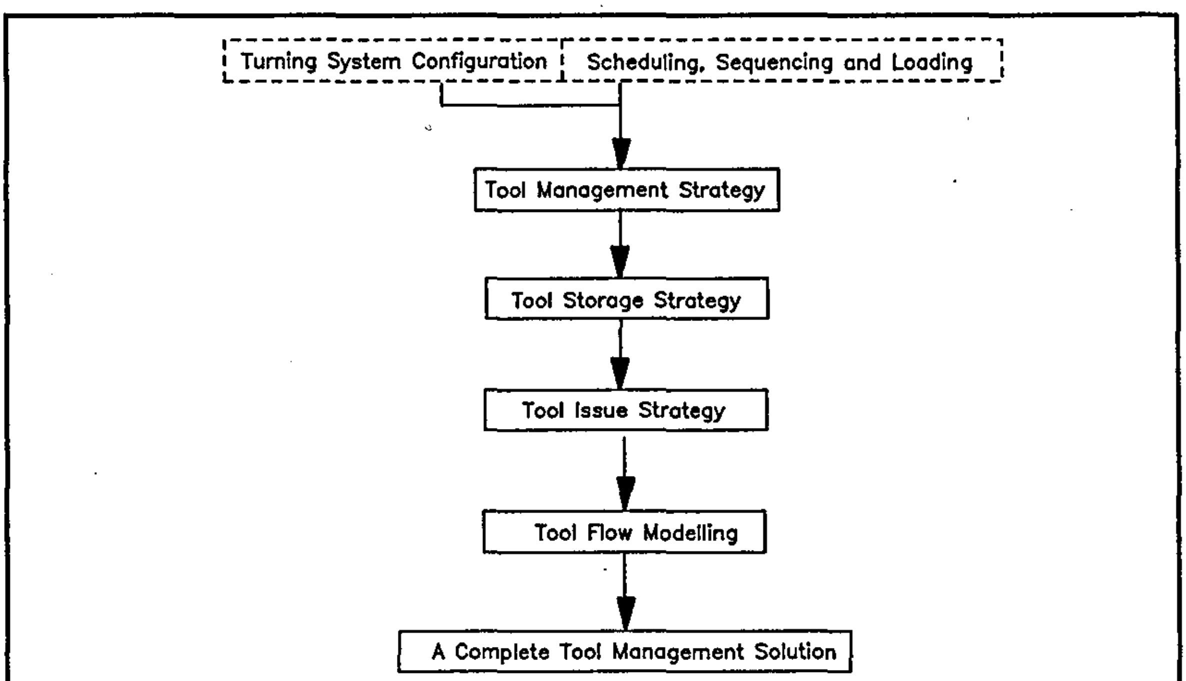

Fig. 7.10
FRAMEWORK FOR TOOL MANAGEMENT

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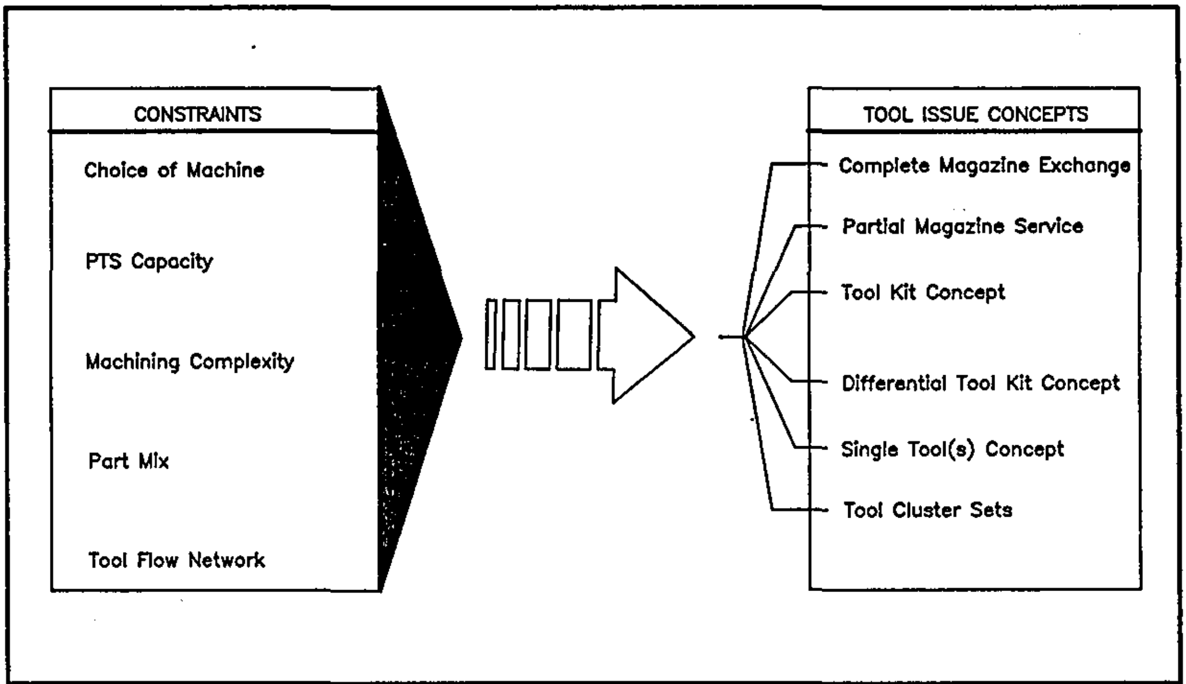

Fig. 7.11
CONSTRAINTS ON TOOL ISSUE

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CHAPTER 8 TOOL FLOW MODEL - SINGLE MACHINE

8.1 INTRODUCTION

This chapter presents the Turning Model in single machine level. As having been indicated in Chapter 7 that the Turning Model is designed to represent turning systems in full detail. Both the basic turning automation features such as turret and magazine tool storage and exchange, and the highly automated features, e.g chuck jaw changing, gripper exchanging, secondary operation and live tooling exchange, have been highly regarded in the model design. The modelling of twin-turret/spindle turning centres have also been discussed.

8.2 OVERVIEW OF SINGLE MACHINE MODEL

The activity diagram of a fully automated CNC turning centre has been shown in Fig. 8.1. When a new batch arrives, a suitable set of chuck jaws (if required) is exchanged to the spindle [215], and at the same time a proper set of grippers is exchanged to the workpiece exchanger. Each batch item will be loaded into the machine, and at the same time a suitable tool will be indexed to the machining position, then the cutting operation can be performed.

If a required tool is not present in the turret, a suitable tool will be indexed in the PTS and exchanged to the turret after the completion of the previous operation [158, 174, 187]. After all operations have been finished on the machine, the component is unloaded. The whole process will be repeated for all the batch items. Once the whole batch has finished its processing, it will leave the machine for further operation on other machines or for storage.

A turning centre's PTS is linked to the cell's STS through the cell level tool transportation mechanism (Ref. to Chapter 7). Tools required are transferred to the PTS by the tool transporter, and exchanged with the used tools [122]. The same transporter is employed to return the used tools back to STS, worn tools are then returned to the CTS for refurbishment.

The logic flow diagram of a single machine is shown in Fig. 8.2.

8.3 CHUCK JAW CHANGING AND GRIPPER EXCHANGING

Automatic chuck jaw storage and exchanging can be modelled. Time required to exchange a set of chuck jaws should be specified. Two types of automatic chuck jaw changing process can be modelled: 1): only the 3 top jaws are changed, 2). the chuck assembly exchanges as a whole (Ref. to 3.3). [127, 182, 215]. Chucks (jaws) are stored in the jaw magazine or pallets. It is anticipated that other kinds of component clamping device, e.g collet, can be modelled in the same way as chuck jaws [127].

Fig. 8.3 shows the logic flow of chuck jaw changing. Part types of different chucking end diameter may require different jaw sets to achieve the best clamping feature according to machine specifications. If a new part type will be loaded for processing, a check will be made to see if the set of jaws in the chuck can handle the workpiece, if not, a suitable set will be found in the jaw magazine, and the selected set will be exchanged to the chuck. The first set that can incorporate the workpiece chucking end diameter will be selected. Part loading and machining can then proceed.

The chuck jaw selection criterion is diameter range. Each set of jaws is specified with an application range in terms of minimum and maximum chucking end diameter of the component that can be handled.

Algorithm 8.1, CHUCK JAW EXCHANGING

'Terminology':

$dmax_c$: The maximum diameter that the chuck jaw set c can handle.

$dmin_c$: The minimum diameter that the chuck jaw set c can handle.

dia_i: Chucking end diameter of part type i.

J: $\{j | j = 1 ...... CNo\}$ index of chuck jaw magazine position.

C: $\{c | c = 1 ...... CNo\}$ index of jaw set.

CNo: No. of jaw sets / chuck jaw magazine positions.

Mag_j: The No. of the chuck jaw set in magazine position j.

$Cmag_c$: The magazine position No. occupied by jaw set c.

$Mag_j = Arc(Cmag_c)$.

Cin: The jaw set No. in the machine spindle.

P_i : Processing time of order i

$'P_i$: Previous process time of order i up to date.

'Algorithm'

Step 1. c = Cin.

If $dmax_c >= dia_i >= dmin_c$ then

the jaw set in the spindle is usable, terminate

Else go to step 2.

Step 2. j = 1.

2.1). c = mag_j.

If $dmax_c >= dia_i >= dmin_c$ then

go to step 3

Else go to 2.2

2.2). if j < CNo then

j = j + 1, go to step 2.1

Step 3. $P_i = 'P_i$ + Chuck jaw exchange time.

$Cmag_c$ = Cin.

Cin = c. Terminate.

The gripper exchanging is modelled in the same principle as chuck jaw changing, fig. 8.4.

8.4 CUTTING TOOLS

Each tool is given a unique number, and the tool type that it belongs to (FTN_t). Tools are used and assigned to operations according to their tool types. Tools of the same type are defined as sister (duplicate) tools. [84, 245, 169]. Three tool status ($Tstatus_t$) values have been defined to force tool behaviour and their transfer inside the turning cell:

'F' (Free), i.e the tool can be used anywhere in the system;
'R' (Reserved), i.e the tool is reserved for a particular tool kit;
'W' (Worn), i.e, a tool (tip) is defined as worn, if its percentage tool life utilisation has reached the maximum permissible percentage life utilisation, which is a predetermined value specifying to which extent that the tool can be used. [43, 245, 320].

Two 'tool life criteria' can be implemented to determine if a tool is worn.

Tool Worn Criterion 1:

If accumulated percentage life utilisation has reached the maximum permissible limit, the tool is worn;

The tool life value of each cutting tool consists of [77]:

(1). The tool life equation and/or the tool life constants to give a specific tool life in a specific cutting condition for a particular workpiece material.

(2). 'Operation tool life', i.e the length of time the tool will last for, in the condition of the tool operation.This is dependent upon such factors as cutting depth, cutting speed, and feed rate, etc. Taylor equation can be used to calculate the tool life [59].

(3). 'Operation tool life used', i.e the length of time required for the tool to last to complete the tool operation.

(4). 'Percentage operation tool life used': calculated as:

(Operation tool life used) / (Operation tool life)

(5). 'Percentage tool life used': calculated as the summation of all tool operations 'percentage operation tool life used'.

(6). 'Percentage available tool life' for this tool calculated as:

current tool life allocation - (Percentage operation tool life used).

A new tool has a current tool life allocation of 100%, and is progressively updated.

(7). 'Maximum permissible life utilisation' defined as a certain limit that a tool can be used. A tool is 'worn' if

Percentage tool life used >= Max. permissible life utilisation.

Tool Worn Criterion 2:

If the total cutting time of the tool has reached the maximum permissible limit, the tool is defined as worn:

(1). Tool engagement time of operation j of part i: $P_{i,j}$.

(2). Total tool engagement time of tool t

$TT_t = {}'TT_t + P_{i,j}$.

$'TT_t$: Tool engagement time up to the operation.

(3). 'Maximum permissible life utilisation' ($TTmax_t$) is defined as a certain limit that tool t can be used.

A tool is 'worn' if $TT_t >= TTmax_t$.

As tool life utilisation for turning systems are most often based on tool cutting time in actual industrial practice [31, 196, 291, 320], the Turning Model is selected to function on the *'criterion 2'*.

In the tool flow pattern where the turning tools' inserts can be indexed at machines, the insert will be indexed for a fresh tip and the percentage life utilisation will be set back to zero, providing that a new tip is available. Tool 'worn' status will be set to false.

8.5 TOOL EXCHANGE BETWEEN TURRET AND PTS

The flow chart of tool exchanging between turret and PTS is illustrated in fig. 8.5.

Tool life is recorded by keeping tool files for tools in the machine. Before an operation is commenced, a check is carried out to see if a tool of the type required by the operation is present, and if the tool life left is sufficient to complete the operation. After each operation, the additional cutting time will be increased to the appropriate accumulated used tool life.

$TT_t = {}'TT_t + P_{i,j}$.

If the accumulated tool life utilisation reaches a certain limit, the tool is considered as worn. [31, 230, 245].

Before an operation is started, the turret position containing the tool required will be indexed to the machining position. Tool indexing time will be added to the part processing time.

Algorithm 8.2, TOOL INDEX TIME CALCULATION

$P_{i,j}$: Processing time of operation j of part i.

$'P_{i,j}$: Processing time of operation j, order i up to the date.

n': Previous turret machining position.

n: New turret machining position.

Itime: Turret index time per position.

Tposits: No. of positions of the turret.

If $|n - n'| <=$ (Tposits div. 2) then

$P_{i,j} = {}'P_{i,j} + |n - n'| * \text{Itime}$

Else

$P_{i,j} = {}'P_{i,j} + \{ (\text{Tposits div. } 2) - |n - n'|\} * \text{Itime}.$

(The turret takes the shortest indexing path).

If a tool required is not available in the turret, a suitable tool will be exchanged to an appropriate position of the turret, and the tool leaving the turret will be replaced back into the PTS.

Algorithm 8.3, LOCATING TOOL IN TURRET

Terminology:

$MTpost_m$: Turret capacity of machine m;

n: turret position No.;

TStock(n): Tool No. in turret position n.

Step 1. $n = 1$, $t = TStock(n)$.

Step 2. Check Tool:

If $FTN_t = TType_{i,j}$ then go to 2.1

Else go to Step 3;

2.1). If $TStatus_t$ = 'F' then go to 2.2

Else go to Step 3;

2.2). If $TT_t + P_{i,j} <= Tmax_t$ then

Locate tool t for operation j of part i, terminate

Else

$TStatus_t$ = 'W', go to Step 3;

Step 3. If $n < MTpost_m$ then

$n = n + 1$,

$t = TStock(n)$, go to Step 2

Else

No suitable tool in turret, locate tool in PTS,

(if applicable, Ref. **Algorithm 8.4**).

Algorithm 8.4, LOCATE TOOL IN PTS

The locating of a tool in the PTS is carried out in the same way as for the turret, except that n is defined as PTS position, tools in PTS (PStock(n)) will be checked with the capacity limitation of the PTS as $MPpost_m$.

A tool leaving the turret for PTS will be decided by the following criteria (the priority decreases as the No. increases):

Tool Leave Criterion 1 :

A tool in the position that is required for some other use has to be transferred to the PTS to vacate the turret position. Turret positions have been specified as positions for external or internal operation tools, or for live tooling [158, 173, 196, 203]. (Fig. 8.6). It is possible to specify one position to accept different tools as is the case when modular tooling system is used.

TP_N: Turret position set dedicated to tool type N,

N = {E (external tool), I (internal), L (Live tooling)}.

N_t: The classification of tool t;

When tool t is to be exchanged into turret, a check is carried out to see if there is a empty position $n \in N_t$, and TStock(n) = 0,

if there is, then turret position for new tool P2 = n

else, P2 = $TP_{Nt}(1)$,

Tool leave turret TTleave = TStock(P2).

Tool Leave Criterion 2:

A 'Worn' tool ($TStatus_t$ = 'W') will be put back to PTS so as to be transferred to the CTS for refurbishment.

Tool Leave Criterion 3:

A 'Free' tool ($TStatus_t$ = 'F') will be put back into the PTS in order to be transferred back to the STS so that it can be used by other machines when tools can be shared between different tool kits.

Tool exchanging between the PTS and the turret will be carried out by the Automatic Tool exchanger (ATC). Turret and PTS indexing time are required to be specified. Tool exchanging time between the PTS and the turret has been divided into 3 parts, viz, time required to load the ATC from the PTS, ATC transfer time to cover the distance between the PTS and the turret, and tool exchange time between the ATC and the turret. [158, 174, 187].

While the machine is in operation, the tool required for the next operation is searched, retracted into the ATC gripper, and transferred to the exchange position. On completion of the previous cutting operation, the tool leaving the turret (if any) is indexed into the exchange position, the ATC will take the old tool out of turret, insert the new tool into the appropriate position. The used tool will be replaced back to the PTS while the machine is performing the new operation.

Algorithm 8.5, TOOL EXCHANGING BETWEEN TURRET AND PTS

Step 1. Position Exchange:

TTleave: Tool No. leaving the turret;

P1: Position that holds the tool leaving turret;

TTnew: New tool No. from PTS;

P2: Turret accepting new tool;

P3: PTS position that holds the new tool;

TStock(P1) = 0;

TStock(P2) = TTnew;

PStock(P3) = TTleave;

Step 2. Tool Exchanging time Calculation:

r1: PTS ready time;

r2: Turret ready time;

T1 = r1 - r2 (if r1 > r2);

= 0 (Otherwise).

Time increase due to tool exchange

T = T1 + Tool transfer time + tool load/unload time;

Having received the required tool, the turret will be indexed to the machining position, the set up and cutting operation can then proceed.

8.6 DISTRIBUTED TOOL STORAGE BETWEEN TURRET AND PTS

The tool exchange between the turret and the PTS features a long cycle time, which may increase the part cycle time even further [158, 174, 187]. The tool storage strategy for the turret is thus that tools required by the batch should be arranged as far as possible into the turret. Worn tools, or tools not required by the batch should be replaced into the PTS for storage.

8.7 TOOL FLOW PATTERNS

Two tool flow patterns have been recognised in the model (Fig. 8.7):

(1). Live tooling and other turning tools with fixed cutting inserts will be transferred back to CTS for refurbishment and regrinding. For turning tools with indexable inserts, e.g. external and internal turning tools, when one tip has been worn, the operator of the machine can index the insert, makes a new tip present, and the tool can be used again on the machine. This pattern can be seen in the partially manned manufacturing systems, where the tool gauging facility has been equipped in the turning centre for tool presetting when a new tip has been indexed for machining [215].

(2). Both live tooling and turning tools will be transferred back to CTS for refurbishment and readjustment. The application area of this pattern can be found in the highly automated turning systems. The modular tooling system also adopts this pattern (Ref. to 4.2).

8.8 TWIN TURRET/SPINDLE TURNING CENTRES

Algorithms have been developed to represent the operating of twin turret /spindle turning centres. Turning centres have been classified into the following basic types: single turret - single spindle, twin turret - single spindle, and twin turret - twin spindle. The last two types are modelled on the basis of the first one but with their unique features.

Tool supply from PTS to turret will take one of the following two patterns:
two PTSs - two turrets: each PTS supplying tools to one turret, in such a case the tool exchanging between each pair of turret and PTS can be modelled in the similar way as that for single turret - single spindle machine.

One PTS - two turrets: the PTS holds tools for the whole machine, tool exchanging between turrets and the PTS will be scheduled in the first come first served mode.

8.8.1 Twin Turret - Single Spindle Turning Centre

By allowing two tool carriage to operate at same time, productivity can be almost doubled. Two tools working on both sides of a bar type component can increase the finished workpiece quality by reducing X-axis force.

Operations that are performed together by both turrets are represented in one operation block. Each block is described by the operations of each turret with associated tools. The processing time of each block is calculated as:

$P_b = \mathrm{Max}\{P_{1,b}, P_{2,b}\}$.

The total processing time of one item is Pb. (Fig. 8.8).

The tooling set up for each turret for a particular block consists of tool exchanging time between the PTS and the turret (if required), insert indexing, if applicable.

Let:

$P_{i,T,b,j}$: Processing time on turret T of block b, operation j of part i (Ref. to the previous sections for processing time calculation);

J: $\{j | j = 1, 2 \ldots$ No of operations in block b$\}$

$\mathrm{Tool}_{i,T,b,j}$: Associated tool; (Ref. to 8.5 for tool location).

T: Turret designation, T = 1, 2;

${}^1X_t = 1$, if tool t in PTS,

$= 0$, if tool t in turret.

${}^2X_t = 1$, if tool t requires tip indexing,

$= 0$, otherwise.

Texch: Tool exchanging time between turret and PTS;

Tindex: Insert index time;

Then

Tooling set-up time for turret T:

$$S_{i,b,T} = ({}^1X_t * \mathrm{Tech}) + ({}^2X_t * \mathrm{Tindex}) \qquad (j \in J)$$

$t = \mathrm{Tool}_{i,T,b,j}$;

Tooling set up time for the machine:

$$S_{i,b} = \text{Max } \{S_{i,b,T}\} \qquad (T = 1, 2)$$

Processing time of block b of part i on turret T:

$$P_{i,T,b} = \Sigma P_{i,T,b,j} \qquad (j \in J)$$

Processing time of block b of part i:

$$P_{i,b} = \text{Max } \{P_{i,T,b}\} + S_{i,b}; \qquad (T = 1, 2)$$

8.8.2 Twin Turret - Twin Spindle Turning Centres

In addition to the increased productivity by operating simultaneously on two workpieces, the twin spindle turning centre requires less work floor space [79]. The processing and tool exchanging on each turret / spindle is carried out in the same way as the single turret - single spindle turning centres (Ref. to the previous sections). The machine available time after the current allocated workpieces, fig. 8.9:

$Tavai = Tavai + \text{Max } \{P_{i,s}\} \qquad (s = 1, 2)$

$P_{i,s}$: The processing time of workpiece i on spindle s.

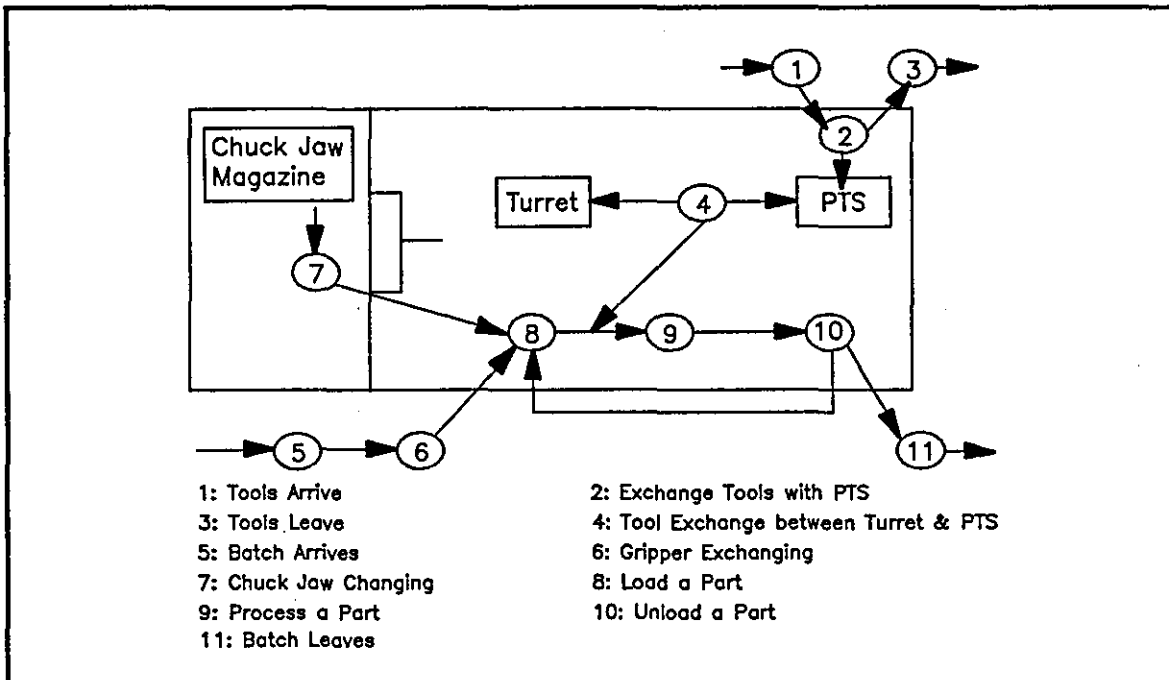

Fig. 8.1
Machine Level Activity Diagram

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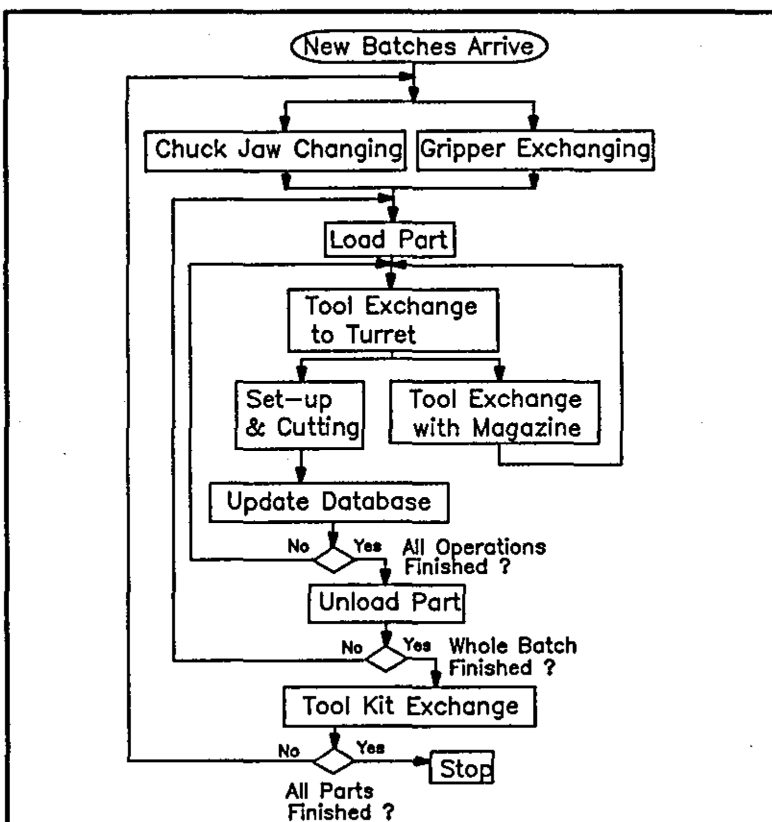

Fig. 8.2
Single Machine Model
Logic Flow Diagram

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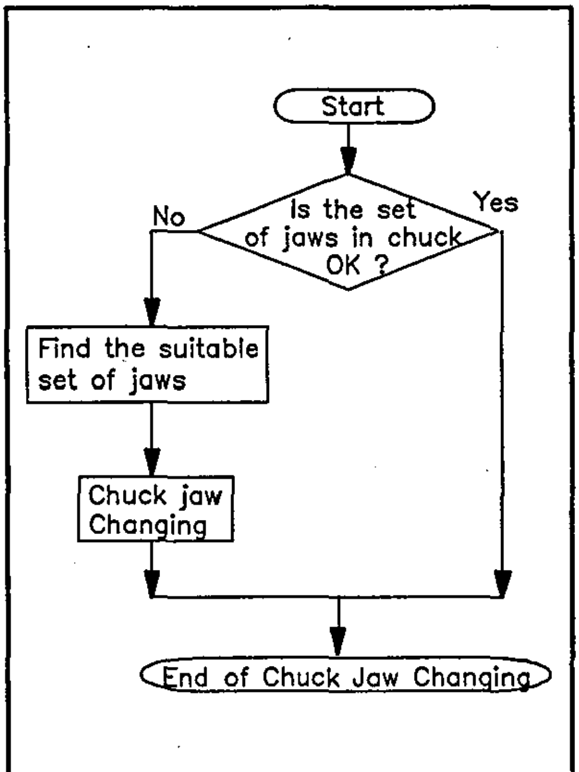

Fig. 8.3 Logic Flow of Chuck Jaw Changing

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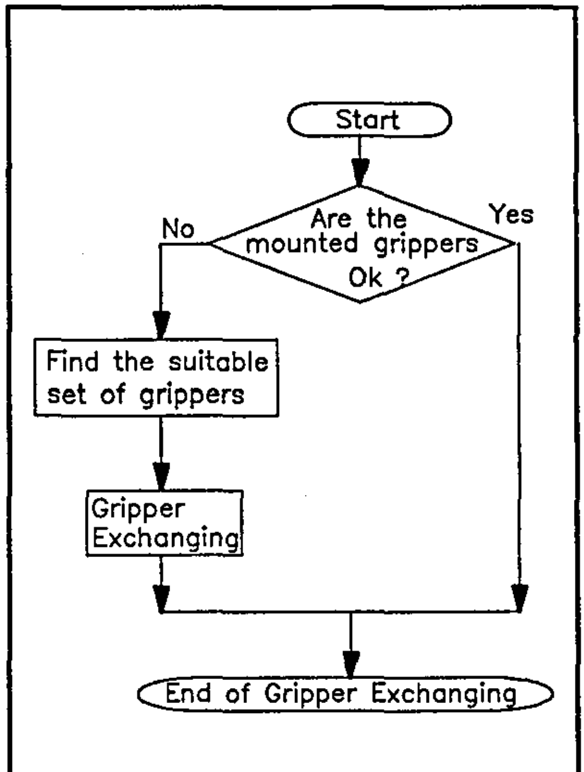

Fig. 8.4 Logic Flow of Gripper Exchanging

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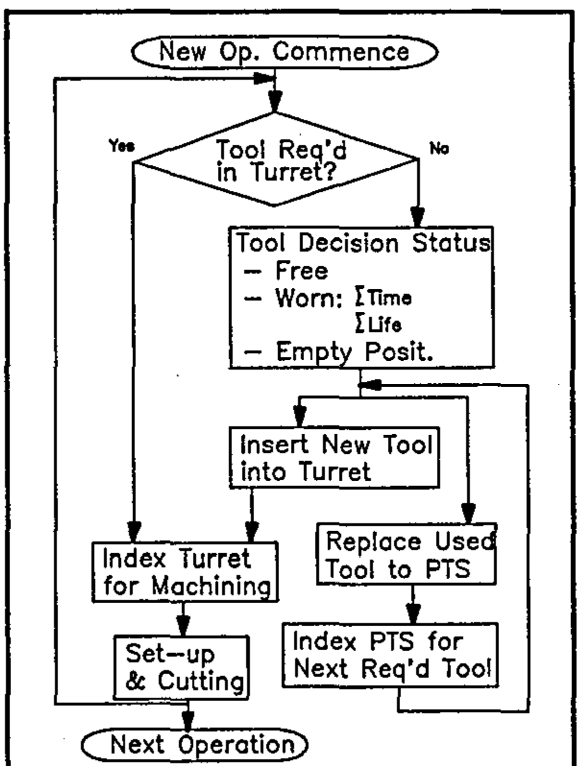

Fig. 8.5
Tool Exchange between Turret and PTS

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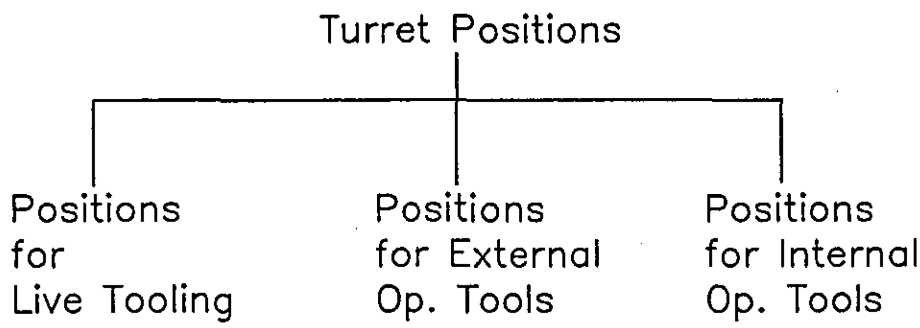

Fig. 8.6 Tool Turret Position Specification

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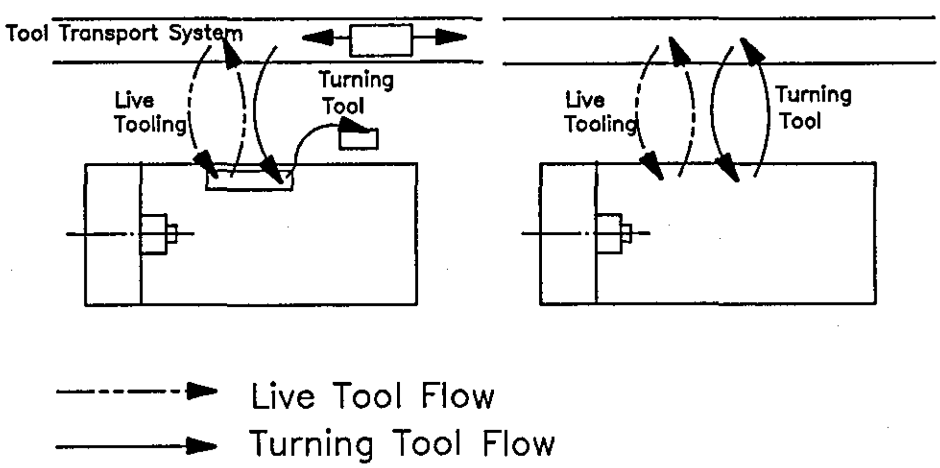

Fig. 8.7 Tool Flow Patterns

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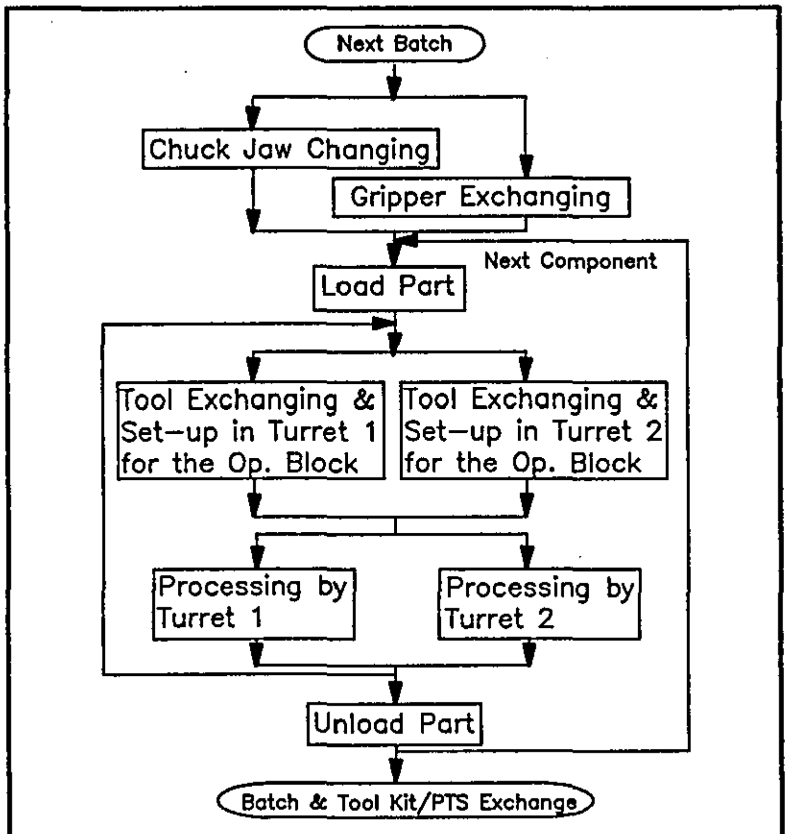

Fig. 8.8 Logic Flow of Twin Turret Single Spindle M/C

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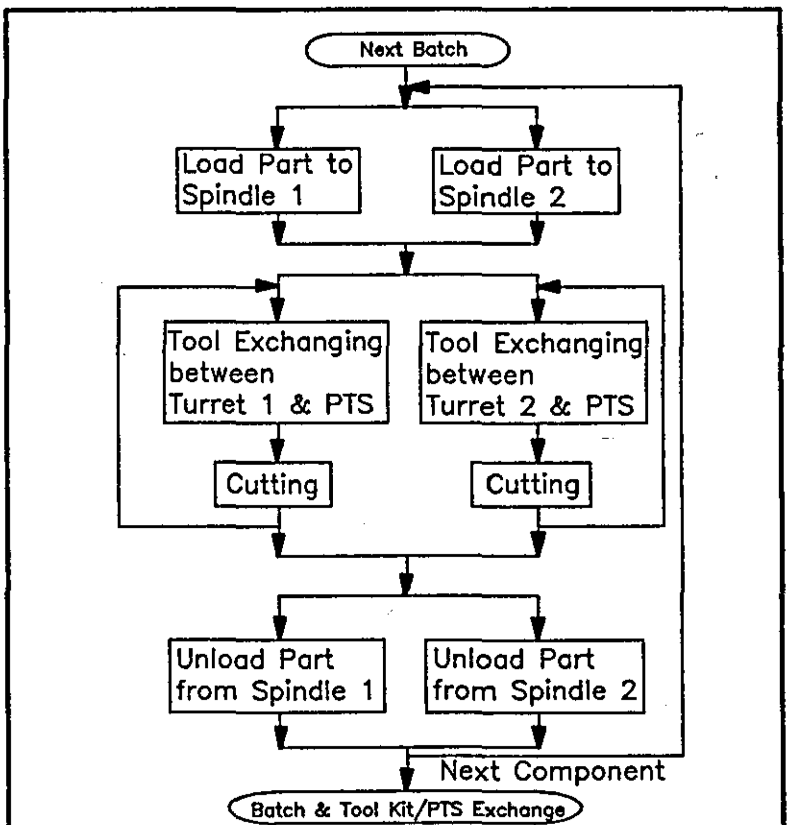

Fig. 8.9 Logic Flow of Twin Turret Twin Spindle M/C

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CHAPTER 9 MODELLING OF A HIGHLY AUTOMATED SINGLE MACHINE TURNING SYSTEM

9.1 INTRODUCTION

The work presented here is the application of the Turning Model to a single machine cell based on realistic industrial practices. The purpose of the work was to illustrate the capability of the Turning Model and the implementation of it when modelling a highly automated turning centre. The user interface of the software is introduced and demonstrated by putting the Turning Model through actual runs (Ref. to Appendix 1B for details) with an aim to provide a guideline for using the software.

9.2 SCOPE OF THE STUDY

It is planned to model a highly automated system in the single machine level with the automated features as discussed in Chapter 3 and 4. The modelling of automatic tool exchange between the tool magazine and the turret, tool flow to and from the machine, live tooling and secondary operation, automatic chuck jaw changing, and gripper exchanging, will be illustrated using of the algorithms developed in Chapter 8 (fig 9.1). A Traub installation has been chosen for the modelling purpose (fig. 9.2, 9.3, 9.4).

A number of runs have been conducted to study the tool flow and the operating of system when a complex of mix of small batches are sequenced for processing by the built-in production scheduler (Ref. to Chapter 12). A mix of pre-scheduled work-to-list of increased batch sizes is then fed through the model to examine the turning system performance. The study is then furthered to explore the nature of over-medium sized production for a long period and to examine the effect of altering tool life limit on tool magazine change-over and their complements.

For each major run the following outputs have been extracted:
- Tool requirements, tool life utilisation, and the frequency of tool usage.
- The effect of tooling strategies on magazine complements and tool requirement;

- Machine schedules and activities;
- Manning pattern including part and tool fllow for operating such a highly automated system.

Due to the lack of information, certain output options e.g tool component requirement (inserts, shanks, holders) are not demonstrated. But the capability of the Model in such aspects will be illustrated in the multi-machine cell case study, and the outputs will be subject to comprehensive analysis.

9.3 DESCRIPTION OF THE HIGHLY AUTOMATED SINGLE MACHINE TURNING SYSTEM

A highly automated turning system has been set up for the modelling experiments. The automatic features and the relevant data is based on TRAUB TNA 480 turning centre with Flexible Handling System 2 (FHS2). (Fig. 9.1,9.2,9.3). [92, 198, 201, 300, 301].

The CNC turning centre handles workpiece and tool exchange automatically. 6 sets of chuck jaws and gripper jaws enable the machine to handle workpieces ranging from 10 to 180 mm in diameter. The automatic chuck jaw changing features 3 top jaws being exchanged simultaneously in 3 sec. The 60 position chain type tool magazine can accommodate turning tools, live tooling, and special tools e.g. probes in any mix. It can be serviced while the machine is in operation thus reduces the machine set-up time. Two workpiece magazines of 40 stations plus 5 empty positions for part circulation have been installed. While one magazine is in use, the the other one can be set-up for next batch. The workpiece exchanger is dedicated to loading raw parts and replacing the finished ones. Its double grippers can swap the raw/finished part in 2 sec. time. The tool exchange gantry is employed both for tool exchange between tool magazine , and for chuck jaw changing. The relevant data of the single machine cell is listed in Fig. 9.2.

5 part types have been derived from TRAUB machining proposals from the company's literature for modelling the purpose, fig. 9.5. [198, 199, 200, 203]. A complex spectrum of operations are required by the 5 part types: external/internal turning, off centre drilling, key way milling, flat milling and polygon turning. The process planning information of a typical part type is shown in fig. 9.8. (Ref. to

Appendix 1A for detailed part description and processing planning information).

A total number of 28 tool types are required, including turning tools, drills, live tooling and contact probes (Fig, 9.9) [300].

The handling of the machine, part, tool information for the modelling purpose, and the Turning Model set-up is demonstrated by illustrating the conversational type screens in Appendix 1B.

9.4 SYSTEM OPERATING AND STRATEGIES

9.4.1 Tooling Strategies

The following tooling strategies have been modelled through out the case study (The framework of tooling strategy selection has been discussed in chapter 7):

(1). *Differential Kitting;* Tools are issued to the tool magazine in kits for each batch. Only the extra required tools that are not available in the machine based tool store are contained in a kit. Common tools can be shared between tool kits.

(2). *Complete Magazine Exchange:* Before the start of next production period, a newly filled tool magazine will be exchanged to the machine. The tools contained in a magazine will be all that are required for the whole production period. A production period is defined as the time required for the production of a integer number of pallets which requires the number of tools up to the magazine capacity. This is a common practice where the whole magazine can be exchanged [95, 188, 189].

(3). *Partially Serviced Tool Magazine:* At the end of previous period, only the worn tools will leave the machine, and new tools required for the next period will be loaded. It is a feasible practice as adopted by the Traub machine, when a operator is available for tool exchanging into the magazine while the machine is in operation. Otherwise, a long delay due to magazine re-set- up will happen. [14, 77, 103].

9.4.2 Production Scheduling Strategies

As will be seen in Chapter12, the user interface of the Turning Model with regards to the production scheduling has been structured in such a way that it is possible to feed the built-in production scheduler with the process and order information to produce a work-list for tool flow modelling, or to accept a pre-scheduled work-to-list. These alternative ways of scheduling the batches for machining were examined:

(1). Production scheduler: Scheduling batch by the built in production scheduling module. The scheduling rules implemented was (SPT), i.e when a part magazine is empty, sequence the batch which requires the shortest processing time to be loaded to the magazine. Part processing at the machine will be first come first served.

(2). Pre-scheduled work-to-list: Batches are given in sequenced order for machining. It was decided to model this case in the purpose of both to examine the cell performance when the cell is used for increased batch size production; and to illustrate the Turning Model's ability of taking the scheduled work-to-list from other production scheduler, e.g. the Emulator of the LUT FMS Design software suit [229].

9.4.3 Manning Operation of the System

The operator involvement for the cell operation is assumed to be carried out in the following steps:

Set-up Period

Step 1: Load the first scheduled batch to the first part magazine; Load tools for the batch to the tool magazine; Start machine processing.

Step 2: While the machine is processing the first batch, Load the second scheduled batch to the second part magazine; Load the extra required tools by the batch to the tool magazine.

Step 3: At the completion of the processing of all the parts in a magazine, the machine will process parts from the other magazine. The operator is required to unload parts from the finished magazine and load the next scheduled batch. Load tools required by the batch to the tool magazine.

Step 4: Repeat Step 3, until the last batch for the shift is loaded, go to Step 5.

Step 5: When the machine has started processing the second last batch of the shift, unload the finished magazine; unload worn tools; Load the first scheduled batch for the next period to the empty part magazine; Load tools required by the second period.

Period After Magazine Change-over

Step 6: At the completion of the last batch of the previous period, the machine will start the processing of the first batch of the second period. The operator is required to unload the finished part magazine; load the second scheduled batch to the empty magazine.

Step 7: On the completion of each magazine, unload the finished part magazine, load the next scheduled batch, while the machine is processing parts from the other magazine.

Step 8: Repeat Step 7, until all batches are loaded.

Step 9: On completion of the second last batch of the period, unload the batch.

Step 10: On completion of the last batch, unload the batch, and all the tools from the machine.

9.4.4 Average Time for Manning Operation

The following parameters were specified for analysis and modelling :

Load/unload time per part item to/from the part magazine: 0.5 min.
Time required to load a tool to the tool magazine: 1 min.
Time required to unload a tool from tool magazine: 0.5 min.

The tool and information flow of the modelled turning system if of the type 'integrated tool information flow' as discussed in Chapter 5 (fig. 5.18).It is assumed that tools are assembled and preset in the central tool store, and are loaded by the machine operator to the machine tool magazine. The preset tool data are stored in the preparation data file, and are linked up to the machine CNC controller through the cell computer. When loading a tool into the tool magazine, the operator simply inputs the No. of the tool to the set-up terminal, all the relevant data of the tool will be loaded from the data base automatically. (Fig. 9.4) [92, 201, 300, 301].

9.5 MODELLING THE PROCESSING OF SMALLER BATCHES UNDER THE PRODUCTION SCHEDULER (RUN 1 - 3)

Run 1, 2, and 3 were planned to model the single machine cell when it is subjected to a complex small batch part mix production (Fig. 9.6). The built in production scheduler was employed for batch sequencing. (Ref. to 9.4.3). The whole production process was divided into two periods according to the tool magazine pockets required. Run 1 modelled the set-up period of the system. Differential Kitting strategy was implemented for tool issuing. After the first part magazine and its associated tool kit has been loaded, the machine can start processing while the part and tool magazine can be set- up for rest of the batches.

Run 2 and 3 are continuous runs following Run 1 to model different magazine service strategies between the two periods. Run 2 represents a complete replenishment of the machine based tool store. The Complete Magazine Exchange tooling strategy has been adopted. At the end of the first period the tool magazine will be exchanged with a newly filled tool magazine with required tools for the next period. Run 3 modelled a partial magazine service.

9.5.1 Machine Utilisation

The break down of the machine utilisation (Fig. 9.10, 9.12) shows that the machine is fully utilised featuring high percentage of cutting time. This is due to that the part and tool magazine can be set up whilst the machine is in operation. The fact that in the first period, tools are loaded into magazine in kits for each batch allows the machine to commence processing as soon as possible, without waiting for the whole magazine to be filled. The two part magazine design allows the machine to process parts for one magazine when the other one is being loaded / unloaded for the next batch.

9.5.2 Manning Pattern

The operator involvement including tool magazine set-up and part magazine service. During the first period (Run 1), the operator is required for part load/unload to the part magazine between batch change over and loading tools for each batch. For the second period (Run 2 and 3), the operator is dedicated mainly for batch change over and unloading all the tools at the end of the period, fig. 9.11 9.13.

9.5.3 Tooling Requirement And Tool Magazine Service

The required number of tools for each run is given in (Fig. 9.18). The output shows that the magazine service is required between the two periods due to the magazine capacity constraints.

The first period (Run 1) requires a total number of 46tools. If the whole magazine is exchanged for the second period, 48 new tools are required (Run 2), which indicates a total number of 94 tools for the whole production period are necessary.

If at the end of the first period only worn tools are unloaded and extra tools required are loaded (Partially Magazine Service), a total number of 72 tools are required for the whole production period (Run 3), which results of saving of over 1/3 of the total tool requirement due to tool sharing between the two periods. This is due to the following two reasons:

(1). The batch sizes are small (5 - 40), and large number of the tools are not used up to the tool life limit during the first period (Ref. to Appendix 1C).

(2). The batches of the same part types are repeated between the two periods, thus the tools of the same types are required, which results a high possibility of tool sharing.

9.6 MODELLING THE PROCESSING OF A PRE-SCHEDULED WORK-TO-LIST (RUN 4 - 6)

Run 4, 5 and 6 were planned to model the processing of the 5 part types according a work-to-list with increased batch sizes compared with Run 1 - 3, fig. 9.7. The purpose of the process was to illustrate the ability of the model to accept a pre-scheduled work list from other production scheduler, and to examine the system performance under such a production requirement. The whole production is divided into two periods due to the tool magazine capacity constraints.

Run 4 modelled the first period with the differential kitting being implemented. Run 5 and 6 modelled the successive period with complete magazine exchange and partial magazine service respectively.

9.6.1 Machine Utilisation

The break down of the machine total processing time into cutting , part and tool set-up time is shown in Fig. 9.14, 9.16. High percentage of total processing is dedicated for metal removal due to the unique feature of being able to set-up while it is in cutting.

9.6.2 Manning Pattern

The manning activities for each situation are shown in Fig. 9.15, 9.17, which are in the similar pattern to Run 1 - 3. But as 'PART2' and 'PART4' requires 3 and 2 part magazines (magazine size = 40) respectively, the operator is also required for part magazine set up during the processing of the batches. This is due to the particular design of the turning cell, which indicates that when larger batches are to be processed, e.g. 40 and over, a cell layout as discussed in Chapter 3 (Fig. 3.22 [58]) which employs stacked type part pallet will be more appropriate, as there will be no manning requirement for part magazine set-up during the batch processing.

9.6.3 Tooling Requirement And Tool Magazine Service

The tool requirement for each Run is given in (Fig. 9.18). 46 tools are required for the first period (Run 4). Run 5 indicates that a new magazine of 58 tools is required, when the complete magazine exchange strategy is to be implemented. Thus a total number of 104 tools are required for the whole period.

If the partially serviced tool magazine strategy which allows tool sharing between the two periods is implemented, as the particular machine is operated, a total number of 102 tools are required, i.e. only 2 tools are saved out of 102 .

This is due to:

(1). When batches are bigger, tools are used up to the tool life limit, which makes tool sharing between shift less possible;
(2). Tools of different types are required by the two period , which reduces the chance of tool sharing even further, fig. 9.18.

Considering the sheer amount of manning requirement for the magazine service for tool loading and unloading, it is concluded that when batches of bigger sizes are to be manufactured, the whole magazine exchange between shifts will be more appropriate to reduce both manning requirement and tool management effort. The block type tool magazine and hence the tooling system as discussed in Chapter 5 should be used [156, 188, 189].

9.7 MODELLING THE PROCESSING OF INCREASED BATCH SIZE FOR A LONG PERIOD (RUN 7 - 8)

9.7.1 Overview

A large batch (600) of a typical workpiece (PART5) has been modelled. (Fig. 9.19). The purpose of this process is to explore the nature of over-medium sized production which is a common practice in cylindrical component manufacturing [103, 105] and to study the effect of altering the tool life on the frequency of magazine over and magazine complements.

Run 7 modelled the case where 50% maximum permissible tool life is specified. Relaxed permissible tool life limits were specified for Run 8. It was assumed that the life limit has been restricted to 30% for two turning tools (T2, T6); and for two live tooling (T17, T21), the permissible tool life has been relaxed to 80% due to the change to the process planning. (Fig. 9.20).

9.7.2 Discussion of the Results

The manning pattern for work flow and tool magazine exchange for the two Runs are shown in Fig. 9.21, 9.22 respectively. It is assumed that the operator is required for pallet change over, and after a integer number of pallets of parts have been processed, the tool magazine change over is required.

It was assumed that 0.5 min. is required for the operator to load/unload a part into/form the pallet; 10 min. for tool magazine exchange.

As the machine has two workpiece magazines, the machine can fly for processing parts form one pallet while the other one is being set-up. The machine has to stop while the magazine is exchanged.

For Run 7, a total number of 3 magazines is required for the processing of the whole batch, with the magazine complements of 51 tools. As for the Run 8, 4 tool magazine exchanges are required due to the change of tool life limits. The first 3 magazines contain 49 tools, and 40 for the magazine No. 4 as the number of part pallets left is less than the previous ones. (Fig. 9.23].

9.8 MANNING PATTERN PREDICTION FOR MULTI-MACHINE TURNING CELLS

As having been discussed in Chapter 7, the turning cell can be classified into 3 types, viz, Manually Supported Turning Cell, fig. 7.4, Manually Operated Turning Cell, fig. 7.5, and Highly Automated Turning Cell, fig. 7.6.

The algorithm approach the the manning pattern of a multi- machine turning cell will find its application in the manually supported cell, As for the manually operated cell, a operator is required for each machine as long as the machine is in operation. And no manning requirement is required by a highly automated cell.

Although not as precise as a discrete event simulation, the algorithm approach indicates the manning pattern across all the machines of a cell in a fast and efficient way. By altering the work schedule to individual machines, different manning patterns can be achieved for the user to experiment.

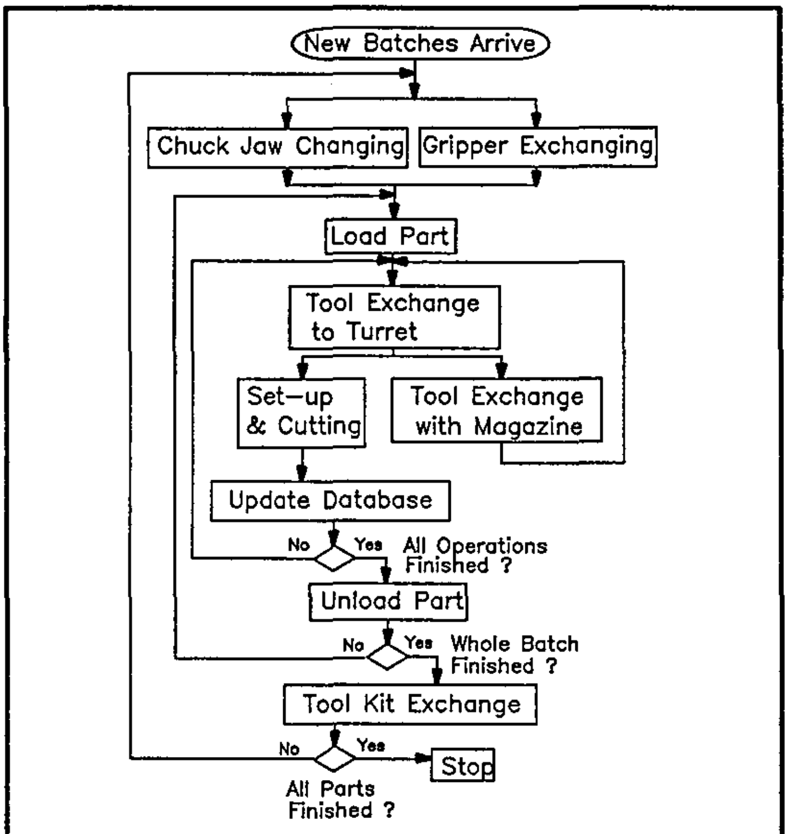

Fig. 9.1
Single Machine Model
Logic Flow Diagram

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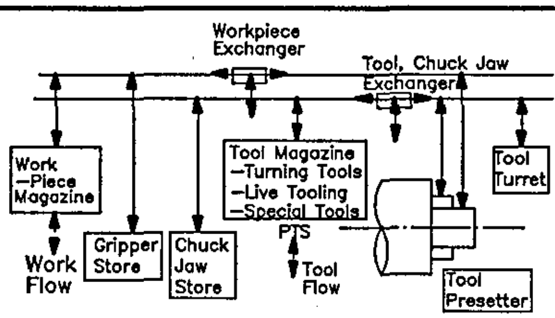

M/C data: (Required by the Model)

Turret Capacity:	14
Turret Index Time:	0.5 sec. / posit.
Tool Magazine Capacity:	60
Magazine Index Time:	0.5 sec. / posit.
Gantry Transfer Time:	2 sec.
Tool Exch. Time	
Turret – Gripper:	3 sec.
Gripper – Magazine:	3 sec.
Part Load/Unload Time:	1 sec.
Workpiece Magazine Capacity:	40
No. of Chuck Jaw Sets:	6
No. of Gripper Sets:	6
Chuck Jaw Exchange Time:	3 sec.
Gripper Exchange Time:	3 sec.

Chuck Jaw / Gripper Application Range

Set No.	1	2	3	4	5	6
Workpiece Dia. (mm)	10 – 30	20 – 40	40 – 60	50 – 100	90 – 140	130 – 180

Fig. 9.2
Synthetic Lathe Data

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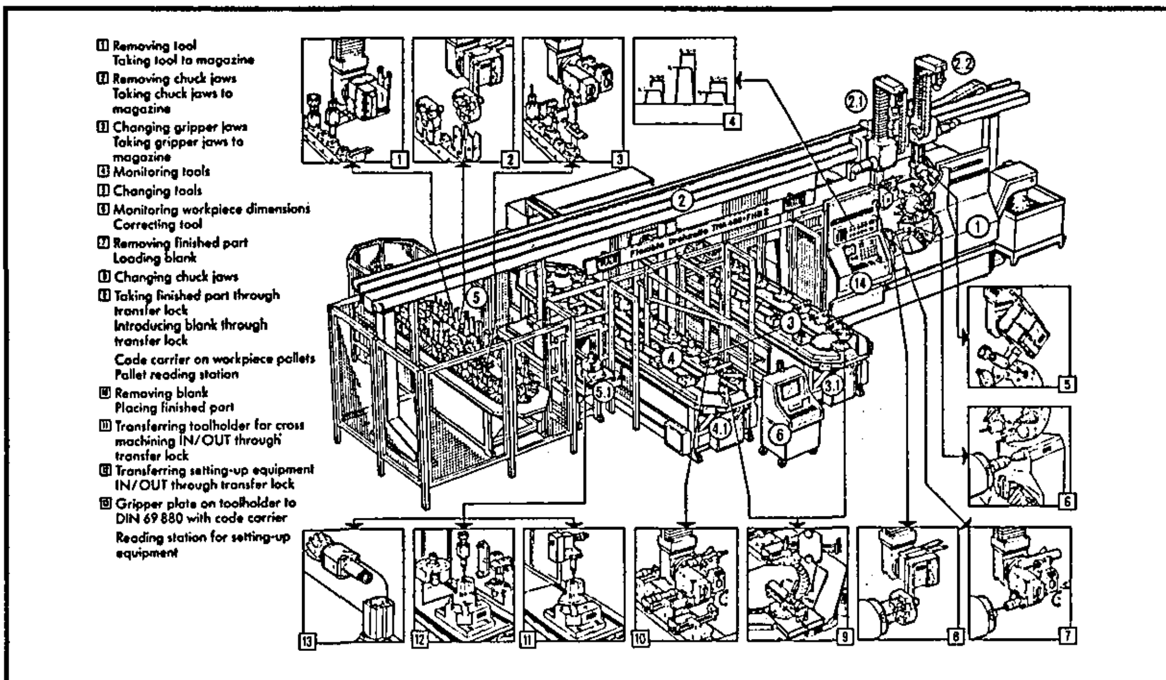

TRAUB

Fig. 9.3
Highly Automated Turning Centre
– TNA 480 with FHS2

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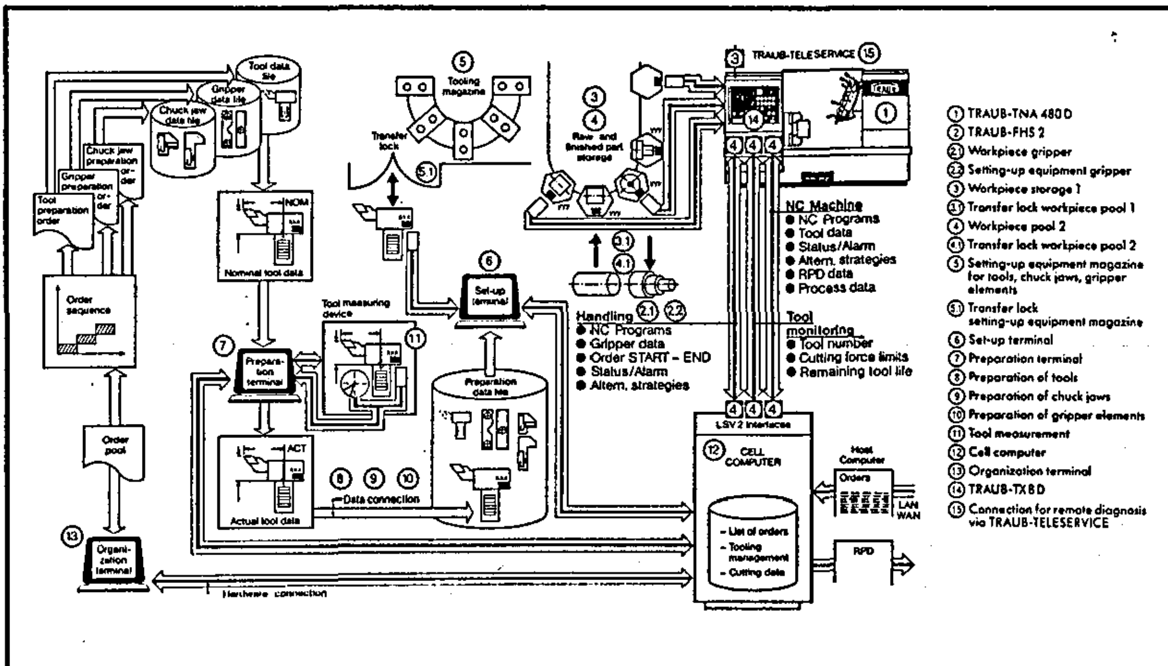

TRAUB

Fig. 9.4
Highly Automated Turning Centre
– Information Flow

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Part Type	Set-up Time/Item (min.)	Total Cutting Time/Item (min.)	Chuck. End Diameter (mm)
Part1	1	4	90
Part2	0.5	3.12	90
Part3	1	2.47	50
Part4	1.2	4.24	120
Part5	1	2.71	24

Fig. 9.5 Single M/C Modelling – Part Spectrum

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Run 1		Run 2, 3	
Part Type	Batch Size	Part Type	Batch Size
Part1	5	Part1	40
Part2	25	Part2	10
Part3	40	Part3	5
Part4	20	Part4	15
Part5	15	Part5	22

Batches will be sequenced according to SPT.

Fig. 9.6
Batch Mix For 2 Shifts Product.

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Run 4		Run 5, 6	
Part Type	Batch Size	Part Type	Batch Size
Part1	40 * 1	Part3	40 * 1
Part2	40 * 3	Part4	40 * 2
		Part5	40 * 1

Batches are listed in sequence for processing.

Fig. 9.7
Multi-shift Work-to-List

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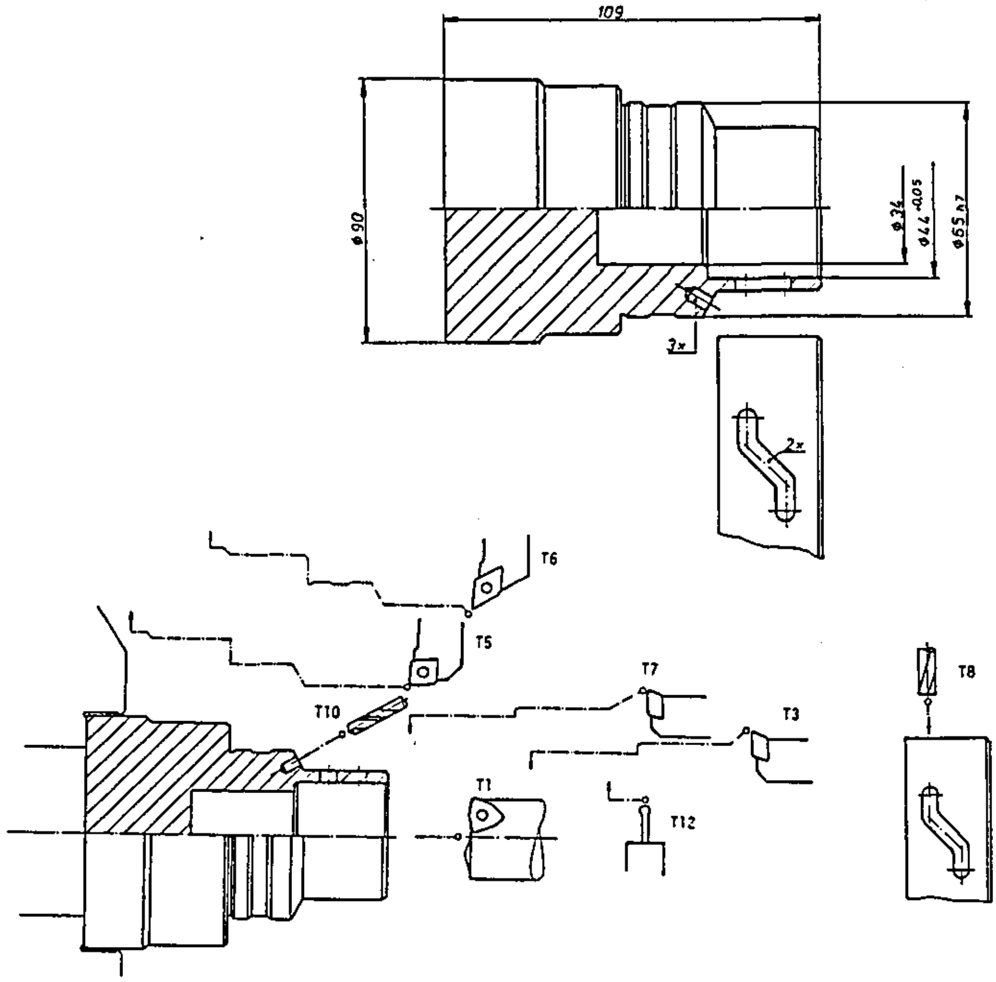
Part Type: Part 1; Material: BS080M30;



Op. No.	Op. Description	Cutting Time (min.)	Tool Type
1	Rough Turning	0.5	T5
2	Finish Profiling	0.5	T6
3	Drilling	0.6	T1
4	Boring	0.6	T7
5	Finish Boring	0.5	T3
6	Milling	1	T8
7	Drilling	0.2	T10
8	Inspection	0.1	T12

TRAUB

Fig. 9.8 Synthetic Workpiece Information

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Tool Type	Tool Description	Tool* Life (min.)
T1	Drill	16
T2	Drill	16
T3	Boring Bar	30
T4	Thread Chaser	20
T5	External Turning Tool	30
T6	External Turning Tool	30
T7	Boring Bar	30
T8	End Miller	20
T9	Parting-off & Grooving Tool	30
T10	Drill – Live	16
T11	Drill	16
T12	Probe	100 **
T13	Boring Bar	30
T14	Gun Drill	16
T15	Tap	10
T16	Drill – Live	16
T17	Circular Saw Blade	20
T18	Profiling Tool	30
T19	Grooving & Parting-off Tool	30
T20	Thread Chaser	20
T21	Polygon Turning Tool	30
T101	Drill	16
T202	External Turning Tool	30
T303	Boring Bar	30
T404	Grooving Tool	30
T707	Thread Chaser	20
T808	Internal Profiling Tool	30
T1010	Internal Profiling Tool	30
T1212	Internal Thread Chaser	20

* Max. % Permissible Tool Life = 50%
** Durable Tool

Fig. 9.9

Tool Information

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Run 1
Clock Time (0 – 457)

Cutting Time	Part (M/C) Set–up Time	Tooling Set–up Time	Idle Time	Total Processing Time
317	107	33	0	457

Run 2
Clock Time (457 – 941)

Cutting Time	Part (M/C) Set–up Time	Tooling Set–up Time	Idle Time	Total Processing Time
320	121	43	0	484

Fig. 9.10
Machine Utilisation
(Run 1, 2)

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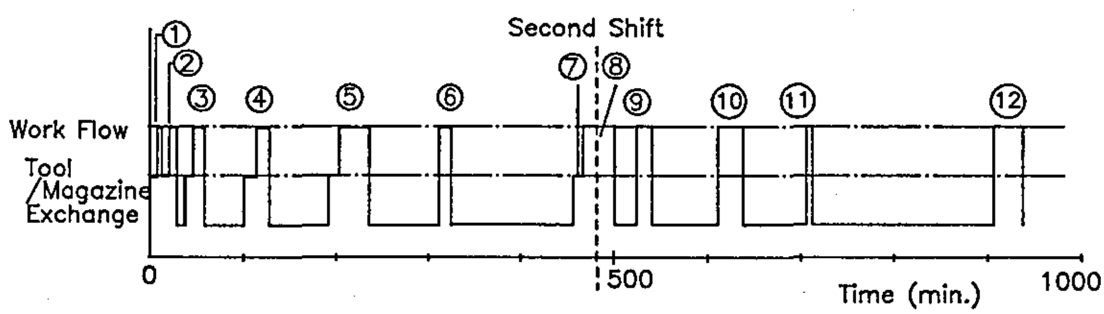

Run 1

No.	Description	Clock Time Start	Clock Time Finish
1	Load 'Part1' & Tools	0	11
2	Load 'PART5' & Tools	11	29
3	Unload 'PART1' Load 'PART2' & Tools	37	58
4	Unload 'PART5' Load 'PART4' & Tools	98	127
5	Unload 'PART2' Load 'PART3' & Tools	193	237
6	Unload 'PART4' Load 'PART3' For Second Period	310	323

Run 2

No.	Description	Clock Time Start	Clock Time Finish
7	Magazine Exchange	457	467
8	Unload 'PART3', Load 'PART2' Unload 'PART3', Load PART4'	467	502
9	Unload 'PART2', Load 'PART5'	525	541
10	Unload 'PART4', Load 'PART1'	612	639
11	Unload 'PART5'	699	710
12	Unload 'PART1' & All the Tools	911	941

Fig. 9.11
Manning Pattern
(Run 1, 2)

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Run 1
Clock Time (0 – 457)

Cutting Time	Part (M/C) Set–up Time	Tooling Set–up Time	Idle Time	Total Processing Time
317	107	33	0	457

Run 3
Clock Time (457 – 945)

Cutting Time	Part (M/C) Set–up Time	Tooling Set–up Time	Idle Time	Total Processing Time
320	120	48	0	488

Time Unit: min.

Fig. 9.12
Machine Utilisation
(Run 1, 3)

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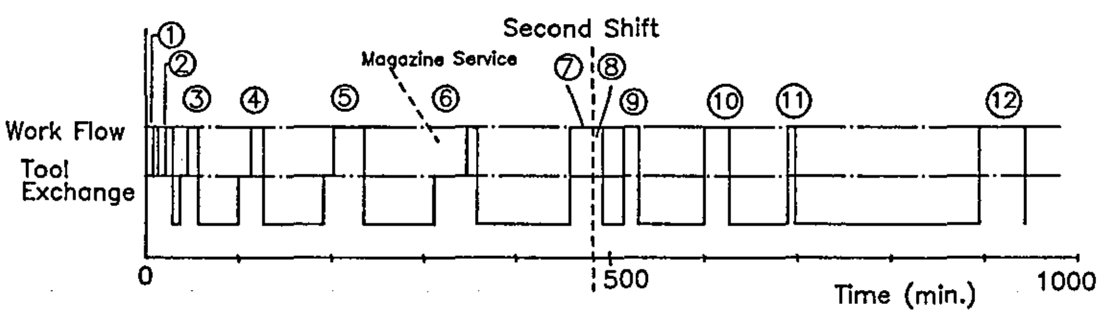

Run 1

No.	Description	Clock Time Start	Clock Time Finish
1	Load 'Part1' & Tools	0	11
2	Load 'PART5' & Tools	11	29
3	Unload 'PART1' Load 'PART2' & Tools	37	58
4	Unload 'PART5' Load 'PART4' & Tools	98	127
5	Unload 'PART2' Load 'PART3' & Tools	193	237
6	Unload 'PART4' & Worn Tools Load 'PART3' & Tools For Second Shift	310	357

Run 3

No.	Description	Clock Time Start	Clock Time Finish
7	Unload 'PART3', Load 'PART2'	457	482
8	Unload 'PART3', Load PART4'	482	492
9	Unload 'PART2', Load 'PART5'	515	531
10	Unload 'PART4', Load 'PART1'	601	628
11	Unload 'PART5'	688	699
12	Unload 'PART1' & All the Tools	897	945

Fig. 9.13
Manning Pattern
(Run 1, 3)

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Run 4
Clock Time (0 – 705)

Cutting Time	Part (M/C) Set–up Time	Tooling Set–up Time	Idle Time	Total Processing Time
518	142	45	0	705

Run 5
Clock Time (705 – 1501)

Cutting Time	Part (M/C) Set–up Time	Tooling Set–up Time	Idle Time	Total Processing Time
538	210	48	0	796

Time Unit: min.

Fig. 9.14
Machine Utilisation
(Run 4, 5)

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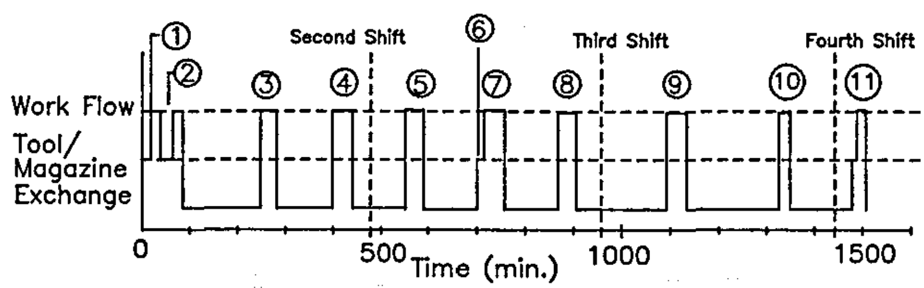

Run 4

No.	Description	Clock Time Start	Clock Time Finish
1	Load 'Part1' & Tools	0	38
2	Load 1st Mag. of 'PART2' & Tools	38	86
3	Unload 'PART1' Load 2nd Magazine of 'PART2'	247	287
4	Unload 1st Magazine of 'PART2' Load 3rd Magazine of 'PART2'	399	439
5	Unload 2nd Magazine of 'PART2' Load 'PART3' For Next Period	552	592

Run 5

No.	Description	Clock Time Start	Clock Time Finish
6	Tool Magazine Exchange	705	715
7	Unload 3rd Magazine of 'PART2' Load 1st Magazine of 'PART4'	715	755
8	Unload 'PART3' Load 2nd Magazine of 'PART4'	861	901
9	Unload 1st Magazine of 'PART4' Load 'PART5'	1090	1130
10	Unload 2nd Magazine of 'PART4'	1314	1334
11	Unload 'PART5' & All the Tools	1471	1501

Fig. 9.15
Manning Pattern
(Run 4, 5)

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Run 4
Clock Time (0 – 705)

Cutting Time	Part (M/C) Set-up Time	Tooling Set-up Time	Idle Time	Total Processing Time
518	142	45	0	705

Run 6
Clock Time (705 – 1521)

Cutting Time	Part (M/C) Set-up Time	Tooling Set-up Time	Idle Time	Total Processing Time
538	210	68	0	816

Time Unit: min.

Fig. 9.16
Machine Utilisation
(Run 4, 6)

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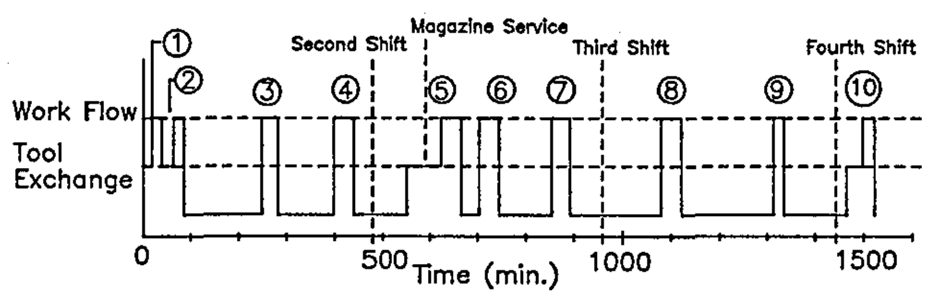

Run 4

No.	Description	Clock Time Start	Clock Time Finish
1	Load 'Part1' & Tools	0	38
2	Load 1st Mag. of 'PART2' & Tools	38	86
3	Unload 'PART1' Load 2nd Magazine of 'PART2'	247	287
4	Unload 1st Magazine of 'PART2' Load 3rd Magazine of 'PART2'	399	439
5	Unload 2nd Magazine of 'PART2' & Worn Tools Load 'PART3' & Tools For Next Period	552	667

Run 6

No.	Description	Clock Time Start	Clock Time Finish
6	Unload 3rd Magazine of 'PART2' Load 1st Magazine of 'PART4'	705	745
7	Unload 'PART3' Load 2nd Magazine of 'PART4'	852	892
8	Unload 1st Magazine of 'PART4' Load 'PART5'	1081	1121
9	Unload 2nd Magazine of 'PART4'	1311	1331
10	Unload 'PART5' & All the Tools	1468	1521

Fig. 9.17
Manning Pattern
(Run 4, 6)

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Tool Type	No. of Sister Tools Required					
	Run 1	Run 2 (New Magazine)	Run 3 Extra. Tools Req'd (Partially Serviced Magazine)	Run 4	Run 5 (New Magazine)	Run 6 Extra. Tools Req'd (Partially Serviced Magazine)
T1	1	4	3	4	0	0
T2	2	2	2	0	4	4
T3	1	2	1	2	0	0
T4	1	1	0	1	0	0
T5	4	3	3	19	0	0
T6	7	5	4	6	11	10
T7	1	2	1	2	0	0
T8	3	6	5	10	4	4
T9	1	1	0	0	1	1
T10	1	1	1	1	0	0
T11	1	1	0	0	1	1
T12	1	1	0	1	1	0
T13	2	1	0	0	2	2
T14	1	1	1	0	1	1
T15	1	1	0	0	1	1
T16	1	1	0	0	1	1
T17	1	1	0	0	1	1
T18	2	1	0	0	2	2
T19	1	1	0	0	1	1
T20	1	1	0	0	1	1
T21	2	2	1	0	3	3
T101	3	2	2	0	10	10
T202	1	1	0	0	1	1
T303	1	1	1	0	3	3
T404	1	1	0	0	1	1
T707	1	1	0	0	1	1
T808	1	1	1	0	4	4
T1010	1	1	0	0	2	2
T1212	1	1	0	0	1	1
Total	46	48	26	46	58	56

Fig. 9.18

Sister Tool Requirement

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Part Type: PART5 (Ref. to Fig. 1A.5);
Quantity: 600;
Pallet Size: 40;
Set-up Time/Item: 1 (min.).

Op. No.	Op. Description	Cutting Time (min.)	Tool Type
1	Facing	0.01	T202
2	Profiling	1	T6
3	Drilling	0.5	T2
4	Chamfering	0.05	T11
5	Threading	0.01	T20
6	Polygon Turning	1	T21
7	Drilling	0.01	T16
8	Milling Flat	0.08	T17
9	Parting-off	0.05	T9

Fig. 9.19 Part Specification
(Run 7, 8)

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Tool Type	Tool Description	Live Tooling [Y/N] ?	Tool Life (min.)	Max. Permissible % Life	
				Run 7	Run 8
T2	Drill	N	16	50	30
T6	External Turning Tool	N	30	50	30
T9	Parting-off & Grooving Tool	N	30	50	50
T11	Drill	N	16	50	50
T16	Drill – Live	Y	16	50	50
T17	Circular Saw Blade	Y	20	50	80
T20	Thread Chaser	N	20	50	50
T21	Polygon Turning Tool	Y	30	50	80
T202	External Turning Tool	N	30	50	50

Fig. 9.20 Tool Life Specification
(Run 7, 8)

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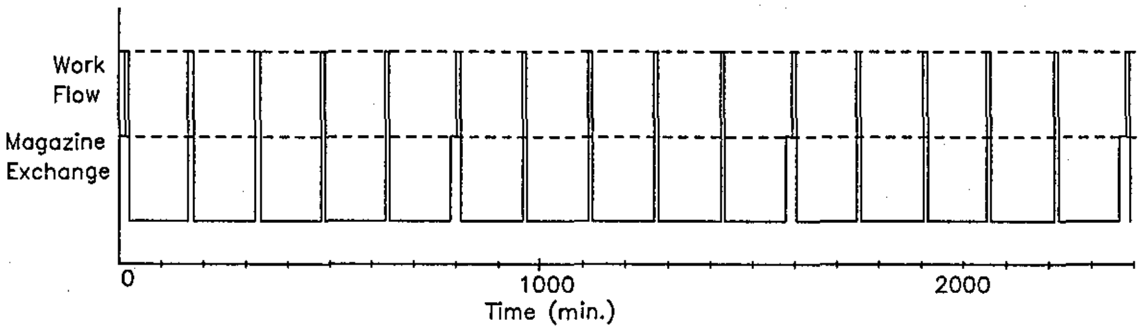

Part Type: 'PART5';
Quantity: 600;
Max. Permissible Tool Life: 50%.

Fig. 9.21 Manning Pattern
(Run 7)

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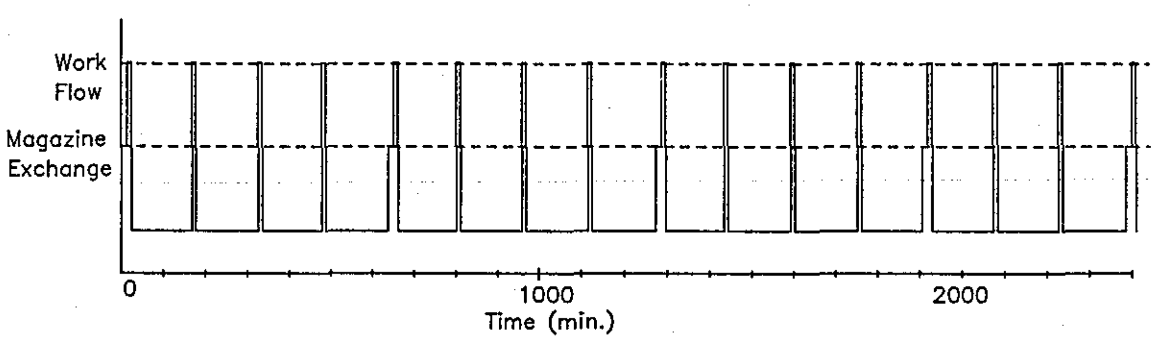

Part Type: 'PART5';
Quantity: 600;
Relaxed Tool Life Limit.

Fig. 9.22 Manning Pattern
(Run 8)

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Part Type: 'PART5';
Quantity: 600;

Magazine Complements

Tool Life Limit: 50%; (Run 7) Magazine No. 1 – 3;		Relaxed Tool Life Limit; (Run 8)			
		Magazine No. 1– 3		Magazine No. 4	
Tool Type	No. of Sister Tools	Tool Type	No. of Sister Tools	Tool Type	No. of Sister Tools
T2	13	T2	18	T2	14
T6	15	T6	18	T6	14
T9	1	T9	1	T9	1
T11	2	T11	1	T11	1
T16	1	T16	1	T16	1
T17	2	T17	1	T17	1
T20	1	T20	1	T20	1
T21	15	T21	7	T21	6
T202	1	T202	1	T202	1
Total No. of Tools: 51		Total No. of Tools: 49		Total No. of Tools: 40	

Fig. 9.23
Summary of Magazine Complements

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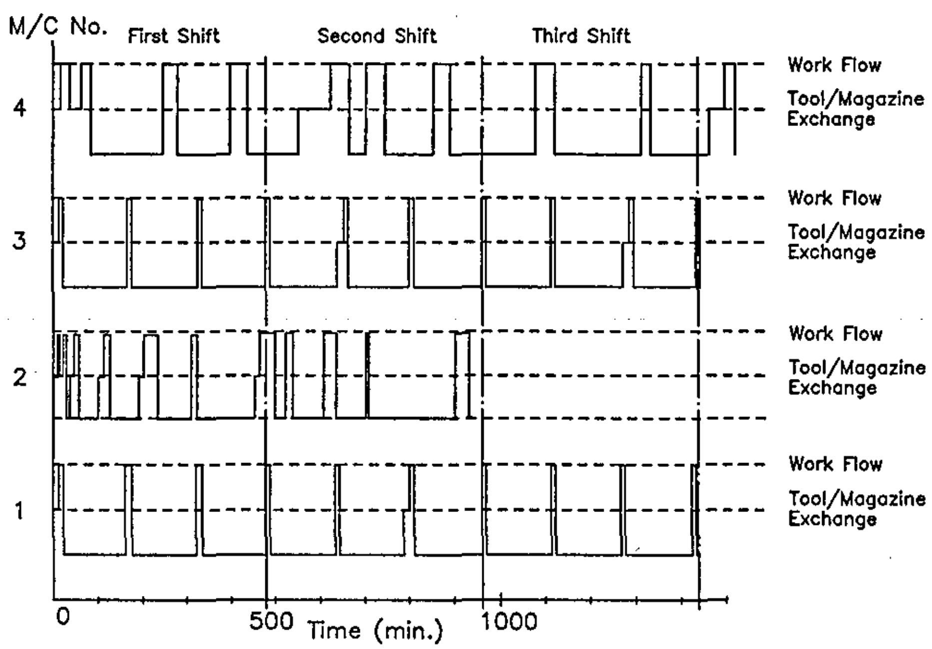

Fig. 9.24
Indication of Cell Manning Pattern

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CHAPTER 10 TOOL FLOW MODEL - MULTI-MACHINE

10.1 INTRODUCTION

This chapter describes the tool flow model in multi-machine turning cell level. As being indicated in Chapter 7 the tool flow model for a turning cell of a mix of turning centres has been concentrated on the cell tool storage, tool transportation and tool exchanging between STS and individual machines. The implementation of the tooling strategies have been discussed in detail in this Chapter, as one of the main implications of the Tool Flow Model will be the evaluation of the tool issue, assignment, and storage strategies for a specified tool configuration.

10.2 OVERVIEW OF CELL LEVEL ACTIVITIES

The multi-machine turning cell model is built up on the basis of single machine models. The individual machines are linked up by the cell level tool flow and part control strategies, with their PTSs being backed up by the cell Secondary Tool Store (STS).

The activity diagram of a turning cell is shown in fig. 10.1. New tools are transferred from CTS to STS and exchanged with tools leaving the turning cell. Before the current batch has finished its processing, the tools required for the next one will be issued from the STS to the machine's PTS. On completion of the current batch, tools leaving the PTS will be exchanged with tools for the new batch, and the used ones will be transported back to STS. [244, 289, 290, 291]. The logic flow chart of multi-machine tool flow model is shown in fig. 10.2.

10.3 Nomenclature

n: position No.;
Stock2(n): The content of STS position n;
Stock3(n): The content of CTS position n;
t : Tool No.;
$Posit_t$: The position No. occupied by tool t;
$L_t = 1$, if tool t is live tooling;
$= 0$, otherwise.

T_t = 1, if tool t is turning tool;

= 0, otherwise.

$TStatus_t$ = 'W', if tool t is worn;

'R', if tool t is reserved;

'F', if tool t is free. (Ref. to 8.3).

$1X_t$ = 1, when all tips have been used for *Tool Flow Pattern 1*, or, the current tip is worn out for *Tool Flow Pattern 2*.

= 0, otherwise.

$2X_t$ = 1, if tool t is required;

= 0, otherwise.

TR: Tool returned list from STS to CTS,

size (TR) <= Transporter capacity;

TI: Tool issue list from CTS to STS;

size (TI) <= Transporter capacity;

SC: STS capacity;

TranT1: Transfer time between STS and CTS.

CUNLT: CTS tool unload time;

CLT: CTS tool load time;

SUNLT : STS tool unload time;

SLT: STS tool load time;

10.4 TOOL EXCHANGE BETWEEN CTS AND STS

The logic flow chart of tool exchange between CTS and the cell STS is shown in fig. 10.3. If any machine requires tools from the STS, the required tools will be searched for in the secondary store. If the desired tools are not found, they will be searched for in the CTS, thus the CTS tool issue list will be formed (Ref. to fig. 7.3) [41].

Tools not required and worn tools will be returned to CTS (Fig. 10.4) and disposed. The returned tool list will include the live tooling which requires refurbishment, turning tools with one or all tips (if applicable) worn out, and tools which are not required any more for the production period.

Algorithm 10.1, TOOL RETURNING TO CTS LIST

Step 1. n = 1;
Step 2. t = Stock2(n);
   2.1). If $L_t = 1$ and $TStatus_t$ = 'W' then
      Add tool t to TR, go to Step 3
    Else go to Step 2.2;
   2.2). If $T_t = 1$ and ${}^1X_t = 1$ then
      Add tool t to TR, go to Step 3
    Else go to Step 2.3
   2.3). If ${}^2X_t = 1$ then
      Add tool t to TR, go to Step 3,
    Else go to Step 3;
Step 3. If n <= SC then n = n + 1, go to Step 2
  Else Terminate.

Algorithm 10.2, TOOL EXCHANGING BETWEEN STS AND CTS

```
Step 1. Load Transporter with New Tools from CTS:
      For t := 1 to Size(TI) do
      Begin
         n := Posit_t;
         Stock3(n) := 0;
      End;
Step 2. Unload Tools from the STS:
      For t := 1 to Size(TR) do
      Begin
         n := Posit_t;
         Stock2(n) := 0;
      End;
Step 3. Load STS with New Tools:
      For t := 1 to Size(TI) do
      Begin
         Search the first empty position n;
         Stock2(n) := t;
         Posit_t := n;
      End;
```

Step 4. Replace Tools Returned to CTS:

For t := 1 to Size(TR) do

Begin

Search the first empty position n;

Stock3(n) := t;

$Posit_t$:= n;

End;

Step 5. Update Make-span (M) and Flow Time (F_i):

M = M' + 2 * TranT + CUNLT + SUNLT + SLT + CLT;

F = F' + TranT + CUNLT + SUNLT + SLT;

M': Previous make-span up to date;

F': Previous flow time up to date;

Step 6. Update Transporter Utilisation (TU):

TU = TU' + 2 * TranT + CUNLT + SUNLT + SLT + CLT;

TU': Transporter utilisation up to date;

10.5 TOOL ISSUE AND EXCHANGE BETWEEN PTS AND STS

The tool issue to individual machines follows either the tool kitting concept or the single tool concept (Ref. Chapter 7). In the former case the tool list will be the tool kit. When single tool issue strategy is adopted, the following algorithm is implemented to form the tool issue list (TI2) to individual machines:

Algorithm 10.3 , STS TOOL ISSUE TO INDIVIDUAL MACHINES

Let:

$X_{i,p,j,m} = 1$, if operation j of order i, pallet p, is assigned to machine m;

$= 0$, otherwise;

$j \in J$ (Set of operations of part i);

Step 1. J = 1;

Step 2. If $X_{i,p,j,m} = 1$ then

Locate Single Tool t for operation j

(Ref. to Chapter 8 for Algorithm 8.3 and 8.4),

go to 2.1

Else go to 3

2.1). If tool t is not in turret or PTS then

Add to TI2, go to 3

Else go to 3;

Step 3. If j < No. of operations of part i then

j = j + 1, go to Step 2

Else go to Step 4;

Step 4. Repeat the same procedure for all batch items, with the continuous update of tool life consumption. The final result will be the Tool Issue List to machine m.

Once tools for a CNC lathe are transferred to its PTS, they are exchanged with the tools leaving the PTS (if any), at the appropriate point in the machining cycle. The tool file for the machine will be updated with new tool identifications and the relevant data. Tools, which have been decided as to be removed, will be returned form the PTS to the cell's Secondary Tool Store (STS). [41, 46]. (Fig. 10.5). The tool transfer and exchange time will be taken into the calculation of part processing time and transporter utilisation.

If tool requirements from several machines arise in the same time, or in a short time interval, the service of respective PTS will be operated on a First Come First Served (FCFS) base, the tie-breaker will be the machine number.

The tool issue and exchanging to individual machines solves one of the most important parts of the machine loading problem which is one of the three phases of production scheduling and control problem of the Turning Model. (Ref. to Chapter 12). The selection of tooling strategies has been discussed in chapter 7.

10.6 INITIAL TOOL POSITION ARRANGEMENT

Initial tool arrangement into different tool stores is possible (39, 40, 41). Tools can be assigned initially, before running the model, into specified positions of tool stores (CTS, STS, PTSs, and turrets). Thus a specific initial system status can be modelled.

Alternatively, all tools can be assumed to be in the CTS at the beginning of modelling period, thus the effort of inputting the initial tool arrangement can be eliminated.

It has been decided to assume that all the tools are stored initially in the CTS sequentially according to the tool numbers, unless the user is willing to input his own specified initial tool arrangement.

10.7 OBTAIN TIME RELATED RESULTS

The algorithmic approach differs form the discrete event simulation in that it is not based on minimum time incremental. Instead, the *'major activity* time incremental is used. The *'major activity'* is defined as the event which causes a machine to be interactive with outside facilities, e.g cell level tool and part flow. With in the time interval between 'major activities' the model handles the events of tool and part exchange and machining in the machine level and keeps the records of a event start and finish time, fig. 10.6. At the end of each *'major activity'* a check is carried out to back trace other major activities that should have happened since last time update for all the machines in the cell. The machine which has the earliest start will be chosen, and will be modelled for its detailed event activities.

This approach is not time synchronised, but is time related and the outputs can be obtained with reasonable level of accuracy, as it is considered that the event happened during the *'major activity'* intervals will not effect the cell level decision making concerned with tool and part flow and manning requirement.

It is only when cell level tool and part transfer is required, the comparison of the requirement time of each machine and its status at the time point is carried out. The machine with its earliest requirement time will be served.

This modelling approach reduces the run time by cutting the comparison loops for machine level activity event.

The manning operation of each machine is based on the earliest start time. No constraints of manning resource is considered. Thus the approach assumes that no delays will be caused by the unavailability of operators. It predicts the manning requirement density and forms the base for fine tuning the manning pattern.

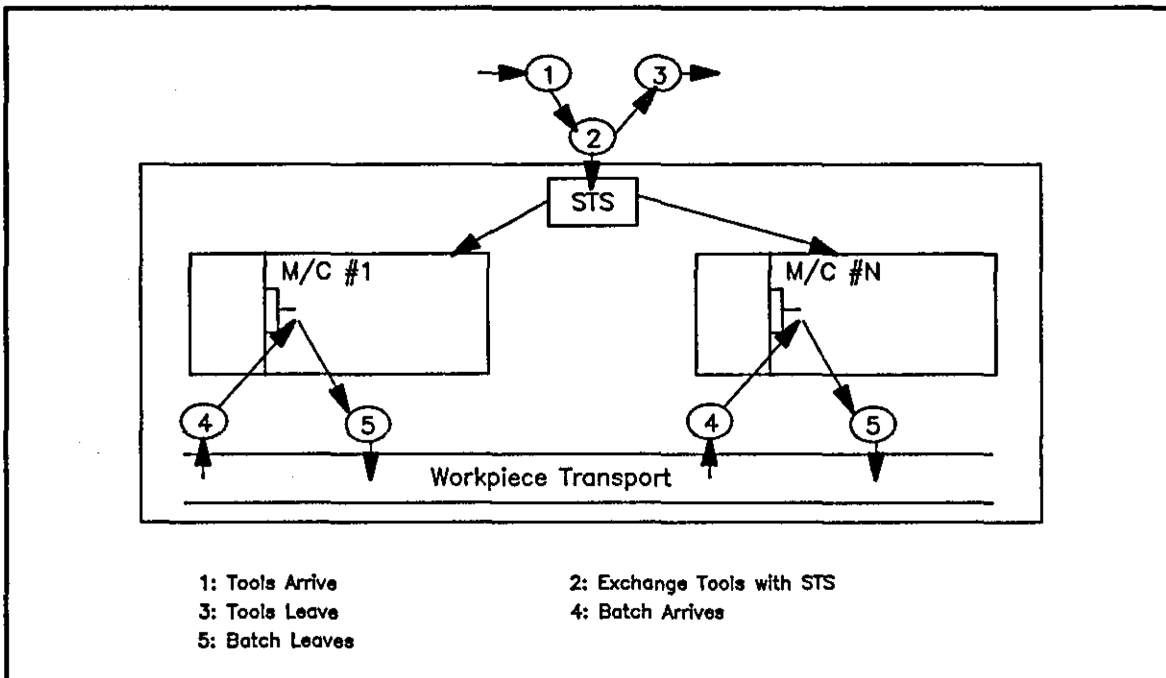

Fig. 10.1
Turning Cell Activity Diagram

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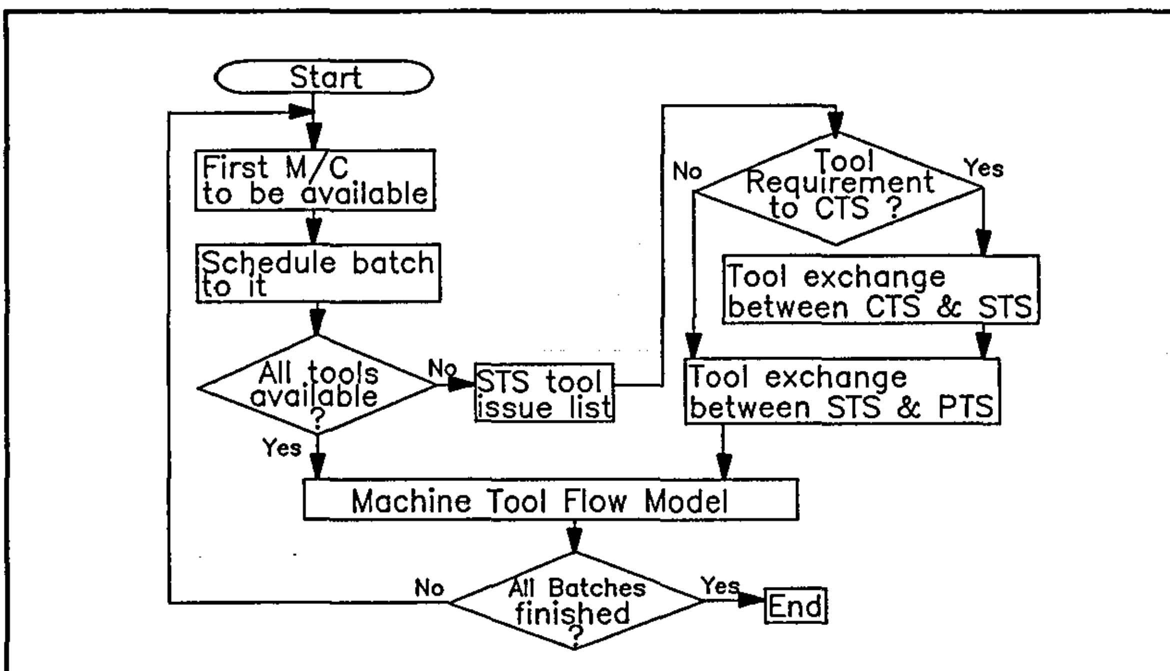

Fig. 10.2 Logic Flow of
Multi–machine Tool Flow Model

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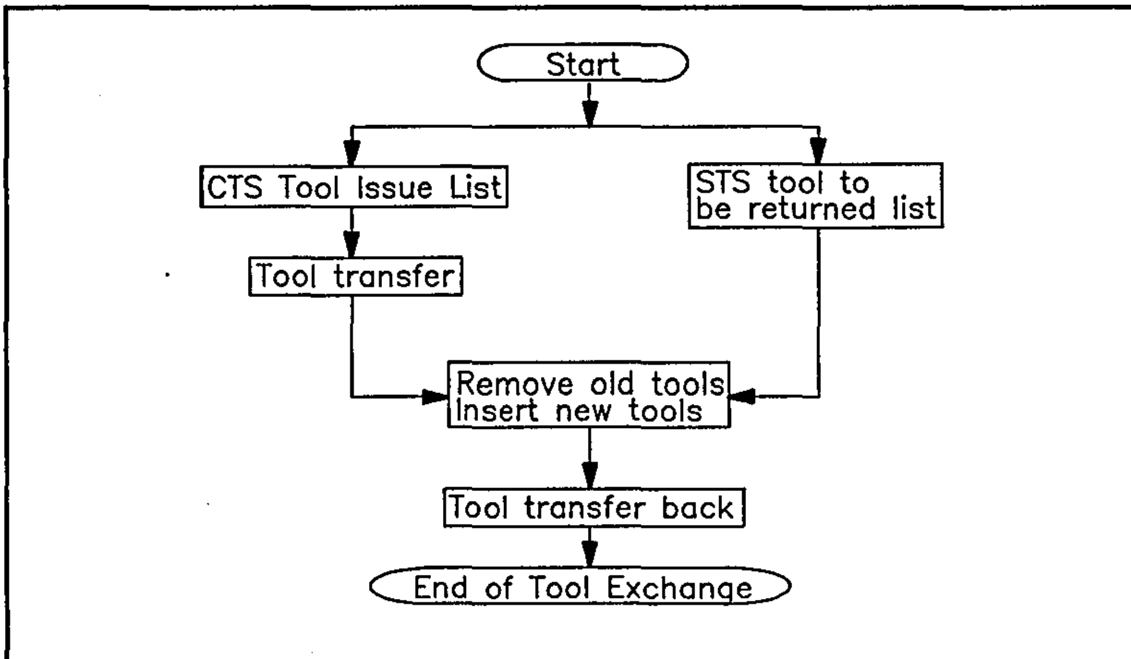

Fig. 10.3
Tool Exchange between CTS & STS

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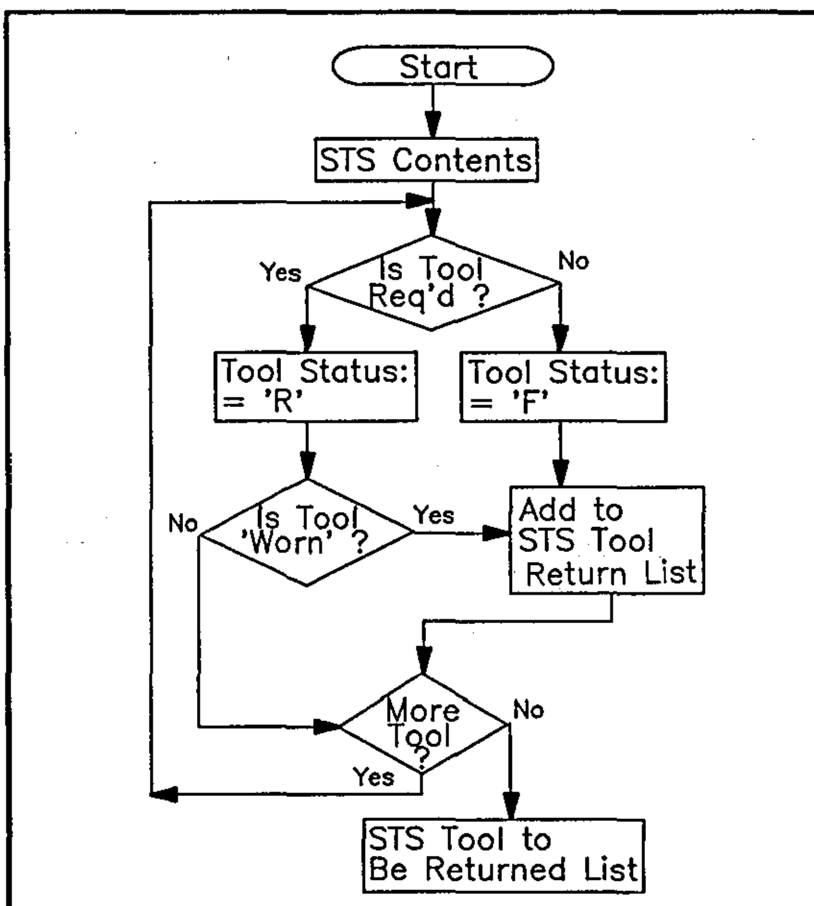

Fig. 10.4
STS Tool Return Planning

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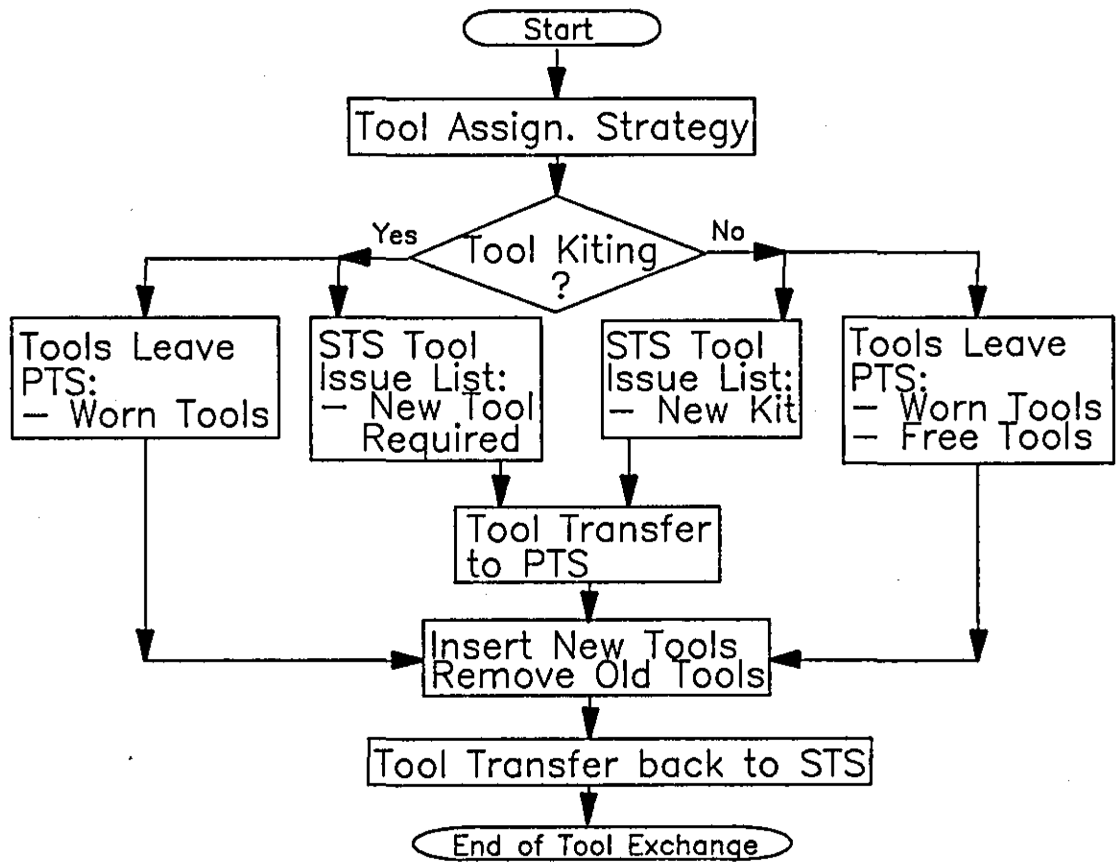

Fig. 10.5

Tool Exchange between STS and PTS

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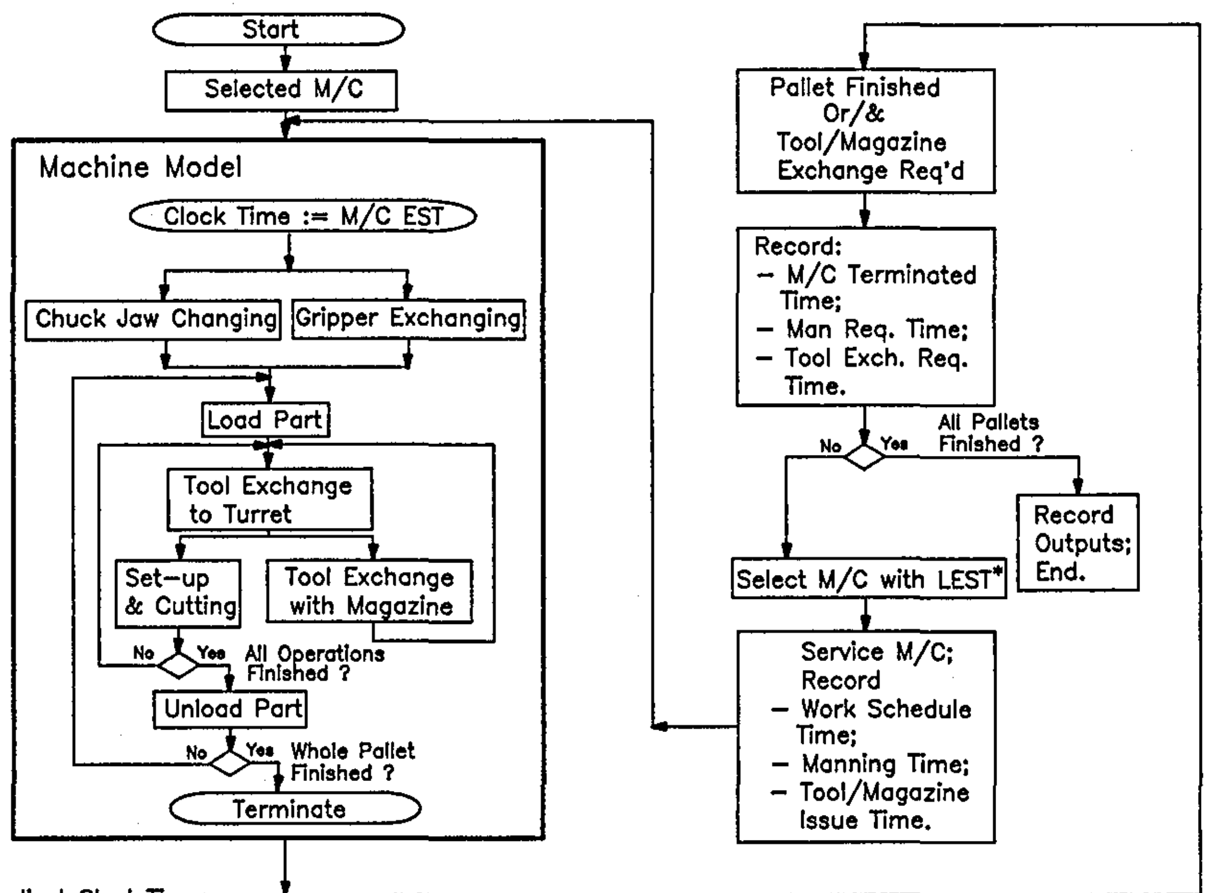

* LEST = Least Earliest Start Time;

Fig. 10.6

Algorithmic Approach for Time Related Outputs

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CHAPTER 11 TOOL FLOW MODEL - CENTRAL TOOL STORE ACTIVITIES

11.1 INTRODUCTION

This Chapter presents the Tool Flow Model with respect to Central Tool Store (CTS) activities. It handles the CTS in the following aspects: tool issue planning, returned tool disposal, tool assemble and preset, and tool part requirement planning. As having been indicated in Chapter 7, the CTS model has been devoted in two folds: the modelling of tool handling and the forecasting of tool preparation and tool part inventory control, fig 11.1.

11.2 NOMENCLATURE

IList: Tool issue list of CTS;
IList(n): The tool No. of the nth tool in the tool issue list;
SRList: Returned tool list to CTS;
SRlist(m): The tool No. of mth tool in the returned tool list;
RecList: Recondition tool list;
RecList(l): The tool No. of lth tool in the Recondition tool list;
AList: Tool assembly list;
Alist(l): The tool No. of lth tool in Alist;
PList: Tool Presetting list;
PList(m): The tool No. of mth tool in PList;
TRList: Tool requirement list;
TRList(n): The tool No. of nth tool in TRList;
TPRList: Tool part requirement list;
Stock2(n): The tool No. contained in position n of STS;
ETT_t: Expected tool usage;
$TMax_t$: Maximum permissible tool life of tool t;
FTN_t: Functional tool No. (Tool type) of tool t;
$P_{i,j}$: Cutting time of operation j of part i;
$TType_{i,j}$: Tool type required by operation j of part i;
$Tips_t$: No. of usable tips of tool t;
$TipUsed_t$: No. of tips used of tool t;

N_t = E, if tool t is a external op. tool (Including probes);
= I, If tool t is a internal op. tool (Including probes);
= L, if tool t if a secondary op. tool;

^1X_t = 1, if tool t is available;
= 0, otherwise;

^2X_t = 1, if tool t is preset;
= 0, otherwise;

^3X_t = 1, if tool t is required later;
= 0, otherwise;

11.3 TOOL ISSUE PLANNING

Tools are issued to the turning cell according to the production schedule. Tools are issued either for the next manufacturing period (e.g, one shift), or for the next batch. The former matches centralised tool storage strategy (Ref. to Chapter 7), where tools for the planned period are stored in the machine based tool stores (most likely, block type tool magazines), and are replenished at the end of the period. Tool sharing is allowed across all batches visiting the machine, fig. 11.1.

The latter is aimed to suit the decentralised tool storage strategy, accompanied by tool issue strategy of kit concept, for more automated turning systems with frequent tool flow. The tool issue planning solves the FMS loading problem with regard to the tooling side (Ref. to Chapter 12).

Tool issue list for the next manufacturing period is generated by referring to the production requirement for the period. Tools of the same type required by each operation, with sufficient life is added to the issue list, fig. 11.2. In such a case, the tool leave machine list will be the contents of machine based tool stores.

Algorithm 11.1, TOOL ISSUE FOR NEXT MANUFACTURING PERIOD

Step 1. Initialise tool issue list IList.
Step 2. n = 1;
2.1). t = IList(n);
If $FTN_t = TType_{i,j}$ then go to 2.2
Else go to 2.3;

2.2). If $ETT_t + P_{i,j} <= TMax_t$ then go to 4

Else go to 2.3;

2.3). If n < Size(IList) then

n = n + 1, go to 2.1

Else

go to Step 3;

Step 3. Add tool t ($FTN_t = TType_{i,j}$) to IList;

n = Size(IList) + 1;

IList(n) = t;

go to Step 4;

Step 4. Update expected tool life utilisation;

$ETT_t = ETT_t' + P_{i,j}$;

(ETT_t': Previous ETT_t)

go to Step 5;

Step 5. If all operations finished then

go to Step 6

Else j = j + 1, go to Step 2;

Step 6. Repeat Step 2 - 5 for all items of all batches.

The STS tool issue list to a machine for the next batch is worked out by comparing the tools required by the batch with the machine based tool store contents, which is then compared with the STS contents. The required tools which are not in the STS will form the tool issue list for the next batch [41] (Fig. 11.3).

Algorithm 11.2, TOOL ISSUE FOR NEXT BATCH

Step 1. Initialise IList;

Step 2. Generate tool requirement List (TRList) of the machine.

(Ref. to Chapter 10).

Step 3. Check the STS Contents:

IList = TRList - Intersection(TRList, STock2);

11.4. TOOL ASSEMBLE AND PRESETTING

Tools are assembled and preset in the CTS according to the tool issue planning.The tool issue list compared with the CTS contents and the gauged tool file works out the tools to be assembled and preset list. Tools not available are assembled and the un-gauged tools are preset (if applicable) for entering the turning cell. [57, 96, 101, 127, 149, 163, 164] (Fig. 11.4).

Algorithm 11.3, TOOL ASSEMBLE AND PRESET

Step 1. n = 1;
Step 2. t = IList(n);
    2.1). If ${}^1X_t = 0$ then
            Add tool t to Alist,
            Add tool t to PList, go to 3
        Else go to 2.2;
    2.2). If ${}^2X_t = 0$ then
            Add tool t to PList;
            Go to 3;
Step 3. If n < Size(IList) then
        n = n + 1, go to 2
    Else Stop.

11.5 TOOL PART REQUIREMENT PLANNING

The tool assembly has been considered to consist of the following parts: the insert, the shank, and the tool holder (if applicable) for mounting into the turret.

The requirement of tool parts come from two sources: the insert requirement for tool recondition, and the requirement of various parts for tool assembly. By referring to the tool assembly data base which gives the tool part requirement for each tool type, combined with the tools to be prepared list, the tool part requirement can be produced .[96, 101, 149]. (Fig. 11.5).

Algorithm 11.4, TOOL PART REQUIREMENT

Step 1. Tool Part Requirement due to Tool Conditioning:
    1.1). Tool recondition list (REcList) is the sub-set of Returned tool list (SRList), which contains tools satisfying $TStatus_t$ = 'W',
        where t = SRList(m)   (m = 1...Size(SRList)).

1.2). l = 1;

1.3). t = RECList(l);

If N_t = 'L' then go to 1.4

Else

If $TipUsed_t = Tips_t$ then

Add to TPRList, go to 1.4;

1.4). If l < Size(RECList) then

l = l + 1,

go to 1.3

Else go to Step 2;

Step 2. Tool Part Requirement due to New Tool Assembly:

2.1). l = 1;

2.2). t = AList(l);

If tool parts required by tool t available in TPRList then

go to Step 3

Else go to 2.3;

2.3). Add to TPRList, go to 3;

Step 3. If l < Size(AList) then l = l + 1 then

go to 2.2

Else stop.

The tool part requirement planning can be used either to give the detailed information including of time and tool components to facilitate the CTS tool assemble and recondition for the immediate manufacturing, or, to give an aggregate forecast of CTS tool part inventory and purchasing for a medium to long planning period.

11.6 RETURNED TOOL DISPOSAL

A tool returned from the machining area is assessed, if it is reusable, it will be preset for re-entering the circulation. [40, 41, 57, 101]. The logic of this process of handling is presented with the flow chart in fig. 11.6. Live tooling regrindable will be refurbished [93]. Turning tools with indexable inserts will be reconditioned with a fresh tip presented. Tools not required will be disassembled and the tool record will be erased from the tool file.

Algorithm 11.5, RETURNED TOOL DISPOSAL

Step 1. $l = 1$;

Step 2. $t = SRList(l)$;

If ${}^3X_t = 1$ then

go to Step 3

Else

disassemble tool t,

go to Step 6;

Step 3. If $TStatus_t =$ 'W' then

go to Step 4

Else add to PList,

go to Step 6;

Step 4. If $N_t =$ 'L' then

Refurbish tool t, add to PList, go to Step 6

Else

go to Step 5;

Step 5. If $Tipused_t = Tips_t$ then

exchange tip,

go to Step 6

Else

index tip,

go to Step Step 6;

Step 6. If $l <$ size(SRList) then

$l = l + 1$,

go to Step 2

Else Stop.

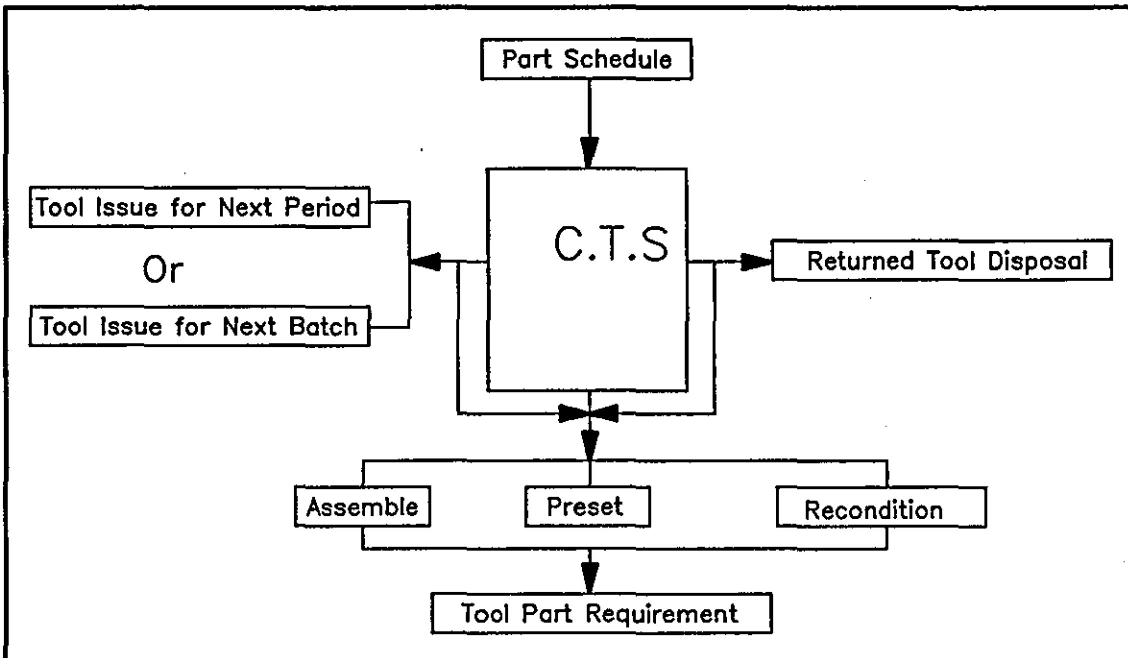

Fig. 11.1
Modelling of CTS

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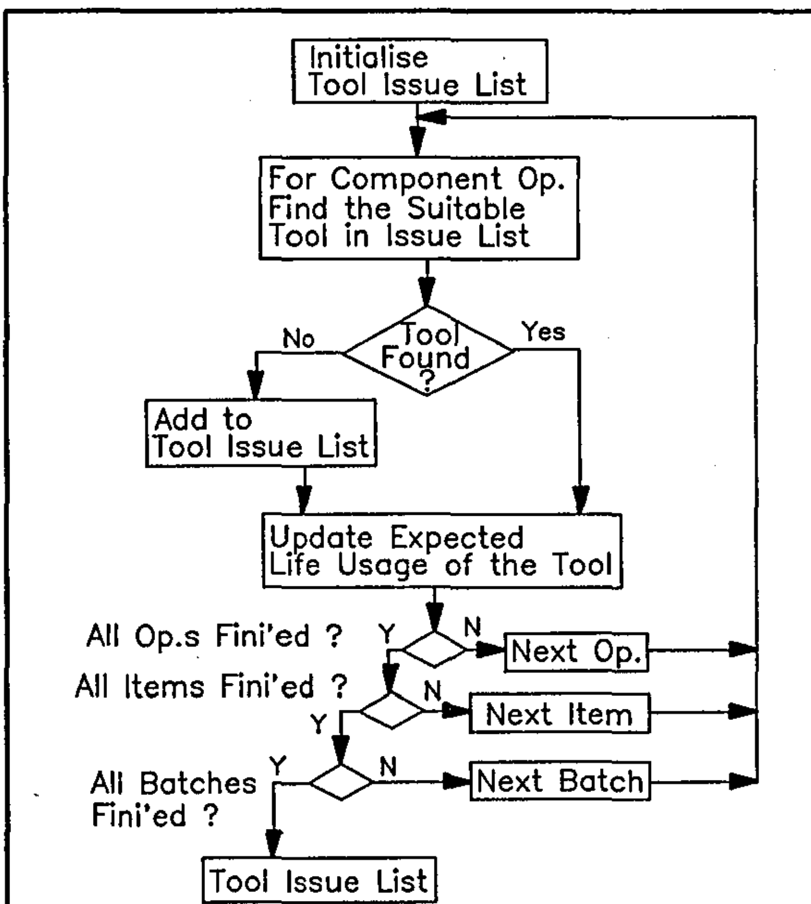

Fig. 11.2
CTS Tool Issue for
Next Period

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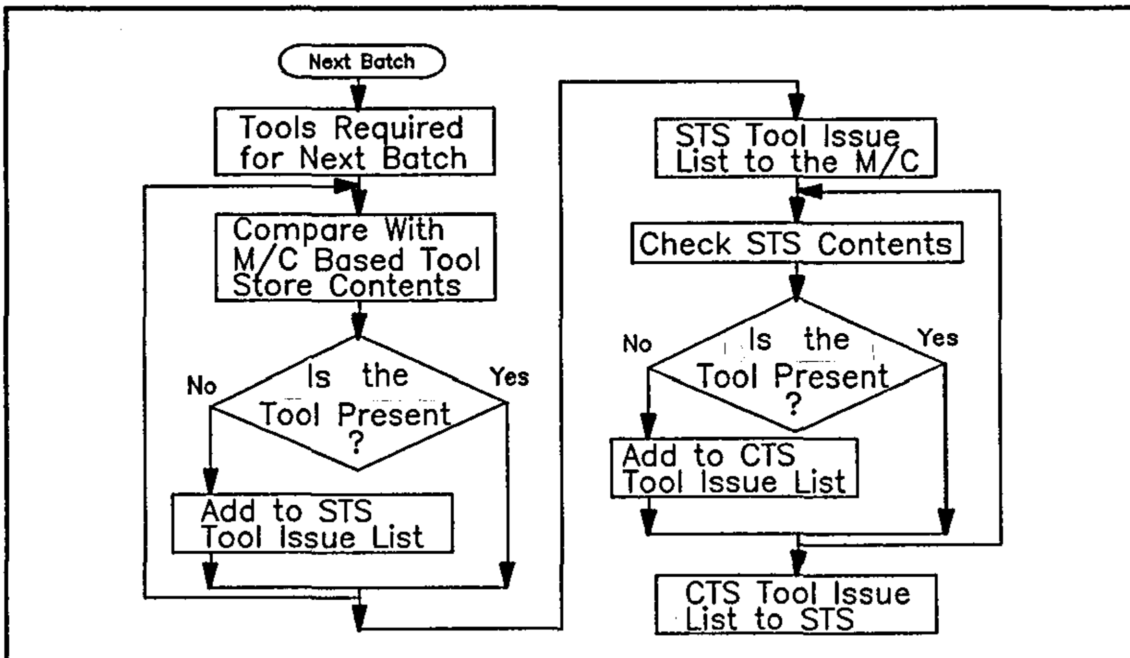

Fig. 11.3
CTS Tool Issue for Next Batch

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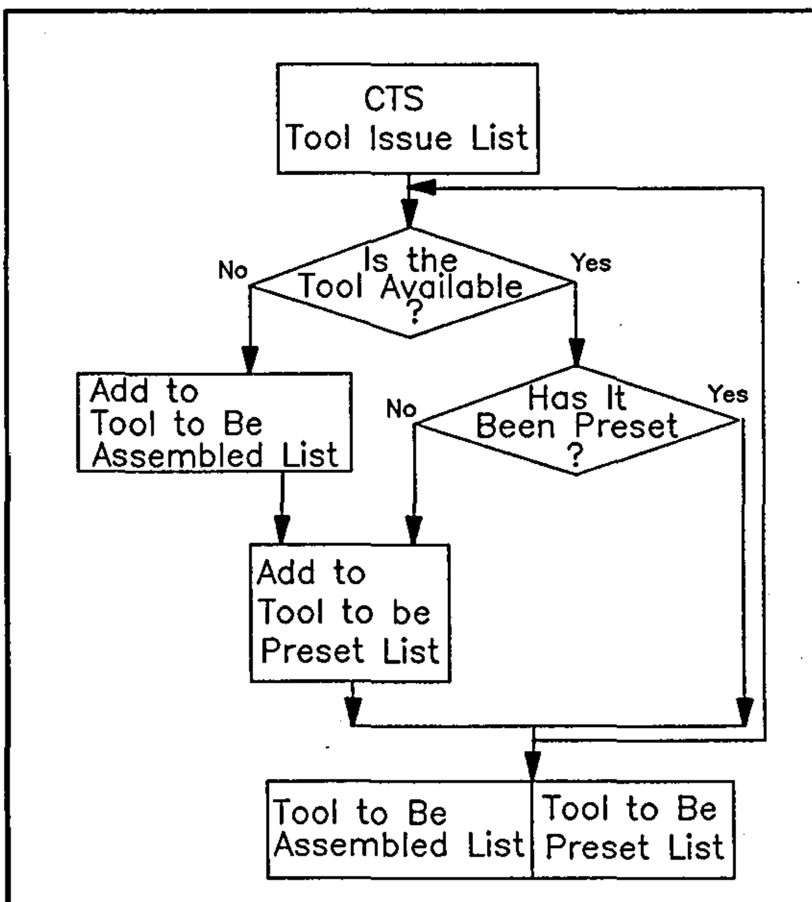

Fig. 11.4
CTS Tool Assemble
& Preset Planning

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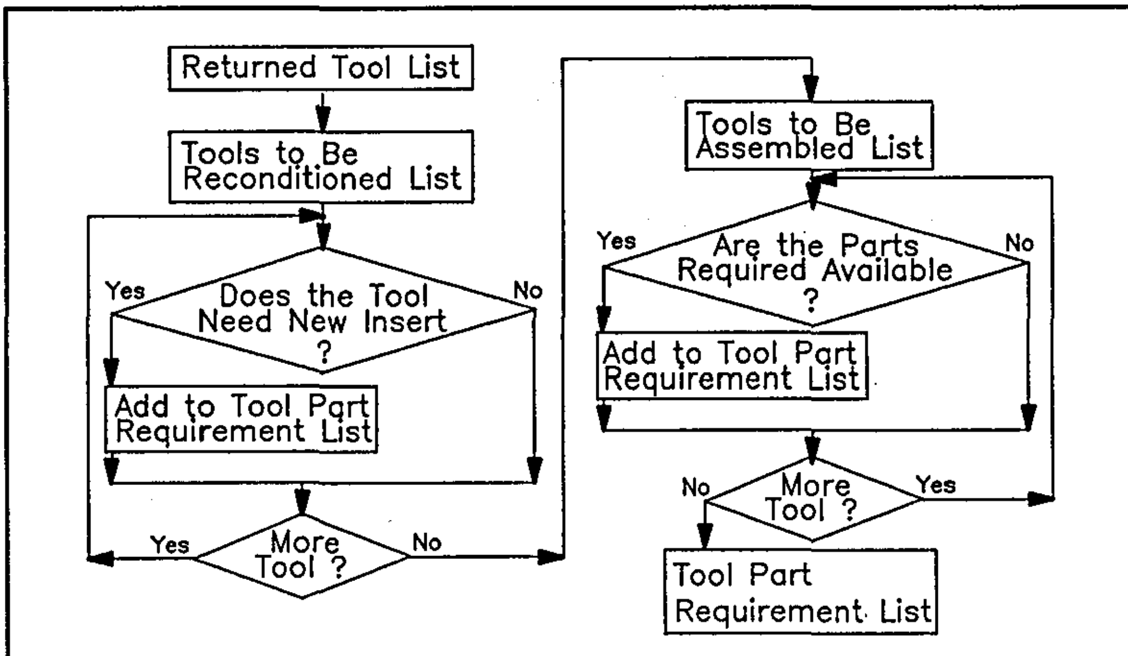

Fig. 11.5
Tool Component Requirement

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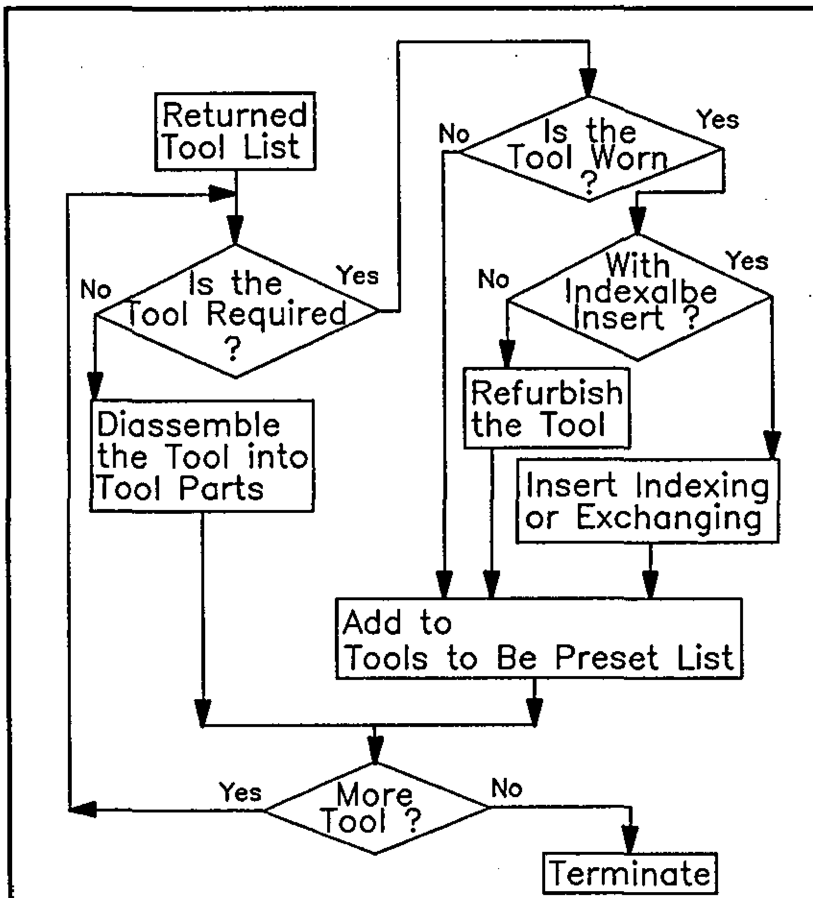

Fig. 11.6
CTS Returned Tool
Disposal

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CHAPTER 12 PRODUCTION SCHEDULING IN THE TURNING MODEL

12.1 INTRODUCTION

As has been indicated in Chapter 6 that the production scheduling functions have been added with an aim to examine the production scheduling rules interactively with tool flow management systems. No attempt is made to develop optimal scheduling rules, but the production module has been incorporated to maximise the efficiency of the modelling; and to schedule the part flow with the objective for tool saving by making use of the tool flow model.

This chapter presents the workload assignment algorithms and two types of sequencing algorithms, i.e External and Internal scheduling algorithms, for two types of production environments.

The incorporating of the production scheduling front-end into the Turning Model structure has been summarised in fig. 12.9.

12.2 OVERVIEW OF THE PRODUCTION SCHEDULING MODULE

The control and operation of FMS embraces the following aspects: part type selection, machine grouping, production ratio determination, and resource loading and part sequencing. [261, 263, 268, 275]. The whole process can be classified into the following steps [60]:

(1). The tactical step: *Level 1*, aggregate plan, the capacity limit as a function of the product mix must be incorporated. The objective of this plan is to minimise total cost composed of inventory and storage cost. *Level 2*, part (orders) are assigned to machine groups (machines) [35], with the objective of maximising tool-machine efficiency under the constraints of technical capability of machine tools. This is the field where the Computer Aided Cluster Analysis module of the research group [77] can be used where the tool clusters and part families are formed, thus maximising the tool sharing by parts and part sharing by tools by loading the machines with the tool clusters that are required the most by part families. The output of this level is the master schedule for the planning period.

(2). The operational step, *level 3*, launching parts into the system and routing parts on the machines is determined at this level. The production scheduling module of the thesis has been concentrated at this level. The part flow is relegated to scheduling of part routing and sequencing. Part palletisation, storage, and transportation are not modelled. [88, 263]. The production scheduling process has been carried out in a modularised way: launching parts into the system, loading and pallet allocation, and the sequencing of operations on machines, fig. 12.1. [35, 42, 50, 78, 268].

12.3 TERMINOLOGY AND PERFORMANCE EVALUATION MEASURES

The nomenclature and terminology used through the scheduling problem in this chapter is set out as below. [60, 67, 133, 268].

I : $\{i \mid i = 1, 2 \ldots L\}$, the index set of parts (orders).

J : $\{j \mid j = 1, 2 \ldots M_i\}$, the index set of operations of part type i.

K : $\{k \mid k = 1, 2 \ldots N\}$, the index set of machines.

T : $\{t \mid t = 1, 2 \ldots Q\}$, the index set of tools.

$a_{i,j}$: the set of machine that can perform operation j of part i.

$a_{i,j}$ is a sub set of K.

Q_i: Order quantity of order i.

$PALC_i$: Pallet capacity for part type i.

$PALN_i$: No. of pallets for order i.

$PAL_{i,p}$: No. of items in pallet p of order i.

$p = 1, 2 \ldots PALN_i$

$X_{i,p,j,k}$ = 1, if operation j of pallet p of order i is assigned to machine k;
= 0, otherwise.

$Y_{i,p,j}$ = 1, if operation j of pallet p of order i is assigned.
= 0, otherwise.

${}^1X_{i,p}$ = 1, if the previous operations of pallet p of order i has been assigned;
= 0, otherwise.

${}^{2}X_{i,p}$ = 1, if pallet p of order i is ready;

= 0, otherwise.

A order is defined as a batch of items of the same part type which requires a set of operations.

$P_{i,p,j}'$: the processing time of op. j of all items of pallet p, order i.

$P_{i,j,k}$: the summation of processing time of op. j of items performed on machine k, order i.

$$P_{i,j,k} = \sum_{p=1}^{PALNi} (P'_{i,j,k} * X_{i,p,j,k})$$

Cycle time ($P_{i,j}$): The time required to perform operation j on one item of the batch.

Processing time ($P_{i,j}'$): The time required to complete operation j of all items of order i.

By the definition,

$$P_{i,j}' = P_{i,j} * Q_i.$$

Total processing time (P_i) is the time it will take to finish order i.

$$P_i = \sum_{j \in J} P'_{i,j} = \sum_{j=1}^{Q_i} P_{i,j} = \sum_{k \in K} \sum_{j \in J} P_{i,j,k} = \sum_{p=1}^{PALN\,i} \sum_{j \in J} P'_{i,p,j}$$

Pallet processing time (${}^{1}P_{i,p}$): The time required to complete pallet p of order i.

$${}^{1}P_{i,p} = (\Sigma P_{i,j}) * PALN_i \qquad (j \in J)$$

Ready or Launch Time (r_p): The time that pallet p is available for processing.

Waiting Time ($w_{i,p,j}$): The time that the pallet p of order i should wait before the commence of operation j.

Total waiting time of order i:

$$W_i = \sum_{p=1}^{PALN\,i} \sum_{j \in J} w_{i,p,j}$$

Flow Time or Manufacturing Interval of order i (F_i) is defined as the time that job i spends in the manufacturing system. It is also called Shop Time.
Make Span or Throughput Time (M) is the sum of the processing times of all orders.
Completion Time (C_i) : The time point at which all the operations of the the order i have been finished.

$$C_i = r_i + P_i + W_i.$$

Due Date (d_i) is the dead-line when the processing of the order should be completed.
Lateness of job i: $L_i = C_i - d_i$.
Tardiness of order i: $T_i = \max\{L_i, 0\}$.
Earliness $E_i = \max\{0, -L_i\}$

Lateness, Tardiness and Earliness are three different ways of comparing the completion time of the job with its desired time, where, Tardiness considers jobs finished later than their due date, Earliness considers jobs completed earlier than their due dates, Lateness considers the different between the completion time and the due date of a job, be it completed earlier or later. [35, 69, 253].

The average or maximum of completion times, flow times, lateness or tardiness are regular measures. A regular measure is defined as a value to be minimised that can be expressed as a function of the completion times, and which increases only if at least one of the completion times increases. The weighted averages, combination of average and maximum of those measures also falls into this category. [69].

12.4 PART LAUNCHING AND PRODUCTION ENVIRONMENT

Two types of part launching and production environments have been recognised:

A). 'Static-Flow' type production (Fig. 12.2): All parts to be processed must be available when they required. In other words, it is assumed that the part launching process does not effect the system operation or pallets are available at the start of the modelling period [42], no parts are permitted to leave and re-enter during the production period.

This assumption is intended to represent isolated turning cells of unmanned operations, where parts are prepared for the shift or 2 or 3 shifts of unattended operation. At the end of the period, new parts will be palletised, and tools will be replenished.

B). 'Stochastic-Interrupted' Production (Fig. 12.3): Parts are permitted to arrive during the period of system operation. Some of them may leave temporarily for outside operation and re-enter the system again. [11, 35]. This assumption is extremely true when modelling a manufacturing cell which has interactions with outside facilities for a long period, where parts are transferred to and from other manufacturing cells, or, a turning cell of attended operation, where palletised parts are launched in the appropriate time intervals.

Additional parameters need to be specified for this situation: The first parameter (r_i) would be when a new batch is ready to enter. The second parameter would be in the specification of the operation, after which completed, the part may leave the system temporarily for processing elsewhere, or for temporary storage. The third parameter would be specified as an interval of time between departure and re-entering into the system ($^1P_{i,p,j}$). At re-entry the part processing will be treated as per original with appropriate delay.

This facility also offers the flexibility to accept the part launching sequence generated by other software [42, 268, 275], e.g. the Emulator of the LUT-FMS group [229].

12.5 WORKLOAD ASSIGNMENT AND PALLET ALLOCATION

In the cylindrical components manufacturing, turning centres can be formed into groups. Each group may consist of one or several machines which are capable of processing the same operations providing the required tools are available. Alternative routing is possible, i.e a operation may be given a choice of machines for processing. [53, 67, 274]. Specific loading algorithms have been implemented to assign parts to individual machines.

The loading problem involves the determination of the allocation of operations and associated cutting tools of a set of orders among the machines subject to the technical and capacity constraints. [50, 276]. In general any solution of the loading problem must comply with the following constraints:

(1). Each operation and its associated tool must be assigned to at least on machine.

(2). A operation can only be assigned to a machine that can process it, providing that the required tools present.

(3). The selected machine must have sufficient capacity.

(4). Tools required for the entire set of operations assigned to any machine must not exceed the capacity of machine based tool store. [261, 268].

The allocation of tools has been a most important issue in the loading problem, loading of tools involved in *constraints* 1 and 2, which have not been considered or not with accuracy by the loading algorithms in the available literatures, have been dealt with in full detail by tool issue, exchange, and storage strategies both for workpiece and tool oriented systems as having been presented in the previous chapters.

The tool magazine capacity constraint has been considered with accuracy and reality as opposed to the assumptions made by other authors which either assume that tools cannot be shared by different batches or that tool flow is not permitted. The tool flow model presented in the previous chapters has tackled this issue in the following aspects:

(1). when turning centres have been equipped with magazines of big capacity which will be serviced only at the end of each shift, the machine based tool store capacity will become a hard constraint, that it should be able to hold tools for the whole period. Tool sharing is permissible between different batches, which will rationalise the tool life utilisation.

2). When tool flow is permitted for turning centres with tool magazine of limited capacity, e.g chain type magazine both for live tooling and stationary turning tools, tool magazine becomes a 'soft constraint', that it should be of reasonable size to contain tools between tool exchange periods.

The loading problem presented in this Chapter has been concentrated on workload assignment and batch splitting. Heuristic algorithms have been implemented with the intended objectives of workload balancing, minimisation of movement from machine to machine, thus maximisation of the production rate and/or system utilisation. [53, 67, 268, 275, 276]

Algorithm 12.1, WORKLOAD ASSIGNMENT AND BATCH SPLIT (Fig. 12.4, 12.5).

Step 1. Orders are sequenced in a increasing order of processing (operation) time. i.e if $P_i < P_{i'}$ then order i comes first than order i'.

Step 2. Split orders into pallets.

The No. of pallets required by order i:

$PALN_i$ = Integer part of $[(Q_i \ / PALC_i) + 0.5]$

The No. of items contained in pallet p of order i:

$PAL_{i,p} = PALC_i, \quad p = 1, \dots PALN_i - 1;$

$PAL_{i,p} = Q_i - (PALN_i - 1) * PALC_i, \quad p = PALN_i.$

Step 3. Select the machine with least workload.

If $\quad WorkLoad_k = \min\{\Sigma\,\Sigma\,\Sigma\,(P'_{i,p,j} * X_{i,p,j,k})\} \qquad (k \in K \ \ i \in I \ \ p \in P \ \ j \in J)$

then machine k is selected.

$Workload_k$: the work contents assigned to machine k:

$$workload_k = \Sigma\,\Sigma\,\Sigma\ (P'_{i,p,j} * X_{i,p,j,k}) = \Sigma\,\Sigma\,P_{i,j,k} \qquad (i \in I \ \ p \in P \ \ j \in J)$$

Step 4. Assign pallet to machine k. (Fig. 12.5).

4.1). Select the pallet in the order of sequenced orders formed in Step 1 and 2;

4.2). For the select pallet p of order i,

If $Y_{i,p,j} = 0 \quad (i \in I, p \in P, j \in J)$

and $k \in a_{i,j}$

and ${}^1X_{i,p} = 1$

then The suitable pallet has been found, go to 4.6

Else go to 4.3

4.3). If all operations of the pallet have been tried and no suitable op. has been found for machine k then

go to 4.4

Else increase operation No., go to 4.2

4.4). If all pallets have been tried

then go to 4.5

Else

select the next pallet p form the sequenced orders formed in Step 1 and 2, go to 4.2;

4.5). If no more operation requires machine k then

delete machine k from K, go to Step 3, until K is empty (all pallets have been assigned)

Else

delete machine k temporarily until the next assignment has been made, go to Step 3;

4.6). If operation j, pallet p, order i have been loaded to machine k

then

$X_{i,p,j,k} = 1$

While ($j + 1 <= j' <= M_i$) and ($k \in a_{i,j'}$) do

Begin

$X_{i,p,j',k} = 1$

$j' = j' + 1$

End;

If $j' < M_i$ then ${}^1X_{i,p} = 1$;

go to Step 3 until all operations have been assigned.

Step 1 sequences orders according to their processing times. The order with the shorter processing time will receive the higher priority in the workload assignment sequence. *Step 2* makes batch split and overlapping possible. Each pallet will hold items up to its capacity, unless for the last pallet of a order, which will contain items left by the previous pallet.

The key issue of the algorithm is to find the machine with the least workload assigned so far and allocate operations of a suitable pallet to it. Pallets will be tried according to the sequence of orders formed in *Step 1*. The first pallet that can be processed by the machine will be assigned provided that its previous operations have been allocated. All the consecutive operations that can be processed on the same machine will be kept together to reduce the pallet movement.

If all operations that require the machine have been assigned then the machine will eliminated from the list. If no operations can be assigned to the machine due to the previous operation constraint, then the next machine in the increasing order of workload will be selected for pallet assignment.

12.6 OVERVIEW OF BATCH SEQUENCING ALGORITHMS

Batch sequencing in the Turning Model has been conducted in two alternative ways, viz. external scheduling (Production scheduler) and internal scheduling ('Next-step' scheduler). (Fig. 12.9). The external scheduling algorithm offers the possibility both to accept the scheduled work-list from other production schedule generator, or to schedule the work flow according to the heuristic priority rules proposed for the purpose of enhancing the Turning Model efficiency. The internal scheduling algorithm is intended to enhance the tool flow model to incorporate scheduling of parts to match the selected suitable tooling strategies under the criteria of tool requirement and tool exchanging.

The purpose of the model enhancement is to examine the tool flow interactively with production scheduling, to gain a more realistic understanding of the tool management problem.

12.7 EXTERNAL PRODUCTION SCHEDULING - Production Scheduler

The external scheduling module is built separately from the tool flow modelling module. Besides meeting the requirement of the Turning Model, it also gives the flexibility to change the scheduling rules, so that different algorithms can be implemented without changing the mainstream tool flow module. As having been indicated in Chapter 6 (Fig. 12.9), the external production scheduling module has been built with the following two options: the production scheduler which employs the built-in heuristic dispatching rules, and mechanism to accept the pre- scheduled work-list.

To use the production scheduler, a production requirement file (i.e. A part file) is necessary specifying the batch size, due date, number of operations, cutting and setting-up time, tool type and machine required by each operation, etc. Specific orders are selected and assigned to individual machines by the Workload Assignment Module introduced in Algorithm 12.1. Then the assigned pallets on each machine is sequenced under the machine availability and previous operation constraints, to facilitate the Tool Flow Model (Fig. 6.2).

Alternatively, a user can choose to use the production scheduling rules reviewed in the previous sections [60, 81, 250, 261, 268, 280], or any other rules of his own preference, e.g the Emulator by the FMS group of the parallel research project [229], to schedule the part flow and to take the scheduled work-list as the input for running the tool requirement and tool flow modules directly. (Fig. 12.9). In such a case, the tool flow model will be implemented as a module for overall system performance modelling. The method to accept data from other production scheduling mechanism is via ASCII formatted files.

Two heuristic rules have been built in the Production Scheduler: the earliest due date (EDD) [1, 35, 65, 69], and shortest processing (operation) time [2, 43, 137, 142, 144]. The production Scheduler is operated on a non-delay mode [35, 69, 78]. (Fig. 12.6). No preference has been given to these two type of rules. The choice has been left to the user to sequence the pallet flow in terms of work contents or the due date.

ALGORITHM 12.2, PRODUCTION SCHEDULER

Step 1. Priority Sequencing.

1.1). When SPT is selected, Sequence pallets according to work contents, i.e:

If ${}^1P_{i,p} <= {}^1P_{i',p'}$ then

pallet p of order i, comes earlier than pallet p', order i';

1.2). When EDD is selected, Sequence pallets according to their due date, i.e:

If $d_i <= d_{i'}$ then

Pallets of order i come earlier than pallets of order i'.

The tie-breaker is SPT;

Step 2. Find the first available machine k with :

$$MavaiT_k = Min \{MavaiT_k\}; \quad (k \in K)$$

$MavaiT_k$: Available time of machine k;

$$MavaiT_k = \Sigma\Sigma\, P_{i,j,k}; \qquad (i \in I \;\; j \in J)$$

go to Step 3;

Step 3. Locate Pallet;

Try pallets from the list formed in Step 1. The first one which satisfies:

$r_i <= MavaiT_k$

${}^2X_{i,p} = 1$

$X_{i,p,j,k} = 1$

is selected, pallet located.

If pallet located go to Step 5 Else go to Step 4;

Step 4. If no more op. requires machine k

then delete machine k from K, go to Step 2, until K is empty (all pallets have been assigned)

Else delete machine k temporarily until the next sequence has been made, go to Step 2;

Step 5. Update pallet processing time,

Update machine available time,

Delete operations of the pallet from the waiting list,

Go to Step 6;

Step 6. Pallet Entry and Leave (fig. 12.7):

6.1). If pallet enters the cell, insert waiting list,

go to 6.2;

6.2). If pallet requires to leave for outside operation, then update pallet available time, go to step 2;

Goto step 7;

Step 7. If all pallets finish operation,then stop

Else go to Step 2;

The Production Scheduler will always find the first machine available, and then search through the sequenced part file in order to see if there are any parts requiring the machine. If there are, the machine will be scheduled with the first batch that is ready for scheduling under the constraint of precedence. The same procedure will be repeated until all the parts have been scheduled [35, 69, 78].

A machine will not be kept on idle as long as there are some batches available, that is the scheduling of parts is based on the earliest start time (EST) - Non-delay processing.

For pallets which require outside operations later on, a temporary due date ($d_{i,p}'$) is assigned to it, taking into the consideration of the possible delay, in order to meet the required due date of the batch:

$$d_{i,p}' = d_i - [(\sum_{j=j'}^{Mi} P_{i,j}) * PALN_i] * f$$

f: Safety factor: f = 0, 1, 1.1, 1.2 1.3;

j': The operation which should be performed outside the cell.

When f = 0, it is assumed that the due date assigned to a batch was assigned considering the characteristics of the part and cell situations, thus the outside operation will not influence the part sequence procedure. The safety factor cannot be too big, as the expediting of one pallet means the possible delay of the others.

12.8 INTERNAL PRODUCTION SCHEDULING - 'Next-step' Scheduler

When the external priority has not been (or is not necessary) assigned to orders, e.g when modelling a short period, that the meeting of due date is not necessary during the period, the internal production scheduling model can be implemented. It is built as part of the Tool Flow Model (Fig. 12.9) and is run dynamically to sequence the next batch into the machine when a machine finishes the processing of the previous one - 'Next-step' Scheduler. The 'Next-step' scheduler aimes to minimise the tool requirement and tool exchange effort, it makes use of the result of tool flow modelling and tool life recording up to the stage.

The input to the Next-step scheduler can either be from the workload assignment module, or from the Computer Assisted Cluster Analysis of the research group which gives the preferred tool clusters and the associated part families in which case each tool cluster set may be treated as a tool kit dedicated to a part family as opposed to a part type; [77].

Two scheduling rules have been incorporated: the *Least Tool Requirement,* or the *Highest Tooling Similarity.* Both of them examine the tool tools present in the machine based tool stores and the tools required from the STS.

The Least Tool Requirement works out the tools that need to be exchanged to the machine by comparing tools that are available at the machine and the total tool requirement of a batch. The batch which requires minimum number of tools from STS for processing will receive a highest priority.

The Highest Tooling Similarity is based on the similarity measure which is defined as:

Similarity = (Common tools that are present in the machine based tool stores)
divided by (Total number of tools required by the batch)

The batch that has the highest similarity will be selected. [48, 52, 54, 126, 261, 290].

The former aims to reduce the tool requirement and tool exchange between PTS and STS for the introduction of each part type (batch). The machine down time due to the tool exchanging can also be reduced. The latter emphasises the sharing of tools between the previous part types that have already been processed by the machine. It is expected that by introducing the part which has the highest similarity with respect to the tools present in the tool magazine and tool turret, the total tool requirement for the machine and consequently the whole cell will be reduced.

Algorithm 12.3, NEXT-STEP SCHEDULER

Step 1. Select the first available machine k;

Step 2. Form the waiting list P' for machine k:

P' contains all pallets which satisfies

$X_{i,p,j,k} = 1$

${}^{2}X_{i,p} = 1$

${}^{1}X_{i,p} = 1;$

Step 3. Let:

$T1_p \in T$: total tool requirement by pallet p;

$T2_k \in T$: Total tool contents of the machine based tool stores.

$T3_p \in T$: Tools out of $T1_p$ that are available at the machine;

$T3_p$ is the inter-section of $T1_p$ and $T2_k$.

$T4_p \in T_p$: Tools that need to be transferred to machine k for pallet p.

$$T4_p = T1_p - T3_p;$$

Ref. to Chapter 8 for the calculation of $T1_p$, $T2_k$, $T3_p$, $T4_p$.

Step 4. Sequence pallet to machine:

4.1). When Least Tool Requirement is implemented:

Pallet p is selected if

$$T3_p = \text{Min } \{T3_p\}; \qquad (p \in P')$$

4.2). When the Highest Similarity is implemented,

Pallet p is selected if

$$S_p = \text{Max } \{S_p\} \qquad (p \in P')$$

where $S_p = \text{Size}(T3_p) / \text{Size}(T1_p)$;

Step 5. If $T4_t = 0$ then go to Step 6

Else Tool exchanging to the machine go to Step 6;

Step 6. Machining and update data.

Pallet entry and leave (Ref. to section 12.7).

Repeat step 1 to 6 until all operations have been finished.

The logic flow of 'Next-step' scheduler is shown in fig. 12.8. For each machine in the cell, if there are parts that require it, and if the machine is not loaded, the most suitable part type will be introduced to the machine according to either of the criteria selected.

If all the tools required by the batch are in the tool magazine or the tool turret, the machine will commence the operation. Otherwise, tool requirement will be issued to the STS. Tools required will be transferred from STS to the respective PTS, tool exchange to the magazine will be carried out, and the processing of the batch can be started. [54, 126, 290].

The *'Next-step'* scheduler also works on the basis of local- optimum manner -

only the batches ready for the next step is considered - that is a machine will always start operation as early as possible - on the non-delay mode. [35, 69, 78].

The best tool issue strategy to suit the *'Next-step'* Scheduler is the *differential kitting* concept, of which the essence is to share tools across batches. The *Least Tool Requirement* algorithm can be used when the *tool kitting* concept has been implemented with the objective to reduce the tool exchanging effort and the conflict between tool requirement across individual machines.

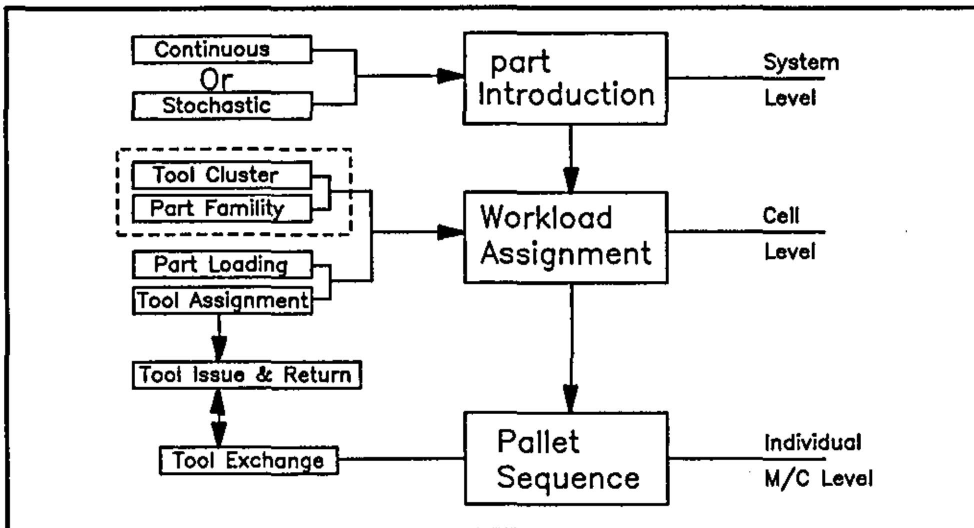

Fig. 12.1
Production Scheduling Structure

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Research Group

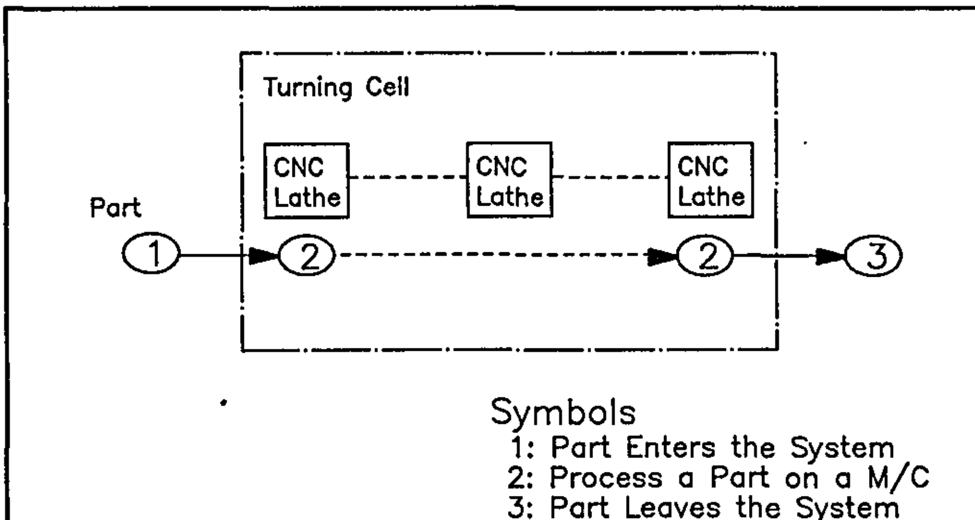

Fig. 12.2
Deterministic–Flow Production

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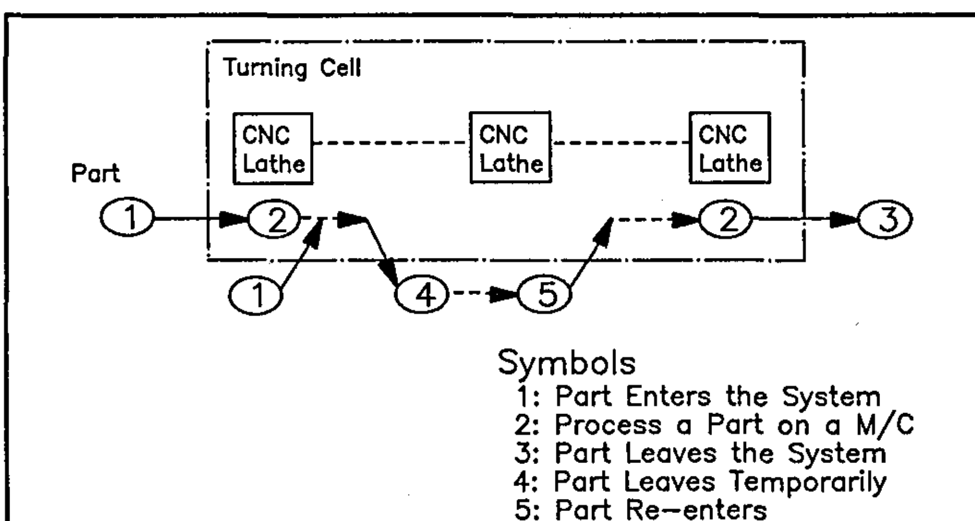

Fig. 12.3
Stochastic–Interrupted Production

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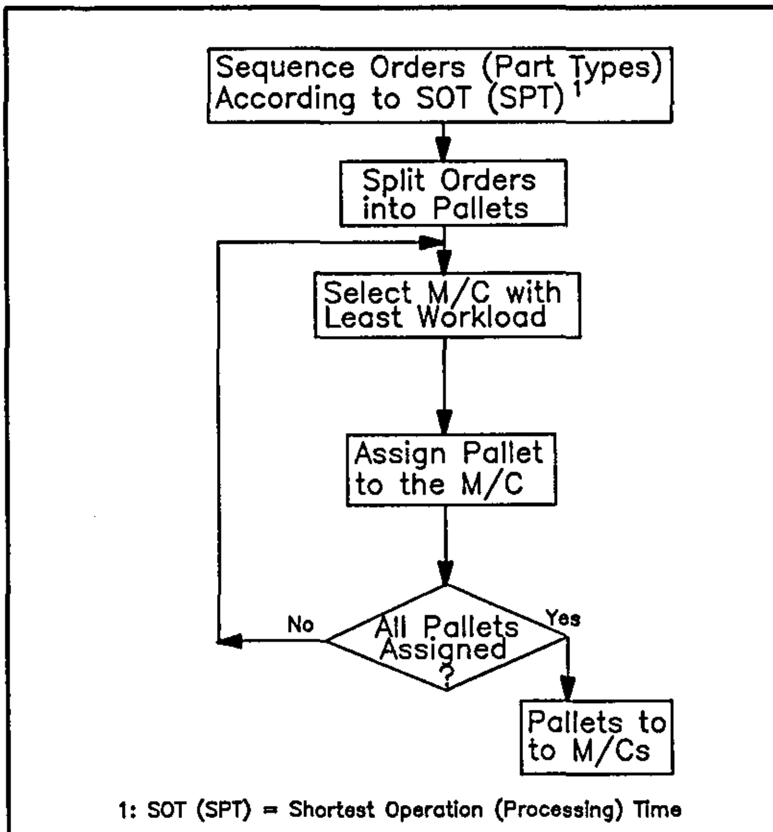

Fig. 12.4
Workload Assignment

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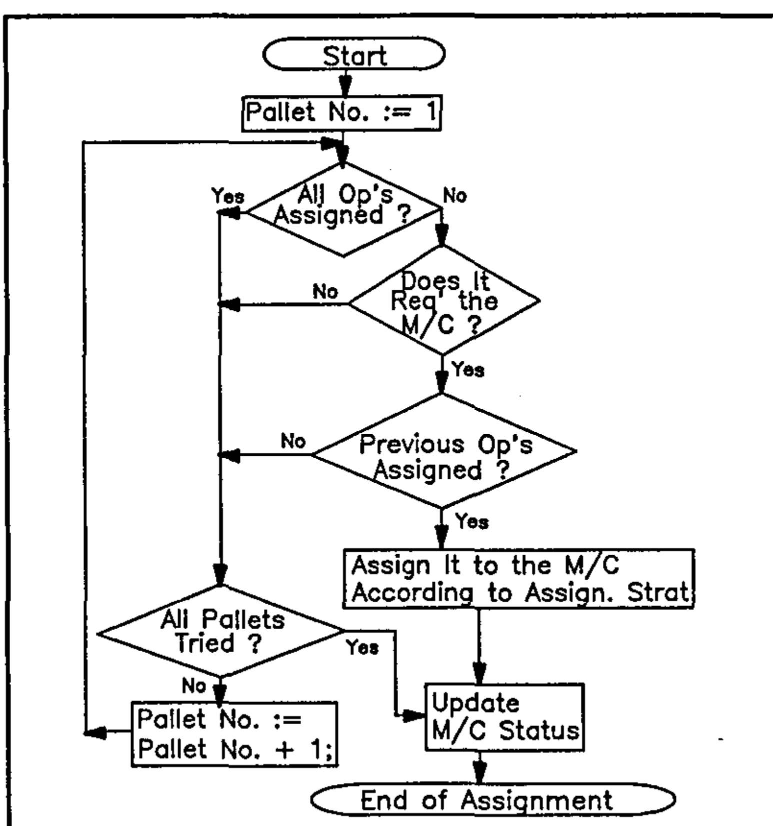

Fig. 12.5
Assign Pallet to M/C

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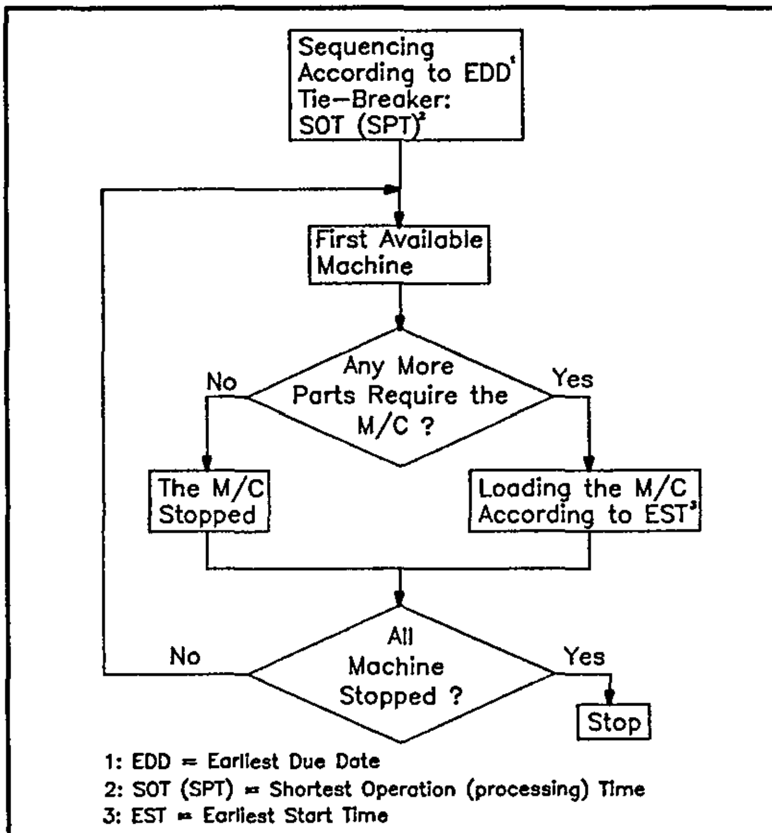

Fig. 12.6 Logic Flow of the Production Scheduler

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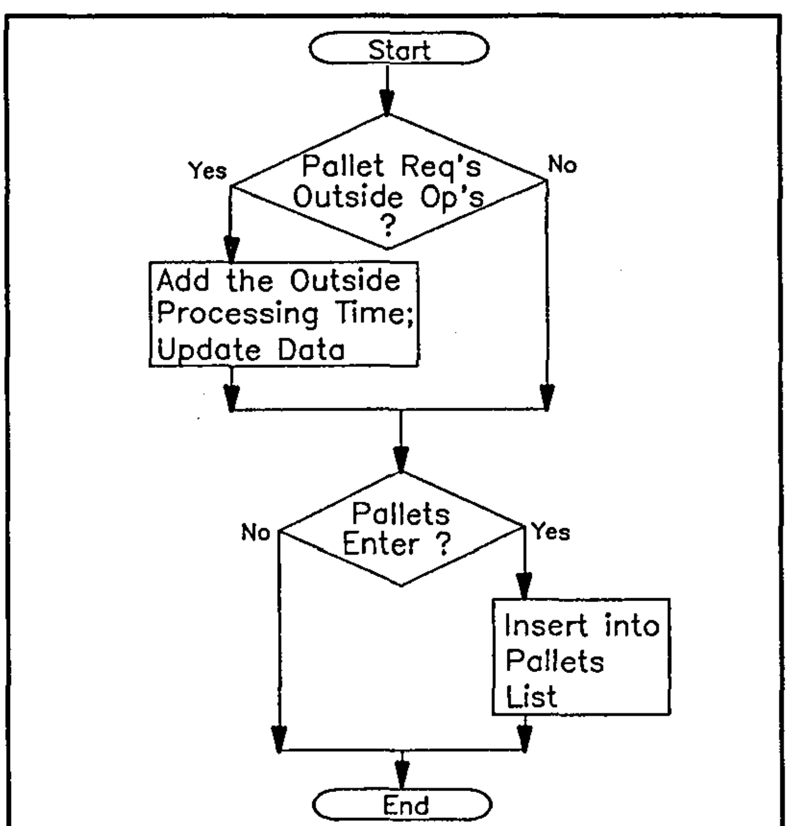

Fig. 12.7 Pallets Entry & Leave

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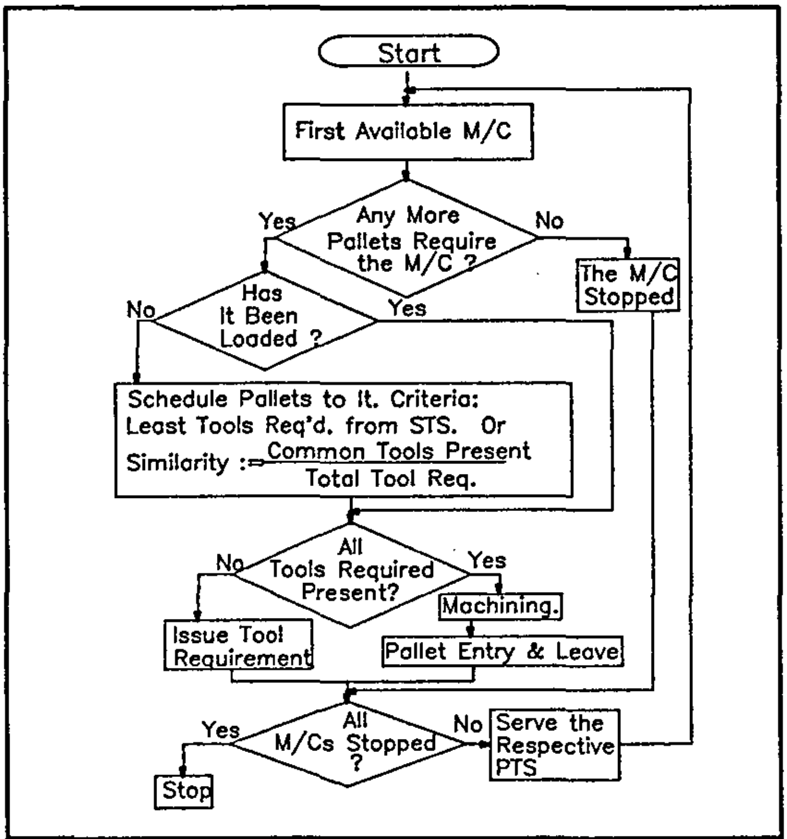

Fig. 12.8
Internal Scheduling Algorithm

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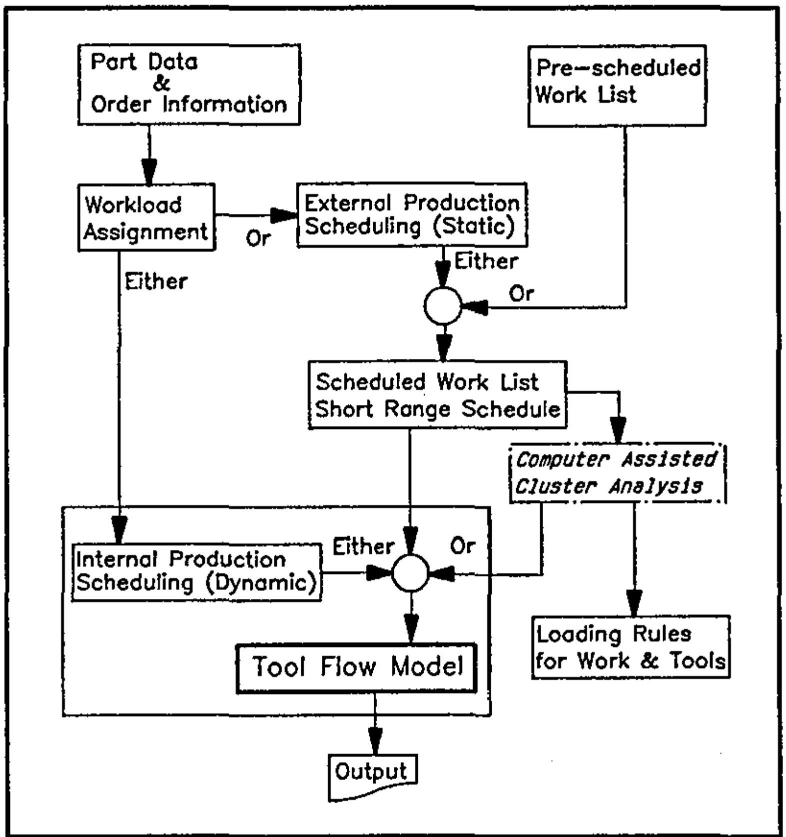

Fig. 12.9
Integration of Scheduling With Tool Flow Model

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CHAPTER 13 MODELLING OF A MULTI-MACHINE CNC TURNING CELL

13.1 INTRODUCTION

The work reported here is the result of a case study carried out with data supplied by a British company Normalair Garrett Ltd. (Thereafter referred as NGL). The purpose of the study is to examine the performance of the 5 machine CNC turning cell operation, and to evaluate the alternative designs with the aid of the Turning Model.

The result reported in this chapter represents a number of significant runs for major stages of evaluating. The whole process is supported by a rich number of runs which are not reported due to the length of the thesis. This is only made realistic by the short running time of the Turning Model.

13.2 SCOPE OF THE CASE STUDY

The supplied data is first subjected to a number of comprehensive runs to examine the installed 5 machine CNC turning cell, by applying a number of production scheduling strategies and tooling strategies.

The total required batches are then doubled to evaluated the system performance when large number of batches are put through.

The case study is then extended to examine the consequence of eliminating the under-utilised machine (proved in the previous steps), by shifting the workload of machine 5 to machine No. 4 which is of the same type as the eliminated machine.

The modelling result indicates that a large percentage of machine processing time is spent for part and tooling set-up. This due to the fact that:

(1). Different chuck jaws are required for different batches, a substantial length of time is required for the operator to set-up the machine with the right jaw sets;

(2). The machine operator is required for tool presetting and tool unloading from/ mounting to the tool turret, which results long tooling set-up time.

It is therefore appropriate to study the alternative system design by adopting highly automated machines with highly automated features including Automatic ChuckJaw Changing (ACJC) and equipped with tool magazines.

As will be discussed in the turbine cell description and production scheduling strategy sections, most of the batches require processing by the supportive machines out of the CNC turning cell. This fact, as can be seen from the modelling process, effects the system performance to a large extent. It was therefore planned to evaluate the system performance when there is no part exit/re-entry.

The overview of the case study is given in fig. 13.8.

The manning patterns (as having been discussed in the single machine case study in Chapter 9) are given to accompany the outputs for a number of major runs to predict the manning requirement of the modelled CNC turning cell.

The tool and tooling requirement were worked out for each run for a number of tooling strategies. This includes the tool presetting and exchanging required to fulfill the production, and the tool component requirement for the Central Tool Store (CTS) inventory control.

13.3 TURBINE CELL DESCRIPTION

The turbine cell is a dedicated workshop for bar and chuck type components for turbine assemblies. It consists of a group of 5 Index CNC lathes supported by a number of NC and conventional machines. It has been required to model the 5 Index machine CNC turning cell, with the tooling back up by the tool set-up area (CTS). The interaction between the CNC turning cell and the outside machines has been fully represented with regards to the part flow out and in the CNC turning cell.

The CNC turning cell consists 3 Index GU610 CNC lathes, a GE42 and a GE65 (thereafter referred as machine No. 1 - 5), (Fig. 13.1). The GU610 has the ability of machining bars of up to 65mm and chuck parts of up to approximately 200mm in diameter. The crown turret with 12 tool stations permits the use of 12 internal and external tools. The tool driving attachment of the turret allows up to 6 live tooling being accommodated. (Fig. 13.2). GE42 and GE 65 has the 42 and 65 mm bar machining capacity respectively. Both of them can turn chuck parts of up to 200mm in diameter. External and internal turning tools can be arranged in their 14 station turret in any order.

With C-axis control facility and the tool driving mechanism attached to the turret, the GE 42 and GE 65 can carry secondary operations by accommodating up to 7 live tools. (Fig. 13.3 and 13.4). [160, 161, 162].

13.4 COMPONENTS AND PRODUCTION REQUIREMENT

11 part types have been given for the case study. The part spectrum includes turbine wheel, exducer, compressor impeller, impeller fan axial, and exducer for cooling turbine (Ref. to Appendix 2A). The processing of of these components inside the CNC turning cell is assigned to one of the 3 groups i.e BLN (3 GU610 machines), BLK (GE65), BLM (GE42). The tool operations performed in the CNC cell ranges between 2 to 14. (Fig. 13.3). All the components require the machining inside the CNC turning cell and operations out the CNC cell e.g milling, turning, grinding, deburring, inspection and balancing, etc. (Fig. 13.4).

A typical part routing is given in fig. 13.5. Before entering the CNC turning cell to the machine GU610-1, the part requires operations on machine BLA. Then 11 tool operations including turning, boring, and central drilling will be performed on GU610-1, after which the part leaves the CNC turning cell for outside operations on machines PNE and BLA. In the due time, the batch will leave the CNC turning cell for deburr, inspection and final boring and will be returned to compressor room. (Fig. 13.6).

13.5 PRODUCTION SCHEDULING STRATEGIES

As having been discussed in Chapter 12, the production scheduling algorithm adopts a 3 step approach, i.e, part launching, work load assignment, and batch sequencing.

13.5.1 Part Launching

The part launching and production environment of the modelled CNC turning cell is of typical stochastic interrupted type as defined in Chapter 12 (12.2). 4 part types require outside operation before entering the CNC turning cell and 6 part types require exit and re-entry to the CNC cell during its total processing in the turbine cell. The launching rule adopted was: a batch can only enter the CNC turning cell when its previous operations have been finished out of the cell.

13.5.2 Workload Assignment

The fact that 3 GU610 CNC turning centres are pooled into a group indicates that the workload for the 3 machine should be balanced among each individual one. Two alternative rules have been implemented for assigning work load to individual machines:

(1). *Workload Assignment Rule 1:* The machine with the least workload of the group will be assigned with the batch that has the maximum work-content that can be performed by the machine.

(2). *Workload Assignment Rule 2:* The machine with the least workload of the group will be assigned with the batch that has the minimum work-content that can be performed by the machine.

13.5.3 Batch Sequencing

Assigned batches will be sequenced by one of the following rules:

(1). *Sequencing Rule 1:* When a machine is available, the ready batch which requires the longest time interval between its exit and re-entry later on during its processing will be sequenced first. For batches with the same amount of outside operation time, the one with shortest processing time will be sequenced first;

(2). *Sequencing Rule 2:* No priority is given to batches that require exit/re-entry. Shortest Processing Time (SPT) is employed for sequencing: i.e the batch which requires the shortest processing time among all the batches waiting for an available machine will be sequenced first;

(3). *Sequencing Rule 3*: When a machine is available, all the batches waiting for the machine are listed, the batch which requires least number of tools to be exchanged to the machine will be sequenced first. This rule is implemented with the combination of differential Kitting strategy which will be described in **Tooling Strategy** section. It is aimed to maximise the tool sharing between successive tool kits. Among these 3 sequencing rules, the first 2 are the function of External Production Scheduler; and the sequencing rule 3 is the function of the Next-step Scheduler (Ref. to Chapter 12).

13.5.4 List of the Scheduling Strategies

6 production strategies have been resulted by combining the 2 workload assignment with the 3 sequencing strategies (Fig. 13.9):

Scheduling Strategy 1: *workload assignment rule 1* combined with *sequencing rule 1;*
Scheduling Strategy 2: *workload assignment rule 2* combined with *sequencing rule 1;*
Scheduling Strategy 3: *workload assignment rule 2* combined with *sequencing rule 2;*
Scheduling Strategy 4: *workload assignment rule 1* combined with *sequencing rule 2;*
Scheduling Strategy 5: *workload assignment rule 1* combined with *sequencing rule 3;*
Scheduling Strategy 6: *workload assignment rule 2* combined with *sequencing rule 3;*

13.6 TOOLING AND TOOLING STRATEGY

13.6.1 Tooling Strategies

3 tooling strategies have been implemented to suit different system designs and automation levels, and to examine the tooling requirement under the adopted strategies:

(1). *Kitting:* tool kits are issued to a machine to accompany each batch. When the processing of a batch is finished, the tool kit in the machine will be exchanged with the new kit for next batch. The used kit will then be transferred back to the tool presetting area and disposed of. No tool sharing between kits are permitted.

This is the tooling strategy implemented by NGL. During the tooling set-up period for each batch, the operator is required to prepare tools in the kits, unload tools in the old kit, and mount the tools in the new kit to the machine tool turret. It is specified that 15 min. is required for each tool preparing and exchange. The machine is not in operation during this tooling set-up time.

(2). *Differential Kitting:* Tools are assigned in kits for each batch, but common tools can be shared between successive tool kits. A tool kit contains only tools that are not available in the machine. Tool saving can be achieved, but it requires tool life management in the machine CNC controller and system controlling computer to record tool life usage across different batches, and to recording tooling off-set. It is only advisable on highly automated machines with tool magazine equipped.

(3). *Complete Tool Magazine Exchange:* Tools for a production period are stored in the magazine up to the magazine capacity. After the completion of the processing of the period, the whole magazine will be exchanged for the next period.

The framework for tool management and tooling strategy selection is discussed in chapter 7.

13.6.2 Tool Component Requirement

A cutting tool consists of 3 main parts: cutting unit, shank (if applicable), and the tool holder. The cutting unit for external turning tools and boring tools is the indexable insert, for drilling and tapping tools is the tool itself. Drilling and tapping tools do not have a shank.

The tool holders according to DIN69880 permit quick tool change and assure highly accurate axial and radial location. A typical tool is shown in Fig. 13.7.

Tools are assembled, reconditioned, and preset in the tool presetting area (CTS). It is assumed that used tools will be disposed of in either of the following two way:

(1). Tools of the type required later will have its indexable insert indexed, presenting a new tip. Cutting tools without indexable inserts will refurbished.

(2). Tools not required will be disassembled, so that the tool component can be used for other tool assembling and reconditioning.

Cutting units are regarded as consumable. A indexable insert is regarded as worn out after all its usable tips have been used. A cutting tool without indexable inserts e.g dill, tap, are worn out if it has been reground for a specified number of times. Special tools, e.g probes, are classified as cutting tools, but treated as durable, i.e, they can be used for tool assembling for any number of times.

Tool shanks and holders are regarded as durable.

A cutting tool is an assembly of tool components, and is referred to a individual tool No.. Once being disassembled, the tool assembly will no longer exist. Whereas a tool component refers to fixed item, which unless being worn out, can be used by different tool assemblies.

The tool part requirement planning works out the total number of items required for each item i.d for inserts, shanks, and holders respectively to fulfill the required tool assembling and reconditioning. The logic flow and the algorithms for tool part planning was discussed in Chapter 11.

13.7 SYSTEM PERFORMANCE EVALUATION CRITERIA AND NOMENCLATURE

The following definition of machine activity times have been employed for the system performance evaluation purpose:

The total processing time of a machine is defined as the time interval between the machine starts processing the first batch and the stage that the last batch has been finished. It is broken down into cutting time, which is the time a machine is actually doing the metal removal; part set-up time, which is the time for batch set-up and part loading/unloading; tooling set-up time, which the time that a machine spent for tool presetting, exchanging, and turret indexing; and the machine idle time, which is the sum of the time that a machine spent during its total processing period waiting for batches to finish their previous operations before they can be sequenced to the machine.

The longest total processing time of individual machines is defined as the throughput time of the turning cell.

Total idle time of the cell is defined as the sum of machine idle time of all machines in the cell.

The throughput time is used as the most important criterion for cell performance evaluation. The total idle time is meaningful only when examining the waste of the cost of manpower and equipment.

Nomenclature:

$M_{s,t}$: Throughput of the CNC turning cell under scheduling strategy s, tooling strategy t;

$IT_{m,s,t}$: total idle time of machine No. m under scheduling strategy s, tooling strategy t;

$TIT_{s,t}$: total machine idle time of the cell under scheduling strategy s, tooling strategy t;

$$TIT_{s,t} = \Sigma\, IT_{m,s,t};$$

s: Scheduling strategy index; s := 1, 2, 3, 4; Ref. to fig. 13.9.1 for the description of these strategies.

t: Tooling strategy index; t := 1, 2, 3; representing *kitting, differential kitting,* and *complete magazine exchange* respectively, fig. 13.9.2.

m := machine index;

In the NGL CNC turning cell m := 1, 2, 3, 4, 5; represents machine GU610-1, GU610-2, GU610- 3, GE65, GE42 respectively;

And in the synthetic highly automated cell

m := 1, 2; represents synthetic turning centre 1 & 2;

13.8 MODELLING OF THE 5 MACHINE CNC TURNING CELL

4 Runs (Run 1 - 4) have been completed to model the CNC turning cell installation. NGL supplied machine, tool, and workpiece data were used to conduct modelling experiment under 4 scheduling strategies. Tooling strategy adopted was *kitting* (Strategy 1) as being implemented by NGL. It was specified that 15 min. is required for preparing and exchange a tool into machine turrets. A machine is not in operation during the part loading/unloading, and tool exchange. The following results have been obtained:

13.8.1 MACHINING HISTORY AND ACTIVITIES

13.8.1.1 Modelling Results

The summarised machine utilisation under the modelled 4 scheduling strategies (thus the number of Runs) is shown in Fig. 13.10.

It has been illustrated clearly that each machine spends long time for set-up, only a very short time has been employed for metal cutting. This is mainly because that the high accuracy and value of the parts dictates a long machine set-up time for each batch. Secondly, each tool requires 15 min. for assembling and presetting, which is carried out by the machine operator. If the required tools were assembled and preset by a dedicated tool preparing operator, great gain could be achieved with regards to reduced machine setting-up time.

Machine GU610-2, GE65, GE42 feature a long idle time waiting for suitable pallets. For GU610-2, this is because that no pallets are available for operation. While for GE65 and GE42, since only one batch has been assigned to each machine, the machine is kept idle when the batch is away form the CNC turning cell for outside operation.

According to the definition, the *throughput time* of the CNC turning cell under the four production scheduling strategies are:

$M_{1,1}$ = 1436 min.

$M_{2,1}$ = 1346 min.

$M_{3,1}$ = 1812 min.

$M_{4,1}$ = 1829 min.

The total idle time of the CNC turning cell under Scheduling Strategy 1 is:

$$TIT_{1,1} = \Sigma\, IT_{m,1,1} = 0 + 129 + 0 + 135 + 700 = 964 \text{ (min.)};$$

Similarly, the total idle time under scheduling strategies 2 to 4 are:

$TIT_{2,1}$ = 946 min.

$TIT_{3,1}$ = 1420 min.

$TIT_{4,1}$ = 1456 min.

13.8.1.2 Discussion on the Cell Throughput Time

From the modelling results, the following conclusion can be drawn:

The scheduling strategies (1 and 2) which consider the outside operation requirement when sequencing the batches certainly result a better system performance both for the throughput time and total idle time over the scheduling strategy 3 and 4 which ignores the exit/re-entry effect in the later stage.

Scheduling strategy 2 is the the best among the 4 strategies with a minimum throughput time and the least total machine idle time (1346 min. and 964 min. respectively).

13.8.2 CELL TOOL REQUIREMENT

Assuming each tool has a 30 min. total tool life of which up to 50% can be used, i.e the maximum permissible tool life is 15 min. For the given list of 11 batches

(Fig.13.3), a total number of 110 tools are required. As all tools are transferred back to tool set-up area for refurbished, a tool is regarded as 'worn' if the current tip has been used up to the limit. A tip is defined as 'worn' if its accumulated engagement time has reached 15 min., or under 15 min., but will exceed if the next operation is carried out.

All of the 4 scheduling strategies require the same number of tool assemblies (111), this is due to the fact that the tool kitting strategy is implemented (Ref. to sections 13.5, 13.6). But the tool components required for tool assembling and refurbished are expected to be different due to the components sharied, as will be discussed in the next section.

13.8.3 TOOL COMPONENTS REQUIREMENT

Tool part requirement forms the base for both the short term modelling to facilitate tool assembling and presetting, and the medium to long term period for forecasting of tool room inventory control and part purchasing. The tool parts have been classified as consumable: inserts and cutters; and durable: shanks and holders. A consumable part has the predetermined number of indexable tips (for inserts) or number of permitted regrinds (drills, taps), after which the part cannot be used. A durable part can be shared across tool assemblies.

The total requirement of inserts (cutters), shanks, and holders for each control strategy are given in the table and Fig. 13.25.

The strategy that requires less tool inserts in sequence are (with the required number of inserts in bracket following each strategy):

Scheduling Strategy 1 (74), Scheduling Strategy 3 (77), Scheduling Strategy 4 (78), Scheduling Strategy 2 (84).

The strategy that requires less tool shanks in sequence are (with the required number of shanks in bracket following each strategy):

Scheduling Strategy 1 (43), Scheduling Strategy 3 (54), Scheduling Strategy 2 (56), and Scheduling Strategy 4 (56).

The strategy sequence that requires less number of holders are:

Scheduling Strategy 1 (66), Scheduling Strategy 3 (67), Scheduling Strategy 2 (71), Scheduling Strategy 4 (79).

The strategies producing the overall better tooling requirement performance are (in sequence): Scheduling Strategy 1, 3, 2, 4. Strategy 2 is better than 4 due to the fact that although more inserts are required by scheduling strategy 2, it is well compensated by the smaller tool holder requirement, due to the high cost of tool holders.

13.9 MODELLING THE PRODUCTION OF INCREASED NUMBER OF BATCHES

Run 5 and 6 were planned to examine the system performance when the production requirement is doubled. Production scheduling strategies 1 and 2 were selected because that in the Run 1 - 4 these two strategies performed better than the other 2 strategies.

The throughput time of the CNC turning cell under respective scheduling strategies and tooling strategies are:

$M_{1,1} = 2567$ min. (Run 5);

$M_{2,1} = 2678$ min. (Run 6).

These are not the double that the throughput time of Run 1 and 2 which adopted the same tooling and scheduling strategies, although the time saving in not significant.

In this case production scheduling strategy 1 performed better than scheduling 2 with respect to the throughput time, which is in contrary to Run 1 and 2. It also proved that scheduling strategy 1 requires less tool assemblies and tool components than scheduling strategy 2, which is in synonymous with Run 1 and 2. It can be concluded that scheduling strategy 1 results in better overall performance than strategy 2. It is also observed that the performance of the scheduling strategies is production requirement dependent.

In both Run 5 and 6 the idle times of machine No. 1 - 4 are 0, which means that when large number of batches are put through, the effect of out of cell operation is reduced. Machine No. 5, however, still features long idle time (509 min. in both runs), which means that the outside operation effects the machine performance to a large extent, although decreased compared to Run 1 & 2. (Fig. 13.11). It is also noticed that both machine 4 and 5 feature short total processing times, fig. 13.11.

13.10 EXTENDED CASE STUDY - 4 MACHINE CELL DESIGN

The previous 6 runs showed that machine 4 and 5 are under utilised, fig. 13.10, 13.11. According to the machine manufacturer's specification, these two machines, GE42 & GE65, are of the same type. And in NGL's case they have the same processing capability. It has therefore been decided to eliminate machine 5 from the cell layout by shifting the production requirement of the machine to machine 4, and to examine the consequence.

The result proved that for the given 11 batches with their associated processing information, this is an appropriate approach.

In this cell design the *'tool kitting'* strategy, fig. 13.9.2, was adopted according to NGL practice. Scheduling strategy 1 & 2 were selected for their better performance in the previous runs.

The throughput time under these strategies are:

$M_{1,1}$ = 1436 min. (Run 7);

$M_{2,1}$ = 1346 min. (Run 8);

These are equal to the result of Run 1 and 2. This is due to the fact that the throughput time are decided in these runs by machine 3 and 1 respectively, thus the eliminating of machine 5 has not increased the turning cell's throughput time.

Same as in the 5 machine cell case (Run 1 - 4), scheduling strategy 2 resulted a shorter through time than scheduling strategy 1; and scheduling strategy 1 requires less tool assemblies and tool components, fig. 13.25. This is because that the difference between these two strategies are their workload assignment rules, fig. 13.9.1, which effects only the workload among the GU610 (BLN) group consisting of machine 1 - 3. And the shifting of workload of machine 5 to machine 4 does not effect the workload distribution on machine 1 - 3.

The manning pattern of the 4 machine turning cell under one combination of the production scheduling strategy and tooling strategy (Run 8) shows that as the machines are manually operated, one operator is required for each machine except when the machine is idle (Fig. 13.13).

13.11 EXTENDED CASE STUDY - 2 HIGHLY AUTOMATED MACHINE TURNING CELL

13.11.1 Cell Design

The case study is extended to examine an alternative system design using 2 highly automated CNC turning centres. This extension is planned due to the fact that the previous runs showed that very large percentage of processing time has been engaged for setting-up and the actually cutting time of each machine is very low. This is caused by the following 2 reasons:

(1). Each batch requires different chuck jaws to fulfill the processing requirements and the high accuracy of the parts required results long part set-up time;

(2). The tools required are assembled and preset by the machine operator. The machine is idle during the tooling set-up periods.

It is therefore appropriate to study the possibility of employing highly automated machines with the automated features including tool magazine support and automated chuck jaw changing. It is assumed that 2 machines of the type studied in chapter 9 has been employed, fig. 9.2.

For these 2 highly automated machines tooling strategies *differential kitting* and *complete magazine exchange* can be implemented as each machine has a tool magazine.

In this cell, it is assumed that tools are assembled / disassembled, and preset in the tool presetting area by dedicated tool preparing staff. It is assumed that 30 min. is required for a tool magazine exchange and 15 min. for a tool kit exchanging. A machine is assumed to be not in operation when its tool magazine is being serviced.

13.11.2 Results Discussion

The throughput time of the two machine cell under different scheduling and tooling strategies are:

$M_{1,2} = 965$ min.

$M_{2,2} = 965$ min.

$M_{1,3} = 980$ min.

$M_{2,3} = 980$ min.

The results proved that the two highly automated machine can fulfill the production requirement specified for the original 5 machine cell design (Run 1 - 4) with a reduced throughput time. This conclusion of course needs to be examined by the technical feasibility and economical acceptance, which is out of the scope of this thesis. A further examine of the results showed that under the same tooling strategy, whether *'differential kitting'* or *'complete magazine exchange'*, the two scheduling strategies requires the same throughput time: $M_{1,2} = M_{2,2}$; $M_{1,3} = M_{2,3}$. This because that in all the situations the throughput time is determined by the total processing time of the fully loaded machine, fig. 13.14.

The idle time, however, is different under different strategies:

$IT_{1,1,2}$ = 175 min.;	$IT_{2,1,2}$ = 0.
$IT_{1,2,2}$ = 0;	$IT_{2,2,2}$ = 106 min.
$IT_{1,1,3}$ = 295 min.;	$IT_{2,1,3}$ = 0.
$IT_{1,2,3}$ = 0;	$IT_{2,2,3}$ = 240 min.

The scheduling strategy 2 resulted less idle time than the strategy 1 under the two tooling strategies respectively, which means that the under utilised machine can finish processing earlier for other uses, if applicable.

The tooling strategy 2 *'differential kitting'* performs better than strategy 3 *'complete magazine exchange'* with respect to the length of throughput time required, although the difference is very small.

The tool / tool component requirement under tooling strategy 2 is less than tooling strategy 3 under the two scheduling strategies respectively, fig. 13.25. This is because that when *'differential kitting'* is adopted, tools can be shared between the two machines, but at the expense of tool flow.

When *differential kitting* is implemented one man is required to look after the two machines for both work and tool flow. And there are occasions that a extra man is required for support, unless the machine 1 is to be delayed, which is feasible in this case as this machine is not fully utilised, fig. 13.15.

When *complete magazine exchange* is adopted one man is required to attend the two machines except in the initial set-up period for tool magazine exchange. And the manning requirement is so low that from time to time the operator is available for some other miscellaneous work, fig. 13.16.

13.12 MODELLING OF THE 4 MACHINE CELL WITH NO PART EXIT/RE-ENTRY

So far, the previous runs have been dedicated to the particular production requirement of stochastic-disturbed' type, see Chapter 12, with batches exit/re-entry the CNC turning cells during their processing. It is decided to model the stand-alone turning cells with no out of the cell operations. The control experiment (Run 7 & 8) 4 machine cell design is adopted. The NGL part data with outside operation being eliminated is used for the modelling purpose.

Two runs (Run 13 & 14) have been conducted, using production scheduling strategies 3 & 4. The scheduling strategies 1 & 2 are not applicable in this cell as there is no outside operation requirement any more.

The results showed that the throughput time under the 2 scheduling strategies are of the same level as with the control experiment (Run 7 & 8, fig. 13.8), although with some variance. Run 14 adopting scheduling strategy 4 resulted the longest throughput time. The reason for this is that the workload distribution across different machines is less balanced in this case. The machine idle time is 0 for all the machines, i.e no time has been spent to wait for batches, as a result some of the machines finish process much earlier than others, e.g machine 1 of Run 14, fig. 13.17, which can be used for other tasks.

The comparison of the results of Run 13 and 14 showed that production scheduling strategy 3 performed better than strategy 4 with regard to both shorter throughput time and less tooling requirement, fig. 13.25.

One operator is required for each machine for both tooling and part set-up, fig, 13.18.

13.13 TWO HIGHLY AUTOMATED MACHINE CELL WITH NO PART EXIT/RE-ENTRY

Six runs (Run 15 - 20) have been carried out to examine the cell performance, with outside operation being eliminated. The machine cell is as for Run 9 - 12. The production requirement and part processing planning of Run 9 -12 were used with outside operation time being set to 0. (Fig. 13.8).

Scheduling strategy 5 & 6 were also examined, besides other scheduling strategies, as there is no there is no outside operation required and the highly automated machine design permitting tool sharing between batches.

The comparison of tooling strategy 2 *'differential kitting* with tooling strategy 3 *complete magazine exchange* showed that the latter is better with regard to shorter throughput time requirement, fig. 13.19, 13.20, and less manning involvement for tool and part flow, fig. 13.21, 12.22. However, when *complete magazine exchange* is adopted more set-up effort is required in the tooling preset area to fill the tool magazines.

The comparison of the individual scheduling strategies showed that strategy 3 and 6 are better than strategy 4 and 5 respectively. Scheduling strategy 3 and 6 adopt the workload assignment strategy of '*assigning the batch with the longest work contents to the available*'; while scheduling strategy 4 and 5 adopt the workload assignment strategy of '*assigning the batch with the least work content to the available machine*'. In this production situation, the former produces a better workload balance between the two machines.

Scheduling strategy 5 and 6 which considers tool requirement between different batches result less tool/component requirements, although the saving is not significant.

13.14 EXAMINE THE EFFECT OF TOOL LIFE LIMITS

The effects of relaxing the limit of permissible percentage tool life utilisation has been examined. Four runs have been conducted. Run 21 and 22 were planned to examine the effect of this relaxation in the 4 Index machine cell. Run 8 has been used as the control. The relaxing of the tool life limits of the 2 highly automated machine cell has been examined by Run 23 and 24 based on Run 10.

13.14.1 Effects of Tool Life Limit Relaxation in the 4 Index Machine Cell

As having been specified for Run 8, the tool life limit was set to 50%, fig. 13.8, i.e. once a tool's accumulated life utilisation has reached 50% of its life unit, the tool is regarded as worn, Ref. to Chapter 8 for tool life limit discussion. Run 22 examined the effect of increasing this limit to 65%. The result showed that the saving of 9 items of tool assemblies and inserts, and 8 items of shanks and holders has been achieved. A further increase of the limit up to 80%, Run 21, showed that a further saving of 3 items of tool assemblies and inserts and 2 items of shanks and holders respectively have been resulted. The effects of those relaxation individual tools types have been listed in fig 13.23, 13.24.

The results showed that under this particular condition of cell design and production requirement the increase of tool life limit for 50% to 65% resulted more tool/tool components savings than the further increase form 65% to 80%.

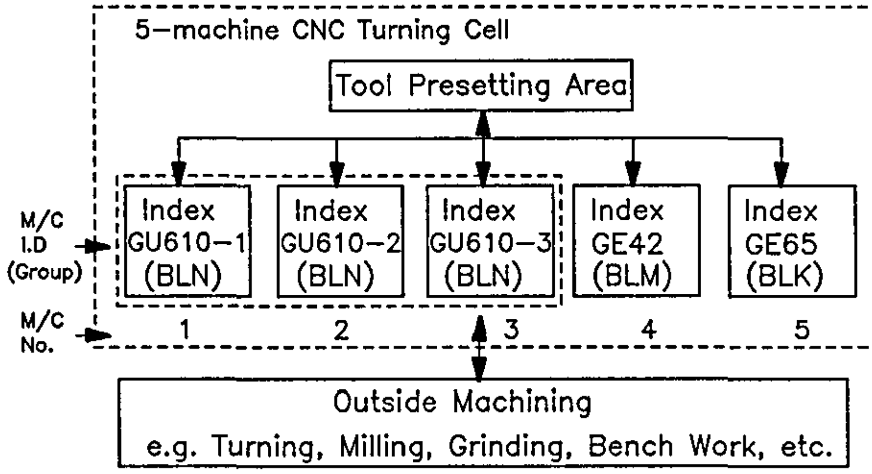
13.14.2 Effects of Tool Life Limit Relaxation in the 2 Highly Automated Machine Cell

Similar to the process of the previous section, Run 23 and 24 were planned to examine the effects of increasing tool life limit up to 80& and 65% respectively, based on Run 10 with the tool life limit of 50%.

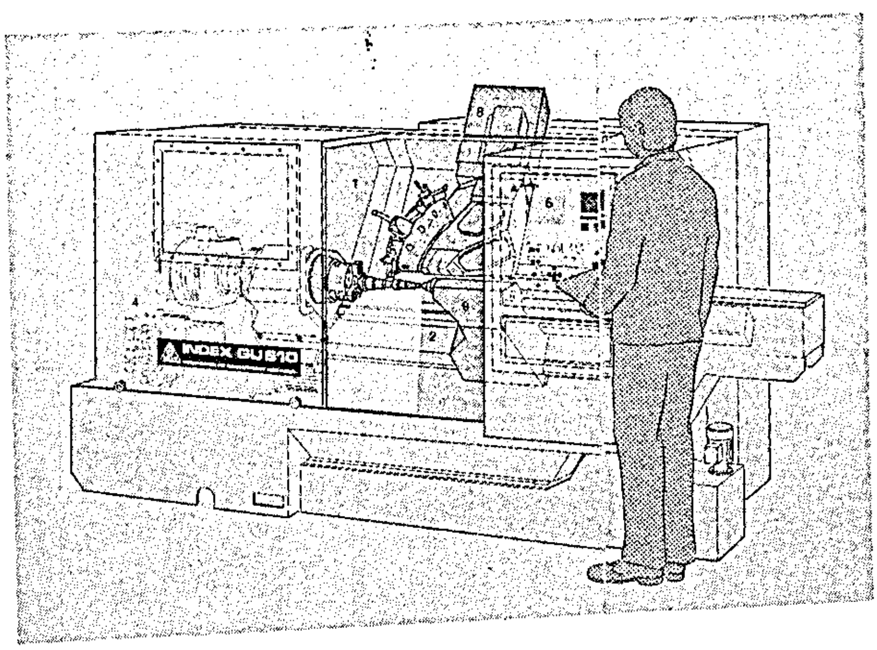
The results showed that the relaxing of tool life limit form 50% (Run 10) to 65% (run 24) decreased the tool/tool component requirement by 9 for tool assemblies, 4 for inserts, 5 for shanks, and none for holders. Further increasing of this limit form 65% to 80% resulted the tooling saving of 9 for tool assemblies, 8 for inserts, 6 for shanks, and 7 for holders.

These results showed that under this particular manufacturing condition, the increase of tool life limit form 65% to 80% produced more tooling saving than the increase form 50% to 65%, although the difference is not significant, fig. 13.25.

It has been noticed that this result is contrary to that of the 4 Index machine cell of the previous section. The explanation to this is that there is no apparent, simple mathematical relations between the extent of relaxation of tool life limit and the number of tooling saving that can be achieved, due to the complexity of tool flow and the large number of tool/tool components involved. One conclusion which is obvious is that the increase of tool life limit will certainly result tooling saving.



NGL	Fig. 13.1 Turbine Cell Configuration	LUT – FMS Research Group



Machine Type	GU610
M/C Group	BLN
Turret Positions	12
Turret Index Time / Position	0.6 sec.
Max. Turning Diameter	210mm

NGL	Fig. 13.2 Machine Description	LUT–FMS RESEARCH GROUP

Part Type	Assigned M/C Group	No. of Tool Op.s	Quantity
1087J012	BLM	12	10
1087J022	BLN	11	10
1088J012	BLN	12	10
1088J042	BLN	12	10
1095J022	BLN	13	1
1095J032	BLN	13	1
1095J052	BLN	14	1
1112J010	BLN	2	10
1112J012	BLN	9	10
1112J022	BLK	11	10
1112J062	BLN	12	5

NGL	Fig. 13.3 Turbine Cell Part List	LUT – FMS Research Group

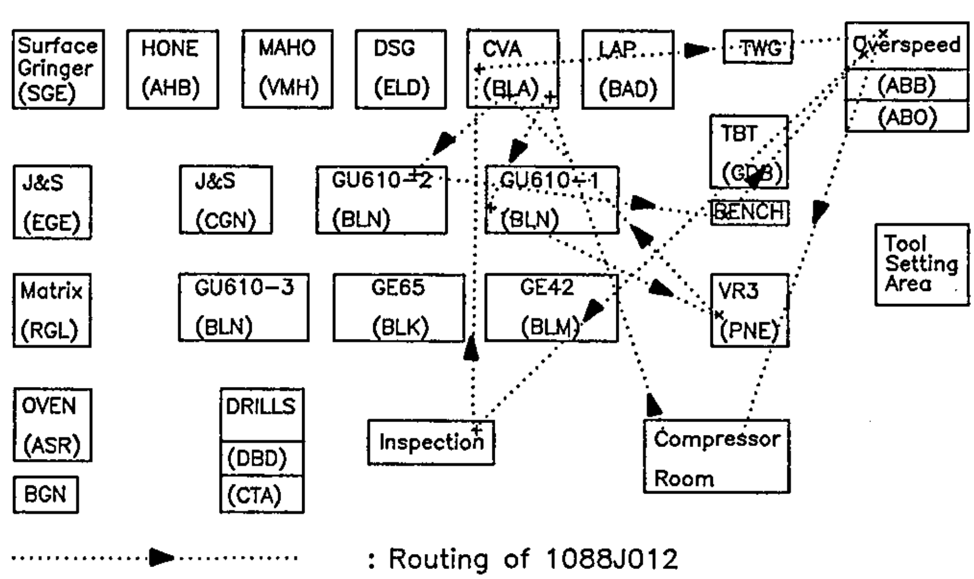
Part Type	Outside Machining	CNC Turning Cell	Outside Machining	CNC Turning Cell
1087J012		*	*	*
1087J022	*	*	*	*
1088J012	*	*	*	*
1088J042		*	*	*
1095J022	*	*	*	
1095J032	*	*	*	
1095J052		*	*	*
1112J010		*	*	
1112J012		*	*	
1112J022		*	*	*
1112J062		*	*	

NGL	Fig. 13.4 Turbine Cell Part Routing	LUT – FMS Research Group

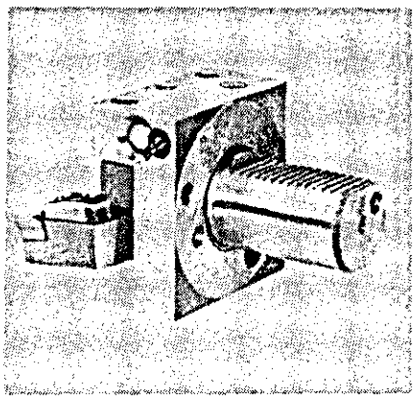
Part I.D: 1088J012 Description: Compressor
Material: Casting 203697–3

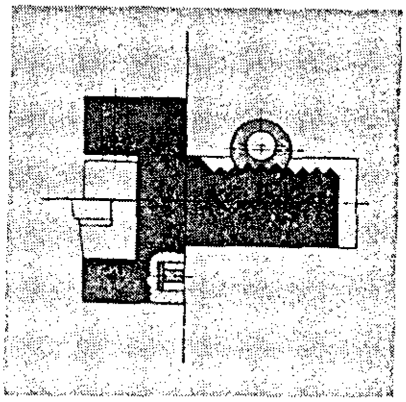
M/C (Group)	Set–up Time	Op. Time (min.)	Operation Description	Tool Type
BLA	1H30M	4	NC Turn	
GU610 –1 (BLN)	45M	1.4	Rough Face & Turn	TU01
		0.2	C/Drill	DR01
		0.9	Drill 0.4331	DR07
		0.5	Finish Face & Turn	TU02
		3.1	Finish Bore to SKT.2	B003
	1H45M	0.3	Rough Face	TU01
		0.1	Rough C/Bore	DR08
		0.1	Finish Face to SKT.3	TU02
		1.2	Finish C/Bore	B003
PNE (BNA)	6H0M	4	NC Mill	
BLA	1H30M	11	Bore, Face, Reset & Face	
GU610 –2 (BLN)	3H	0.8	Rough&Finish to FKT.7	TU06
		1.2	Rough M/C Profile	TU01
		0.5	Finish Profile as SKT.8	TU07
Bench	15M	25	Deburr	
Inpection Overspeed	3H		Inspection, Balance	
BLA	2H30M	11	Bore	
ABB	1H		Balance	

NGL | Fig. 13.5 Part Routing | LUT–FMS RESEARCH GROUP



NGL | Fig. 13. 6 Turbine Cell Layout With Typical Part Routing Examples | LUT— FMS Research Group





TOOL DESCRIPTION

```
Tool Type: TU11
        Tool Description /Company I.D:
        Rotational Tool [Y/N] ? .... : N

Insert (Cutting Unit) Information:
 Insert Type ........... : CNMS120408 K68
 Assigned Tool Life Unit :   30.00  Max. Permissible % Tool Life :  50.00
 Percentage Life Used .. :   0.00   No. of Indexable Tips/Regrinds: 4
 No. of Tips Used  ..... : 0

Shank Information:
 Shank Type ............ : MCLNR2020 H12
 External / Internal Tool [E/I]: E  Shank Size  .....  :   1

Holder Information:
 Holder Type ........... : W633000400
```

Continue: <Enter>	Edit Data Entry <Ctrl-B>	Hard Copy: <Shift-PrtSc>		Quit: <Esc>

NGL	Fig. 13.7 A Typical Tool Information	LUT-FMS RESEARCH GROUP

Run No.	Data Specification & System Design	Tooling Strategy (Ref. to Fig. 13.9.2)	Schedule. Strategy (Ref. to Fig. 13.9.1	Comments
1	- NGL part data - NGL 5 M/C cell design - 11 part types - 50% permissible tool life	1. Kitting	1	- NGL data plus synthetic scheduling strategies
2			2	
3			3	
4			4	
5	- NGL system design - Original part mix * 2	1. Kitting	1	- Increased No. of batches - Scheduling strategy 1 & 2 proved better than 3 & 4
6			2	
7	- NGL part data - 4 Index M/C cell - 50% permissible tool life	1. Kitting	1	- Control Experiment - M/C 4 & 5 under-utilised - M/C 4 & 5 of same type - Check what-if M/C 5 is eliminated
8			2	
9	- NGL order requirement - 2 M/C cell - Auto. Chuck Jaw Changing (ACJC) M/C - Tool magazine added - 1/4 control exp. part set-up time - Synthetic data Ref. to Fig. 9.2	2. Differential Kitting	1	- 2 highly auto. M/C cell - Control exp. part data with reduced part & tooling set-up time - Differential kitting proved tool /tool component saving over kitting - Differential kitting applicable only when tool magazine equipped - Tooling strat. 3 reduces tool exchanging interfere
10			2	
11		3. Complete Magazine Exchange	1	
12			2	
13	- Control exp. data with no exit/re-entry - 4 Index M/C cell	1. Kitting	3	- Stand-alone cell with no interaction with outside M/Cs - Scheduling strategies 1 & 2 not applicable
14			4	
15	- Control exp. part data outside op. time of 0 - 2 highly auto. M/C cell - Synthetic data Ref. to Fig. 9.2	2. Differential Kitting	3	- Stand-alone cell - Control exp. part data with reduced part & tooling set-up time - Scheduling strategy 5 & 6 examined
16			4	
17			5	
18			6	
19		3. Complete Magazine Exchange	3	
20			4	
21	- Control exp. part data - 4 Index M/C cell - Increased/ decreased permissible tool life limit	1. Kitting	2	- Permissible tool life = 80% - Sche. Strat. 2 of best in control exp.
22			2	- Permissible tool life = 65%
23	- 2 highly auto. M/C cell - Control exp. part data with reduced set-up time - Increased/ decreased permissible tool life limit	2. Differential Kitting	2	- Permissible tool life = 80%
24			2	- Permissible tool life = 65%

Fig. 13.8
Overview of
Modelling Experiment

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No.		M/C Workload	Batch Op. Time	Batch Outside Op. Time	Additional Batch Tool Req. for M/C
1	Workload Assign. Rule	Least	Shortest	–	–
	Sequencing Rule	–	–	Longest	–
2	Workload Assign. Rule	Least	Longest	–	–
	Sequencing Rule	–	–	Longest	–
3	Workload Assign. Rule	Least	Longest	–	–
	Sequencing Rule	–	Shortest	–	–
4	Workload Assign. Rule	Least	Shortest	–	–
	Sequencing Rule	–	Shortest	–	–
5	Workload Assign. Rule	Least	Shortest	–	–
	Sequencing Rule	–	–	–	Least
6	Workload Assign. Rule	Least	Longest	–	–
	Sequencing Rule	–	–	–	Least

Fig. 13.9.1
Production Scheduling Strategy List

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No.	Description
1. Kitting	A tool kit consisting of all the tools for a batch is issued to a M/C accompany the part batch. Successive kits are exchanged at the completion of each batch.
2. Differential Kitting	Only tools not available in the M/C are contained in a kit. Tools can be shared between tool kits
3. Complete Magazine Exchange	All tools required for the production period by a M/C are stored in the M/C based tool store (magazine).

Fig. 13.9.2
Tooling Strategy List

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Run No.: 1; Schedule. Strat.: 1; Tooling Strat.: 1;	M/C	Cutting Time	Part (M/C) Set-up Time	Tooling Set-up Time	Idle Time	Total Processing Time
	1	192	600	422	0	1214
	2	172	630	406	129	1337
	3	175	795	466	0	1436
	4	86	165	166	135	552
	5	132	280	211	700	1323
	Throughput Time: 1436					

Run No.: 1; Schedule. Strat.: 2; Tooling Strat.: 1;	M/C	Cutting Time	Part (M/C) Set-up Time	Tooling Set-up Time	Idle Time	Total Processing Time
	1	205	660	481	0	1346
	2	130	750	406	0	1286
	3	205	615	407	111	1338
	4	86	165	166	135	552
	5	132	280	211	700	1323
	Throughput Time: 1346					

Run No.: 3; Schedule. Strat.: 3; Tooling Strat.: 1;	M/C	Cutting Time	Part (M/C) Set-up Time	Tooling Set-up Time	Idle Time	Total Processing Time
	1	205	660	481	0	1346
	2	130	750	406	0	1286
	3	205	615	407	585	1812
	4	86	165	166	135	552
	5	132	280	211	700	1323
	Throughput Time: 1812					

Run No.: 4; Schedule. Strat.: 4; Tooling Strat.: 1;	M/C	Cutting Time	Part (M/C) Set-up Time	Tooling Set-up Time	Idle Time	Total Processing Time
	1	192	600	422	0	1214
	2	172	630	406	621	1829
	3	175	795	466	0	1436
	4	86	165	166	135	552
	5	132	280	211	700	1323
	Throughput Time: 1829					

Time Unit: min.

M/C No.:
1: GU610 – 1; 2: GU610 – 2; 3: GU610 – 3; 4: GE65; 5: GE42.

Fig. 13.10

Machine Utilisation

(Run 1 – 4)

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Run No.: 5; Schedule. Strat.: 1; Tooling Strat.: 1;	M/C	Cutting Time	Part (M/C) Set-up Time	Tooling Set-up Time	Idle Time	Total Processing Time
	1	315	1425	782	0	2522
	2	391	1260	888	0	2539
	3	374	1365	918	0	2657
	4	172	330	332	0	834
	5	264	560	423	509	1756
	Throughput Time: 2657					

Run No.: 6; Schedule. Strat.: 2; Tooling Strat.: 1;	M/C	Cutting Time	Part (M/C) Set-up Time	Tooling Set-up Time	Idle Time	Total Processing Time
	1	363	1350	858	0	2571
	2	350	1425	903	0	2678
	3	367	1275	828	0	2470
	4	172	330	332	0	834
	5	264	560	423	509	1756
	Throughput Time: 2678					

Time Unit: min.

M/C No.:
1: GU610 – 1; 2: GU610 – 2; 3: GU610 – 3; 4: GE65; 5: GE42.

Fig. 13.11

Machine Utilisation

(Run 5 – 6)

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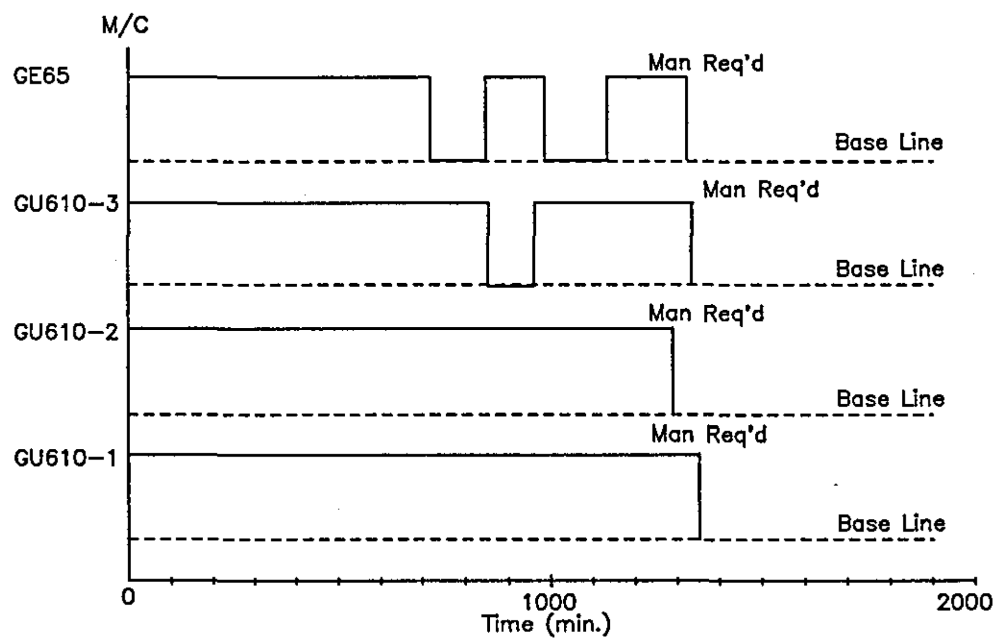
Run No.: 7; Schedule. Strat.: 1; Tooling Strat.: 1;	M/C	Cutting Time	Part (M/C) Set-up Time	Tooling Set-up Time	Idle Time	Total Processing Time
	1	192	600	422	0	1214
	2	172	630	406	129	1337
	3	175	795	466	0	1436
	4	218	445	377	283	1323
	Throughput Time: 1436					

Run No.: 8; Schedule. Strat.: 2; Tooling Strat.: 1;	M/C	Cutting Time	Part (M/C) Set-up Time	Tooling Set-up Time	Idle Time	Total Processing Time
	1	205	660	481	0	1346
	2	130	750	406	0	1286
	3	205	615	407	111	1338
	4	218	445	377	283	1323
	Throughput Time: 1346					

Time Unit: min.

M/C No.:
1: GU610 – 1; 2: GU610 – 2; 3: GU610 – 3; 4: GE65.

NGL	Fig. 13.12 Machine Utilisation (Run 7, 8)	LUT – FMS Research Group



NGL	Fig. 13.13 Manning Pattern – 4 M/C Cell (Run No. 8)	LUT – FMS Research Group

Run No.: 9; Schedule. Strat.: 1; Tooling Strat.: 2;	M/C	Cutting Time	Part (M/C) Set-up Time	Tooling Set-up Time	Idle Time	Total Processing Time
	1	330	320	140	175	965
	2	428	300	127	0	855
	Throughput Time: 965					

Run No.:10; Schedule. Strat.: 2; Tooling Strat.: 2;	M/C	Cutting Time	Part (M/C) Set-up Time	Tooling Set-up Time	Idle Time	Total Processing Time
	1	345	330	125	0	800
	2	413	290	156	106	965
	Throughput Time: 965					

Run No.:11; Schedule. Strat.: 1; Tooling Strat.: 3;	M/C	Cutting Time	Part (M/C) Set-up Time	Tooling Set-up Time	Idle Time	Total Processing Time
	1	330	320	35	295	980
	2	428	300	37	0	765
	Throughput Time: 980					

Run No.:12; Schedule. Strat.: 2; Tooling Strat.: 3;	M/C	Cutting Time	Part (M/C) Set-up Time	Tooling Set-up Time	Idle Time	Total Processing Time
	1	345	330	36	0	711
	2	413	290	37	240	980
	Throughput Time: 980					

Time Unit: min.

Fig. 13.14

Machine Utilisation

(Run 9 – 12)

LUT-FMS RESEARCH GROUP

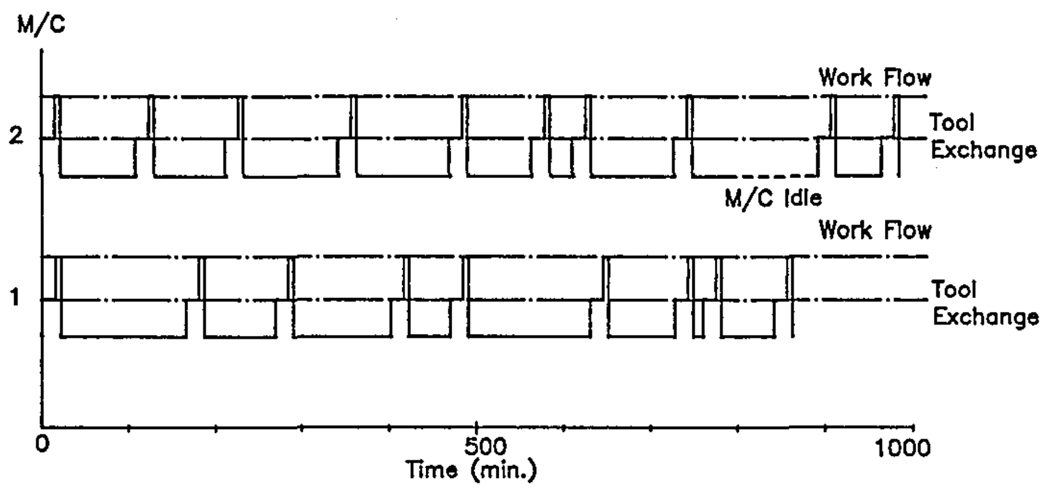


Fig. 13.15 Manning Pattern
– 2 M/C Cell; Tooling Strat.: 2
(Run 10)

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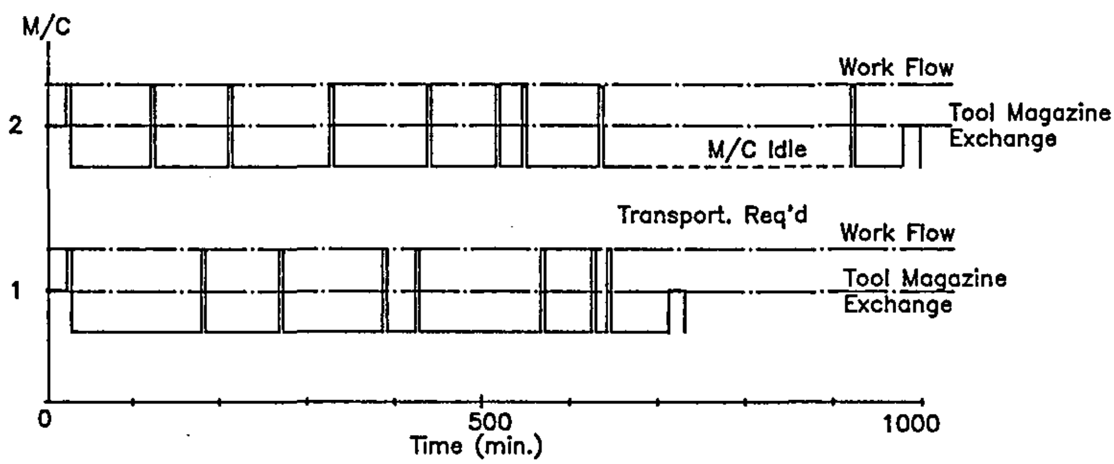

Fig. 13.16 Manning Pattern
– 2 M/C Cell; Tooling Strat.: 3
(Run 12)

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Research Group

Run No.:13; Schedule. Strat.: 3; Tooling Strat.: 1;	M/C	Cutting Time	Part (M/C) Set-up Time	Tooling Set-up Time	Idle Time	Total Processing Time
	1	189	570	347	0	1106
	2	185	660	466	0	1311
	3	166	795	466	0	1427
	4	218	445	348	0	1011
	Throughput Time: 1427					

Run No.:14; Schedule. Strat.: 4; Tooling Strat.: 1;	M/C	Cutting Time	Part (M/C) Set-up Time	Tooling Set-up Time	Idle Time	Total Processing Time
	1	206	420	332	0	958
	2	168	810	481	0	1459
	3	166	795	466	0	1427
	4	218	445	348	0	1011
	Throughput Time: 1459					

Time Unit: min.

Fig. 13.17
Machine Utilisation
(Run 13 – 14)

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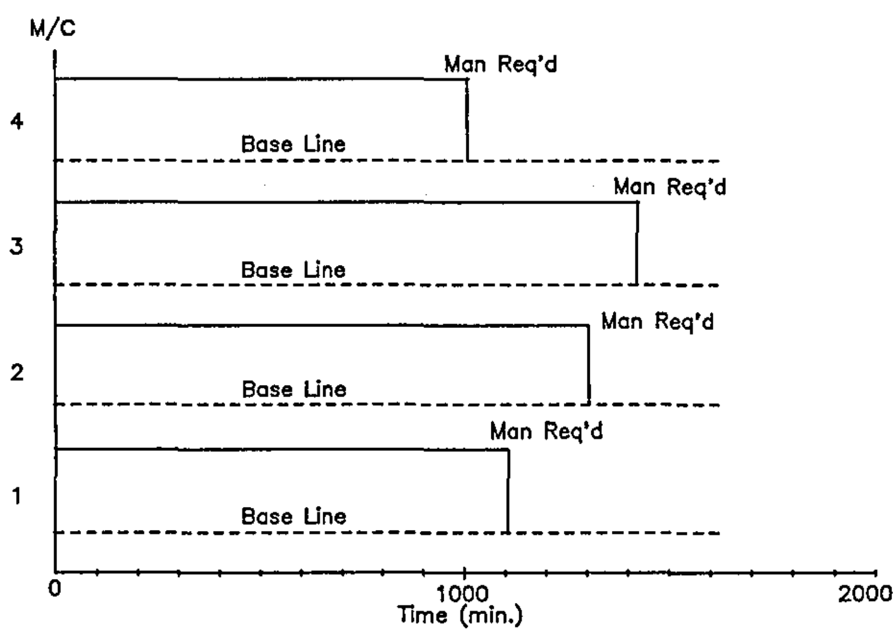

Fig. 13.18 Manning Pattern
– 4 M/C Cell without Exit/Re–entry
(Run 13)

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Run No.:15; Schedule. Strat.: 3; Tooling Strat.: 2;	M/C	Cutting Time	Part (M/C) Set-up Time	Tooling Set-up Time	Idle Time	Total Processing Time
	1	353	341	95	0	789
	2	405	278	82	0	765
	Throughput Time: 789					

Run No.:16; Schedule. Strat.: 4; Tooling Strat.: 2;	M/C	Cutting Time	Part (M/C) Set-up Time	Tooling Set-up Time	Idle Time	Total Processing Time
	1	456	281	96	0	833
	2	301	339	80	0	720
	Throughput Time: 833					

Run No.:17; Schedule. Strat.: 5; Tooling Strat.: 2;	M/C	Cutting Time	Part (M/C) Set-up Time	Tooling Set-up Time	Idle Time	Total Processing Time
	1	456	281	96	0	833
	2	301	339	80	0	720
	Throughput Time: 833					

Run No.:18; Schedule. Strat.: 6; Tooling Strat.: 2;	M/C	Cutting Time	Part (M/C) Set-up Time	Tooling Set-up Time	Idle Time	Total Processing Time
	1	353	341	95	0	789
	2	405	278	81	0	764
	Throughput Time: 789					

Time Unit: min.

Fig. 13.19

Machine Utilisation

(Run 15 – 18)

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Run No.:19; Schedule. Strat.: 3; Tooling Strat.: 3;	M/C	Cutting Time	Part (M/C) Set-up Time	Tooling Set-up Time	Idle Time	Total Processing Time
	1	353	341	35	0	729
	2	405	278	36	0	719
	Throughput Time: 729					

Run No.:20; Schedule. Strat.: 4; Tooling Strat.: 3;	M/C	Cutting Time	Part (M/C) Set-up Time	Tooling Set-up Time	Idle Time	Total Processing Time
	1	456	281	37	0	774
	2	301	339	35	0	675
	Throughput Time: 774					

Time Unit: min.

Fig. 13.20 Machine Utilisation (Run 19 – 20) | LUT – FMS Research Group

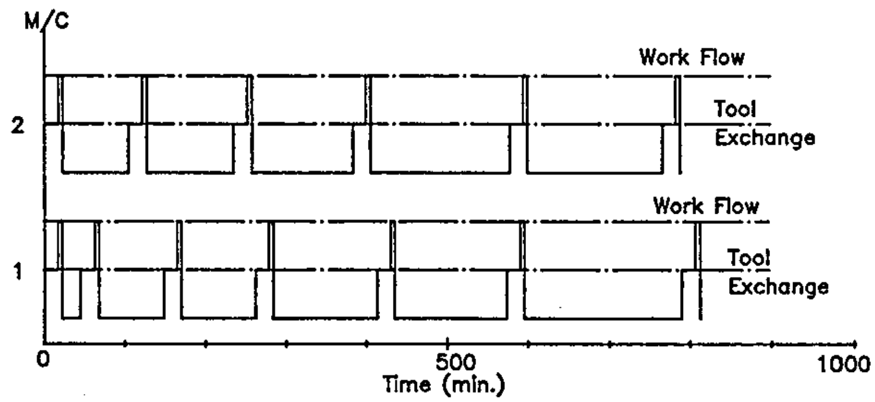

Fig. 13.21 Manning Pattern – Stand-alone Cell; Tooling Strat. 2 (Run 15) | LUT – FMS Research Group

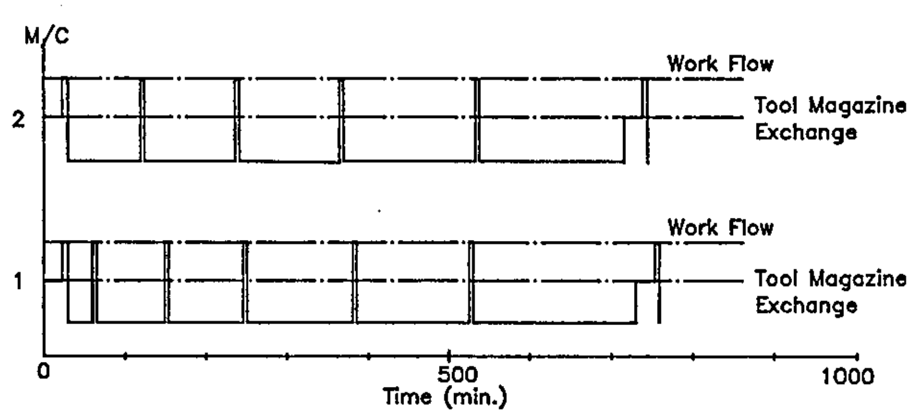

Fig. 13.22 Manning Pattern – Stand-alone Cell; Tooling Strat.: 3 (Run 19) | LUT – FMS Research Group

Tool Type	No. of Sister Tooling Required					
	4 Index M/C Cell Schedule. Strat.: 2 Tooling Strat. : 1			2 Highly Auto. M/C Cell Schedule. Strat.: 2 Tooling Strat. : 2		
	% Permissible Tool Life			% Permissible Tool Life		
	50% (Run 8)	65% (Run 22)	80% (Run 21)	50% (Run 10)	65% (Run 24)	80% (Run 23)
TU01	20	18	17	18	14	11
TU02	16	13	13	11	9	7
TU03	1	1	1	1	1	1
TU04	1	1	1	1	1	1
TU05	3	2	2	2	2	2
TU06	1	1	1	1	1	1
TU07	2	2	2	1	1	1
TU08	4	2	2	4	2	2
TU09	2	2	2	1	1	1
TU10	1	1	1	1	1	1
TU11	1	1	1	1	1	1
TU12	1	1	1	1	1	1
TU13	2	2	1	2	2	1
TU14	1	1	1	1	1	1
TU15	1	1	1	1	1	1
TU16	1	1	1	1	1	1
TU17	1	1	1	1	1	1
TU18	1	1	1	1	1	1
TU19	1	1	1	1	1	1
TU20	1	1	1	1	1	1
TU21	1	1	1	1	1	1
B001	1	1	1	1	1	1
B002	7	7	7	5	5	3

Fig. 13.23

Effect of %
Permissible Tool Life

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Tool Type	No. of Sister Tooling Required					
	4 Index M/C Cell Schedule. Strat.: 2 Tooling Strat. : 1			2 Highly Auto. M/C Cell Schedule. Strat.: 2 Tooling Strat. : 2		
	% Permissible Tool Life			% Permissible Tool Life		
	50% (Run 8)	65% (Run 22)	80% (Run 21)	50% (Run 10)	65% (Run 24)	80% (Run 23)
B003	4	3	2	4	3	2
B004	2	2	2	1	1	1
B005	2	2	2	1	1	1
B006	1	1	1	1	1	1
B007	1	1	1	1	1	1
B008	1	1	1	1	1	1
B009	1	1	1	1	1	1
B010	1	1	1	1	1	1
DR01	3	3	3	1	1	1
DR02	1	1	1	1	1	1
DR03	2	2	2	1	1	1
DR04	2	2	2	1	1	1
DR05	3	3	3	2	2	2
DR06	1	1	1	1	1	1
DR07	1	1	1	1	1	1
DR08	1	1	1	1	1	1
DR09	2	2	2	1	1	1
DR10	2	2	2	1	1	1
DR11	1	1	1	1	1	1
DR12	3	3	3	2	2	2
DR13	1	1	1	1	1	1
DR14	2	2	2	2	2	2
DR15	2	2	2	2	2	2
Total	111	102	99	89	80	71

Fig. 13.24

Effect of % Permissible Tool Life

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Run No.	Data Specification & Cell Design	Tool. Strat.	Sched. Strat.	Throughput Time (min.)	Tool/Tool Component Req.			
					Tools	Inserts	Shanks	Holders
1	– NGL 5 M/C Cell	1	1	1436	111	74	47	66
2			2	1346	111	84	56	71
3			3	1812	111	77	54	66
4			4	1829	111	78	56	79
5	– NGL 5 M/C Cell; – Part Kit * 2.	1	1	2657	222	137	89	99
6			2	2678	222	139	89	103
7	– 4 Index M/C Cell	1	1	1436	111	76	48	64
8			2	1346	111	87	57	70
9	– 2 High Auto. M/C Cell.	2	1	965	88	74	50	71
10			2	965	89	70	46	55
11		3	1	980	95	95	68	95
12			2	980	97	97	70	97
13	– 4 Index M/C Cell; – No Exit/Reentry	1	3	1427	108	95	65	85
14			4	1459	108	97	69	90
15	– 2 Highly Auto. M/C Cell; – No Exit/Reentry	2	3	789	97	82	56	77
16			4	833	95	83	53	79
17			5	833	95	79	53	68
18			6	789	97	77	52	69
19		3	3	729	97	97	70	97
20			4	774	95	95	68	95
21	– 4 Index M/C Cell; – Relaxed Tool Life Limit.	1	2	1293	99	75	47	60
22			2	1308	102	78	49	62
23	– 2 Highly Auto. M/C Cell; – Relaxed Tool Life Limit.	2	2	964	71	58	35	49
24			2	964	80	66	41	55

Fig. 13.25

Summary of Outputs

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CHAPTER 14 CONCLUDING REMARKS

14.1 INTRODUCTION

This chapter presents a critical review of the research work. The merits of the algorithmic modelling approach are discussed.

14.2 THE FRAMEWORK OF TOOL FLOW SYSTEM EVALUATION

The literature survey of chapter 2 indicated the requirement of tool flow management and studied the various modelling media and FMS models. The study of turning automation developments ranging from tooling support, chuck jaw changing to secondary operation facilities, see chapter 3 and 4, and the study of tooling system for turning systems, chapter 5, has provided the impetus for studying the unique features of tool flow systems for cylindrical part manufacturing.

The algorithmic modelling approach has been adopted to study the tool flow problems in detail and with relegated features representing the system operation with regard to part flow, and the manning pattern of turning systems with various levels of automation, chapter 6. The framework has been built up which allows fast and efficient evaluation of the design of and operating strategies for tool flow systems for tool flow management in batch manufacturing systems for cylindrical components, chapter 7.

14.3 GENERIC REPRESENTATION OF TOOL FLOW SYSTEMS

The generic representation of tool flow systems, chapter 7, provides the capability of evaluating a broad range of flexible turning systems operating under a whole host of strategies and rules. In most of the cases this is sufficient to examine and explore alternative rules and strategies for turning systems with varying level of automation. The part flow has been represented in a limited scope by the production scheduling facility. Although at its earlier stage, the modelling of tool and part flow interactively in the full scale is under development in a complementary project [223].

14.4 THE ALGORITHMIC APPROACH

The algorithmic approach focused on turning automation and tool flow. The power of the approach lies in its ability to handle the large body of data required to define individual tool status and activities in a efficient and fast way. The algorithmic approach is not synchronised. Instead scan and back trace of *major activities* are implemented. Computer run time has been reduced by cutting the comparison loops. The resultant run time is shorter than that required by simulation for a similar number of entities.

The primary objective of the approach is to examine tool flow problems. The secondary features derived from the use of the model, including manning requirement and machine utilisation, which is time related, complements the main stream tool flow modelling and has produced a balanced modelling tool. The time related outputs feature of the model can be used to evaluate a turning system performance in general to gain a quick view of the modelled system, but can generate misleading data. The secondary outputs can be much more dependent by dividing a longer production period into a number of successive runs. With each one modelling a shorter period, intermediate results have been obtained, thus overcoming the limitations of the model, i.e that the outputs can only be accessed at the end of a run. By doing so, a turning system can be evaluated almost as accurately as a time synchronised approach. The algorithms for manning operation modelling is based on earliest start time and is under the assumption that a man is available when required.

The Turning model at the single machine level handles a full scale of turning automation including turret tool storage and location, magazine tooling support and tool exchange, chuck jaw and gripper exchanging. Full range of tools can be incorporated, including external / internal turning tools, live tooling, and contact probes. The machine set-up can be modelled both to calculate the machine utilisation, and to examine the manning involvement, chapter 7, 8. A case study has been carried out for a highly automated machine centre illustrate the model capability. The machine has been modelled both for small batch and larger batch production, chapter 9.

The modelling of cell level activities, chapter 10, incorporates a full range of tool assignment, issue, storage and transfer strategies. The operating of turning cells of categories range from manually operated, manually supported, to highly automated cells can be modelled.

The Turning Model at the central tool store (CTS) level models the CTS tool issue, tool preparation, and disposal. The tooling inventory control features both tool assembly requirement planning and the inventory control of tool components, i.e inserts, shanks, and holders requirement to fulfill the production requirement.

14.5 THE PRODUCTION SCHEDULING FRONT END

The primary objective of production scheduling front end, chapter 12, is not to examine the effectiveness of the scheduling function, but to complement the tool flow management package to provide a adequate modelling facility. However, through the multi-machine case study, chapter 13, it has been found that the scheduling strategies effect the system performance and tooling requirement significantly. Similarly the tooling strategies have significant influences on manning patterns, besides their influence on tooling requirement.

Efforts have been taken to build the production scheduling module to suit different production environments, viz. static- flow and stochastic-interrupted cells. A number of heuristic priority rules considering either work contents, outside operation requirement, or tool exchange requirement, have been applied in different level of the scheduling processes.

14.6 THE USER INTERFACE

Conversational screens have been built to enhance the user friendliness of the software, Appendix 1B. The user is guided by the screens through the process of data input, tooling system configuration, production scheduling and tooling strategy selection, model running, and the output obtaining. The objective of the user-interface building is that it is possible for a user new to the software to set-up the model in a short time and to examine a specific turning installation, and to obtain the results easily. The user interface is very dependent on workstation specifications.

14.7 THE WORKSTATIONS

The model has been mounted on a extended version of IBM PC-AT until recently, which is efficient to model a turning cell for a shorter production period. The current implementation of the software onto a more powerful SUN 386i workstation with the capability for emulating DOS and the more powerful UNIX environment has offered the scope of a full range of enhancements to the proto type software. The run time can be reduced by both its powerful processor and its multi-window facility. The multi-window feature allows the several runs to be carried out concurrently, thus the results can be compared. It also allows the viewing of inputs and accessing of outputs side by side. More important is its reliability as the IBM version of the software relies largely on the RAM disc and the experience showed that the reliability of the RAM disc is effected severely by the heat of the extended run time which is inevitable when model the production of longer period. The multi-window and parallel processing capability of the SUN 386i has opened a wide scope for the software enhancement, see chapter 16.

14.8 THE CASE STUDIES

The single machine case study, chapter 9, has illustrated the modelling capability in a full scale with regard to the turning automation features. It has proved that the tooling requirement and the tooling strategy performance depends very much on the features such as production requirement, part process planning, part type mix, and batch sizes.

The multi-machine case study, chapter 13, has proved that the scheduling strategies affect both the system performance and the tooling requirement, so do the tooling strategies. The scheduling strategies which consider the turning cell production environment, i.e the part exit/re-entry have resulted significant shorter throughput times than others. The effectiveness and the performance of the scheduling strategies and tooling strategies are very much production requirement and tooling system dependent. The density of manning requirement is effected to a significant extent by the tool issue strategies.

The break down of tool assemblies into tool components has been an efficient forecasting tool for central tool store inventory control.

The two case studies has also proved that the altering of permissible tool life utilisation limit affects the tool requirement. The relationship between the tool life limit changing and the tool requirement variation is system dependent, and no apparent mathematical relationship has been found. The multi-machine cell case study has also proved that the Turning Model can be employed for turning system configuration evaluation with respect to number of machines required and the associated automation levels, although it is the secondary feature of the model.

CHAPTER 15 CONCLUSIONS

15.1 INTRODUCTION

This chapter presents the conclusions drawn from the modelling exercises and the case studies.

15.2 THE ALGORITHMIC MODELLING APPROACH

The algorithmic modelling approach based on generic representation of tool flow networks has been proved to be an adequate, fast, and efficient modelling tool both for system design and operation. Turning systems ranging from a single machine to a multi-machine cell and the central tool store can be modelled. The algorithmic approach has focused on specific areas with greater detail rather than the normal statistic results. Besides its efficiency for the management of both tool flow and tool component requirement, the secondary features of the model has proved to be a quick tool for turning system performance evaluation and manning pattern prediction.

15.3 THE PROTOTYPE SOFTWARE

The model has proved to be efficient as it allows short computing times. The user interface has made the the tool flow system configuring and re-configuring, and tooling strategy selection easy to handle. Thus a large number of runs can be conducted to examine the alternatives and the consequences, as having been done in the case studies, which is almost prohibitive for other simulation tools.

15.4 THE PRODUCTION SCHEDULING FACILITY

The production scheduling module which is capable of both scheduling the work-flow for different production environments, chapter 13, and accepting a user specified pre-scheduled work-to- list, chapter 9, has been proved to be a useful expansion to the main stream tool flow model, and has enhanced the Turning Model efficiency by producing the work flow schedules. However it will be strenthened in the future by the addition of the Computer Aided Cluster Analysis.

15.5 THE CASE STUDIES

The experience gained through the case studies showed that in many companies, collecting the data can prove to be a mammoth task. In most manually operated/supported turning cells the tool life utilisation limits are set up by the operator according to his own experience.

The areas of tool flow that requires particular attention are tool preparation, tool life limit specification, individual tool tracking, and tool components inventory control. Significant throughput time saving can be achieved by organising the tool assembling and presetting activities effectively.

CHAPTER 16 FURTHER WORK

16.1 INTRODUCTION

It is recommended that further work be carried out in the following areas.

16.2 MANNING OPERATION MODELLING

The manning requirement modelling, although the secondary objective of the model, has been seen as an important complements. Algorithms need to be developed for production schedule altering and man assignment under the constraint of limited man power resource to achieve a certain manning pattern, based on the outputs that can be obtained form the current modelling approach.

16.3 IMPLEMENTATION OF THE SOFTWARE ON SUN386i

The IBM PC/AT version of the software features frequent file read/write form/to the disc, which is inevitable for the 64K limit of the compiler. To exploit the full advantage of the Sun 386i processing capability, the large array organizer is suggested as the disc read/write slows down the processing speed, and it is suggested that the screen message writing during the model running be eliminated as the screen access on the Sun environment is slow.

A even further enhancement to the software is recommended to use the Sun 386i's multi-processing capability, so that the modelling of multi-machines and tool store activities can be carried out in high speed by parallel processing.

16.4 INCORPORATE THE CACA MODULE IN FULL SCALE

Although the stand alone Computer Aided Cluster Analysis (CACA) developed by a complementary project in the research group can provide a short range production schedule with regard to part and tool clusters to the model, the effect of the tool-oriented rules and strategies on the actual flow of work and tool flow requires to be considered in more detail particularly within dynamic scheduling environments.

16.5 ANIMATED TOOL EXCHANGING AND TRANSFERRING

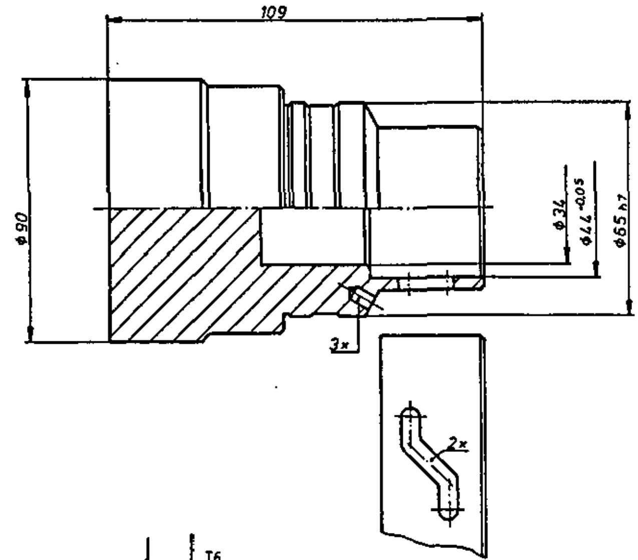
The application of a animation post processor, e.g SIMAN/CINEMA could provide a helpful aid to the interpretation of outputs from the model.

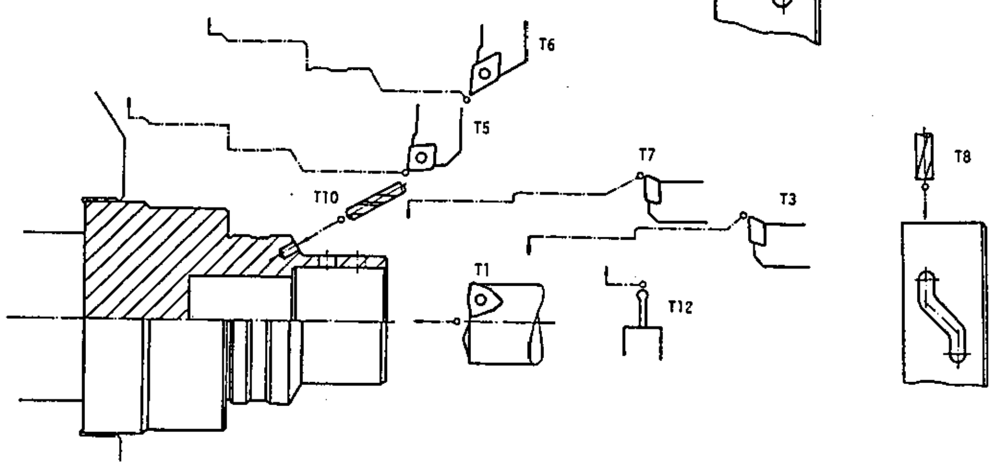
APPENDIX 1A

WORKPIECE INFORMATION
FOR THE SINGLE MACHINE CASE STUDY

(Supplement to Chapter 9)

Part Type: Part 1;   Material: BS080M30;





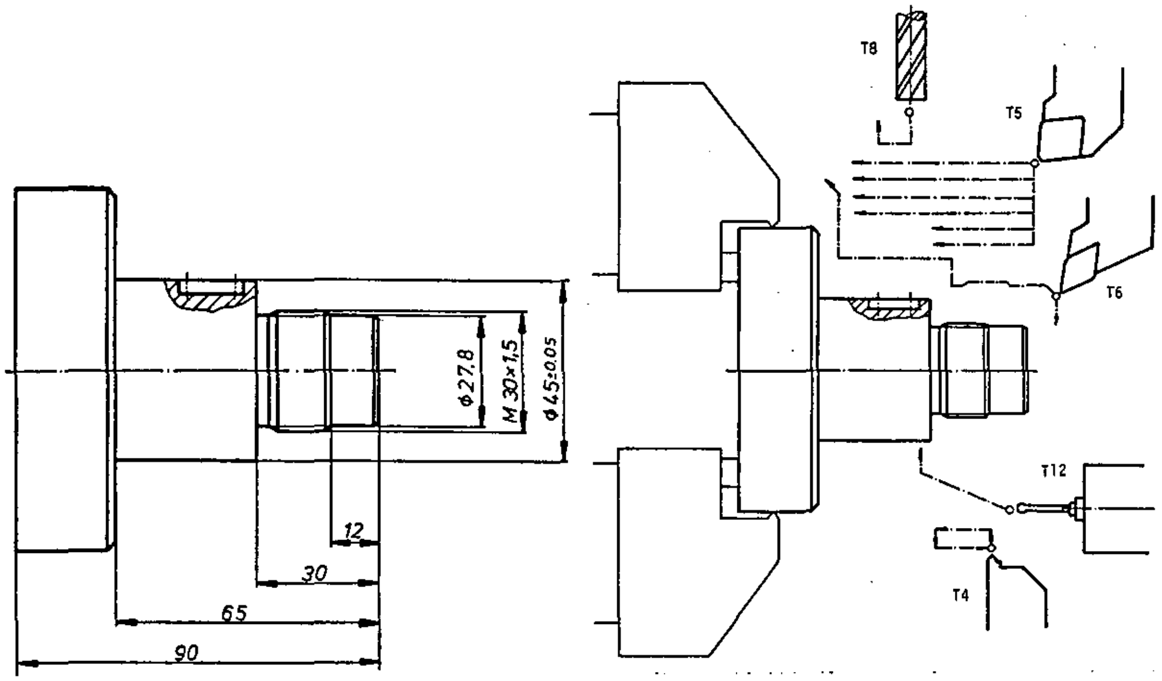
Op. No.	Op. Description	Cutting Time (min.)	Tool Type
1	Rough Turning	0.5	T5
2	Finish Profiling	0.5	T6
3	Drilling	0.6	T1
4	Boring	0.6	T7
5	Finish Boring	0.5	T3
6	Milling	1	T8
7	Drilling	0.2	T10
8	Inspection	0.1	T12

TRAUB

Fig. 1A.1 Synthetic Workpiece Information

LUT-FMS RESEARCH GROUP

Part Type: Part2; Material: BS080M30;



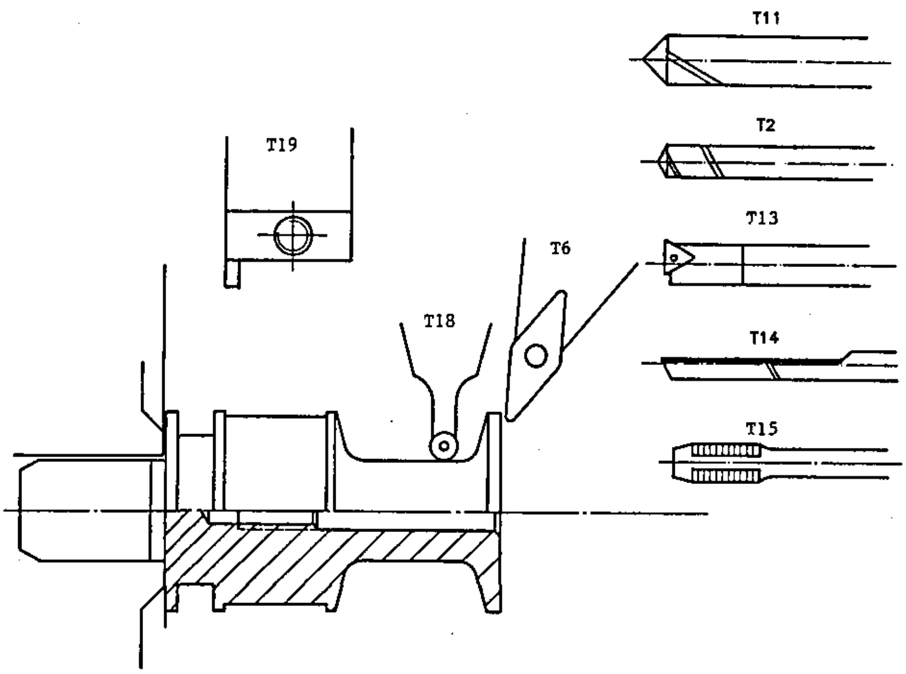
Op. No.	Op. Description	Cutting Time (min.)	Tool Type
1	Rough Turning	2	T5
2	Finish Profiling	0.5	T6
3	Key-way Milling	0.5	T8
4	Thread Chasing	0.02	T4
5	Inspection	0.1	T12

TRAUB

Fig. 1A.2 Synthetic Workpiece Information

LUT-FMS RESEARCH GROUP

Part Type: Part3; Material: Al–CuMgPb F37;



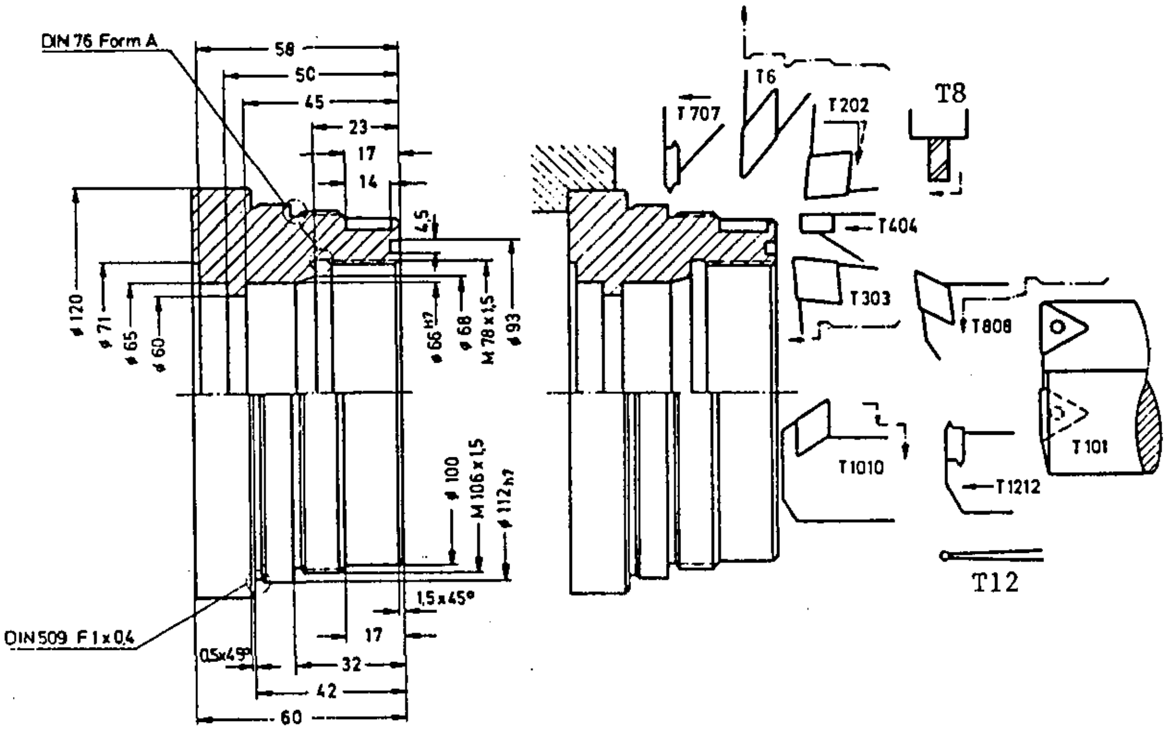
Op. No.	Op. Description	Cutting Time (min.)	Tool Type
1	Turning and Facing	1	T6
2	Drilling	0.2	T14
3	Drilling	0.2	T2
4	Tapping	0.02	T15
5	Chamfering	0.05	T11
6	Boring	0.5	T13
7	Profiling	0.4	T18
8	Grooving	0.1	T19

TRAUB

Fig. 1A.3 Synthetic Workpiece Information

LUT–FMS RESEARCH GROUP

Part Type: Part4; Material: X12CrNiS188



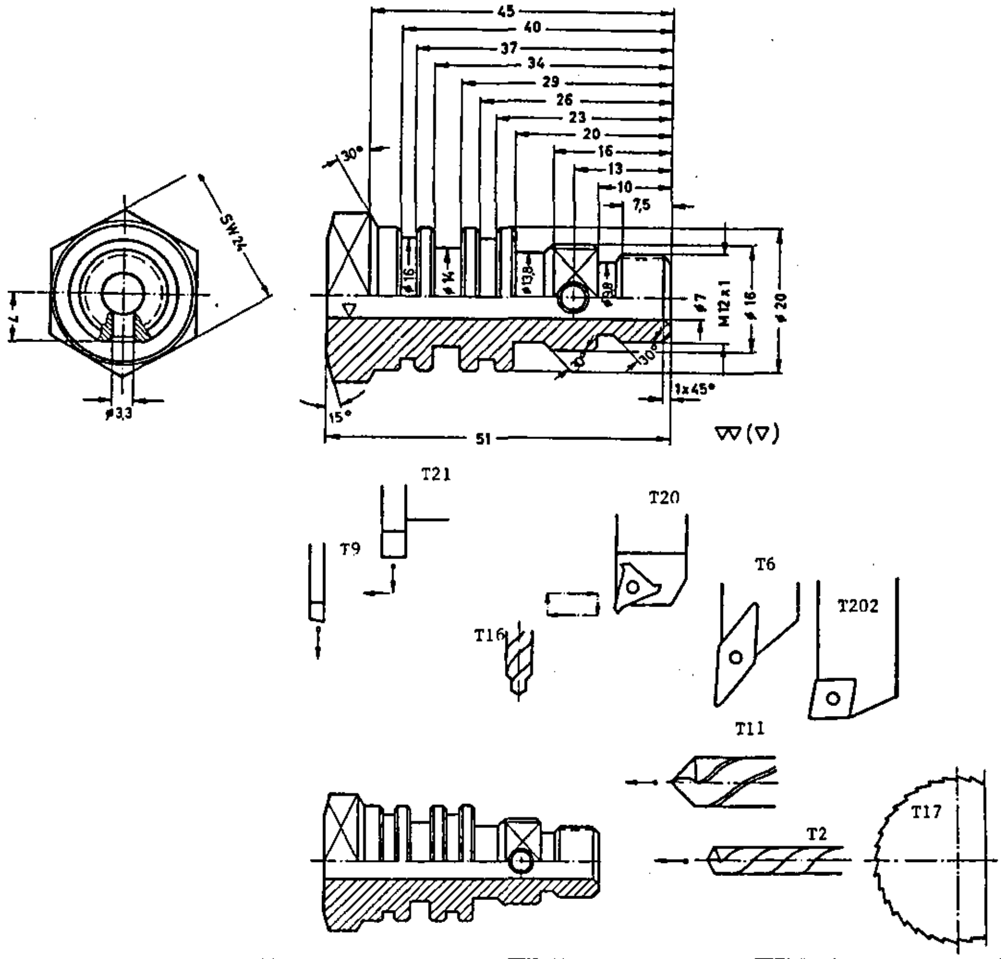
Op. No.	Op. Description	Cutting Time (min.)	Tool Type
1	Profiling	0.3	T1010
2	Facing	0.1	T202
3	Drilling	1	T101
4	Grooving	0.1	T404
5	Rough Boring	0.5	T303
6	Finish Boring	0.7	T808
7	Thread Chasing	0.02	T1212
8	Profiling	0.9	T6
9	Key-way Milling	0.5	T8
10	Threading	0.02	T707
11	Inspection	0.1	T12

TRAUB

Fig. 1A.4 Synthetic Workpiece Information

LUT-FMS RESEARCH GROUP

Part Type: Part5; Material: BS230M07;



Op. No.	Op. Description	Cutting Time (min.)	Tool Type
1	Facing	0.01	T202
2	Profiling	1	T6
3	Drilling	0.5	T2
4	Chamfering	0.05	T11
5	Threading	0.01	T20
6	Polygon Turning	1	T21
7	Drilling	0.01	T16
8	Milling Flat	0.08	T17
9	Parting–off	0.05	T9

TRAUB

Fig. 1A.5

Synthetic Workpiece Information

LUT–FMS RESEARCH GROUP

APPENDIX 1B USER INTERFACE

1B.1 INTRODUCTION

This Appendix presents the user-interface of the Turning Model. The conversational screens designed and implemented for data inputting, model running and output accessing are illustrated. Explanation are presented for each stage and screens, with the purpose of guiding users to the use of the software.

1B.2 OVERVIEW

The Turning Model consists of Data Base Management, Scheduling and Tool Flow Model, and Output Access modules. The entering of each module is led by the main menu (Fig. 1B.1). After the completion of a module, the main menu is resumed, until an Exit action is selected.

Select 1, 2, 3 from the main menu to enter the Data Base Management System for machine, workpiece and tool respectively, where the user can input, view, edit, and select data entries for modelling. The data records input through this module will be stored in relevant data files, which will in turn be extracted by the main stream model for tool flow modelling.

Choice 4 and 5 on the main menu should be selected in sequence to run the main stream model for scheduling batches and model the tool flow activities.

Select 6 to access the detailed outputs gained from the tool flow model. Large body of data concerning part and tool activities can be recorded, which once subjected to the analysis, together with the user's experience, can be employed to improve the total turning cell performance for an existing or proposed installation.

Select 7 to exit from the Turning Model.

1B.3 DATA BASE MANAGEMENT SYSTEM

1B.3.1 DATA BASE MANAGEMENT SYSTEM OVERVIEW

The data base management system has been configured into three modules (Fig. 12.2), for machine, part, tool respectively. It has been built in such a way that:

(1). Once the machine, tool, and workpiece information has been input into the data base, it is possible to run the main stream model (choice 4, 5 on the main menu) any number of times to examine the alternative system operating strategies, e.g tooling strategies, scheduling strategies, and the effects of altering system parameters, e.g. tool transporter capacity and transferring time, without changing large body of data of individual tools, parts, and machines.

(2). The Machine, Workpiece, and Tool data base management modules can be run in any sequence and for any number of times, so that the machine, part, tool information can be changed individually without touch the rest.

(3). Once the data have been input, it is possible to edit any individual data entry without requiring the need of input the whole data record again.

(4). It is possible to take company supplied data directly through a IBM-AT formatted disk, provided that the data is compiled into the ASCII File in the specified format.

1B.3.2 Principle of the Data Searching

The data management works on the principle of storing data and recording the search code (key) of each data record in two separate files. Access to data is done by searching the desired search code in the code file. Once the search code has been found, the data position in the data base can be located, and the data can be accessed. In such a way, the data searching can be done much faster than actually searching the data record in the data base. Thus the data handling can be performed much more efficiently and quickly.

1B.3.3 DATA ENTRY
- CNC Turning Centre Data Base Management Module

Select 1 on the main menu, fig. 1B.1 to enter this module, and the module menu will follow, fig. 1B.2.

Inside the machine data management module, the machine information can be viewed, input, and edited.

The List function (option 1) allows the data entries already in the database to be accessed sequentially.

The Find function (option 2) allows a data record of the specified search code to be found in the data file and the relevant information will be displayed on the screen.

The Search function (option 3) locates a data record on the base of partially input search code. If option 2 or 3 is entered, a prompt window will appear on the screen asking the user to input the desired i.d code, fig. 1B.3.

The Next (option 4) and Previous (option 5) functions allow the succeeding or the proceeding data record of the current one to be accessed and viewed.

The Edit function (option 6) allows the user to edit a exiting data record. Following the selection of this option, a window, fig. 1B.3 will appear on the screen asking the i.d code of a machine record to be edited. Type the i.d code of the intended machine record, the information related to this code will be displayed on the screen, data fields can then be updated. Press <Ctrl-B> keys simultaneously to move the cursor one field back, or <Enter> to move the cursor to the next field. Edit the data on the desired field, press <Enter> when finish editing.

The Add function (option 7) allows the user to add to the data base a new part record. The machine data entry screens will follow, and the user is led by the cursor for data inputting.

The Delete function (option 8), will delete a data record form the data base. Following the selection the prompt window, fig. 1B.3 will appear on the screen allowing the user to input the intended record i.d, type in the machine i.d code and the related data will be deleted.

Option 9 is selected when the index (key) file of the data base if damaged accidentally.

These options can be selected by entering either the option number or the first letter of the option, e.g L for List, F for Find, in the choice field.

Machine information specified include tool turret and magazine capacity and indexing time. Tool exchanging times between turret, magazine, and the automatic tool exchanger are also required (fig. 1B.4). 'M/C Group' is the group i.d in a manufacturing cell that the machine belongs to. It correspondences to the 'M/C Group' specification in the part routing information of the part data base module. The 'PTS Capacity' is the number of tools that the machine's tool magazine (if any) can accommodate. 'No. of Racks' and 'Posits/Rack' are for block type tool magazine description. Input number of racks and positions per rack when the block type magazine is implemented. Tool exchange time between magazine and ATC, between ATC and turret are the times (in min.) required for tool exchange between the tool exchanger and the turret, and the time required for tool exchanging between the automatic tool exchanger and the magazine respectively. ATC transfer time between magazine and turret is the tool exchanger transfer time / journey between the tool magazine and the tool turret. The rest of the data fields in the screen are self explained straightforward.

The turret position can be specified to accept different kinds of tools (Fig. 1B.5), viz positions to accept external and internal tools, and positions for live tooling. The same position can be specified for different uses, i.e. to accept several or all kinds of tools. This limitation makes the computer model more realistic, as positions of a turret can be designed to accept all kinds of tools e.g. modular tooling system; Or, different positions for different tools e.g. turret design for Index and Yamazaki Slant Turn 40N (Ref. to Chapter 4).

Input number of positions of the turret designated for accommodating live tooling, and specify these position numbers. The similar process applies to external and internal operating tools. Input number of positions for internal operating tools in the field 'No. of positions for internal turning tools (Shank Size 1)', and input these position numbers in the following fields; unless the turret is designed in such a way that the internal operating tools are further classified into different holder size categories, in which case the turret positions for internal turning tools should be specified for 'shank size 1' and 'shank size 2' respectively. This part is correspondence to the tool data entry fields of 'shank size' and 'external/internal operating tools'.

In the tool flow computer model, whenever a new tool is exchanging to the turret, a check will be carried out to see if the required position is available, if not, the tool in the desired position has to leave the turret to allow the new tool to enter.

The chuck jaw specification screen, fig. 1B.6, will follow the machine information and turret specification screens. Input the jaw set application range in terms of minimum and maximum workpiece chucking end diameter in respective fields, and the screen will be repeated for a number of times according to number of jaw sets implemented.

The same process applies to the gripper specification screen, fig. 1B.7.

Input '10' or 'Q' in the data base menu, fig. 1B.8, when finish this module and the main menu will be resumed.

1B.3.4 DATA ENTRY - Workpiece Data Base Management Module

This module works in on the same principle as the machine module. Select 2 in the main menu, fig. 1B.9, the part database menu the option menu will follow, fig. 1B.10.

Enter either the number or the first letter of a particular option to list all the existing data entries, to find or search a particular data entry, to view the previous or next data record, to edit or delete a data entry, or to input a new data record. When options 2, 3, 7 or 8 is selected the prompt window, fig. 1B.11 will appear which allows the user to type in the specific part i.d code.

The information recorded in the data base for a workpiece includes its part i.d., description and number of operations. The order information such as batch size and due date is also included, fig. 1B.12.

Input number of tool operations required for the part type in 'No. of operations/item' field. Input the order quantity in terms of number of component required in the 'Quantity' field. Input the pallet size in terms of number of component per pallet in 'pallet capacity' field. Input the earliest time that the batch is ready to enter the cell when the cursor is in 'Order Earliest Available time' field. All the other data entry field is self- explained by the screen. Press <Ctrl-B> keys simultaneously to go one field back, or press <Enter> to go to the next field.

For each operation of a part, the process planning information should be input. These data will include the set-up and cutting time of the operation, tool type required, and the machine group that the operation has been assigned to, fig. 1B.13.

When 'Add' a part data entry, the information for fields 'Order No.', 'Part i.d', 'Op. No.' will appear automatically on the screen to remind the user. Input the 'Machine Group' field is correspondence to the 'M/C Group' field in the machine data specification screen (fig. 1B.4). After each data record display or update, the part database menu, fig. 1B.14, will appear. Select a desired option, or enter '10' or 'Q' to exit this session and return to the main menu.

1B.3.5 DATA ENTRY - Tool Data Base Management Module

Select 3 on the main menu, fig. 1B.15, to enter the Tool data management module.

This module works in the similar way as the machine and workpiece data management module, in which tool information can be input, accessed and displayed, updated, and new tool data can be added to the tool data base (fig. 1B.16).

The description of a cutting tool has been broken down into four sections: the general information concerning the tool assembly as a whole, cutting unit description, shank description, and the holder description. (fig. 1B.17).

The cutting record includes the insert i.d. type (i.d), and its usage information. Tool life unit needs to be specified. A certain limit can be set as the maximum permissible tool life to control the tool life utilisation. It is defined as a certain percentage of the usable tool life that can be used. Once the accumulated tool life has reached the limit, the tip is regarded as worn.

The tool shank information concerns the type and size, external or internal tool. These information will be required when modelling the tool exchanging into tool turret. As the turret positions can be designed to accept certain tool categories of certain sizes.

Input 1 at the 'Shank size' field, unless the internal operating tools are further classified into two shank types, in which case input 1 or 2 according to shank classification. It is correspondence to the machine turret position specification.

The holder (if any) is the part which links the tool shank to the turret.

A physical tool will consist of a cutting unit (insert) and its shank and holder (if any). This information will be employed for efficient central tool store assembly and inventory control. Ref. to fig. 13.5 for a typical tool description.

Tools can be classified as tools with indexable inserts, and tools without indexable tips. The former will typically include external and internal turning tools, threading and grooving tools, and some drilling tools. The later will include drilling, tapping, and milling tools.

Modular tooling systems can be described by this classification. Contact probes can be described in the same way, except that a probe will have a very long life unit. This data record structure allows different flow pattern for turning system to be modelled. Tools can be specified to be refurbished in the central tool store; or tools with indexable tips are indexed for a new tip at machines, tools without indexable insert (mainly live tooling) will be transferred back to CTS for refurbished.

At the end of the session enter '10' or 'Q' in the module menu, fig. 1B.18, to return to the main menu.

1B.4 PRODUCTION SCHEDULING FRONT END

Select 4 in the main menu, fig. 1B.19, to enter the production scheduling module. The workload assignment strategy selection screen will follow, fig. 1B.20.

The *workload assignment strategy 1* will assign the first available machine with the batch of maximum work-content that can be processed by the machine; The *workload assignment strategy 2* will assign the first available machine with the batch of minimum work-content that can be processed by the machine. Enter either 1 or 2 in the choice field. The workload assignment strategy selection screen will be followed by the batch sequencing strategy screen.

Sequencing strategy 1 sequence the batch with the longest outside operation time (time interval between the batch exit and re-entry) first; *Sequencing strategy 2* sequence the batch with the shortest operation time to be machined first; *Sequencing strategy 3* is going to be used in combined with the '*differential kitting* strategy. It sequence the batch that requires the least tool exchanged to the machine to be processed first.

Enter 1, 2 or 3 in the choice field where the cursor will flash. A detailed discussion of the production scheduling and the related strategies have been presented in chapter 12 and 13.

After these two strategy selection screens, the batches will be scheduled. Upon the completion of the scheduling module the prompt screen, fig. 1B.22 will appear. Press <Enter> to resume the main menu.

1B.5 TOOL FLOW MODEL

Select 5 on the main menu, fig. 1B.23 to run the tool flow model.

The user-interface of the main stream Tool Flow Model facilitates the tool flow network specification and tooling strategy selection. A user will be guided by screens to input his decisions and specifications, and to run the model. Fig. 1B.24 is the prompt screen, press <Enter> to proceed.

Fig. 1B.25 shows the tool flow network specification. Number of machines should be input. Detailed machine information will be loaded automatically from the machine data base (Ref. to fig.1B.2). Secondary Tool Store capacity (if applicable) is specified as number of tool compartments. If the cell hasn't a STS, input 0 for the STS capacity.

Tool transporter description screen is illustrated in fig. 1B.26. Type AGV for automated tool transporter, or MAN if a manual cart(s) is used. For the transporter capacity, input the number of tools that can be transferred in one time. In case of single tool exchange, the transporter capacity is 1. While for tool kit exchange, the transporter capacity should be no less than the biggest kit size. Transportation time matrix between major tool stores should be input (in min.s).

Tool issue strategy selection screen (fig. 1B.27) allows the user to select one of the 3 strategies:

Select 1 to adopt the *tool kitting* concept, where a kit of tools accompanying the scheduled batch to the machine is issued. When arrive at the machine, the new kit will replace the previous one. Select 2 to adopt the *differential kitting* concept, which is based on the kitting concept but allows sharing of tools between successive kits. Select 3, if tools are stored in the tool magazine for a production period, at the end of the period the whole magazine is exchanged. Ref. to chapter 7 for tooling strategy discussion.

Tool flow pattern selection screen, fig. 1B.28, is to facilitate the modelling of a tool flow system incorporating live tooling:

Select 1, if all worn tools will be transferred back to the CTS for refurbishment; Or select 2, if the living tooling will be transferred back to the CTS for regrinding and turning tools with indexable inserts will have their inserts indexed at machines. The second option will usually require the machine mounted tool presetter, while for the first option, all tools will be preset in the CTS away from machines.

The time required to unload/unload a component between the spindle and the pallet should be specified for each machine (fig. 1B.29). This screen will be repeated for all the machines. The machine i.d code will appear automatically on the screen to prompt the user.

The initial tool arrangement specification screens, fig. 1B.30, allows the user to model different start conditions:

Select 1 to model a user specified initial tool arrangement pattern;

Select 2 to assume that all tools are stored sequentially in the central tool store;

Select 3 to start the modelling (run) based on the tool status and tool store contents of the last run. In this case it is assumed that worn tools of the last run have been sent back to the CTS for refurbishment.

When option 1 is chosen, the screens shown in fig. 1B.31, 1B.32 will appear in turn to allow the user to input tool numbers against the pocket numbers in turret and the PTS respectively for each machine. The user is led by the curser to go through all the turret and magazine pocket numbers. The machine i.d code, the turret capacity or the

PTS capacity will appear on the screen to prompt the user.

The manning operation time specification screen, fig. 1B.33 allows the user to to input the respective manning involvement times. Tooling exchange time is the time required for tooling service to the machine. When 'tool kitting' has been adopted input tool exchange time per kit; When 'differential kitting strategy is implemented input tool exchange time per tool; When 'complete magazine exchange strategy has been selected input the magazine exchange time.

Input 'Y' is the machine can be in operation while the tool magazine is serviced, 'N' otherwise.

Input pallet exchange time and input 'Y' or 'N' to to specify if the machine can be in operation while part pallets are exchanged.

The reminding screen, fig. 1B.34, will appear following the input screens, press <Enter> to run the tool flow model.

At the end of the modelling, the prompt screen, fig. 1B.35, will appear press <Enter> to resume the main menu.

1B.6 OUTPUT MODULE

The output module can only be selected after the completion of the modelling modules, and can be run any number of times.

Select 6 on the main menu, fig. 1B.36, the output menu, fig. 1B.37 will follow. The output options range from the specific to more general information. It is open to the user for his interpretation and judgement. The options can be selected in any sequence for any number of times. The following describes a general interpretation, but by by no means the sole one, to the listed options.

Select 1 on the output menu, fig. 1B.37, to view the finished work schedule details, fig. 1B.38. The machining requirement of the batch is echoed from the data base. The start, finish, and processing time of the batch ,and thus the occupation time to the assigned machine by the batch is displayed. The machine idle time spent waiting for the batch is also displayed.

Select 2 on the output menu, fig. 1B.39, to get the summarised machine utilisation of each machine in the cell. The activity times, displayed for each individual machine, include total cutting time, part and tooling set-up time, the total processing time of the machine and the total idle time of the machine spent for waiting either tools or pallets during its occupied period. (fig. 1B.40).
The longest machine total processing time makes the through time of the cell for a given order.

Select 3 on the output menu, fig. 41, for manning pattern. This will include information as the start point and the time interval of a manning operation and the description of the operation.(fig. 1B.42).

Select 4 on the output menu, fig. 1B.43 to get the final tool status after the modelling period, fig. 1B.44. This includes the general information such as tool type and life unit (in min.s), echoed from the data base, and finished tool status: percentage tool life used, number of tips used, frequency of usage, and if a tool is worn. The location of the tool after the production period is given in terms of which store and which position it is in. On this screen, in the 'store' column, 'C' represents Central tool store, 'S' represents Secondary tool store, 'P' represent Primary tool store (magazine), and 'T' represents tool turret.

Select 5 on the output menu, fig.1B.45 to view the final store contents. The output illustrates for every machine ,the tool held in each pocket of the turret (fig. 1B.46) and magazine (fig. 1B.47). After the last machine's tool store contents have been shown, the user is led to the cell secondary tool store contents (if applicable), fig. 1B.48, which will be followed by the output menu.

Select 6 on the output menu, fig. 1B.49 to obtain the tool kit assignment details for each batch which gives the tool numbers in the kit assigned to a machine to fulfill the tooling requirement by the machine to process the scheduled operations of the batch. When tool issue strategy 'complete magazine exchange' has been adopted, the tool magazine content will be shown.

Tool components requirement planning for tool assembly and refurbishment forms the base for the CTS inventory control for the planning period. When run the model for a medium to long period, it dictates the purchasing of holders, shanks and inserts.

Select 7 on the output menu, fig. 1B.51 to access the insert requirement to fulfill the production requirement, fig. 1B.52. The information is given in the form of total numbers of items required for each insert type (i.d).

Select 8 on the output menu, fig. 1B.53 to get the tool shank requirement. This includes total number required for each shank type and the number of tools using the shank type, fig. 1B.54.

Select 9 on the output menu, fig. 1B.55, to obtain the tool holder requirement, fig. 1B.56, which is given in the form of total number of holders required for each type, and the number of tools requiring the holder type.

Inserts are regarded as consumable, which means a insert is thrown away after its tips has been worn out, whereas, shanks and holders can be shared accross tools, that is they are durable.

Select 10 on the output menu, fig. 1B.57 to obtain the summarised sister tooling requirement , fig. 1B.58, for each tool type required for the modelled period. The detailed tooling status of individual tools is given in option 4.

Select 11 on the output menu, fig. 1B.59, to get the workload pattern of the turning cell, fig. 1B.60, which is a graphic illustration of the data form information which can be obtained from option 1.

Select 0 in the output menu, fig. 1B.61 to resume the main menu.

Select 7 in the main menu, fig. 1B.62, to quit the Turning Model.

TURNING MODEL — MAIN MENU

DATA BASE MANAGEMENT

Input, Edit, View, Select:

1. Machine Data Entry.
2. Workpiece Data Entry.
3. Tool Data Entry.

Modelling Modules

4. Pallet Assign. & Scheduling.
5. Run the Tool Flow Model.
6. View Outputs.

7. Exit.

Choice: 1

Continue:	Edit Data Entry:	Hard Copy:	Quit:
<Enter>	<Ctrl—B>	<Shift—PrtSc>	<Esc>

Fig. 1B.1
MAIN MENU

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MACHINE DATABASE MODULE — Enter Choice:

1. List Machine Records Sequentially
2. Find a Record by Machine I.D Code
3. Search on Partial Machine I.D Code
4. Next Record
5. Previous Record
6. Add to Machine Database
7. Edit a Machine Record
8. Delete a Machine Record
9. Rebuilt Index Files
10. Quit

Choice: 6

Continue:	Edit Data Entry:	Hard Copy:	Quit:
<Enter>	<Ctrl—B>	<Shift—PrtSc>	<Esc>

Fig. 1B.2
MACHINE DATABASE MODULE — MENU

LUT — FMS
Research Group

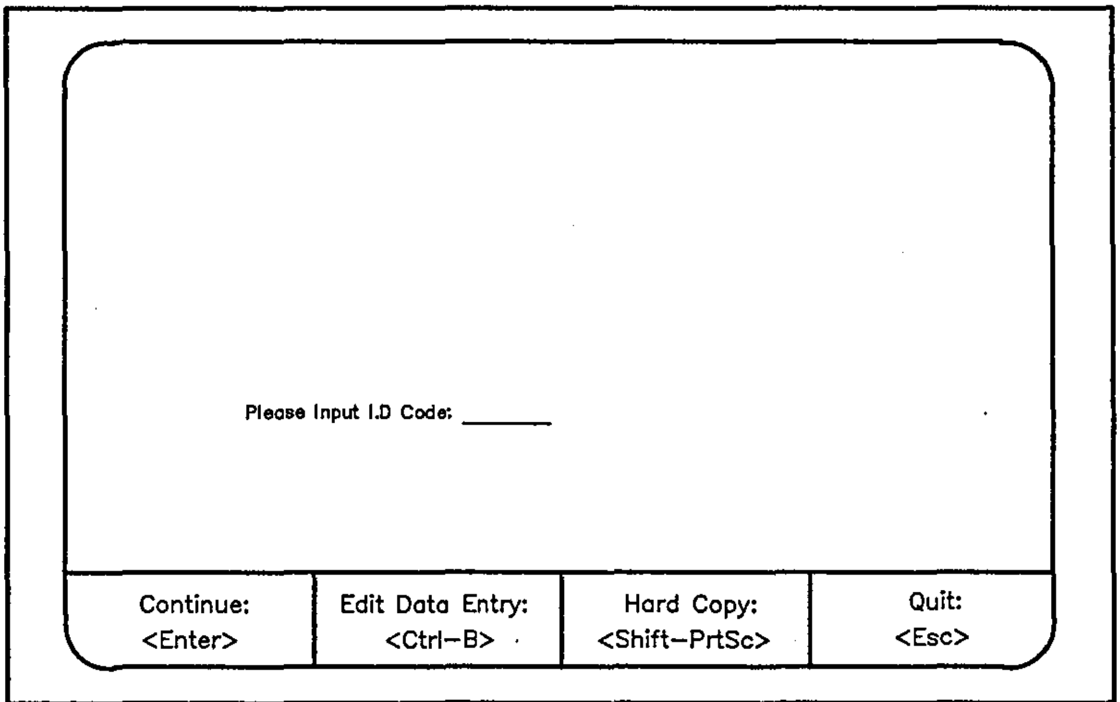

Fig. 1B.3
Prompt Screen

LUT – FMS Research Group

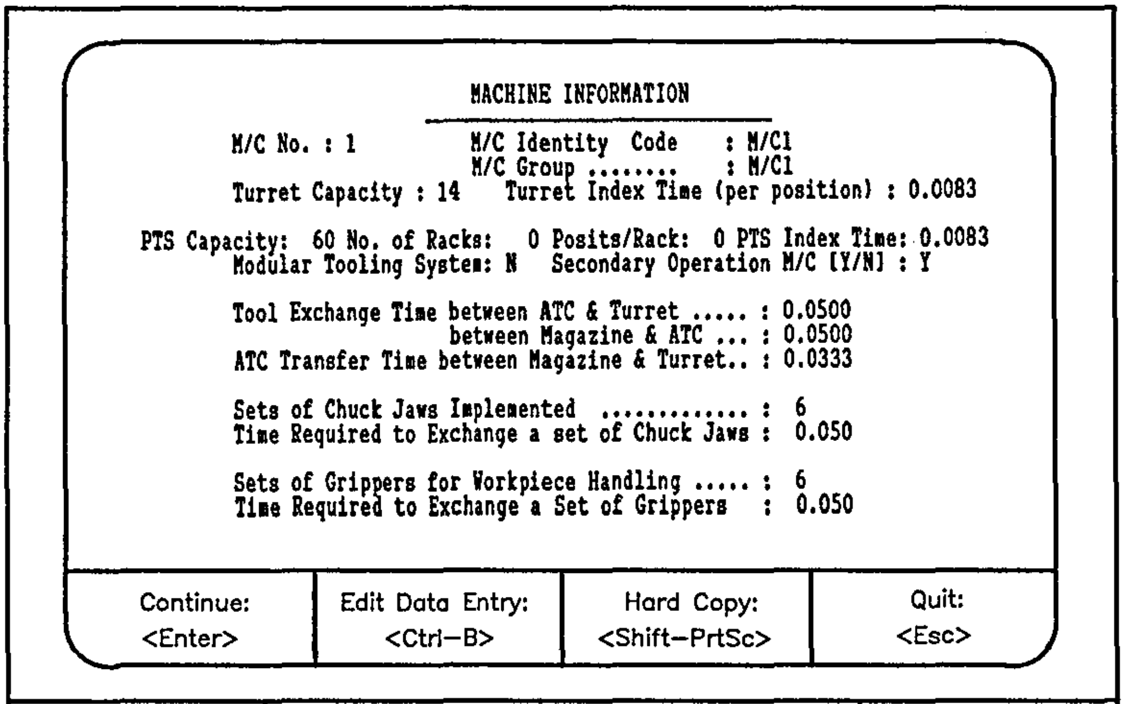

Fig. 1B.4
Machine Description

LUT – FMS Research Group

TURRET POSITION SPECIFICATION

No. of positions suitable for sec. op. tools .... : 14
Position No.s Specification:
1 2 3 4 5 6 7 8 9 10 11 12 13 14

No. of positions suitable for external working tools .... : 14
Position No.s Specification:
1 2 3 4 5 6 7 8 9 10 11 12 13 14

No. of positions for internal working tools (Shank size 1): 14
Position No.s Specification:
1 2 3 4 5 6 7 8 9 10 11 12 13 14

No. of positions for internal working tools (Shank size 2): 0
Position No.s Specification:

Continue: <Enter>	Edit Data Entry: <Ctrl–B>	Hard Copy: <Shift–PrtSc>	Quit: <Esc>

Fig. 1B.5
Turret Position Specification

LUT - FMS
Research Group

CHUCK JAW SPECIFICATION

Jaw Set No. : 1

Chuck Jaw Application Range:

Min. Workpiece Diameter .... : 10.00

Max. Workpiece Diameter .... : 30.00

Continue: <Enter>	Edit Data Entry: <Ctrl–B>	Hard Copy: <Shift–PrtSc>	Quit: <Esc>

Fig. 1B.6
Chuck Jaw Set Specification

LUT - FMS
Research Group

GRIPPER SPECIFICATION

Gripper Set No. : 1

Gripper Application Range:

Min. Workpiece Diameter .... : 10.00

Max. Workpiece Diameter .... : 30.00

Continue: <Enter>	Edit Data Entry: <Ctrl-B>	Hard Copy: <Shift-PrtSc>	Quit: <Esc>

Fig. 1B.7
Gripper Set Specification

LUT - FMS
Research Group

MACHINE DATABASE MODULE - Enter Choice:

1. List Machine Records Sequentially
2. Find a Record by Machine I.D Code
3. Search on Partial Machine I.D Code
4. Next Record
5. Previous Record
6. Add to Machine Database
7. Edit a Machine Record
8. Delete a Machine Record
9. Rebuilt Index Files
10. Quit

Choice: 11

Continue: <Enter>	Edit Data Entry: <Ctrl-B>	Hard Copy: <Shift-PrtSc>	Quit: <Esc>

Fig. 1B.8
MACHINE DATABASE MODULE - MENU

LUT - FMS
Research Group

TURNING MODEL – MAIN MENU

DATA BASE MANAGEMENT

Input, Edit, View, Select:

1. Machine Data Entry.
2. Workpiece Data Entry.
3. Tool Data Entry.

Modelling Modules

4. Pallet Assign. & Scheduling.
5. Run the Tool Flow Model.
6. View Outputs.

7. Exit.

Choice: 2

Continue: <Enter>	Edit Data Entry: <Ctrl–B>	Hard Copy: <Shift–PrtSc>	Quit: <Esc>

Fig. 1B.9
MAIN MENU

LUT – FMS
Research Group

WORKPIECE DATABASE MODULE – Enter Choice:

1. List Part Records Sequentially
2. Find a Record by Part I.D Code
3. Search on Partial Part I.D Code
4. Next Record
5. Previous Record
6. Add to Workpiece Database
7. Edit a Part Record
8. Delete a Part Record
9. Rebuilt Index Files
10. Quit

Choice: 6

Continue: <Enter>	Edit Data Entry: <Ctrl–B>	Hard Copy: <Shift–PrtSc>	Quit: <Esc>

Fig. 1B.10
WORKPIECE DATABASE MODULE – MENU

LUT – FMS
Research Group

Please Input I.D Code: ______

Continue: <Enter>	Edit Data Entry: <Ctrl–B>	Hard Copy: <Shift–PrtSc>	Quit: <Esc>

Fig. 1B.11
Prompt Screen

LUT – FMS Research Group

PART INFORMATION

Order No. : 1

Part I.D Code .... : PART1

Part Description .... : SYNTHETIC

No. of Operations/Item ..... : 8

Quantity .... : 5 Pallet Capacity ... : 5

Chuck End Diameter .... : 90.00 Due Date .... : 0.00

If the order enters the system during the planning period, specify:

Order Earliest Available Time : 0.00

Continue: <Enter>	Edit Data Entry: <Ctrl–B>	Hard Copy: <Shift–PrtSc>	Quit: <Esc>

Fig. 1B.12
Part Information

LUT – FMS Research Group

ROUTING INFORMATION

Order No. : 1 Part I.D : PART1 Machine Group : M/C1

Op.No. : 1

Operation Description ..... : ROUGH TURNING

Set-up Time .... : 1.00

Cutting Time .... : 0.50

Tool Type Required .... : T5

Secondary Operation [Y/N] ? : N

N.B: For outside processing, input 'OutsideM/C' for Machine Group.

Continue: <Enter>	Edit Data Entry: <Ctrl–B>	Hard Copy: <Shift–PrtSc>	Quit: <Esc>

Fig. 1B.13
Routing Information

LUT – FMS
Research Group

WORKPIECE DATABASE MODULE – Enter Choice:

1. List Part Records Sequentially
2. Find a Record by Part I.D Code
3. Search on Partial Part I.D Code
4. Next Record
5. Previous Record
6. Add to Workpiece Database
7. Edit a Part Record
8. Delete a Part Record
9. Rebuilt Index Files
10. Quit

Choice: 11

Continue: <Enter>	Edit Data Entry: <Ctrl–B>	Hard Copy: <Shift–PrtSc>	Quit: <Esc>

Fig. 1B.14
WORKPIECE DATABASE MODULE – MENU

LUT – FMS
Research Group

TURNING MODEL — MAIN MENU

DATA BASE MANAGEMENT

Input, Edit, View, Select:
1. Machine Data Entry.
2. Workpiece Data Entry.
3. Tool Data Entry.

Modelling Modules

4. Pallet Assign. & Scheduling.
5. Run the Tool Flow Model.
6. View Outputs.

7. Exit.
Choice: 3

Continue:	Edit Data Entry:	Hard Copy:	Quit:
<Enter>	<Ctrl–B>	<Shift–PrtSc>	<Esc>

Fig. 1B.15
MAIN MENU

LUT – FMS
Research Group

TOOL DATABASE MODULE — Enter Choice:

1. List Tool Records Sequentially
2. Find a Record by Tool I.D Code
3. Search on Partial Tool I.D Code
4. Next Record
5. Previous Record
6. Add to Tool Database
7. Edit a Tool Record
8. Delete a Tool Record
9. Rebuilt Index Files
10. Quit

Choice: 6

Continue:	Edit Data Entry:	Hard Copy:	Quit:
<Enter>	<Ctrl–B>	<Shift–PrtSc>	<Esc>

Fig. 1B.16
TOOL DATABASE MODULE — MENU

LUT – FMS
Research Group

TOOL DESCRIPTION

Tool Type: TU01
Tool Description /Company I.D:
Rotational Tool [Y/N] ? .... : N

Insert (Cutting Unit) Information:
Insert Type .... : CNMS120408 K68
Assigned Tool Life Unit : 30.00 Max. Permissible % Tool Life : 50.00
Percentage Life Used .. : 0.00 No. of Indexable Tips/Regrinds: 4
No. of Tips Used ..... : 0

Shank Information:
Shank Type .... : MCLNR2020 H12
External / Internal Tool [E/I]: E Shank Size ..... : 0

Holder Information:
Holder Type .... : W633000200

Continue: <Enter>	Edit Data Entry: <Ctrl–B>	Hard Copy: <Shift–PrtSc>	Quit: <Esc>

	Fig. 1B.17 Tool Description	LUT – FMS Research Group

TOOL DATABASE MODULE – Enter Choice:

1. List Tool Records Sequentially
2. Find a Record by Tool I.D Code
3. Search on Partial Tool I.D Code
4. Next Record
5. Previous Record
6. Add to Tool Database
7. Edit a Tool Record
8. Delete a Tool Record
9. Rebuilt Index Files
10. Quit

Choice: Q

Continue: <Enter>	Edit Data Entry: <Ctrl–B>	Hard Copy: <Shift–PrtSc>	Quit: <Esc>

	Fig. 1B.18 TOOL DATABASE MODULE – MENU	LUT – FMS Research Group

TURNING MODEL – MAIN MENU

DATA BASE MANAGEMENT

Input, Edit, View, Select:

1. Machine Data Entry.
2. Workpiece Data Entry.
3. Tool Data Entry.

Modelling Modules

4. Pallet Assign. & Scheduling.
5. Run the Tool Flow Model.
6. View Outputs.

7. Exit.

Choice: 4

Continue: <Enter>	Edit Data Entry: <Ctrl–B>	Hard Copy: <Shift–PrtSc>	Quit: <Esc>

Fig. 1B.19
MAIN MENU

LUT – FMS
Research Group

Workload Assignment Strategies

1. Assign batch with max. workcontent to the available M/C;

2. Assign batch with min. workcontent to the available M/C.

Choice: 1

Continue: <Enter>	Edit Data Entry: <Ctrl–B>	Hard Copy: <Shift–PrtSc>	Quit: <Esc>

Fig. 1B.20
Workload Assignment Strategy Selection

LUT – FMS
Research Group

Batch Sequencing Strategies

1. Longest Outside Operation Time;

2. Shortest Operation Time;

3. Least Tool Requirement.

Choice: 1

Continue: <Enter>	Edit Data Entry: <Ctrl–B>	Hard Copy: <Shift–PrtSc>	Quit: <Esc>

Fig. 1B.21
Batch Sequencing Strategy Selection

LUT – FMS
Research Group

All Batches Scheduled

Return to Main Menu ...

Continue: <Enter>	Edit Data Entry: <Ctrl–B>	Hard Copy: <Shift–PrtSc>	Quit: <Esc>

Fig. 1B.22
Prompt Screen

LUT – FMS
Research Group

TURNING MODEL — MAIN MENU

DATA BASE MANAGEMENT

Input, Edit, View, Select:

1. Machine Data Entry.
2. Workpiece Data Entry.
3. Tool Data Entry.

Modelling Modules

4. Pallet Assign. & Scheduling.
5. Run the Tool Flow Model.
6. View Outputs.

7. Exit.

Choice: 5

Continue: <Enter>	Edit Data Entry: <Ctrl—B>	Hard Copy: <Shift—PrtSc>	Quit: <Esc>

Fig. 1B.23
MAIN MENU

LUT — FMS
Research Group

TOOL FLOW MANAGEMENT IN BATCH MANUFACTURING SYSTEMS
FOR CYLINDRICAL PARTS

— Data Input Screens

Continue: <Enter>	Edit Data Entry: <Ctrl—B>	Hard Copy: <Shift—PrtSc>	Quit: <Esc>

Fig. 1B.24
Tool Flow Model — Title Screen

LUT — FMS
Research Group

SYSTEM CONFIGURATION

Please Input:
No. of Machines in the Cell: 1
Planning Horizon (min.): 480
Secondary Tool Store Capacity: 0

Continue:	Edit Data Entry:	Hard Copy:	Quit:
<Enter>	<Ctrl-B>	<Shift-PrtSc>	<Esc>

Fig. 1B.25
SYSTEM PARAMETER

LUT – FMS
Research Group

TRANSPORTATION SYSTEM SPECIFICATION

Please Specify:

Transporter Description:	MAN
Transporter Capacity:	25
Average Transfer Time between CTS & STS:	0
Average Transfer Time between STS & PTSs:	5

Time Unit: Min.

Continue:	Edit Data Entry:	Hard Copy:	Quit:
<Enter>	<Ctrl-B>	<Shift-PrtSc>	<Esc>

Fig. 1B.26
TRANSPORTATION SYSTEM DESCRIPTION

LUT – FMS
Research Group

TOOLING STRATEGY SELECTION

1. KITTING – Issue a Tool Kit for Each Batch;

2. DIFFERENTIAL KITTING
   – Tools Issued in Kits, Tool Sharing between Kits Permitted;

3. Complete Magazine Exchange

Strategy Selected: 3

Continue:	Edit Data Entry:	Hard Copy:	Quit:
<Enter>	<Ctrl–B>	<Shift–PrtSc>	<Esc>

Fig. 1B.27
TOOLING STRATEGY SPECIFICATION

LUT – FMS
Research Group

TOOL FLOW PATTERN SELECTION

1. All Tools Are Transfered Back to CTS for Refurbishment;

2. Turning Tools with Indexable Inserts Are Adjusted
   at M/Cs for New Tips;
   Live Tooling back to CTS for Refurbishment.

Flow Pattern Selected: 1

Continue:	Edit Data Entry:	Hard Copy:	Quit:
<Enter>	<Ctrl–B>	<Shift–PrtSc>	<Esc>

Fig. 1B.28
TOOL FLOW PATTERN SELECTION

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Research Group

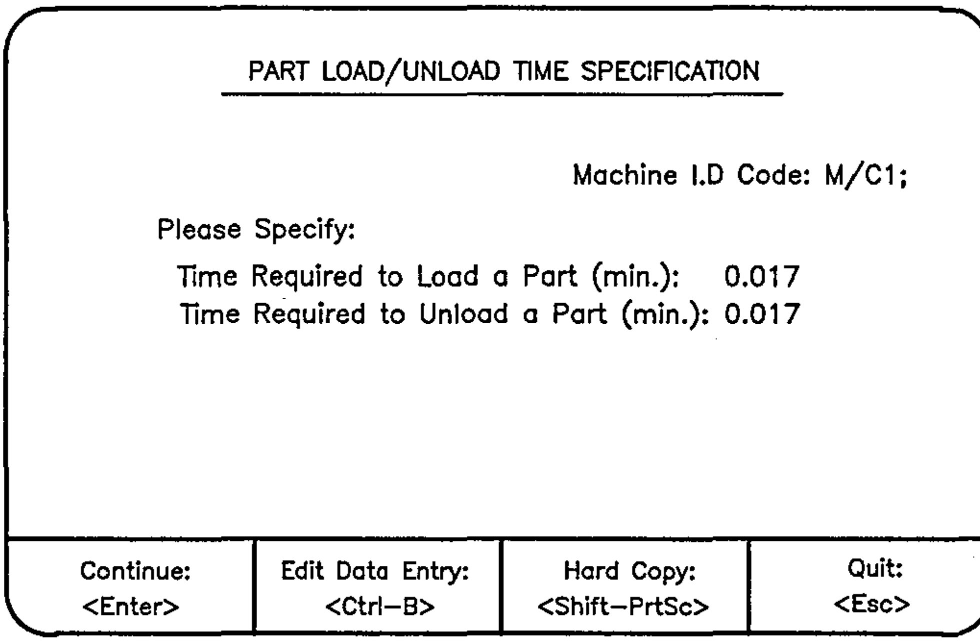

Fig. 1B.29
AVERAGE TIME FOR PART LOADING/UNLOADING

LUT – FMS
Research Group

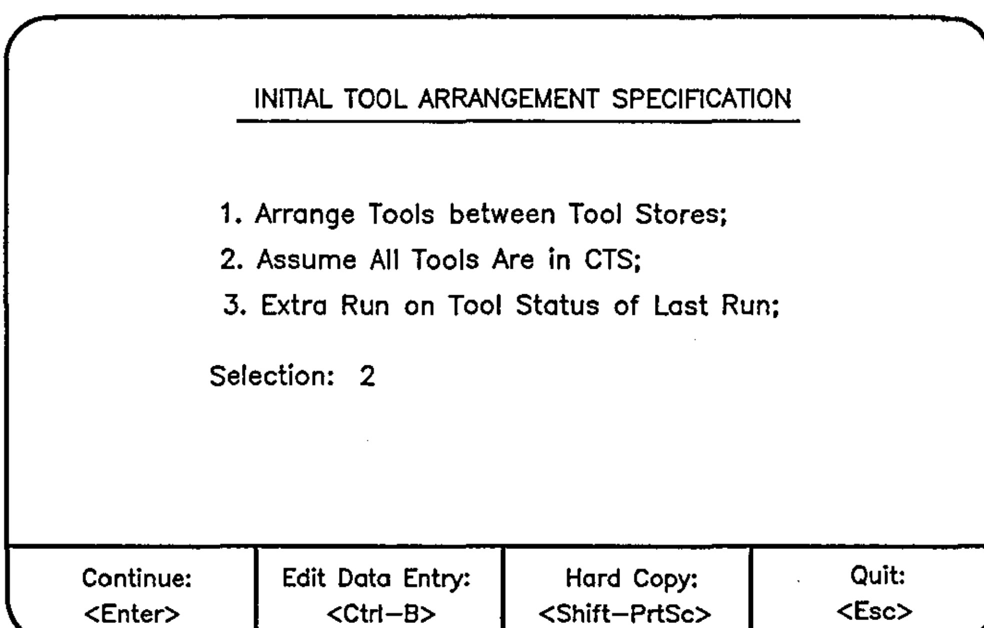

Fig. 1B.30
INITIAL TOOL ARRANGEMENT

LUT – FMS
Research Group

Tool Arrangement for the Turret

M/C id : M/C1 Turret Capacity: 14

Please Arrange Tools:

Position	1	2	3	4	5	6	7	8
Tool No.	0	0	0	0	0	0	0	0
Position	9	10	11	12	13	14	15	16
Tool No.	0	0	0	0	0	0	0	0

If not applicable input 0.

Continue: <Enter>	Edit Data Entry: <Ctrl–B>	Hard Copy: <Shift–PrtSc>	Quit: <Esc>

Fig. 1B.31
Initial Tool Arrangement – Turret

LUT – FMS
Research Group

Initial Tool Arrangement – Magazine

M/C id: M/C1 PTS Capacity: 60

Please Arrange Tool:

Pocket No.	Tool No.	Pocket No.	Tool No.	Pocket No.	Tool No.	Pocket No.	Tool No.	Pocket No.	Tool No.
1	–								

Continue: <Enter>	Edit Data Entry: <Ctrl–B>	Hard Copy: <Shift–PrtSc>	Quit: <Esc>

Fig. 1B.32
Initial Tool Arrangement – Magazine

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Research Group

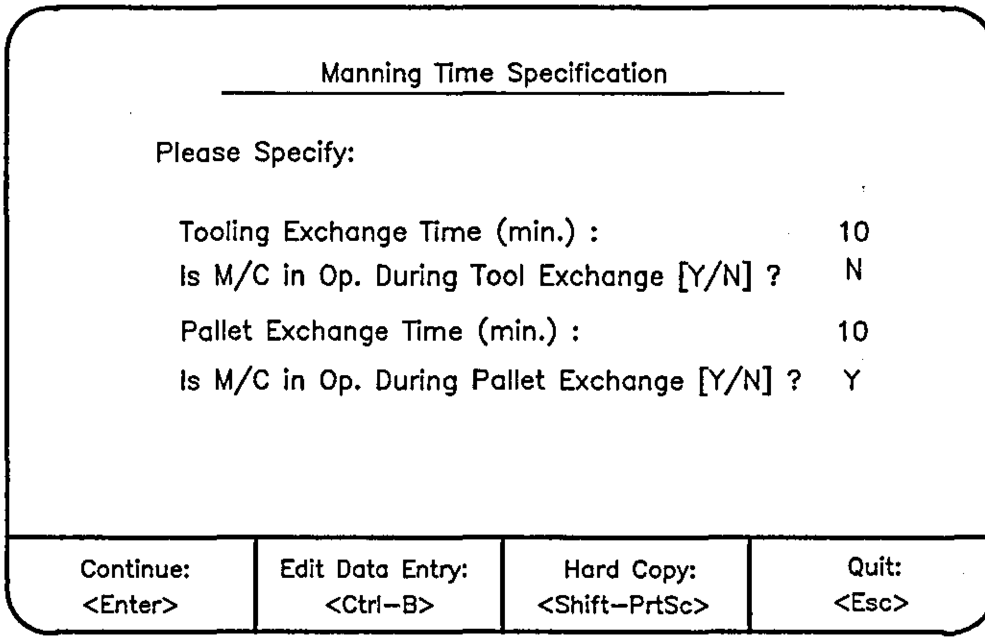


Fig. 1B.33

Manning Operation Time Specification

LUT – FMS Research Group

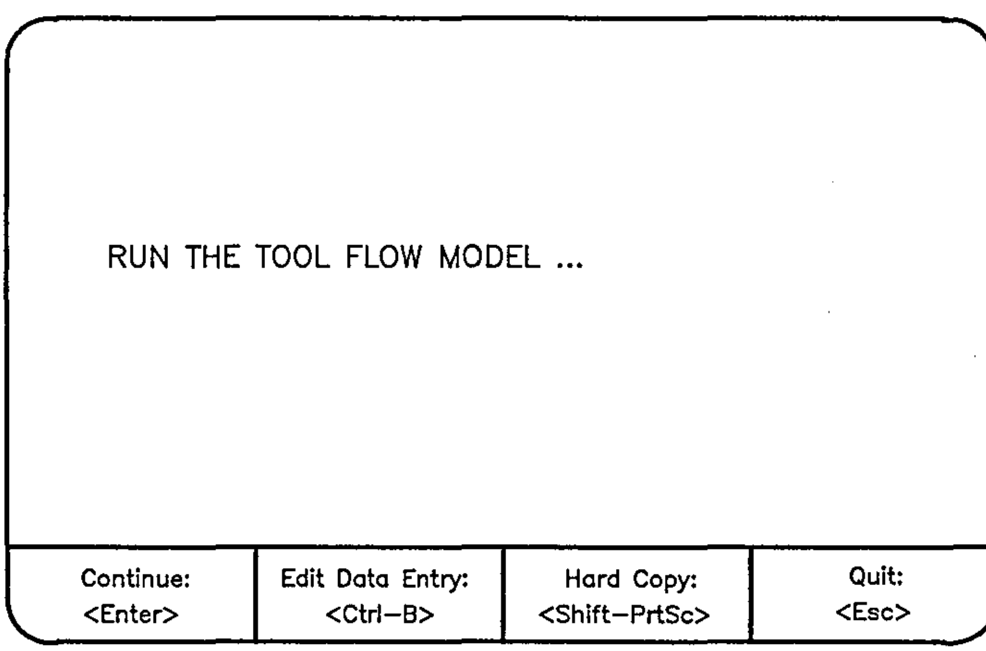


Fig. 1B.34

Prompt Screen

LUT – FMS Research Group

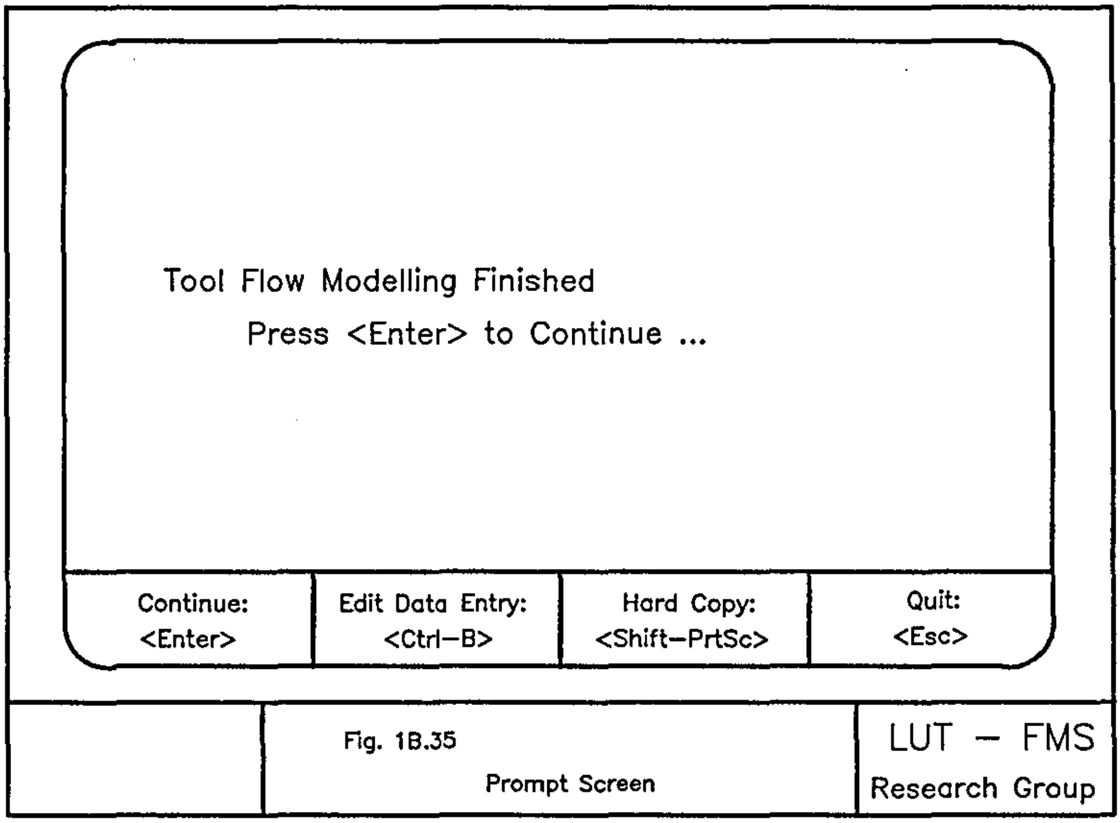


Fig. 1B.35
Prompt Screen

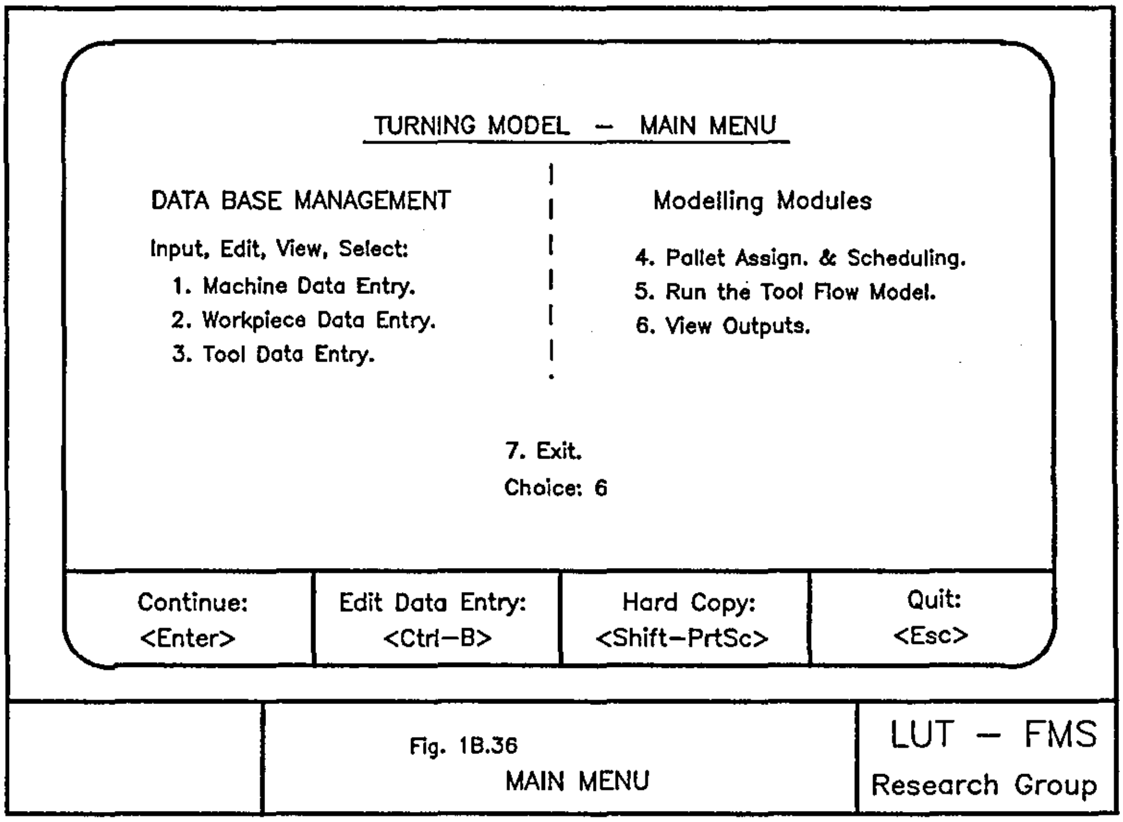


Fig. 1B.36
MAIN MENU

MODEL OUTPUT

1. Finished Work Schedule;
2. Machine Utilisation;
3. Manning Pattern;
4. Tool Requirement and Final Tool Status;
5. Final Tool Store Contents;
6. Tool Kit Requirements/Magazine Complements
7. Insert Requirement Planning;
8. Tool Shank Requirement;
9. Tool Holder Requirement;
10. Sister Tooling Requirement;
11. Workload Pattern;

0. Exit.

CHOICE: 1

Continue: <Enter>	Edit Data Entry: <Ctrl–B>	Hard Copy: <Shift–PrtSc>	Quit: <Esc>

Fig. 1B.37

Output Menu

LUT – FMS Research Group

MODEL OUTPUT

OPERATION DETAILS: Machine I.D : M/C1

Order No. : 1 Part I.D : PART1 Batch No. : 1

Operation No.	Operation Description	Set-up Time	Cutting Time	Tool I.D	Sec. Op [Y/N] ?
1	ROUGH TURNING	1.00	0.50	T5	N
2	FINISH PROFILE	0.00	0.50	T6	N
3	DRILLING	0.00	0.60	T1	N
4	BORING	0.00	0.60	T7	N
5	FINISH BORING	0.00	0.50	T3	N
6	MILLING	0.00	1.00	T8	Y
7	DRILLING	0.00	0.20	T10	Y
8	INSPECTION	0.10	0.00	T12	N

No. of Items in the Batch : 5 Processing Time of the Batch : 26.98

Start Time of the Batch : 10.50 Finish Time of the Batch .. : 37.48

M/C Idle Time due to Waiting for the Pallets: 0.00

Continue: <Enter>		Hard Copy: <Shift–PrtSc>	Quit: <Esc>

Fig. 1B.38

Model Output – Batch Processing Information

LUT – FMS Research Group

MODEL OUTPUT

1. Finished Work Schedule;
2. Machine Utilisation;
3. Manning Pattern;
4. Tool Requirement and Final Tool Status;
5. Final Tool Store Contents;
6. Tool Kit Requirements/Magazine Complements
7. Insert Requirement Planning;
8. Tool Shank Requirement;
9. Tool Holder Requirement;
10. Sister Tooling Requirement;
11. Workload Pattern;

0. Exit.

CHOICE: 2

Continue: <Enter>	Edit Data Entry: <Ctrl-B>	Hard Copy: <Shift-PrtSc>	Quit: <Esc>

Fig. 1B.39
Output Menu

LUT – FMS Research Group

MACHINE UTILISATION

Machine I.D	Cutting Time	Part (M/C) Set-up Time	Tooling Set-Up Time	Idle Time	Total Processing Time
M/C1	317	108	32	0	457

Continue: <Enter>		Hard Copy: <Shift-PrtSc>	Quit: <Esc>

Fig. 1B.40
Model Output – Machine Utilisation

LUT – FMS Research Group

MODEL OUTPUT

1. Finished Work Schedule;
2. Machine Utilisation;
3. Manning Pattern;
4. Tool Requirement and Final Tool Status;
5. Final Tool Store Contents;
6. Tool Kit Requirements/Magazine Complements
7. Insert Requirement Planning;
8. Tool Shank Requirement;
9. Tool Holder Requirement;
10. Sister Tooling Requirement;
11. Workload Pattern;

0. Exit.

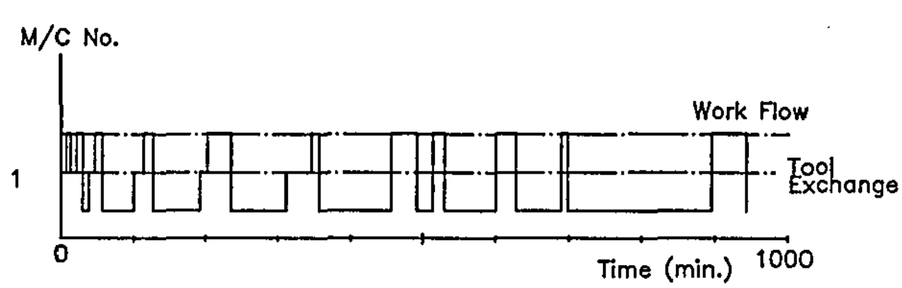
CHOICE: 3

Continue: <Enter>	Edit Data Entry: <Ctrl–B>	Hard Copy: <Shift–PrtSc>	Quit: <Esc>

Fig. 1B.41
Output Menu

LUT – FMS
Research Group

Manning Pattern



Continue: <Enter>		Hard Copy: <Shift–PrtSc>	Quit: <Esc>

Fig. 1B.42
Model Output – Manning Pattern

LUT – FMS
Research Group

MODEL OUTPUT

1. Finished Work Schedule;
2. Machine Utilisation;
3. Manning Pattern;
4. Tool Requirement and Final Tool Status;
5. Final Tool Store Contents;
6. Tool Kit Requirements/Magazine Complements
7. Insert Requirement Planning;
8. Tool Shank Requirement;
9. Tool Holder Requirement;
10. Sister Tooling Requirement;
11. Workload Pattern;

0. Exit.

CHOICE: 4

Continue: <Enter>	Edit Data Entry: <Ctrl–B>	Hard Copy: <Shift–PrtSc>	Quit: <Esc>

Fig. 1B.43
Output Menu

LUT – FMS Research Group

MODEL OUTPUT / FINAL TOOL STATUS

Tool No.	Tool Type	Life Unit	Life Used (%)	Usage Freq.	Tips Used	Worn	M/C No.	Store	Rack No.	Posit.
1	T5	30.00	48.33	11	0	Y	1	P	0	20
2	T6	30.00	48.33	17	0	Y	1	P	0	17
3	T1	16.00	18.75	5	0	N	1	P	0	16
4	T7	30.00	10.00	5	0	N	1	P	0	15
5	T3	30.00	8.33	5	0	N	1	P	0	19
6	T8	20.00	50.00	15	0	Y	1	P	0	21
7	T10	16.00	6.25	5	0	N	1	P	0	26
8	T12	100.00	0.00	50	0	N	1	T	0	14
9	T202	30.00	7.17	35	0	N	1	T	0	1
10	T2	16.00	49.38	17	0	Y	1	P	0	41

Continue: <Enter>		Hard Copy: <Shift–PrtSc>	Quit: <Esc>

Fig. 1B.44
Model Output – Final Tool Status

LUT – FMS Research Group

MODEL OUTPUT

1. Finished Work Schedule;
2. Machine Utilisation;
3. Manning Pattern;
4. Tool Requirement and Final Tool Status;
5. Final Tool Store Contents;
6. Tool Kit Requirements/Magazine Complements
7. Insert Requirement Planning;
8. Tool Shank Requirement;
9. Tool Holder Requirement;
10. Sister Tooling Requirement;
11. Workload Pattern;

0. Exit.

CHOICE: 5

Continue: <Enter>	Edit Data Entry: <Ctrl-B>	Hard Copy: <Shift-PrtSc>	Quit: <Esc>

Fig. 1B.45
Output Menu

LUT – FMS Research Group

MODEL OUTPUT: TURRET CONTENTS

The Turret Capacity: 14 Machine I.D : M/C1

Position	1	2	3	4	5	6	7	8
Tool No.	9	36	41	37	11	44	45	40
Position	9	10	11	12	13	14	15	16
Tool No.	46	29	30	32	31	8	0	0

Continue: <Enter>		Hard Copy: <Shift-PrtSc>	Quit: <Esc>

Fig. 1B.46
Final Turret Contents

LUT – FMS Research Group

PTS CONTENTS

Machine I.D Code: M/C1 PTS Capacity: 60

Pock No.	Tool No.	Pock No.	Tool No.	Pock No.	Tool No.	Pock No.	Tool No.	Pock No.	Tool No.	Pock No.	Tool No.	Pock No.	Tool No.
1	0	11	0	21	6	31	18	41	10	51	0		
2	0	12	0	22	20	32	21	42	35	52	0		
3	0	13	0	23	22	33	26	43	42	53	0		
4	0	14	0	24	17	34	33	44	38	54	0		
5	0	15	4	25	12	35	24	45	39	55	0		
6	0	16	3	26	7	36	16	46	43	56	0		
7	0	17	2	27	14	37	23	47	0	57	0		
8	0	18	13	28	15	38	25	48	0	58	0		
9	0	19	5	29	28	39	34	49	0	59	0		
10	0	20	1	30	19	40	27	50	0	60	0		

Continue: <Enter>	Edit Data Entry: <Ctrl–B>	Hard Copy: <Shift–PrtSc>	Quit: <Esc>

Fig. 1B.47

Final Tool Magazine Contents

LUT – FMS Research Group

STS CONTENTS

STS Capacity: 100

Pock No.	Tool No.	Pock No.	Tool No.	Pock No.	Tool No.	Pock No.	Tool No.	Pock No.	Tool No.	Pock No.	Tool No.	Pock No.	Tool No.
1	0	11	0	21	0	31	0	41	0	51	0	61	0
2	0	12	0	22	0	32	0	42	0	52	0	62	0
3	0	13	0	23	0	33	0	43	0	53	0	63	0
4	0	14	0	24	0	34	0	44	0	54	0	64	0
5	0	15	0	25	0	35	0	45	0	55	0	65	0
6	0	16	0	26	0	36	0	46	0	56	0	66	0
7	0	17	0	27	0	37	0	47	0	57	0	67	0
8	0	18	0	28	0	38	0	48	0	58	0	68	0
9	0	19	0	29	0	39	0	49	0	59	0	69	0
10	0	20	0	30	0	40	0	50	0	60	0	70	0

Continue: <Enter>		Hard Copy: <Shift–PrtSc>	Quit: <Esc>

Fig. 1B.48

Final Secondary Tool Store Contents

LUT – FMS Research Group

MODEL OUTPUT

1. Finished Work Schedule;
2. Machine Utilisation;
3. Manning Pattern;
4. Tool Requirement and Final Tool Status;
5. Final Tool Store Contents;
6. Tool Kit Requirements/Magazine Complements
7. Insert Requirement Planning;
8. Tool Shank Requirement;
9. Tool Holder Requirement;
10. Sister Tooling Requirement;
11. Workload Pattern;

0. Exit.

CHOICE: 6

Continue: <Enter>	Edit Data Entry: <Ctrl-B>	Hard Copy: <Shift-PrtSc>	Quit: <Esc>

	Fig. 1B.49 Output Menu	LUT – FMS Research Group

Tool Kit / Magazine Complements

Kit / Magazine No. : 1

Tool No.s:

1, 2, 3, 4, 5, 6;

Continue: <Enter>		Hard Copy: <Shift-PrtSc>	Quit: <Esc>

	Fig. 1B.50 Tool Kits Requirement / Magazine Complements	LUT – FMS Research Group

MODEL OUTPUT

1. Finished Work Schedule;
2. Machine Utilisation;
3. Manning Pattern;
4. Tool Requirement and Final Tool Status;
5. Final Tool Store Contents;
6. Tool Kit Requirements/Magazine Complements
7. Insert Requirement Planning;
8. Tool Shank Requirement;
9. Tool Holder Requirement;
10. Sister Tooling Requirement;
11. Workload Pattern;

0. Exit.

CHOICE: 7

Continue: <Enter>	Edit Data Entry: <Ctrl–B>	Hard Copy: <Shift–PrtSc>	Quit: <Esc>

Fig. 1B.51

Output Menu

LUT – FMS Research Group

TOOL PART REQUIREMENT - INSERT

Insert Identity	No. s	Insert Indentity	No. s	Insert Identity	No. s
CNMS120408 K68	24	DRILL (592726)	2	NCT12628	2
NO.5 C/DRILL	8	SLOT DRILL (982461)	2	CPGM060202 K68	4
11MM DRILL	7	NCT8253	2	CNMP120408 K68	2
CNMP120404 K68	15	EPMM060204	2	DNMP150404 K68	6
EPMM060202 K20	16	VNMP160404 K68	2	13.3MM DIA. DRILL	2
3/4'' SLOT DRILL	5	3/4'' DRILL(GUHRING)	3	NG330L K68	4
19.05MM T/SDRILL	1	NG451L K68	9	NCT11912	4
NCT12450	2	CPGM060208 K68	3	NCT11073	2
KNUX110305L15 K68	1	KNUX110302 K68	3		
BS5 CENTRE DRILL	2	KNUX110302R15 K68	4		

Continue: <Enter>		Hard Copy: <Shift–PrtSc>	Quit: <Esc>

Fig. 1B.52

Model Output – Tool Insert Requirement

LUT – FMS Research Group

MODEL OUTPUT

1. Finished Work Schedule;
2. Machine Utilisation;
3. Manning Pattern;
4. Tool Requirement and Final Tool Status;
5. Final Tool Store Contents;
6. Tool Kit Requirements/Magazine Complements
7. Insert Requirement Planning;
8. Tool Shank Requirement;
9. Tool Holder Requirement;
10. Sister Tooling Requirement;
11. Workload Pattern;

0. Exit.

CHOICE: 8

Continue: <Enter>	Edit Data Entry: <Ctrl–B>	Hard Copy: <Shift–PrtSc>	Quit: <Esc>

Fig. 1B.53
Output Menu

LUT – FMS
Research Group

TOOL PART REQUIREMENT - SHANK

Shank Identity	No.	Use. Freq.	Shank Identity	No.	Use. Freq.
MCLNR2020 H12	34	84	S12M-SCLPR-06	4	4
STELLRAM E015-V08R	9	20	MDJNR2020 H15	2	2
S12K-NKLNR-11	1	2	MDJNR2020 H12	4	4
STELLRAM E015V08R	8	8	MODNER2525-M3	2	2
S16M-PVXNR-16	2	2	MODNEG2525-M3	2	2
AC65171	9	12			
S12M-SCLCR-06	3	4			
S12M-NKLCR-11	3	4			
NKLCR2020 H12	4	6			
NER2020 H3	2	2			

Continue: <Enter>		Hard Copy: <Shift–PrtSc>	Quit: <Esc>

Fig. 1B.54
Model Output – Tool Shank Requirement

LUT – FMS
Research Group

MODEL OUTPUT

1. Finished Work Schedule;
2. Machine Utilisation;
3. Manning Pattern;
4. Tool Requirement and Final Tool Status;
5. Final Tool Store Contents;
6. Tool Kit Requirements/Magazine Complements
7. Insert Requirement Planning;
8. Tool Shank Requirement;
9. Tool Holder Requirement;
10. Sister Tooling Requirement;
11. Workload Pattern;

0. Exit.

CHOICE: 9

Continue: <Enter>	Edit Data Entry: <Ctrl-B>	Hard Copy: <Shift-PrtSc>	Quit: <Esc>

Fig. 1B.55
Output Menu

LUT – FMS Research Group

TOOL PART REQUIREMENT - HOLDER

Holder Identity	No.	Use. Freq.	Holder Identity	No.	Use. Freq.
W633000200	32	104			
W632102000	23	50			
W633000400	6	10			
W632112000	23	24			
W632100300	4	6			
W632210200	12	24			
W632100000	3	4			

Continue: <Enter>		Hard Copy: <Shift-PrtSc>	Quit: <Esc>

Fig. 1B.56
Model Output – Tool Holder Requirement

LUT – FMS Research Group

MODEL OUTPUT

1. Finished Work Schedule;
2. Machine Utilisation;
3. Manning Pattern;
4. Tool Requirement and Final Tool Status;
5. Final Tool Store Contents;
6. Tool Kit Requirements/Magazine Complements
7. Insert Requirement Planning;
8. Tool Shank Requirement;
9. Tool Holder Requirement;
10. Sister Tooling Requirement;
11. Workload Pattern;

0. Exit.

CHOICE: 10

Continue: <Enter>	Edit Data Entry: <Ctrl-B>	Hard Copy: <Shift-PrtSc>	Quit: <Esc>

Fig. 1B.57
Output Menu

LUT – FMS
Research Group

Sister Tooling Requirement

Tool Identity	No. s	Tool Identity	No. s	Tool Identity	No. s
T1	1	T11	1	T21	2
T2	2	T12	1	T101	3
T3	1	T13	2	T202	1
T4	1	T14	1	T303	1
T5	4	T15	1	T404	1
T6	7	T16	1	T707	1
T7	1	T17	1	T808	1
T8	3	T18	2	T1010	1
T9	1	T19	1	T1212	1
T10	1	T20	1		

Continue: <Enter>		Hard Copy: <Shift-PrtSc>	Quit: <Esc>

Fig. 1B.58
Model Output – Sister Tooling Requirement

LUT – FMS
Research Group

MODEL OUTPUT

1. Finished Work Schedule;
2. Machine Utilisation;
3. Manning Pattern;
4. Tool Requirement and Final Tool Status;
5. Final Tool Store Contents;
6. Tool Kit Requirements/Magazine Complements
7. Insert Requirement Planning;
8. Tool Shank Requirement;
9. Tool Holder Requirement;
10. Sister Tooling Requirement;
11. Workload Pattern;

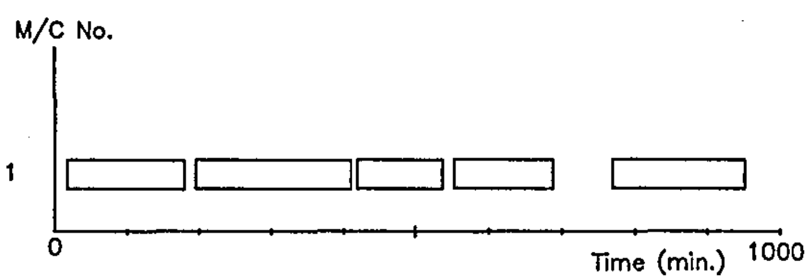
0. Exit.

CHOICE: 11

Continue: <Enter>	Edit Data Entry: <Ctrl-B>	Hard Copy: <Shift-PrtSc>	Quit: <Esc>

	Fig. 1B.59 Output Menu	LUT – FMS Research Group

Workload Pattern



Continue: <Enter>		Hard Copy: <Shift-PrtSc>	Quit: <Esc>

	Fig. 1B.60 Model Output – Workload Pattern	LUT – FMS Research Group

MODEL OUTPUT

1. Finished Work Schedule;
2. Machine Utilisation;
3. Manning Pattern;
4. Tool Requirement and Final Tool Status;
5. Final Tool Store Contents;
6. Tool Kit Requirements/Magazine Complements
7. Insert Requirement Planning;
8. Tool Shank Requirement;
9. Tool Holder Requirement;
10. Sister Tooling Requirement;
11. Workload Pattern;

0. Exit.

CHOICE: 0

Continue: <Enter>	Edit Data Entry: <Ctrl–B>	Hard Copy: <Shift–PrtSc>	Quit: <Esc>

Fig. 1B.61
Output Menu

LUT – FMS Research Group

TURNING MODEL – MAIN MENU

DATA BASE MANAGEMENT

Input, Edit, View, Select:
1. Machine Data Entry.
2. Workpiece Data Entry.
3. Tool Data Entry.

Modelling Modules

4. Pallet Assign. & Scheduling.
5. Run the Tool Flow Model.
6. View Outputs.

7. Exit.
Choice: 7

Continue: <Enter>	Edit Data Entry: <Ctrl–B>	Hard Copy: <Shift–PrtSc>	Quit: <Esc>

Fig. 1B.62
MAIN MENU

LUT – FMS Research Group

APPENDIX 1C

DETAILED SAMPLES OF TOOLING OUTPUT FOR THE SINGLE MACHINE CASE STUDY

(Supplement to Chapter 9, Run No. 1)

MODEL OUTPUT / FINAL TOOL STATUS

Tool No.	Tool Type	Life Unit	Life Used (%)	Usage Freq.	Tips Used	Worn	M/C No.	Store	Rack No.	Posit.
1	T5	30.00	48.33	11	0	Y	1	P	0	20
2	T6	30.00	48.33	17	0	Y	1	P	0	17
3	T1	16.00	18.75	5	0	N	1	P	0	16
4	T7	30.00	10.00	5	0	N	1	P	0	15
5	T3	30.00	8.33	5	0	N	1	P	0	19
6	T8	20.00	50.00	15	0	Y	1	P	0	21
7	T10	16.00	6.25	5	0	N	1	P	0	26
8	T12	100.00	0.00	50	0	N	1	T	0	14
9	T202	30.00	7.17	35	0	N	1	T	0	1
10	T2	16.00	49.38	17	0	Y	1	P	0	41

Continue: <Enter>		Hard Copy: <Shift-PrtSc>		Quit: <Esc>

MODEL OUTPUT / FINAL TOOL STATUS

Tool No.	Tool Type	Life Unit	Life Used (%)	Usage Freq.	Tips Used	Worn	M/C No.	Store	Rack No.	Posit.
11	T11	16.00	17.19	55	0	N	1	T	0	5
12	T20	20.00	0.75	15	0	N	1	P	0	25
13	T21	30.00	46.67	14	0	Y	1	P	0	18
14	T16	16.00	0.94	15	0	N	1	P	0	27
15	T17	20.00	6.00	15	0	N	1	P	0	28
16	T9	30.00	2.50	15	0	N	1	P	0	36
17	T6	30.00	50.00	27	0	Y	1	P	0	24
18	T21	30.00	3.33	1	0	N	1	P	0	31
19	T4	20.00	2.50	25	0	N	1	P	0	30
20	T5	30.00	46.67	7	0	Y	1	P	0	22

Continue: <Enter>		Hard Copy: <Shift-PrtSc>		Quit: <Esc>

MODEL OUTPUT / FINAL TOOL STATUS

Tool No.	Tool Type	Life Unit	Life Used (%)	Usage Freq.	Tips Used	Worn	M/C No.	Store	Rack No.	Posit.
21	T8	20.00	50.00	20	0	Y	1	P	0	32
22	T5	30.00	46.67	7	0	Y	1	P	0	23
23	T5	30.00	33.33	5	0	N	1	P	0	37
24	T6	30.00	49.67	17	0	Y	1	P	0	35
25	T1010	30.00	20.00	20	0	N	1	P	0	38
26	T101	16.00	50.00	8	0	Y	1	P	0	33
27	T404	30.00	6.67	20	0	N	1	P	0	40
28	T303	30.00	33.33	20	0	N	1	P	0	29
29	T808	30.00	46.67	20	0	N	1	T	0	10
30	T1212	20.00	2.00	20	0	N	1	T	0	11

Continue: <Enter>		Hard Copy: <Shift-PrtSc>		Quit: <Esc>

MODEL OUTPUT / FINAL TOOL STATUS

Tool No.	Tool Type	Life Unit	Life Used (%)	Usage Freq.	Tips Used	Worn	M/C No.	Store	Rack No.	Posit.
31	T707	20.00	2.00	20	0	N	1	T	0	13
32	T8	20.00	37.50	15	0	N	1	T	0	12
33	T101	16.00	50.00	8	0	Y	1	P	0	34
34	T101	16.00	25.00	4	0	N	1	P	0	39
35	T6	30.00	48.67	15	0	Y	1	P	0	42
36	T14	16.00	50.00	40	0	N	1	T	0	2
37	T15	10.00	8.00	40	0	N	1	T	0	4
38	T13	30.00	50.00	30	0	Y	1	P	0	44
39	T18	30.00	49.33	37	0	Y	1	P	0	45
40	T19	30.00	13.33	40	0	N	1	T	0	8

Continue: <Enter>		Hard Copy: <Shift-PrtSc>		Quit: <Esc>

MODEL OUTPUT / FINAL TOOL STATUS

Tool No.	Tool Type	Life Unit	Life Used (%)	Usage Freq.	Tips Used	Worn	M/C No.	Store	Rack No.	Posit.
41	T2	16.00	47.50	38	0	N	1	T	0	3
42	T6	30.00	46.67	14	0	Y	1	P	0	43
43	T6	30.00	46.67	14	0	Y	1	P	0	46
44	T13	30.00	16.67	10	0	N	1	T	0	6
45	T18	30.00	4.00	3	0	N	1	T	0	7
46	T6	30.00	3.33	1	0	N	1	T	0	9

Continue: <Enter>		Hard Copy: <Shift-PrtSc>		Quit: <Esc>

APPENDIX 2A

WORKPIECE INFORMATION FOR THE MULTI-MACHINE CASE STUDY

(Supplement to Chapter 13)

Part I.D: 1087J012 Description: Turbine Wheel
Material: Impact Extrusion 204002-1

M/C (Group)	Set-up Time /Batch	Op. Time /Item (min.)	Operation Description	Tool Type
GE42 (BLM)	1H10M	1.8	Rough Face & Turn	TU01
		0.5	Finish Face & Turn	TU02
	30M	1.8	Rough Face & Turn	TU01
		0.2	C/Drill	DR01
		0.7	Drill 0.4331 & Through	DR02
		0.7	Finish Face to SKT.2	TU02
		0.2	Chamf. in Bore Mouth	TU03
	60M	3.7	Rough Face & Turn	TU01
		0.5	Finish Face & Turn	TU02
		0.5	Finish Bore & Chamf.	B001
Outside M/C	5H15M	43	NC Mill; Bore, Face, Reset & Face.	
GE42 (BLM)	2H	0.9	Rough Face & Turn	TU02
		1.7	Finish Face & Turn	TU05
Outside M/C	1H30M	60M	Deburr; Inspection, Balance; Clean; Overspeed; Bore; Balance.	

NGL	Fig. 2A.1 Workpiece Information	LUT-FMS RESEARCH GROUP

Part I.D: 1087J022 Description: Exducer
Material: Casting 203095-3

M/C (Group)	Set-up Time /Batch	Op. Time /Item (min.)	Operation Description	Tool Type
Outside M/C	15M	12	Dress	
GU610 (BLN)	75M	0.8	Rough Face & Turn	TU01
		0.2	C/Drill	DR03
		0.6	Drill 0.4331	DR04
		1.1	Finish Face to SKT.1	TU02
		1.1	Finish Bore & Chamf.	B002
	1H15M	0.3	Rough Face	TU01
		0.1	Rough M/C	DR05
		0.1	Finish Face to SKT.2	TU02
		1.2	Finish M/C to SKT.2	DR06
Outside M/C	1H45M	5	Bore & Face;	
GU610 (BLN)	45M	0.8	Rough & Finsh C/Bore	B002
		1.2	Rough & Finish Profile	TU02
Outside M/C	1H20M	27	N/C Turn; Clean; Deburr; Inspection, Balance; Bore; Balance.	

NGL	Fig. 2A.2 Workpiece Information	LUT-FMS RESEARCH GROUP

Part I.D: 1088J012 Description: Compressor
Material: Casting 203697-3

M/C (Group)	Set-up Time /Batch	Op. Time /Item (min.)	Operation Description	Tool Type
Outside M/C	1H30M	4	NC Turn	
GU610 (BLN)	45M	1.4	Rough Face & Turn	TU01
		0.2	C/Drill	DR01
		0.9	Drill 0.4331	DR07
		0.5	Finish Face & Turn	TU02
		3.1	Finish Bore to SKT.2	B003
	1H45M	0.3	Rough Face	TU01
		0.1	Rough C/Bore	DR08
		0.1	Finish Face to SKT.3	TU02
		1.2	Finish C/Bore	B003
Outside M/C	7H30M	15	NC Mill; Bore, Face, Reset & Face.	
GU610 (BLN)	3H	0.8	Rough&Finish to FKT.7	TU06
		1.2	Rough M/C Profile	TU01
		0.5	Finish Profile as SKT.8	TU07
Outside M/C	6H45M	36	Deburr; Inspection, Balance; Bore; Balance.	

NGL	Fig. 2A.3 Workpiece Information	LUT-FMS RESEARCH GROUP

Part I.D: 1088J042 Description: Turbine Wheel;
Material: Casting 203832-3

M/C (Group)	Set-up Time /Batch	Op. Time /Item (min.)	Operation Description	Tool Type
GU610 (BLN)	15M	2.1	Rough Face & Turn	TU01
		0.2	C/Drill	DR03
		0.9	Drill 0.4331	DR04
		0.5	Finish Face & Turn	TU02
		2.1	Finish Bore to SKT.1	B002
	2H0M	0.6	Rough Face	TU01
		0.4	Rough C/Bore	DR05
		0.1	Finish Face to SKT.2	TU02
		0.6	Finish C/Bore	B002
Outside M/C	1H30M	8	Bore	
GU610 (BLN)	45M	0.9	Rough Face & Turn	TU02
		0.9	Finish Face&Turn to SKT.5	TU05
		2.7	Rough Profile	TU01
Outside M/C	1H35M	66	Deburr; Inspection, Balance; Bore; Blance, Clean.	

NGL	Fig. 2A.4 Workpiece Information	LUT-FMS RESEARCH GROUP

Part I.D: 1095J022 Description: Wheel, Second Stage
Material: Casting 801138-3

M/C (Group)	Set-up Time /Batch	Op. Time /Item (min.)	Operation Description	Tool Type
Outside M/C	60M	6	Grind.	
GU610 (BLN)	60M	0.8	Rough Face & Turn	TU01
		0.2	C/Drill	DR09
		1.4	Drill 0.4331	DR10
		9.4	Rough Profile	TU08
		0.4	Rough Bore	B004
		2.6	Finish Profile	TU09
		0.4	Finish Bore to SKT.2	B005
	2H45M	2.7	Rough Face & Turn	TU01
		8.6	Rough Profile	TU08
		0.4	Rough Bore & C/Bore	B004
		2.5	Finish Profile to SKT.3	TU09
		0.5	Finish Bore & C/Bore	B005
		0.7	Form U/Cut to SKT.3	TU10
Outside M/C	5H	44	Turn; Clean; Balance; Overspeed, Inspection; Turn; Inspection;	

NGL	Fig. 2A.5 Workpiece Information	LUT-FMS RESEARCH GROUP

Part I.D: 1095J032 Description: Turbine Wheel
Material: Casting 801138-3

M/C (Group)	Set-up Time /Batch	Op. Time /Item (min.)	Operation Description	Tool Type
Outside M/C	60M	6	Grind.	
GU610 (BLN)	60M	0.8	Rough Face & Turn	TU01
		0.2	C/Drill	DR09
		1.4	Drill 0.4331	DR10
		9.5	Rough Profile	TU08
		0.3	Rough Bore	B004
		2.6	Finish Profile to SKT.2	TU09
		0.4	Finish Bore to SKT.2	B005
	2H45M	2.7	Rough Face & Turn	TU01
		9.5	Rough Profile	TU08
		0.3	Rough Bore	B004
		0.7	Finish Profile	TU09
		3.6	Finish Bore	B005
		0.4	Finish Face	TU02
Outside M/C	5H30M	49	Turn; Clean; Balance; Overspeed, Inspection; Turn; Inspection;	

NGL	Fig. 2A.6 Workpiece Information	LUT-FMS RESEARCH GROUP

Part I.D: 1095J052 Description: Impeller;
Material: Casting 801414-3

M/C (Group)	Set-up Time /Batch	Op. Time /Item (min.)	Operation Description	Tool Type
GU610 (BLN)	60M	2.0	Rough Face & Turn	TU11
		0.3	C/Drill	DR01
		0.6	Finish Face & Turn	TU12
		1.0	Drill Through	DR11
		8.5	M/C Recess	TU13
		1.6	M/C Bore & Chamf.	BO10
	2H30M	1.0	Rough Face & Turn	TU11
		0.9	Finish Face & Turn	TU12
		12.3	M/C Recess	TU13
		0.2	M/C Chamf.	BO10
Outside M/C	1H30M	5	M/C Bore to 0.7852" Dia.	
GU610 (BLN)	45M	0.8	Rough M/C Face & C/Bore	BO06
		0.9	Finish M/C C/Bore	BO07
		1.3	Rough Face & O/D	TU14
		0.9	Finifh Face & O/D	TU15
Outside M/C	3H15M	72	Bore; Trun; Deburr & Blend All Radii; Inspection, Balance; Overspeed; Turn; Inspection;	

NGL	Fig. 2A.7 Workpiece Information	LUT-FMS RESEARCH GROUP

Part I.D: 1112J010 Description: Turnbine Wheel;
Material: Casting 571748-3

M/C (Group)	Set-up Time /Batch	Op. Time /Item (min.)	Operation Description	Tool Type
GU610 (BLN)	30M	2.0	Rough Turn Profile	TU01
		0.3	Finish Turn Profile	TU02
Outside M/C	1H45M	36	Deburr; Inspection, Balance; Clean; Treatment; Inspection;	

NGL	Fig. 2A.8 Workpiece Information	LUT-FMS RESEARCH GROUP

Part I.D: 1112J012 Description: Exducer;
Material: Casting 571748-3

M/C (Group)	Set-up Time /Batch	Op. Time /Item (min.)	Operation Description	Tool Type
GU610 (BLN)	1H15M	0.7	Rough Face	TU04
		0.3	Centre	DR12
		1.7	Finish Face	TU02
		1.1	Finish Bore & Chamf.	B002
		0.6	Drill	DR14
	2H15M	0.6	Rough M/C	DR15
		0.6	Finish M/C	B008
		0.2	Finish Face	B002
		0.7	Finish Profile	TU16
Outside M/C	6H35M	45	Turn; Deburr; Inspection; Clean; Crack Detect. Final Inspection;	

NGL	Fig. 2A.9 Workpiece Information	LUT-FMS RESEARCH GROUP

Part I.D: 1112J022 Description: Turbine Wheel
Material: Impact Extrusion (202154-5)

M/C (Group)	Set-up Time /Batch	Op. Time /Item (min.)	Operation Description	Tool Type
GE65 (BLK)	30M	1.6	Rough Turn	TU01
		0.4	Centre	DR12
		0.3	Drill Through	DR14
		0.8	Finish Turn	TU02
	60M	1.5	Rough Turn	TU01
		0.4	Finish Turn	TU02
		0.2	Bore & Chamf.	B002
		1.1	Rough Turn	TU01
		0.5	Rough C/Bore	DR15
Outside M/C	1H30M	10	N/C Bore;	
GE65 (BLK)	1H15M	1.6	Finish Turn	TU02
		0.2	Finish C/Bore	B009
Outside M/C	1H5M	40	Turn; Drill; Deburr; Inspection; Clean; Inspection;	

NGL	Fig. 2A.10 Workpiece Information	LUT-FMS RESEARCH GROUP

Part I.D: 1112J062   Description: Impeller
Material: Casting 571258–5

M/C (Group)	Set–up Time /Batch	Op. Time /Item (min.)	Operation Description	Tool Type
GU610 (BLN)	3H15M	1.0	Rough Face & Turn	TU01
		0.3	Centre	DR12
		0.9	Drill Through	DR13
		0.2	Finish Face & Turn	TU07
		0.6	Rough Recess & C/Bore	TU17
		0.7	Finish Recess	TU18
		0.5	Finish Bore & Chamf.	B002
	3H0M	2.7	Rough Face & Spigot	DR05
		1.0	Rough Recess & Spigot	TU19
		0.6	Finish Recess & Spigot	TU20
		0.2	Form U/Cut in Spigot	TU21
		1.2	Chamf. & Bore	B002
Outside M/C	1H50M	37	Turn; Deburr; Inspection, Balance; Clean; Treatment; Inspection	

NGL	Fig. 2A.11 Workpiece Information	LUT–FMS RESEARCH GROUP

APPENDIX 2B

TOOLING INFORMATION FOR THE MULTI-MACHINE CASE STUDY

(Supplement to Chapter 13)

```
                              TOOL DESCRIPTION

  Tool Type: TU01
          Tool Description /Company I.D:
          Rotational Tool [Y/N] ? .... : N

  Insert (Cutting Unit) Information:
   Insert Type ........... : CNMS120408 K68
   Assigned Tool Life Unit :   30.00  Max. Permissible % Tool Life :  50.00
   Percentage Life Used .. :    0.00  No. of Indexable Tips/Regrinds: 4
   No. of Tips Used  ..... : 0

  Shank Information:
   Shank Type ............ : MCLNR2020 H12
   External / Internal Tool [E/I]: E  Shank Size  .....  :   0

  Holder Information:
   Holder Type ........... : W633000200

 Continue: | Edit Data Entry |  Hard Copy:   |  |  Quit:
  <Enter>  |    <Ctrl-B>     | <Shift-PrtSc> |  |  <Esc>
```

```
                              TOOL DESCRIPTION

  Tool Type: TU02
          Tool Description /Company I.D:
          Rotational Tool [Y/N] ? .... : N

  Insert (Cutting Unit) Information:
   Insert Type ........... : CNMP120404 K68
   Assigned Tool Life Unit :   30.00  Max. Permissible % Tool Life :  50.00
   Percentage Life Used .. :    0.00  No. of Indexable Tips/Regrinds: 4
   No. of Tips Used  ..... : 0

  Shank Information:
   Shank Type ............ : MCLNR2020 H12
   External / Internal Tool [E/I]: E  Shank Size  .....  :   0

  Holder Information:
   Holder Type ........... : W633000200

 Continue: | Edit Data Entry |  Hard Copy:   |  |  Quit:
  <Enter>  |    <Ctrl-B>     | <Shift-PrtSc> |  |  <Esc>
```

```
                              TOOL DESCRIPTION

  Tool Type: TU03
          Tool Description /Company I.D:
          Rotational Tool [Y/N] ? .... : N

  Insert (Cutting Unit) Information:
   Insert Type ........... : NCT8253
   Assigned Tool Life Unit :   30.00  Max. Permissible % Tool Life :  50.00
   Percentage Life Used .. :    0.00  No. of Indexable Tips/Regrinds: 4
   No. of Tips Used  ..... : 0

  Shank Information:
   Shank Type ............ :
   External / Internal Tool [E/I]: I  Shank Size  .....  :   1

  Holder Information:
   Holder Type ........... : W632112000

 Continue: | Edit Data Entry |  Hard Copy:   |  |  Quit:
  <Enter>  |    <Ctrl-B>     | <Shift-PrtSc> |  |  <Esc>
```

```
                              TOOL DESCRIPTION
                          ______________________
  Tool Type: TU04
          Tool Description /Company I.D:
          Rotational Tool [Y/N] ? .... : N
 ==========================================================================
  Insert (Cutting Unit) Information:
   Insert Type ........... : CNMP120408 K68
   Assigned Tool Life Unit :   30.00  Max. Permissible % Tool Life :  50.00
   Percentage Life Used .. :   0.00   No. of Indexable Tips/Regrinds: 4
   No. of Tips Used  ..... : 0
 ==========================================================================
  Shank Information:
   Shank Type ............ : MCLNR2020 H12
   External / Internal Tool [E/I]: E  Shank Size  .....  :   0
 ==========================================================================
  Holder Information:
   Holder Type ........... : W633000200
 --------------------------------------------------------------------------
 Continue:   | Edit Data Entry |  Hard Copy:   |              |    Quit:
  <Enter>    |    <Ctrl-B>     | <Shift-PrtSc> |              |    <Esc>
```

```
                              TOOL DESCRIPTION
                          ______________________
  Tool Type: TU05
          Tool Description /Company I.D:
          Rotational Tool [Y/N] ? .... : N
 ==========================================================================
  Insert (Cutting Unit) Information:
   Insert Type ........... : KNUX110302R15 K68
   Assigned Tool Life Unit :   30.00  Max. Permissible % Tool Life :  50.00
   Percentage Life Used .. :   0.00   No. of Indexable Tips/Regrinds: 4
   No. of Tips Used  ..... : 0
 ==========================================================================
  Shank Information:
   Shank Type ............ : NKLCR2020 H12
   External / Internal Tool [E/I]: E  Shank Size  .....  :   0
 ==========================================================================
  Holder Information:
   Holder Type ........... : W633000200
 --------------------------------------------------------------------------
 Continue:   | Edit Data Entry |  Hard Copy:   |              |    Quit:
  <Enter>    |    <Ctrl-B>     | <Shift-PrtSc> |              |    <Esc>
```

```
                              TOOL DESCRIPTION
                          ______________________
  Tool Type: TU06
          Tool Description /Company I.D:
          Rotational Tool [Y/N] ? .... : N
 ==========================================================================
  Insert (Cutting Unit) Information:
   Insert Type ........... : DNMP150404 K68
   Assigned Tool Life Unit :   30.00  Max. Permissible % Tool Life :  50.00
   Percentage Life Used .. :   0.00   No. of Indexable Tips/Regrinds: 4
   No. of Tips Used  ..... : 0
 ==========================================================================
  Shank Information:
   Shank Type ............ : MDJNR2020 H15
   External / Internal Tool [E/I]: E  Shank Size  .....  :   0
 ==========================================================================
  Holder Information:
   Holder Type ........... : W633000200
 --------------------------------------------------------------------------
 Continue:   | Edit Data Entry |  Hard Copy:   |              |    Quit:
  <Enter>    |    <Ctrl-B>     | <Shift-PrtSc> |              |    <Esc>
```

```
                         TOOL DESCRIPTION
                         ________________
 Tool Type: TU07
        Tool Description /Company I.D:
        Rotational Tool [Y/N] ? .... : N
=====================================================================
 Insert (Cutting Unit) Information:
  Insert Type ........... : DNMP150404 K68
  Assigned Tool Life Unit :   30.00  Max. Permissible % Tool Life :  50.00
  Percentage Life Used .. :   0.00   No. of Indexable Tips/Regrinds: 4
  No. of Tips Used  ..... : 0
=====================================================================
 Shank Information:
  Shank Type ............ : MDJNR2020 H12
  External / Internal Tool [E/I]: E  Shank Size  .....  :   0
=====================================================================
 Holder Information:
  Holder Type ........... : W633000200
---------------------------------------------------------------------
Continue: | Edit Data Entry | Hard Copy:    |  | Quit:
<Enter>   |    <Ctrl-B>     | <Shift-PrtSc> |  | <Esc>
```

```
                         TOOL DESCRIPTION
                         ________________
 Tool Type: TU08
        Tool Description /Company I.D:
        Rotational Tool [Y/N] ? .... : N
=====================================================================
 Insert (Cutting Unit) Information:
  Insert Type ........... : NG451L K68
  Assigned Tool Life Unit :   30.00  Max. Permissible % Tool Life :  50.00
  Percentage Life Used .. :   0.00   No. of Indexable Tips/Regrinds: 4
  No. of Tips Used  ..... : 0
=====================================================================
 Shank Information:
  Shank Type ............ : AC65171
  External / Internal Tool [E/I]: E  Shank Size  .....  :   0
=====================================================================
 Holder Information:
  Holder Type ........... : W633000200
---------------------------------------------------------------------
Continue: | Edit Data Entry | Hard Copy:    |  | Quit:
<Enter>   |    <Ctrl-B>     | <Shift-PrtSc> |  | <Esc>
```

```
                         TOOL DESCRIPTION
                         ________________
 Tool Type: TU09
        Tool Description /Company I.D:
        Rotational Tool [Y/N] ? .... : N
=====================================================================
 Insert (Cutting Unit) Information:
  Insert Type ........... : NG451L K68
  Assigned Tool Life Unit :   30.00  Max. Permissible % Tool Life :  50.00
  Percentage Life Used .. :   0.00   No. of Indexable Tips/Regrinds: 4
  No. of Tips Used  ..... : 0
=====================================================================
 Shank Information:
  Shank Type ............ : AC65171
  External / Internal Tool [E/I]: E  Shank Size  .....  :   0
=====================================================================
 Holder Information:
  Holder Type ........... : W633000200
---------------------------------------------------------------------
Continue: | Edit Data Entry | Hard Copy:    |  | Quit:
<Enter>   |    <Ctrl-B>     | <Shift-PrtSc> |  | <Esc>
```

```
                              TOOL DESCRIPTION

   Tool Type: TU10
          Tool Description /Company I.D:
          Rotational Tool [Y/N] ? .... : N
 ===========================================================================
   Insert (Cutting Unit) Information:
    Insert Type ........... : NCT12628
    Assigned Tool Life Unit :   30.00  Max. Permissible % Tool Life :  50.00
    Percentage Life Used .. :   0.00   No. of Indexable Tips/Regrinds: 4
    No. of Tips Used  ..... : 0
 ===========================================================================
   Shank Information:
    Shank Type ............ : NER2020 H3
    External / Internal Tool [E/I]: E  Shank Size  .....  :   0
 ===========================================================================
   Holder Information:
    Holder Type ........... : W633000400
 ---------------------------------------------------------------------------
 Continue: | Edit Data Entry |  Hard Copy:   |              |    Quit:
  <Enter>  |    <Ctrl-B>     | <Shift-PrtSc> |              |    <Esc>
```

```
                              TOOL DESCRIPTION

   Tool Type: TU11
          Tool Description /Company I.D:
          Rotational Tool [Y/N] ? .... : N
 ===========================================================================
   Insert (Cutting Unit) Information:
    Insert Type ........... : CNMS120408 K68
    Assigned Tool Life Unit :   30.00  Max. Permissible % Tool Life :  50.00
    Percentage Life Used .. :   0.00   No. of Indexable Tips/Regrinds: 4
    No. of Tips Used  ..... : 0
 ===========================================================================
   Shank Information:
    Shank Type ............ : MCLNR2020 H12
    External / Internal Tool [E/I]: E  Shank Size  .....  :   0
 ===========================================================================
   Holder Information:
    Holder Type ........... : W633000400
 ---------------------------------------------------------------------------
 Continue: | Edit Data Entry |  Hard Copy:   |              |    Quit:
  <Enter>  |    <Ctrl-B>     | <Shift-PrtSc> |              |    <Esc>
```

```
                              TOOL DESCRIPTION

   Tool Type: TU12
          Tool Description /Company I.D:
          Rotational Tool [Y/N] ? .... : N
 ===========================================================================
   Insert (Cutting Unit) Information:
    Insert Type ........... : CNMS120408 K68
    Assigned Tool Life Unit :   30.00  Max. Permissible % Tool Life :  50.00
    Percentage Life Used .. :   0.00   No. of Indexable Tips/Regrinds: 4
    No. of Tips Used  ..... : 0
 ===========================================================================
   Shank Information:
    Shank Type ............ : MCLNR2020 H12
    External / Internal Tool [E/I]: E  Shank Size  .....  :   0
 ===========================================================================
   Holder Information:
    Holder Type ........... : W633000400
 ---------------------------------------------------------------------------
 Continue: | Edit Data Entry |  Hard Copy:   |              |    Quit:
  <Enter>  |    <Ctrl-B>     | <Shift-PrtSc> |              |    <Esc>
```

```
                         TOOL DESCRIPTION

  Tool Type: TU13
       Tool Description /Company I.D: RECESS TOOL
       Rotational Tool [Y/N] ? .... : N
=====================================================================
  Insert (Cutting Unit) Information:
   Insert Type ........... : MCT12450
   Assigned Tool Life Unit :   30.00  Max. Permissible % Tool Life :  50.00
   Percentage Life Used .. :   0.00   No. of Indexable Tips/Regrinds: 4
   No. of Tips Used  ..... : 0
=====================================================================
  Shank Information:
   Shank Type ............ :
   External / Internal Tool [E/I]: E  Shank Size  .....  :   0
=====================================================================
  Holder Information:
   Holder Type ........... : W632210200
---------------------------------------------------------------------
 Continue:  | Edit Data Entry |  Hard Copy:   |          |  Quit:
 <Enter>    |    <Ctrl-B>     | <Shift-PrtSc> |          |  <Esc>
```

```
                         TOOL DESCRIPTION

  Tool Type: TU14
       Tool Description /Company I.D:
       Rotational Tool [Y/N] ? .... : N
=====================================================================
  Insert (Cutting Unit) Information:
   Insert Type ........... : CNMP120404 K68
   Assigned Tool Life Unit :   30.00  Max. Permissible % Tool Life :  50.00
   Percentage Life Used .. :   0.00   No. of Indexable Tips/Regrinds: 4
   No. of Tips Used  ..... : 0
=====================================================================
  Shank Information:
   Shank Type ............ : MCLNR2020 H12
   External / Internal Tool [E/I]: E  Shank Size  .....  :   0
=====================================================================
  Holder Information:
   Holder Type ........... : W633000400
---------------------------------------------------------------------
 Continue:  | Edit Data Entry |  Hard Copy:   |          |  Quit:
 <Enter>    |    <Ctrl-B>     | <Shift-PrtSc> |          |  <Esc>
```

```
                         TOOL DESCRIPTION

  Tool Type: TU15
       Tool Description /Company I.D:
       Rotational Tool [Y/N] ? .... : N
=====================================================================
  Insert (Cutting Unit) Information:
   Insert Type ........... : CNMP120404 K68
   Assigned Tool Life Unit :   30.00  Max. Permissible % Tool Life :  50.00
   Percentage Life Used .. :   0.00   No. of Indexable Tips/Regrinds: 4
   No. of Tips Used  ..... : 0
=====================================================================
  Shank Information:
   Shank Type ............ : MCLNR2020 H12
   External / Internal Tool [E/I]: E  Shank Size  .....  :   0
=====================================================================
  Holder Information:
   Holder Type ........... : W633000400
---------------------------------------------------------------------
 Continue:  | Edit Data Entry |  Hard Copy:   |          |  Quit:
 <Enter>    |    <Ctrl-B>     | <Shift-PrtSc> |          |  <Esc>
```

```
                              TOOL DESCRIPTION

  Tool Type: TU16
        Tool Description /Company I.D:
        Rotational Tool [Y/N] ? .... : N
 ==========================================================================
  Insert (Cutting Unit) Information:
   Insert Type ........... : CNMP120404 K68
   Assigned Tool Life Unit :   30.00  Max. Permissible % Tool Life :  50.00
   Percentage Life Used .. :   0.00   No. of Indexable Tips/Regrinds: 4
   No. of Tips Used  ..... : 0
 ==========================================================================
  Shank Information:
   Shank Type ............ : MCLNR2020 H12
   External / Internal Tool [E/I]: E  Shank Size  .....  :   0
 ==========================================================================
  Holder Information:
   Holder Type ........... : W633000200
```

Continue: <Enter>	Edit Data Entry <Ctrl-B>	Hard Copy: <Shift-PrtSc>		Quit: <Esc>

```
                              TOOL DESCRIPTION

  Tool Type: TU17
        Tool Description /Company I.D:
        Rotational Tool [Y/N] ? .... : N
 ==========================================================================
  Insert (Cutting Unit) Information:
   Insert Type ........... : NG330L K68
   Assigned Tool Life Unit :   30.00  Max. Permissible % Tool Life :  50.00
   Percentage Life Used .. :   0.00   No. of Indexable Tips/Regrinds: 4
   No. of Tips Used  ..... : 0
 ==========================================================================
  Shank Information:
   Shank Type ............ : MODNER2525-M3
   External / Internal Tool [E/I]: I  Shank Size  .....  :   1
 ==========================================================================
  Holder Information:
   Holder Type ........... : W633000200
```

Continue: <Enter>	Edit Data Entry <Ctrl-B>	Hard Copy: <Shift-PrtSc>		Quit: <Esc>

```
                              TOOL DESCRIPTION

  Tool Type: TU18
        Tool Description /Company I.D:
        Rotational Tool [Y/N] ? .... : N
 ==========================================================================
  Insert (Cutting Unit) Information:
   Insert Type ........... : NG330L K68
   Assigned Tool Life Unit :   30.00  Max. Permissible % Tool Life :  50.00
   Percentage Life Used .. :   0.00   No. of Indexable Tips/Regrinds: 4
   No. of Tips Used  ..... : 0
 ==========================================================================
  Shank Information:
   Shank Type ............ : MODNEG2525-M3
   External / Internal Tool [E/I]: I  Shank Size  .....  :   1
 ==========================================================================
  Holder Information:
   Holder Type ........... : W633000200
```

Continue: <Enter>	Edit Data Entry <Ctrl-B>	Hard Copy: <Shift-PrtSc>		Quit: <Esc>

TOOL DESCRIPTION

Tool Type: TU19
Tool Description /Company I.D: RECESS TOOL
Rotational Tool [Y/N] ? .... : N

Insert (Cutting Unit) Information:
Insert Type .... : NCT11912
Assigned Tool Life Unit : 30.00 Max. Permissible % Tool Life : 50.00
Percentage Life Used .. : 0.00 No. of Indexable Tips/Regrinds: 4
No. of Tips Used ..... : 0

Shank Information:
Shank Type .... :
External / Internal Tool [E/I]: I Shank Size ..... : 1

Holder Information:
Holder Type .... : W632210200

Continue: <Enter>	Edit Data Entry <Ctrl-B>	Hard Copy: <Shift-PrtSc>		Quit: <Esc>

TOOL DESCRIPTION

Tool Type: TU20
Tool Description /Company I.D: RECESS TOOL
Rotational Tool [Y/N] ? .... : N

Insert (Cutting Unit) Information:
Insert Type .... : NCT11912
Assigned Tool Life Unit : 30.00 Max. Permissible % Tool Life : 50.00
Percentage Life Used .. : 0.00 No. of Indexable Tips/Regrinds: 4
No. of Tips Used ..... : 0

Shank Information:
Shank Type .... :
External / Internal Tool [E/I]: I Shank Size ..... : 1

Holder Information:
Holder Type .... : W632210200

Continue: <Enter>	Edit Data Entry <Ctrl-B>	Hard Copy: <Shift-PrtSc>		Quit: <Esc>

TOOL DESCRIPTION

Tool Type: TU21
Tool Description /Company I.D: FORM TOOL
Rotational Tool [Y/N] ? .... : N

Insert (Cutting Unit) Information:
Insert Type .... : NCT11073
Assigned Tool Life Unit : 30.00 Max. Permissible % Tool Life : 50.00
Percentage Life Used .. : 0.00 No. of Indexable Tips/Regrinds: 4
No. of Tips Used ..... : 0

Shank Information:
Shank Type .... :
External / Internal Tool [E/I]: E Shank Size ..... : 0

Holder Information:
Holder Type .... : W632102000

Continue: <Enter>	Edit Data Entry <Ctrl-B>	Hard Copy: <Shift-PrtSc>		Quit: <Esc>

```
                              TOOL DESCRIPTION

   Tool Type: B001
        Tool Description /Company I.D:
        Rotational Tool [Y/N] ? .... : N

   Insert (Cutting Unit) Information:
    Insert Type ........... : EPMM060204
    Assigned Tool Life Unit :   30.00  Max. Permissible % Tool Life :  50.00
    Percentage Life Used .. :   0.00   No. of Indexable Tips/Regrinds: 4
    No. of Tips Used  ..... : 0

   Shank Information:
    Shank Type ............ : STELLRAM E015-V08R
    External / Internal Tool [E/I]: I  Shank Size  .....  :    1

   Holder Information:
    Holder Type ........... : W632112000

 Continue:     | Edit Data Entry |  Hard Copy:    |               |    Quit:
  <Enter>      |    <Ctrl-B>     | <Shift-PrtSc>  |               |    <Esc>
```

```
                              TOOL DESCRIPTION

   Tool Type: B002
        Tool Description /Company I.D:
        Rotational Tool [Y/N] ? .... : N

   Insert (Cutting Unit) Information:
    Insert Type ........... : EPMM060202 K20
    Assigned Tool Life Unit :   30.00  Max. Permissible % Tool Life :  50.00
    Percentage Life Used .. :   0.00   No. of Indexable Tips/Regrinds: 4
    No. of Tips Used  ..... : 0

   Shank Information:
    Shank Type ............ : STELLRAM E015-V08R
    External / Internal Tool [E/I]: I  Shank Size  .....  :    1

   Holder Information:
    Holder Type ........... : W632102000

 Continue:     | Edit Data Entry |  Hard Copy:    |               |    Quit:
  <Enter>      |    <Ctrl-B>     | <Shift-PrtSc>  |               |    <Esc>
```

```
                              TOOL DESCRIPTION

   Tool Type: B003
        Tool Description /Company I.D:
        Rotational Tool [Y/N] ? .... : N

   Insert (Cutting Unit) Information:
    Insert Type ........... : EPMM060202 K20
    Assigned Tool Life Unit :   30.00  Max. Permissible % Tool Life :  50.00
    Percentage Life Used .. :   0.00   No. of Indexable Tips/Regrinds: 4
    No. of Tips Used  ..... : 0

   Shank Information:
    Shank Type ............ : STELLRAM E015V08R
    External / Internal Tool [E/I]: I  Shank Size  .....  :    1

   Holder Information:
    Holder Type ........... : W632112000

 Continue:     | Edit Data Entry |  Hard Copy:    |               |    Quit:
  <Enter>      |    <Ctrl-B>     | <Shift-PrtSc>  |               |    <Esc>
```

```
TOOL DESCRIPTION

Tool Type: B004
        Tool Description /Company I.D:
        Rotational Tool [Y/N] ? .... : N

Insert (Cutting Unit) Information:
 Insert Type ........... : CPGM060208 K68
 Assigned Tool Life Unit :   30.00  Max. Permissible % Tool Life :  50.00
 Percentage Life Used .. :   0.00   No. of Indexable Tips/Regrinds: 4
 No. of Tips Used  ..... : 0

Shank Information:
 Shank Type ............ : S12M-SCLCR-06
 External / Internal Tool [E/I]: I  Shank Size  .....  :   1

Holder Information:
 Holder Type ........... : W632210200

Continue: | Edit Data Entry | Hard Copy:     |  | Quit:
<Enter>   |    <Ctrl-B>     | <Shift-PrtSc>  |  | <Esc>
```

```
TOOL DESCRIPTION

Tool Type: B005
        Tool Description /Company I.D:
        Rotational Tool [Y/N] ? .... : N

Insert (Cutting Unit) Information:
 Insert Type ........... : KNUX110302 K68
 Assigned Tool Life Unit :   30.00  Max. Permissible % Tool Life :  50.00
 Percentage Life Used .. :   0.00   No. of Indexable Tips/Regrinds: 4
 No. of Tips Used  ..... : 0

Shank Information:
 Shank Type ............ : S12M-NKLCR-11
 External / Internal Tool [E/I]: I  Shank Size  .....  :   1

Holder Information:
 Holder Type ........... : W632210200

Continue: | Edit Data Entry | Hard Copy:     |  | Quit:
<Enter>   |    <Ctrl-B>     | <Shift-PrtSc>  |  | <Esc>
```

```
TOOL DESCRIPTION

Tool Type: B006
        Tool Description /Company I.D:
        Rotational Tool [Y/N] ? .... : N

Insert (Cutting Unit) Information:
 Insert Type ........... : CPGM060202 K68
 Assigned Tool Life Unit :   30.00  Max. Permissible % Tool Life :  50.00
 Percentage Life Used .. :   0.00   No. of Indexable Tips/Regrinds: 4
 No. of Tips Used  ..... : 0

Shank Information:
 Shank Type ............ : S12M-SCLPR-06
 External / Internal Tool [E/I]: I  Shank Size  .....  :   1

Holder Information:
 Holder Type ........... : W632210200

Continue: | Edit Data Entry | Hard Copy:     |  | Quit:
<Enter>   |    <Ctrl-B>     | <Shift-PrtSc>  |  | <Esc>
```

TOOL DESCRIPTION

Tool Type: B007
Tool Description /Company I.D:
Rotational Tool [Y/N] ? .... : N

Insert (Cutting Unit) Information:
Insert Type .... : CPGM060202 K68
Assigned Tool Life Unit : 30.00 Max. Permissible % Tool Life : 50.00
Percentage Life Used .. : 0.00 No. of Indexable Tips/Regrinds: 4
No. of Tips Used ..... : 0

Shank Information:
Shank Type .... : S12M-SCLPR-06
External / Internal Tool [E/I]: I Shank Size ..... : 1

Holder Information:
Holder Type .... : W632210200

Continue: <Enter>	Edit Data Entry <Ctrl-B>	Hard Copy: <Shift-PrtSc>		Quit: <Esc>

TOOL DESCRIPTION

Tool Type: B008
Tool Description /Company I.D:
Rotational Tool [Y/N] ? .... : N

Insert (Cutting Unit) Information:
Insert Type .... : EPMM060202 K20
Assigned Tool Life Unit : 30.00 Max. Permissible % Tool Life : 50.00
Percentage Life Used .. : 0.00 No. of Indexable Tips/Regrinds: 4
No. of Tips Used ..... : 0

Shank Information:
Shank Type .... : STELLRAM E015-V08R
External / Internal Tool [E/I]: I Shank Size ..... : 1

Holder Information:
Holder Type .... : W632102000

Continue: <Enter>	Edit Data Entry <Ctrl-B>	Hard Copy: <Shift-PrtSc>		Quit: <Esc>

TOOL DESCRIPTION

Tool Type: B009
Tool Description /Company I.D:
Rotational Tool [Y/N] ? .... : N

Insert (Cutting Unit) Information:
Insert Type .... : VNMP160404 K68
Assigned Tool Life Unit : 30.00 Max. Permissible % Tool Life : 50.00
Percentage Life Used .. : 0.00 No. of Indexable Tips/Regrinds: 4
No. of Tips Used ..... : 0

Shank Information:
Shank Type .... : S16M-PVXNR-16
External / Internal Tool [E/I]: I Shank Size ..... : 1

Holder Information:
Holder Type .... : W632210200

Continue: <Enter>	Edit Data Entry <Ctrl-B>	Hard Copy: <Shift-PrtSc>		Quit: <Esc>

```
                              TOOL DESCRIPTION

  Tool Type: B010
          Tool Description /Company I.D:
          Rotational Tool [Y/N] ? .... : N
=======================================================================
  Insert (Cutting Unit) Information:
   Insert Type ........... : KNUX110305L15 K68
   Assigned Tool Life Unit :   30.00  Max. Permissible % Tool Life :  50.00
   Percentage Life Used .. :   0.00   No. of Indexable Tips/Regrinds: 4
   No. of Tips Used  ..... : 0
=======================================================================
  Shank Information:
   Shank Type ............ : S12K-NKLNR-11
   External / Internal Tool [E/I]: I  Shank Size  .....  :   1
=======================================================================
  Holder Information:
   Holder Type ........... : W632210200
-----------------------------------------------------------------------
 Continue:   |Edit Data Entry| Hard Copy:   |              |    Quit:
  <Enter>    |   <Ctrl-B>    |<Shift-PrtSc> |              |    <Esc>
```

```
                              TOOL DESCRIPTION

  Tool Type: DR01
          Tool Description /Company I.D:
          Rotational Tool [Y/N] ? .... : N
=======================================================================
  Insert (Cutting Unit) Information:
   Insert Type ........... : NO.5 C/DRILL
   Assigned Tool Life Unit :   30.00  Max. Permissible % Tool Life :  50.00
   Percentage Life Used .. :   0.00   No. of Indexable Tips/Regrinds: 9
   No. of Tips Used  ..... : 0
=======================================================================
  Shank Information:
   Shank Type ............ :
   External / Internal Tool [E/I]: I  Shank Size  .....  :   1
=======================================================================
  Holder Information:
   Holder Type ........... : W632112000
-----------------------------------------------------------------------
 Continue:   |Edit Data Entry| Hard Copy:   |              |    Quit:
  <Enter>    |   <Ctrl-B>    |<Shift-PrtSc> |              |    <Esc>
```

```
                              TOOL DESCRIPTION

  Tool Type: DR02
          Tool Description /Company I.D:
          Rotational Tool [Y/N] ? .... : N
=======================================================================
  Insert (Cutting Unit) Information:
   Insert Type ........... : 11MM DRILL
   Assigned Tool Life Unit :   30.00  Max. Permissible % Tool Life :  50.00
   Percentage Life Used .. :   0.00   No. of Indexable Tips/Regrinds: 9
   No. of Tips Used  ..... : 0
=======================================================================
  Shank Information:
   Shank Type ............ :
   External / Internal Tool [E/I]: I  Shank Size  .....  :   1
=======================================================================
  Holder Information:
   Holder Type ........... : W632112000
-----------------------------------------------------------------------
 Continue:   |Edit Data Entry| Hard Copy:   |              |    Quit:
  <Enter>    |   <Ctrl-B>    |<Shift-PrtSc> |              |    <Esc>
```

TOOL DESCRIPTION

Tool Type: DR03
Tool Description /Company I.D:
Rotational Tool [Y/N] ? .... : N

Insert (Cutting Unit) Information:
Insert Type .... : NO.5 C/DRILL
Assigned Tool Life Unit : 30.00 Max. Permissible % Tool Life : 50.00
Percentage Life Used .. : 0.00 No. of Indexable Tips/Regrinds: 9
No. of Tips Used ..... : 0

Shank Information:
Shank Type .... :
External / Internal Tool [E/I]: I Shank Size ..... : 1

Holder Information:
Holder Type .... : W632102000

Continue: <Enter>	Edit Data Entry <Ctrl-B>	Hard Copy: <Shift-PrtSc>		Quit: <Esc>

TOOL DESCRIPTION

Tool Type: DR04
Tool Description /Company I.D:
Rotational Tool [Y/N] ? .... : N

Insert (Cutting Unit) Information:
Insert Type .... : 11MM DRILL
Assigned Tool Life Unit : 30.00 Max. Permissible % Tool Life : 50.00
Percentage Life Used .. : 0.00 No. of Indexable Tips/Regrinds: 9
No. of Tips Used ..... : 0

Shank Information:
Shank Type .... :
External / Internal Tool [E/I]: I Shank Size ..... : 1

Holder Information:
Holder Type .... : W632102000

Continue: <Enter>	Edit Data Entry <Ctrl-B>	Hard Copy: <Shift-PrtSc>		Quit: <Esc>

TOOL DESCRIPTION

Tool Type: DR05
Tool Description /Company I.D:
Rotational Tool [Y/N] ? .... : N

Insert (Cutting Unit) Information:
Insert Type .... : 3/4'' SLOT DRILL
Assigned Tool Life Unit : 30.00 Max. Permissible % Tool Life : 50.00
Percentage Life Used .. : 0.00 No. of Indexable Tips/Regrinds: 9
No. of Tips Used ..... : 0

Shank Information:
Shank Type .... :
External / Internal Tool [E/I]: I Shank Size ..... : 1

Holder Information:
Holder Type .... : W632102000

Continue: <Enter>	Edit Data Entry <Ctrl-B>	Hard Copy: <Shift-PrtSc>		Quit: <Esc>

```
                           TOOL DESCRIPTION

 Tool Type: DR06
         Tool Description /Company I.D:
         Rotational Tool [Y/N] ? .... : N

 Insert (Cutting Unit) Information:
  Insert Type ........... : EPMM060202 K20
  Assigned Tool Life Unit :   30.00  Max. Permissible % Tool Life :  50.00
  Percentage Life Used .. :   0.00   No. of Indexable Tips/Regrinds: 4
  No. of Tips Used  ..... : 0

 Shank Information:
  Shank Type ............ : STELLRAM E015-V08R
  External / Internal Tool [E/I]: I  Shank Size  .....  :   1

 Holder Information:
  Holder Type ........... : W632102000

Continue:    | Edit Data Entry |  Hard Copy:   |  |  Quit:
 <Enter>     |    <Ctrl-B>     | <Shift-PrtSc> |  |  <Esc>
```

```
                           TOOL DESCRIPTION

 Tool Type: DR07
         Tool Description /Company I.D:
         Rotational Tool [Y/N] ? .... : N

 Insert (Cutting Unit) Information:
  Insert Type ........... : 11MM DRILL
  Assigned Tool Life Unit :   30.00  Max. Permissible % Tool Life :  50.00
  Percentage Life Used .. :   0.00   No. of Indexable Tips/Regrinds: 9
  No. of Tips Used  ..... : 0

 Shank Information:
  Shank Type ............ :
  External / Internal Tool [E/I]: I  Shank Size  .....  :   1

 Holder Information:
  Holder Type ........... : W632112000

Continue:    | Edit Data Entry |  Hard Copy:   |  |  Quit:
 <Enter>     |    <Ctrl-B>     | <Shift-PrtSc> |  |  <Esc>
```

```
                           TOOL DESCRIPTION

 Tool Type: DR08
         Tool Description /Company I.D:
         Rotational Tool [Y/N] ? .... : N

 Insert (Cutting Unit) Information:
  Insert Type ........... : 3/4'' SLOT DRILL
  Assigned Tool Life Unit :   30.00  Max. Permissible % Tool Life :  50.00
  Percentage Life Used .. :   0.00   No. of Indexable Tips/Regrinds: 9
  No. of Tips Used  ..... : 0

 Shank Information:
  Shank Type ............ :
  External / Internal Tool [E/I]: I  Shank Size  .....  :   1

 Holder Information:
  Holder Type ........... : W632112000

Continue:    | Edit Data Entry |  Hard Copy:   |  |  Quit:
 <Enter>     |    <Ctrl-B>     | <Shift-PrtSc> |  |  <Esc>
```

```
                              TOOL DESCRIPTION

  Tool Type: DR09
          Tool Description /Company I.D:
          Rotational Tool [Y/N] ? .... : N

  Insert (Cutting Unit) Information:
   Insert Type ........... : NO.5 C/DRILL
   Assigned Tool Life Unit :   30.00  Max. Permissible % Tool Life :  50.00
   Percentage Life Used .. :   0.00   No. of Indexable Tips/Regrinds: 9
   No. of Tips Used  ..... : 0

  Shank Information:
   Shank Type ............ :
   External / Internal Tool [E/I]: I  Shank Size  .....  :   1

  Holder Information:
   Holder Type ........... : W632100000

Continue:     Edit Data Entry  Hard Copy:                      Quit:
 <Enter>         <Ctrl-B>     <Shift-PrtSc>                    <Esc>
```

```
                              TOOL DESCRIPTION

  Tool Type: DR10
          Tool Description /Company I.D:
          Rotational Tool [Y/N] ? .... : N

  Insert (Cutting Unit) Information:
   Insert Type ........... : 3/4'' DRILL(GUHRING)
   Assigned Tool Life Unit :   30.00  Max. Permissible % Tool Life :  50.00
   Percentage Life Used .. :   0.00   No. of Indexable Tips/Regrinds: 9
   No. of Tips Used  ..... : 0

  Shank Information:
   Shank Type ............ :
   External / Internal Tool [E/I]: I  Shank Size  .....  :   1

  Holder Information:
   Holder Type ........... : W632100300

Continue:     Edit Data Entry  Hard Copy:                      Quit:
 <Enter>         <Ctrl-B>     <Shift-PrtSc>                    <Esc>
```

```
                              TOOL DESCRIPTION

  Tool Type: DR11
          Tool Description /Company I.D:
          Rotational Tool [Y/N] ? .... : N

  Insert (Cutting Unit) Information:
   Insert Type ........... : 19.05MM T/SDRILL
   Assigned Tool Life Unit :   30.00  Max. Permissible % Tool Life :  50.00
   Percentage Life Used .. :   0.00   No. of Indexable Tips/Regrinds: 9
   No. of Tips Used  ..... : 0

  Shank Information:
   Shank Type ............ :
   External / Internal Tool [E/I]: I  Shank Size  .....  :   1

  Holder Information:
   Holder Type ........... : W632100300

Continue:     Edit Data Entry  Hard Copy:                      Quit:
 <Enter>         <Ctrl-B>     <Shift-PrtSc>                    <Esc>
```

```
                              TOOL DESCRIPTION

   Tool Type: DR12
           Tool Description /Company I.D:
           Rotational Tool [Y/N] ? .... : N

   Insert (Cutting Unit) Information:
    Insert Type ........... : BS5 CENTRE DRILL
    Assigned Tool Life Unit :   30.00  Max. Permissible % Tool Life :  50.00
    Percentage Life Used .. :   0.00   No. of Indexable Tips/Regrinds: 9
    No. of Tips Used  ..... : 0

   Shank Information:
    Shank Type ............ :
    External / Internal Tool [E/I]: I  Shank Size  .....  :   1

   Holder Information:
    Holder Type ........... : W632102000

 Continue:     | Edit Data Entry |  Hard Copy:   |   |   Quit:
  <Enter>      |    <Ctrl-B>     | <Shift-PrtSc> |   |   <Esc>
```

```
                              TOOL DESCRIPTION

   Tool Type: DR13
           Tool Description /Company I.D:
           Rotational Tool [Y/N] ? .... : N

   Insert (Cutting Unit) Information:
    Insert Type ........... : 13.3MM DIA. DRILL
    Assigned Tool Life Unit :   30.00  Max. Permissible % Tool Life :  50.00
    Percentage Life Used .. :   0.00   No. of Indexable Tips/Regrinds: 9
    No. of Tips Used  ..... : 0

   Shank Information:
    Shank Type ............ :
    External / Internal Tool [E/I]: I  Shank Size  .....  :   1

   Holder Information:
    Holder Type ........... : W632102000

 Continue:     | Edit Data Entry |  Hard Copy:   |   |   Quit:
  <Enter>      |    <Ctrl-B>     | <Shift-PrtSc> |   |   <Esc>
```

```
                              TOOL DESCRIPTION

   Tool Type: DR14
           Tool Description /Company I.D:
           Rotational Tool [Y/N] ? .... : N

   Insert (Cutting Unit) Information:
    Insert Type ........... : DRILL (592726)
    Assigned Tool Life Unit :   30.00  Max. Permissible % Tool Life :  50.00
    Percentage Life Used .. :   0.00   No. of Indexable Tips/Regrinds: 9
    No. of Tips Used  ..... : 0

   Shank Information:
    Shank Type ............ :
    External / Internal Tool [E/I]: I  Shank Size  .....  :   1

   Holder Information:
    Holder Type ........... : W632102000

 Continue:     | Edit Data Entry |  Hard Copy:   |   |   Quit:
  <Enter>      |    <Ctrl-B>     | <Shift-PrtSc> |   |   <Esc>
```

TOOL DESCRIPTION

Tool Type: DR15
Tool Description /Company I.D:
Rotational Tool [Y/N] ? .... : N

Insert (Cutting Unit) Information:
Insert Type .... : SLOT DRILL (982461)
Assigned Tool Life Unit : 30.00 Max. Permissible % Tool Life : 50.00
Percentage Life Used .. : 0.00 No. of Indexable Tips/Regrinds: 9
No. of Tips Used ..... : 0

Shank Information:
Shank Type .... :
External / Internal Tool [E/I]: I Shank Size ..... : 1

Holder Information:
Holder Type .... : W632102000

Continue: <Enter>	Edit Data Entry <Ctrl-B>	Hard Copy: <Shift-PrtSc>		Quit: <Esc>

APPENDIX 2C

DETAILED SAMPLES OF TOOLING OUTPUT FOR THE MULTI-MACHINE CASE STUDY

(Supplement to Chapter 13, Run No. 1)

MODEL OUTPUT / FINAL TOOL STATUS

Tool No.	Tool Type	Life Unit	Life Used (%)	Usage Freq.	Tips Used	Worn	M/C No.	Store	Rack No.	Posit.
1	TU11	30.00	10.00	2	0	N	0	C	0	17
2	DR01	30.00	1.00	1	0	N	0	C	0	18
3	TU12	30.00	5.00	2	0	N	0	C	0	19
4	DR11	30.00	3.33	1	0	N	0	C	0	20
5	TU13	30.00	28.33	1	0	Y	0	C	0	21
6	B010	30.00	6.00	2	0	N	0	C	0	22
7	TU13	30.00	41.00	1	0	N	0	C	0	23
8	TU01	30.00	47.33	10	0	Y	0	C	0	1
9	DR12	30.00	13.33	10	0	N	0	C	0	2
10	DR14	30.00	10.00	10	0	N	0	C	0	3

Continue: <Enter>		Hard Copy: <Shift-PrtSc>		Quit: <Esc>

MODEL OUTPUT / FINAL TOOL STATUS

Tool No.	Tool Type	Life Unit	Life Used (%)	Usage Freq.	Tips Used	Worn	M/C No.	Store	Rack No.	Posit.
11	TU02	30.00	40.00	20	0	N	0	C	0	4
12	B002	30.00	6.67	10	0	N	0	C	0	5
13	DR15	30.00	16.67	10	0	N	0	C	0	6
14	TU01	30.00	47.00	10	0	Y	0	C	0	7
15	TU01	30.00	45.67	10	0	N	0	C	0	8
16	TU01	30.00	16.67	5	0	N	0	C	0	35
17	DR12	30.00	5.00	5	0	N	0	C	0	36
18	DR13	30.00	15.00	5	0	N	0	C	0	37
19	TU07	30.00	3.33	5	0	N	0	C	0	38
20	TU17	30.00	10.00	5	0	N	0	C	0	39

Continue: <Enter>		Hard Copy: <Shift-PrtSc>		Quit: <Esc>

MODEL OUTPUT / FINAL TOOL STATUS

Tool No.	Tool Type	Life Unit	Life Used (%)	Usage Freq.	Tips Used	Worn	M/C No.	Store	Rack No.	Posit.
21	TU18	30.00	11.67	5	0	N	0	C	0	40
22	B002	30.00	28.33	10	0	N	0	C	0	41
23	DR05	30.00	45.00	5	0	N	0	C	0	42
24	TU19	30.00	16.67	5	0	N	0	C	0	43
25	TU20	30.00	10.00	5	0	N	0	C	0	44
26	TU21	30.00	3.33	5	0	N	0	C	0	45
27	TU01	30.00	48.67	6	0	Y	0	C	0	24
28	TU02	30.00	49.33	26	0	Y	0	C	0	25
29	DR01	30.00	6.67	10	0	N	0	C	0	26
30	DR02	30.00	23.33	10	0	N	0	C	0	27

Continue: <Enter>		Hard Copy: <Shift-PrtSc>		Quit: <Esc>

MODEL OUTPUT / FINAL TOOL STATUS

Tool No.	Tool Type	Life Unit	Life Used (%)	Usage Freq.	Tips Used	Worn	M/C No.	Store	Rack No.	Posit.
31	TU03	30.00	6.67	10	0	N	0	C	0	28
32	B001	30.00	16.67	10	0	N	0	C	0	29
33	TU01	30.00	48.67	6	0	Y	0	C	0	30
34	TU01	30.00	48.67	6	0	Y	0	C	0	31
35	TU01	30.00	48.67	6	0	Y	0	C	0	32
36	TU01	30.00	48.67	6	0	N	0	C	0	33
37	TU02	30.00	7.33	4	0	N	0	C	0	34
38	TU01	30.00	45.00	10	0	Y	0	C	0	9
39	DR03	30.00	6.67	10	0	N	0	C	0	10
40	DR04	30.00	30.00	10	0	N	0	C	0	11

Continue: <Enter>		Hard Copy: <Shift-PrtSc>		Quit: <Esc>

MODEL OUTPUT / FINAL TOOL STATUS

Tool No.	Tool Type	Life Unit	Life Used (%)	Usage Freq.	Tips Used	Worn	M/C No.	Store	Rack No.	Posit.
41	TU02	30.00	20.00	20	0	N	0	C	0	12
42	B002	30.00	45.00	10	0	Y	0	C	0	13
43	DR05	30.00	13.33	10	0	N	0	C	0	14
44	TU01	30.00	45.00	10	0	N	0	C	0	15
45	B002	30.00	45.00	10	0	N	0	C	0	16
46	TU01	30.00	11.67	2	0	N	0	C	0	56
47	DR09	30.00	0.67	1	0	N	0	C	0	57
48	DR10	30.00	4.67	1	0	N	0	C	0	58
49	TU08	30.00	31.67	1	0	Y	0	C	0	59
50	B004	30.00	2.00	2	0	N	0	C	0	60

Continue: <Enter>		Hard Copy: <Shift-PrtSc>		Quit: <Esc>

MODEL OUTPUT / FINAL TOOL STATUS

Tool No.	Tool Type	Life Unit	Life Used (%)	Usage Freq.	Tips Used	Worn	M/C No.	Store	Rack No.	Posit.
51	TU09	30.00	11.00	2	0	N	0	C	0	61
52	B005	30.00	13.33	2	0	N	0	C	0	62
53	TU08	30.00	31.67	1	0	N	0	C	0	63
54	TU02	30.00	1.33	1	0	N	0	C	0	64
55	TU01	30.00	50.00	17	0	Y	0	C	0	46
56	DR01	30.00	6.67	10	0	N	0	C	0	47
57	DR07	30.00	30.00	10	0	N	0	C	0	48
58	TU02	30.00	20.00	20	0	N	0	C	0	49
59	B003	30.00	43.00	6	0	Y	0	C	0	50
60	DR08	30.00	3.33	10	0	N	0	C	0	51

Continue: <Enter>		Hard Copy: <Shift-PrtSc>		Quit: <Esc>

MODEL OUTPUT / FINAL TOOL STATUS

Tool No.	Tool Type	Life Unit	Life Used (%)	Usage Freq.	Tips Used	Worn	M/C No.	Store	Rack No.	Posit.
61	B003	30.00	43.00	6	0	Y	0	C	0	52
62	B003	30.00	43.00	6	0	Y	0	C	0	53
63	TU01	30.00	6.67	3	0	N	0	C	0	54
64	B003	30.00	14.33	2	0	N	0	C	0	55
65	TU02	30.00	48.00	9	0	Y	4	T	0	1
66	B009	30.00	6.67	10	0	N	4	T	0	2
67	TU02	30.00	5.33	1	0	N	4	T	0	3
68	TU01	30.00	50.00	20	0	N	0	C	0	71
69	DR03	30.00	6.67	10	0	N	0	C	0	72
70	DR04	30.00	20.00	10	0	N	0	C	0	73

Continue: <Enter>		Hard Copy: <Shift-PrtSc>		Quit: <Esc>

MODEL OUTPUT / FINAL TOOL STATUS

Tool No.	Tool Type	Life Unit	Life Used (%)	Usage Freq.	Tips Used	Worn	M/C No.	Store	Rack No.	Posit.
71	TU02	30.00	40.00	20	0	N	0	C	0	74
72	B002	30.00	36.67	10	0	N	0	C	0	75
73	DR05	30.00	3.33	10	0	N	0	C	0	76
74	DR06	30.00	10.00	10	0	N	0	C	0	77
75	TU01	30.00	46.67	10	0	N	0	C	0	65
76	TU02	30.00	23.33	10	0	N	0	C	0	66
77	B006	30.00	2.67	1	0	N	0	C	0	67
78	B007	30.00	3.00	1	0	N	0	C	0	68
79	TU14	30.00	4.33	1	0	N	0	C	0	69
80	TU15	30.00	3.00	1	0	N	0	C	0	70

Continue: <Enter>		Hard Copy: <Shift-PrtSc>		Quit: <Esc>

MODEL OUTPUT / FINAL TOOL STATUS

Tool No.	Tool Type	Life Unit	Life Used (%)	Usage Freq.	Tips Used	Worn	M/C No.	Store	Rack No.	Posit.
81	TU04	30.00	23.33	10	0	N	1	T	0	1
82	DR12	30.00	10.00	10	0	N	1	T	0	2
83	TU02	30.00	45.33	8	0	Y	1	T	0	3
84	B002	30.00	43.33	20	0	N	1	T	0	4
85	DR14	30.00	20.00	10	0	N	1	T	0	5
86	DR15	30.00	20.00	10	0	N	1	T	0	6
87	B008	30.00	20.00	10	0	N	1	T	0	7
88	TU16	30.00	23.33	10	0	N	1	T	0	8
89	TU02	30.00	11.33	2	0	N	1	T	0	9
90	TU01	30.00	11.67	2	0	N	0	C	0	81

Continue: <Enter>		Hard Copy: <Shift-PrtSc>		Quit: <Esc>

MODEL OUTPUT / FINAL TOOL STATUS

Tool No.	Tool Type	Life Unit	Life Used (%)	Usage Freq.	Tips Used	Worn	M/C No.	Store	Rack No.	Posit.
91	DR09	30.00	0.67	1	0	N	0	C	0	82
92	DR10	30.00	4.67	1	0	N	0	C	0	83
93	TU08	30.00	31.33	1	0	Y	0	C	0	84
94	B004	30.00	2.67	2	0	N	0	C	0	85
95	TU09	30.00	17.00	2	0	N	0	C	0	86
96	B005	30.00	3.00	2	0	N	0	C	0	87
97	TU08	30.00	28.67	1	0	N	0	C	0	88
98	TU10	30.00	2.33	1	0	N	0	C	0	89
99	TU06	30.00	26.67	10	0	N	0	C	0	78
100	TU01	30.00	40.00	10	0	N	0	C	0	79

Continue: <Enter>		Hard Copy: <Shift-PrtSc>		Quit: <Esc>

MODEL OUTPUT / FINAL TOOL STATUS

Tool No.	Tool Type	Life Unit	Life Used (%)	Usage Freq.	Tips Used	Worn	M/C No.	Store	Rack No.	Posit.
101	TU07	30.00	16.67	10	0	N	0	C	0	80
102	TU02	30.00	30.00	10	0	N	3	T	0	1
103	TU05	30.00	30.00	10	0	N	3	T	0	2
104	TU01	30.00	45.00	5	0	Y	3	T	0	3
105	TU01	30.00	45.00	5	0	N	3	T	0	4
106	B002	30.00	20.00	10	0	N	2	T	0	1
107	TU02	30.00	50.00	5	0	Y	2	T	0	2
108	TU02	30.00	50.00	5	0	N	2	T	0	3
109	TU02	30.00	30.00	10	0	N	5	T	0	1
110	TU05	30.00	45.33	8	0	Y	5	T	0	2

Continue: <Enter>		Hard Copy: <Shift-PrtSc>		Quit: <Esc>

MODEL OUTPUT / FINAL TOOL STATUS

Tool No.	Tool Type	Life Unit	Life Used (%)	Usage Freq.	Tips Used	Worn	M/C No.	Store	Rack No.	Posit.
111	TU05	30.00	11.33	2	0	N	5	T	0	3

Continue: <Enter>		Hard Copy: <Shift-PrtSc>		Quit: <Esc>

TOOL COMPONENTS REQUIREMENT

(Supplement to Chapter 13, Run No. 1)

TOOL PART REQUIREMENT - INSERT

Insert Identity	No.s	Insert Identity	No.s	Insert Identity	No.s
CNMS120408 K68	14	13.3MM DIA. DRILL	1	3/4'' DRILL(GUHRING)	1
NO.5 C/DRILL	5	DNMP150404 K68	2	NG451L K68	3
19.05MM T/SDRILL	1	NG330L K68	2	CPGM060208 K68	1
NCT12450	2	NCT11912	2	KNUX110302 K68	1
KNUX110305L15 K68	1	NCT11073	1	KNUX110302R15 K68	3
11MM DRILL	3	DRILL (592726)	1	CPGM060202 K68	2
CNMP120404 K68	10	SLOT DRILL (982461)	1	CNMP120408 K68	1
EPMM060202 K20	7	NCT8253	1	NCT12628	1
3/4'' SLOT DRILL	3	EPMM060204	1		
BS5 CENTRE DRILL	2	VNMP160404 K68	1		

Continue: <Enter>		Hard Copy: <Shift-PrtSc>		Quit: <Esc>

TOOL PART REQUIREMENT - SHANK

Shank Identity	No.s	Use. Freq.	Shank Identity	No.s	Use. Freq.
MCLNR2020 H12	21	42	STELLRAM E015V08R	4	4
S12K-NKLNR-11	1	1	NKLCR2020 H12	3	3
STELLRAM E015-V08R	5	10	S12M-SCLPR-06	2	2
MDJNR2020 H12	1	2	MDJNR2020 H15	1	1
MODNER2525-M3	1	1	NER2020 H3	1	1
MODNEG2525-M3	1	1			
S16M-PVXNR-16	1	1			
AC65171	3	6			
S12M-SCLCR-06	1	2			
S12M-NKLCR-11	1	2			

Continue: <Enter>		Hard Copy: <Shift-PrtSc>		Quit: <Esc>

TOOL PART REQUIREMENT - HOLDER

Holder Identity	No.s	Use. Freq.	Holder Identity	No.s	Use. Freq.
W633000400	2	5			
W632112000	12	12			
W632100300	2	3			
W632210200	8	12			
W633000200	27	52			
W632102000	14	25			
W632100000	1	2			

Continue: <Enter>		Hard Copy: <Shift-PrtSc>		Quit: <Esc>

REFERENCES

1. Abdin, M. F.
'Solution of Scheduling problems of job-shop type FMS with alternative machine tools'
Proc. of the 8th Annual Conf. on Computers and Industrial Engineering.
Computers and Industrial Engineering, Vol. 11, No. 1-4, 1986, pp241-245.

2. Abdin, M. F. and Mohamed, N. S.
'The Role of Simulation in Design of FMSs'
Proc. of the 8th Annual Conf. on Computers and Industrial Engineering.
Computers and Industrial Engineering, Vol. 11, No. 1-4, 1986, pp. 372 -376.

3. Admas, J, D.
Loughborough University of Technology,
Private Communication, 1989.

4. Afentakis, P.
'Maximum Throughput in Flexible Manufacturing Systems'
Proc. of the Second ORSA/TIMS Conf. on Flexible Manufacturing Systems: Operations Research Models and Applications.
Elsevier Science Publishers B. V., Amsterdam, 1986, pp. 509 - 520.

5. Alting, L., Bilberg, A. and Larsen, N. E.
'Extend Applications of Simulation in Manufacturing Systems'
Annals of the CIRP, Vol. 37/1/1988, pp. 417-420.

6. Anon.
'The Cross Line: Try a New Track'
The FMS Magazine, October 1986, pp195- 198.

7. Anon.
'Flexible Manufacturing System - Notes to Supplement the Video Cassette'
Numerical Engineering Society/Institution of Production Engineers.

8. Anon.
'FMS Will Aid Tool and Die Production'
The FMS Magazine, Oct. 1986, p213.

9. Anon.
'Focus on NC Lathes'
VDI Intl. Magazine, 1/83, pp11 - 17.

10. Anon.
'SCAMP Comes on Stream'
Numerical Engineering, Vol. 4(1), 1983, pp9-11.

11. Anon.
'Second FMS project for Lister-petter'
The FMS Magazine, Oct. 1986, p117.

12. Anon.
'Flexible Approach to Holset FMS Implementation'
The FMS Magazine, July 1985, pp118.

13. Anon.
'Profitable One-off Production...'
Machinery and Production Engineering, March, 1986, pp32-34.

14. Anon.
'Strong Yen Boosts Automated Factory'
Automation, July 1987, pp224-228.

15. Anon.
'Yamazaki Ends FMS Speculation'
Production Engineer, January 1986, p3.

16. Anon.
'Tool Changing on NC Machines'
Translated from 'IVF Result 75622 (Swedish)'
NEL-TT-2700
National Engineering Lab. june 1975.

17. Anon.
'Cincinnati Milacron's Formula for FMS'
The FMS Magazine, January 1985, pp.11 - 14.

18. Anon.
'Atlas Copco Moves towards Full FMS'
Numerical Engineering, Feb. 1985, Reprinted by SMT Machine Company Ltd.

19. Anon.
'Turn, Mill, Drill Centres Come Alive at the NEC'
Machinery and Production Engineering, 2 March 1988, pp. 47- 49.

20. Anon.
'Full-scale FMSs Disappear, MAP Laser Technologies Growing'
Metalworking Engineering and Marketing, Jan. 1987, pp. 22-25.

21. Anon.
'Accepting Different Sorts of Materials under JIT System'
Metalworking Engineering and Marketing, March 1988, pp. 30-33.

22. Anon.
'Three Low-cost Simple FMSs'
Metalworking Engineering and Marketing, March 1988, pp. 26- 28.

23. Anon.
'Seeking Software Solution to Tool Management'
The FMS Magazine, Oct. 1988, pp. 203 - 206.

24. Anon.
'Closely Defined Controls Are Key to System Success'
The FMS Magazine, Oct. 1988, pp. 178 - 180.

25. Anon.
'Latest Mast Simulates Tool Life'
The Journal of Automated Production, March 1988, pp. 11.

26. Anon.
'Tooling Technology Enhances GT Set-up'
Machinery and Production Engineering, 1 January 1988, pp. 35.

27. Anon.
'Productivity from Tool Management Systems'
Engineers Digest, July/August 1985, pp. 23-25.

28. Anon.
'World First in Computerised Tool Management'
The Production Engineer, Feb. 1985, Vol. 64, No. 2.

29. Anon.
'FTL Update - Competition for Speed in Second'
Metalworking Engineering and Marketing, Sept. 1988, pp41-47.

30. Arnaud, O. and Bloche, E.
'Evaluation FMS by Simulation'
Proc. of the 5th Intl. Conf. on Flexible Manufacturing Systems, November 1986, pp. 513-530.

31. Astrop, A.
'£6 Million 'Model' Balancer Unit Line'
Machinery and production engineering, 15 Feb. 1984, pp31-33.

32. Astrop, A.
'Dedicated ... to Automation'
Machinery and Production Engineering, 2 March 1988, pp. 54-58.

33. Atkey, M.
'Only Computers Can Manage ..'
Machinery and Production Engineering, 1 January 1986, pp. 35 - 40.

34. Badir Beshara, S., Magazine, M. J.
'Myopic Heuristics for Single Machine Scheduling Problems'
Intl. Journal of Production Research, 1981, Vol. 19, No. 1, pp. 85-95.

35. Baker, K. R.
'Introduction to Sequencing and Scheduling'
John Wiley and Sons. 1974.

36. Bao, H.
'Application of Dynamic Programming to Optimise Tool Replacement Schedules for Multi-tool Operations Involving Distributed Tool Lives'
Transactions of the A.S.M.E., Vol. 102, July 1980, pp. 446- 451.

37. Bell, R. and De Souza, R. B. R.
'The Management of Tool Flows in Highly Automated Flexible Machining Installations'
Proc. of the 2nd Intl. Conf. on Comp. Aided Prodn. Engg., Edinburg, April 1987, pp.233 - 238.

38. Bell, R.
'Flexible Machining in the United Kingdom'
Paper for SOBRACON, S.P, Brazil, 1987.

39. Bell, R., Roberts, E. A., Shires, N. and Newman, S. T.
'A System for the Design and Evaluation of Highly Automated Batch Manufacturing Systems'
I.Mech.E. Publication, 1986, C367/86, pp. 85-93.

40. Ber, A. and Falkenburg, D. R.
'Tool Management for FMS'
Annals of the CIRP, Vol. 34/1/1985, pp387 - 390.

41. Bill, E.
'The Impact of Tooling in Flexible Manufacturing Systems'
CIM and ManuTch Conf. Proc., Seminar H, London, June 1986, pp. 9-27.

42. Billalis, N. G.
'Design and control of FMS for Rotational Parts'
Ph.D thesis, Loughborough University, 1983.

43. Borghi, L., Briano, M. and Parmeggiani, E.
'Management of the Tool Resource in an FMS'
Proc. of the 5th Intl. Conf. on Flexible Manufacturing Systems,
November 1986, pp. 477-490.

44. Bridgefoot, M.
'It Benefits for Machine Tool Manufacture'
Automation, Jan. 1989.

45. Brohan, P.
'Tool Management'
Tooling and Machining, June 1984, pp9-11.

46. Brohan, P.
'Tool Management for Flexible Manufacturing'
CIM and ManuTch Conf. Proc., Seminar H, London, June 1986, pp.1-7.

47. Butcher, M. C.
'Advanced Integrated Manufacturing System (AIMS) for Aero Engine Turbine and Compressor Discs'
Proc. of the 5th Intl. Conf. on Flexible Manufacturing Systems,
November 1986, pp. 93-104.

48. Butcher, M. C., Perkins, N. R., Wells, K. E., and Peto, M. G.
'An Advanced Integrated Manufacturing System for Turbine and Compressor Discs'
Proc. of Institution of Mechanical Engineers,
Vol. 201 No. B3, 1987, pp.129-135.

49. Carmo Silva, S.
'An Investigation into Tool Requirements and Strategies for FMS Operation'
Ph.d. Thesis, Loughborough University of Technology, 1988.

50. Carrie, A. S. and Petsopoulos, A. C.
'Operation Sequencing in a FMS'
Robotica (1985) Vol. 3, pp.259 - 264.

51. Carrie, A. S., Adhami, E., Stephens, A. and Murdoch, I. C.
'Introducing a Flexible Manufacturing System'
Intl. Journal of Production Research, 1984, Vol. 22, No. 6, pp.904 - 914.

52. Carrie, A. S.
'The Role of simulation in FMS'
Flexible Manufacturing Systems: Methods and Studies.
Elsevier Science Publishers B. V. (North-Holland) 1986 , pp. 191 - 208.

53. Carrie, A. S. and Perera, D. T. S.
'Work allocation in flexible manufacturing systems'
Inter. Conf. on Computer Aided Production Engineering
Edinburgh, April 1986, pp.91 - 95.

54. Carrie, A. S. and Perera, D. T. S.
'Work Scheduling in Flexible Manufacturing Systems under Tool Availability Constraints'
Production Research (National Conf., Nottingham, 1985), pp.11-20.

55. Carrie, A. S. and Adhami, E.
'Introducing an FMS by Simulation'
Proc. of the 2nd Intl. Conf. on Flexible Manufacturing Systems, London, Oct. 1983.

56. Carrie, A. S.
'Simulation of Manufacturing Systems'
John Wiley & Sons, 1988.

57. Castelli, A. and Olivieri, A.
'FERRARI FMS: Communication System Amongst Modules,SW Structure, Performance and Developments'
15th Intl. Symposium on Automative Technology and Automation at Flims, Swizerland, Oct. 1986, Paper No. 86068.

58. Cater, N.
'The Application of a Flexible Tooling System in a Flexible Manufacturing System'
Robotica 1985, Vol.3, pp.221-228.

59. Cederqvist, A.
'Cutting Tool Development for Automation and FMS'
Proc. of the 4th Intl. Conf. on Flexible Manufacturing Systems, Oct. 1985, Stockholm, Sweden, pp.167-178.

60. Chakravarty, A. K.
'Production Planning with Flexibilities in Capacity'
Proc. of the Second ORSA/TIMS Conf. on Flexible Manufacturing Systems: Operations Research Models and Applications, Amsterdam, 1986, pp.333 - 343.

61. Chakravarty, A. K. and Shtub, A.
'Capacity, Cost and Scheduling Analysis for a Multiproduct Flexible Manufacturing Cell'
Intl. Journal of Production Research, 1987, Vol. 25, No. 8, pp. 1143-1156.

62. Chan, T. S. and Pak, H. A.
'Modelling of a Controller for a Flexible Manufacturing Cell'
Intl. Trends in Manufacturing Technology Simulation
- Application in Manufacturing, 1986, pp. 105- 118.

63. Chang, Y. L., Sullivan, R. S., Bagchi, U. and Wilson, J. R.
'Experimental Investigation of Real-Time Scheduling in Flexible Manufacturing Systems'
Annals of Operations Research 3(1985), pp. 355-377.

64. The Charles Stark Draper Laboratory, inc.
'Flexible Manufacturing System Handbook'
NOYES Publications, Park Ridge, New Jersey, USA, 1984.

65. Cheng, E. T. C.
'A combined approach to due-date scheduling'
IFIP Working Conf., Bordeaux, France, 24-27 August 1982, pp295 - 306.

66. Choi, C. K.
'Tool Management in Advanced Batch Manufacturing of Rotational Parts - A Preliminary Study'
Msc. Thesis, Loughborough University of Technology, 1988.

67. Chung, C.
'Loading flexible manufacturing systems: A heuristic approach'
Proc. of the 8th Annual Conf. on Computers and Industrial Engineering.
Computers and Industrial Engineering, Vol. 11, No. 1-4, 1986, pp. 246-250.

68. Co. H., Wu, A., and Reisman, A.
'A Throughput-Maximising Facility Planning and Layout Model'
Intl. Journal of Production Research, 1989, Vol. 27, No. 1, pp. 1-12.

69. Conway, R. W., Maxwell, W. L. and Miller, L. W.
'Theory of Scheduling'
Addison - Wesley Publishing Company. 1967.

70. Crite, G., Mills, R. and Talavage, J.
'PATHSIM - A Modular Simulation for Automated Tool Handling System Evaluation in FMS'
Journal of Manufacturing Systems, Vol. 4, No. 1, pp. 15-28.

71. Crookall, J. R., and Jamil, A. T. M.
'An Analysis of of Automatic Tool-changing Systems for Numerical Control'
Proc. of the 3rd Production development and Manufacturing Technology Conf.
University of Strathclyde, Sep. 1973, pp12.1-12.26.

72. Crookall, J. R., and Jamil, A. T. M.
'The Machining-centre Concept, An Analysis of a Tool-changing Manufacturing System'
Proc. of the 15th Intl. Machine Tool Design and Research Conf., Birmingham, Sept. 1974, pp.89-96.

73. Crookall, J. R., and Jamil, A. T. M.
'On the Optimal Performance of NC Positioning and Tool Changing Systems'
Annals of the CIRP, Vol. 25/1/1976, pp.407-412.

74. Cuppan, B. C.
Tool Management Concerns for Machine Tool Cells and FMS'
Cutting Tool Engineering, Vol. 39, No. 3, June 1987.

75. Daoud, Z. AL. and Purcheck, G. F. K.
'Multi-tool job sequencing for tool-change reduction'
Intl. Journal of Production Research, 1981, Vol. 19, No. 4, pp.425 - 435.

76. Das, D. and Dowsland, W. B.
'A model to examine the effect of loading conditions on scheduling rules in a job shop environments'
Intl. Journal of Production Research, 1981, Vol. 19, No. 5, pp.577 - 587.

77. De souza, R. B. R.
'The Management of Tool Flow in Highly Automated Batch Manufacturing Systems'
Ph.D Thesis, Loughborough University of Technology, 1988.

78. Denzler, D. R. and Boe, W. J.
'Experimental investigation of flexible manufacturing system scheduling decision rules'
Intl. Journal of Production Research, 1987, Vol. 25, No. 7, pp.979-994.

79. Dormehl, E.
'Two-Spindle Simultaneously Turning in one Load'
Industrial & Production Engineering, 10 (1986) 3, pp. 103 - 107.

80. Douglas, D. E. and Johnston, R.
'A Network Model Using the Micro Simulation Language SIMAN'
Proc. of the 8th Annual Conf. on Computers and Industrial Engineering.
Computers and Industrial Engineering, Vol. 11, No. 1-4, 1986, pp. 377 - 381.

81. Doulgeri, Z., Hibberd, R. D. and Husband, T. M.
'The scheduling of flexible manufacturing systems'
Annals of the CIRP, Vol.36/1/1987, pp.343-346.

82. Dupont-Gatelmand, C.
'A Survey of Flexible Manufacturing Systems'
Journal of Manufacturing Systems, 1982, pp. 1-15.

83. Economic Commission for Europe
'Recent Trends in Flexible Manufacturing'
United Nations Publication, Sales No. E.85.II.E.35, 1986.

84. Egalini, P. and Ferrari, A.
'Ferrari Auto: An FMS of the Latest Generation Designed to Resolve the Machining Problems of One of the Most Sophisticated Car Industries'
Proc. of the 4th Intl. Conf. on Flexible Manufacturing Systems, Oct. 1985, Stockholm, Sweden, pp.107 - 123.

85. El-Gomayel, J. and Nader, V.
'Optimisation of Machine Set-up and Tooling Using the Principles of Group Technology'
Computing and Industrial Engineering, Vol. 7, No. 3, 1983, pp. 187-198.

86. El-Maraghy, H.
'Automated Tool Management in Flexible Manufacturing'
Journal of Manufacturing Systems, Vol. 4, No. 1.

87. English, A. C. and Kochhar, A. K.
'Evaluation of Capacity Planning and Practical Scheduling Algorithms in Machine Tool Manufacturing Systems'
Proc. of the 24th Intl. Machine Tool Design and Research Conf.,Manchester, 1983, pp399 - 405.

88. Erschler, J., Leveque, D. and Roubellat, F.
'Periodic Loading of Flexible Manufacturing Systems'
IFIP Working Conf., Bordeaux, France, 24-27 August 1982, pp.327 - 339.

89. Eversheim, W., Jacobs, S. and Wienand, L.
'Structure and Application of a Universal Company - Independent Data Bank for Tools'
Annals of the CIRP Vol.36/1/1987, pp. 321-325.

90. Fellers, G.
'Use of GPSS/PC to Establish Manning Levels of a Proposed Just-In-Time Production Facility'

Proc. of the 8th Annual Conf. on Computers and Industrial Engineering.
Computers and Industrial Engineering, Vol. 11, No. 1-4, 1986, pp. 382 - 384.

91. Fingberg, W.
'Advanced Tool Management Systems'
Manufacturing Technology Intl., Europe 1987, pp. 149-150.

92. Ganiyusufoglu, O. S.
'Building Automated Machine Cells - A Step by Step Approach'
Flexible Manufacturing for Small to Medium Enterprises - A European Conf., June 1988, Dublin.

93. Gouldings, M.
'British Aerospace: Small Machined Parts: Flexible Manufacturing System: A Case Study'
Proc. of the 4th Intl. Conf. on Flexible Manufacturing Systems, Oct. 1985, Stockholm, Sweden, pp.257 - 267.

94. Gouldings, M.
'Communication for CIM - a User View'
British Aerospace Publication, Preston.

95. Graham, R.L., Lawler, E.L., Lenstra, J.K., and Rinnooy Kan, A.H.G.
'Optimization and Approximation in Deterministic Sequencing and Scheduling: A Survey'
Annals of Discrete Mathematics, 5(1979), pp.287-326.

96. Green, G. C.
'Presetting Systems for Tool Management'
Presented at Section 1C: Tool Management Systems,
National Machine Tool Builder's Association,
2nd Biennial Intl. Machine Tool Technical Conf.
September 1984, Chicago, pp. 1_143 - 1_155.

97. Griffin, R. and Warby, A. H.
'Choosing and Using a Simulation System'
Intl. Trends in Manufacturing Technology Simulation
- Application in Manufacturing, 1986, pp.261-270.

98. Grunwald, H., Striekwold, P. E. T., and Weeda, P. J.
'A Framework for Quantitative Comparison of Production Control Concept'
Intl. Journal of Production Research, 1989, Vol. 27, No. 2, pp. 281-292.

99. Gupta, J.N.D., and Dudek, R.A.
'Optimality Criteria for Flowshop Schedules'
AIIE Transactions, September 1971, pp.199 - 205.

100. Hammer, H.
'Flexible Manufacturing Cells and Systems with computer Intelligence'
Proc. of the 5th Intl. Conf. on Flexible Manufacturing Systems, November 1986, pp.145 - 158.

101. Hankins, S. L.
'The Impact of Tooling in Flexible Manufacturing Systems'
2nd Biennial Intl. Machine Tool Technical Conf.
September 1984, Chicago, pp.1_176 - 1_198.

102. Hannam, R. G.
'Computer Assisted Tooling Control for FMS'
Session 9A, Computer Aided Engineering, Proc. of SERC/ACME Research Conf., 1988, Nottingham University, pp. 1-4.

103. Hartley, J.
'FMS AT WORK'
IFS(Publications) Ltd., UK, North-Holland, 1984.

104. Hartley, J.
'Mammoth FMS'
The FMS Magazine, Oct. 1983, pp277-281.

105. Hartley, J.
'Fanuc Combines Machining and Assembly in FMS'
The FMS Magazine, July 1983, pp. 246 - 249.

106. Haxby, C.
'Developments in Flexible Turning'
The FMS Magazine, April 1987, Vol. 5, No. 2, pp. 90-92.

107. Henderson, M. J.
'Economical Computer Integrated Manufacturing'
Proc. of the 5th Intl. Conf. on Flexible Manufacturing Systems, November 1986, pp167-178.

108. Herrington, G.
'Tool Management Starts in the Tool Store'
Manufacturing Technology Intl., Europe, 1987, pp. 122-126.

109. Hitomi, K., Nakajima, M. and Osaka, Y.
'Analysis of the Flow Type Manufacturing Systems Using the Cyclic Queuing Theory'
Transactions of the ASME, Vol. 100, Nov. 1978, pp468 - 474.

110. Hollingum, J.
'Learning and Growing: Five Years with SCAMP'
The FMS Magazine, July 1987, pp133-137.

111. Hollingum, J.
'STC Beats Bottlenecks by Optimising Its Technology'
The FMS Magazine, Oct. 1988, pp. 189-190.

112. Hong, L. K.
'A Simulation System for Heuristic Scheduling of Jobs through a Flexible Machining System with Automated Tool Control'
Msc. Thesis, Cranfield Institute of Technology, 1984.

113. Hull, G. M.
'Advances in Manufacturing Technology I (Machining Centres)'
Numerical Engineering, July 1984, pp. 22 - 23.

114. Hurrion, R. D.
'Visual Interactive Modelling'

Intl. Trends in Manufacturing Technology Simulation - Application in Manufacturing, 1986, pp. 3-13.

115. Hwang, S.
'A Constraint-Directed Method to Solve the Part Selection Problem in Flexible Manufacturing systems Planning Stage'
Proc. of the Second ORSA/TIMS Conf. on Flexible Manufacturing Systems: Operations Research Models and Applications, Amsterdam, 1986, pp.297 - 309.

116. Ingersoll Engineers.
'Integrated Manufacture'
IFS(Publications) Ltd., UK,Spirnger-Verlag Berlin Heidelberg , 1985.

117. Iwata, K., Murotsu, Y., Oba, F., and Uemura, T.
'Optimisation of Selection of Machine Tools, Loading Sequence of Parts and Machining Conditions in Job-shop Type Manufacturing Systems'
Annals of the CIRP, Vol. 27/1/1978, pp. 447-451.

118. Iwata, K., Murotsu, Y., and Oba, F.
'Solution of Large-scale Scheduling Problems for Job-shop Type Machining Systems with Alternative Machine Tools'
Annals of the CIRP, Vol. 29/1/1980, pp. 335-338.

119. Iwata, K., Murotsu, Y., Oba, F., and Yasuda, K.
'Simulation for Design and operation of Manufacturing Systems'
Annals of the CIRP, Vol. 33/1/1984.

120. Iwata, K.
'Production Scheduling of FMS'
Annals of the CIRP, Vol. 31/1/1982.

121. Johnson, S.M.
'Optimal Two and Three-Stage Production Schedules with Setup Times Included'
Naval Research Logistics Quarterly, Vol. 1, No. 1, 1954.

122. Kay, J. M.
'Tooling for FMS - Can Simulation Help'

Proc. of the 1st Intl. Conf. on Simulation in Manufacturing, March 1985, pp195 - 204.

123. Kellock, B.
'Satisfying the Needs of an FMS'
Machinery and Production Engineering, 1 January, 1986, pp. 44-48.

124. Kimemia, J. and Gershwin, S. B.
'Flow Optimisation in Flexible Manufacturing Systems'
Intl. Journal of Production Research,1985, Vol. 23, No. 1, pp. 81-96.

125. Kiran, A. S. and Krason, R. J.
'Automating Tooling in a Flexible Manufacturing System'
Industrial Engineering, April 1988, pp. 52 -57.

126. Knight, M. A. and Spurgeon, D.
'Optimizing Tooling for CNC Turning'
Proc. of the 23rd Intl. Machine Tool Design and Research Conf., pp125-131.

127. Knight, J. A. G., Lebrecht, H. M.
'Tool Control and distribution and workholding Requirements in Flexible Manufacture'
Proc. of the 2nd Joint Polytech. Symposium on Manufacturing Engineering, Coventry, June 1979, pp.14-24.

128. Kochan, A.
'Holset Takes Bold but Unorthodox Approach'
The FMS Magazine, July 1986, pp133-135.

129. Kochan, A.
'Will Yamazaki's Estern Promise Be Fulfilled?'
The FMS Magazine, July 1987, pp123-125.

130. Kochan, A.
'Completion in Sight for Yamazaki's UK Factory'
The FMS Magazine, July 1986, pp137-138.

131. Kordysh, L. M.
'A Method for Determining the Time of Automatic Change of Tools and Workpieces'
Soviet Engineering Research, Vol. 7, No. 3, pp. 48-50.

132. Kusiak, A.
'Flexible Manufacturing Systems: A Structural Approach'
Intl. Journal of Production Research, 1985, Vol. 23, No. 6, pp1057-1073.

133. Kusiak, A.
'Scheduling Flexible Machining and Assembly Systems'
Proc. of the Second ORSA/TIMS Conf. on Flexible Manufacturing Systems: Operations Research Models and Applications, Amsterdam, 1986, pp.521 - 532.

134. Kusiak, A.
'FMS Scheduling: A Crucial Element in an Expert System Control Structure'
Proc. of the IEEE Conf. on Robotics and Automation, 1986, pp. 653-658.

135. Kusiak, A.
'Application of Operational Research Models and Techniques in Flexible Manufacturing Systems'
European Journal of Operational Research 24(1986), pp. 336- 345.

136. Kusiak, A.
'Grouping Problems in Scheduling Flexible Manufacturing Systems'
Robotica (1985), Vol. 3, pp. 245-252.

137. Lewis, L. and Pegels, H.
'Multiflex - A Tool Change System for Improved Efficiency on Lathe Operations'
Presented at Section 11A: Modern Tooling Concepts
2nd Biennial Intl. Machine Tool Technical Conf.
September 1984, Chicago, pp. 11.29 - 11.54.

138. Maimon, O. Z. and Choong, Y. F.
'Dynamic Routing in Reentrant FMS'
Proc. of the Second ORSA/TIMS Conf. on Flexible Manufacturing Systems: Operations Research Models and Applications, Amsterdam, 1986, pp. 467-475.

139. Mamalis, A. G., Billalis, N. G., and Konstantinidis, M. J.
'Analysis of Tool Flow System Requirements for an FMS'
Proc. of the 26th Intl. Machine Tool Design and Research Conf., Sep. 1986, pp.191 - 198.

MANUFACTURERS' LITERATURE

140. Anon.
'Boehringer VDF Machine Tools, Made in Germany'
Boehringer Werkzeugmaschinen GmbH, Document No.:245/e/1.88.

141. Anon.
'Boehringer VDF CA-Series Flexible Production Turning Cells'
Boehringer Werkzeugmaschinen GmbH, Document No.:244/e/10.87.

142. Jenson, R. L.
'Current Trends in Integrated and Flexible Turning Systems'
Oerlikon Machines.

143. Anon.
'What Is It That Makes VDF NC Turning Machines from Oerlikon-Boehringer Even Better ?'
Oerlikon Machines, Oerlikon-Boehringer GmbH.

144. Anon.
'Acramatic 8500MC Machining Centre'
Cincinnatati Milacron, Lebanon, Ohio 45036, Publication No. CTL-467.

145. Clementson, A. T.
E.C.S.L (Extended Control and Simulation Language)
User's Manual
CLE Com. Ltd., 8 Stanley Road, Birmingham, B14 7NB, UK.

146. Anon. 'B35, BX35 CNC Turning Machine'
DAINICHI KINZOKU KOGYO Co., Ltd.

147. Anon.
'B40M, BX40M CNC Mill-Turning Centre'
DAINICHI KINZOKU KOGYO Co., Ltd.

148. Anon.
'B82 CNC Turning Machine'
DAINICHI KINZOKU KOGYO Co., Ltd.

149. Anon.
'The Devlieg Tool Management System'
Devlieg Machine Company, Devlieg Microbore
Tooling System Division, Fair Street, Royal Oak, M1 U.S.A.

150 . Anon.
'Manufacturing Simulation and Control'
Hawker Siddeley Group Plc., Chippenham, U.K.

151 . Anon.
'Manufacturing Cell FS 300'
Maschinenfabrik Heid Aktiengesellschaft, Austria, Document No.: W839e/0388.

152. Anon.
'Multi-DNC Software Description'
Gebr. HELLER Maschinenfabrik GmbH D-744- Nurtingen.

153. Anon.
'Check-mate Your Costs by Higher Productivity'
HEYLIGENSTAEDT & COMP. Werkzeugmaschinenfabrik GmbH
Document No.: 666e 20000486(VI).

154. Anon.
'HERTEL-FTS (Flexible Tooling System)'
Document No. 1050 GB, Hertel Intl..

155. Anon.
'Flexible Tooling System - HEYLIGENSTAEDT HEYNUMAT 21 U-4000'
Kat./Cat. 7M06D/GB, Hertel Intl..

156. Anon.
'Hertel Flexible Tooling System'
Katalog 7011-D, Hertel Intl..

157. Anon.
'Flexible Compact System for Turning, Drilling and Milling
- Flexible Tooling System'
HEINEMAAN Kat./Cat. 7M01 D/GB, Hertel Intl..

158. Anon.
'INDEX GS 65, INDEX GSC 65 mit, Y-Achse'
INDEX - Werbe KG,Hahn and Tessky, D-7300 Esslingen/N
LL2000, 4006-311.0985.50DM.

159. Anon.
'INDEX GS42S-65-100; INDEX GSC42S-65-100 with INDEX Y-axis'
INDEX-Verkaufs-GmbH, LL2000.4010-354e.0987.30HF.

160. Anon.
'CNC Universal Turret Automatics - INDEX GE42 - GE65'
INDEX-Verkaufs-GmbH, LG 7000.4046-241e0987.20ME.

161. Anon.
'INDEX GU610 - CNC Automatic Lathe of Latest Design'
INDEX-Verkaufs-GmbH, LG 6000.4015-264e 1084.10HF

162. Anon.
'INDEX - A Complete Range of Automatic Lathes'
INDEX-Verkaufs-GmbH, LY000.4.212-330e0287.10sE.

163. Anon.
'ISIS ToolWare'
ISIS Information Ltd, 8 Croft Road, Godalming. Surry, GU7 1BY, UK.

164. Herrington, G.
'Tool Management Starts in the Tool Stores'
ISIS Information Ltd, 8 Croft Road, Godalming. Surry, GU7 1BY, UK.

165. Anon.
'Kennametal KV Tooling'
Kennametal Inc. Latrobe, PA 15650, U.S.A, NT 86-4(11) E6. 1986

166. Anon.
'Krupp Widia - Tool Engineering'
Document No.1589/19, Krupp Widia UK Ltd, High Wycombe, Bucks., U.K.

167. Anon.
'WIDAX ROTAFLEX Tool System'
Krupp Widia UK Ltd., W 2.3-99.0 e1082.

168. Anon.
'KTM Machining Cells and Systems'
KTM Ltd., Brighton, U.K.

169. Anon.
'General Description of Makino 'MAX' Flexible Manufacturing System'
Makino Milling Machine Co., Ltd., 13/July/1984.

170. Anon.
'MMC - The Makino Machining Complex' Makino Milling Machine Co., Ltd., M249aE 8612 1(3P-F).

171. Anon.
'Module MMC - Powerful Support for CIM and Unmanned Operation'
Makino Milling Machine Co., Ltd., M254aE 8710 1(3P-F).

172. Anon.
'Churchill Two Series'
Matrix Churchill Ltd. Coventry, England.

173. Anon.
'Churchill Three Series'
Matrix Churchill Ltd. Coventry, England.

174. Anon.
'Churchill HC 4/15, HC 5/35 and HC 5/45 CNC Turning Centres'
Matrix Churchill Ltd., Coventry, England. LPS/1.5M/6.86/U.K.

175. Anon.
'Power Driven Tooling'
MHP MACHINES LTD., Gloucester, U.K.

176. Anon.
'AL-2 CNC Lathe'
MORI SEIKI CO., LTD., Japan, Document No.: BAEA28610F05.

177. Anon.
'TMC15 CNC Turning Centre'
NAKAMURA-TOME PRECISION INDUSTRY Co., Ltd., Japan
Cat No. B-1121AE/022705.

178. Anon.
'TMC20 CNC Turning Centre'
NAKAMURA-TOME PRECISION INDUSTRY Co., Ltd., Japan
Cat No. B-112240E/03-86.05.

179. Anon.
'Efficient Workshop Scheduling - MOSES a computer Bar Chart for Better Workshop Control'
National Engineering Lab., DTI, U.K.

180. Anon.
'The Modular Design of Handling Systems'
Norgren Martonair Ltd., Linchfield, U.K.

181. Anon.
'ACT-5 CNC Lathe'
OKUMA and HOWA Machinery Ltd., 1111 Maeno, Konan, Aichi 483, Japan
Publication No. ACT5-81-8.

182. Anon.
'Recent NC Lathe and Advanced Technology
- Flexible machining cells and sophisticated peripherals to support unattended operations - Information No. 1289-Lathe.'
OKUMA Machinery Works Ltd., Japan. 8509,100-500.

183. Anon.
'News Notes', Vl. 3, No. 2, March 1987.
OKUMA Machinery Works Ltd., Japan.

184. Anon.
SAME/AGVS User's Manual.

185. Anon.
'Still in the Dark About Probing'
Renishaw Metrology Ltd., Wotton-under-Edge, U.K.
Document No.H/2000/3041, 1988.

186. Anon.
'The Turret Revolution'
Sandvik Coromant, C-1040:005-ENG/1, 1985.

187. Anon.
'The Block Tool Story'
Sandvik Coromant. C-6700:002 ENG 1985.

188. Anon.
'Block Tool System'
Sandvik Coromant. C-1004:1-ENG. 85.08.

189. Anon.
'Block Tool System - Rotating magazine holders for Block Tool Cutting Units, Size BT25, 32, 40 and 50'
Sandvik Coromant. C-100:121-ENG 1985.

190. Anon.
'Block Tool system - Disc Magazines for Block Tool Cutting Units'

Sandvik Coromant. C-1000:122-ENG. 1985.

191. Anon.
'Block Tool System - Rotating Block Tools'
Sandvik Coromant. 342-BTS:001-ENG. 1985.

192. Anon.
'Block Tool System - Read/Write Coding for BT Cutting Units'
Sandvik Coromant. C-1004:101-ENG. 1986.

193. Anon.
'GRAFSIM 20-32 How to Design and Control Your Flexible Manufacturing System'
Siemens Aktiengesellschaft, W. Germany.

194. Anon.
'Flexible Manufacturing Systems - The Modern Response to New Production Requirements - FMS 20-32'
Siemens Aktiengesellschaft, W. Germany.

195. Anon.
'Swedturn'
SMT Machine Company AB.
Box 800, S-72122 Vasteras, Sweden, Document No. 8606,3000.

196. Anon.
'Sweturn 6'
SMT Machine Company AB.
Box 800, S-72122 Vasteras, Sweden, Document No. 8607.2000 kentab.

197. Anon.
'SMT CPC (Computerised Part Changer)'
SMT Machine Company AB.
Box 800, S-72122 Vasteras, Sweden, Document No. 87.05 1000.

198. Anon.
'Flexible Automation - Examples of Manufacturing Cells'

KW-Nr.: 84.559/1
TRAUB GmbH, D-7313 Reichenbach/Fils, P.O. Box 1180 W-Germany.

199. Anon.
'Workpiece Examples: TNS60 + FHS1, TI 31/03.88; TNS60 + FHS1, TI 36/03.88'
TRAUB GmbH, 1988.

200. Anon.
'TNS30 Series: Machining Examples'
TRAUB GmbH, Kw-Nr.: 02.87-576/0, 1987.

201. Anon.
'The Target: Flexible Automation;
The Realisation' TRAUB GmbH.

202. Anon.
'The UK Single Source for Complete Mill-Turning'
TRAUB GmbH, Traub UK No. 143-6/86-5K.

203. Hekeler, M.
'Complete Machining on CNC Turning Centres Using Driven Tools'
TRAUB GmbH.

204. Sonnek, W. and HaBlauer, H.
'Bar loading Magazines for CNC Turning Machines'
Special reprint from TZ for metal-working production 6/83.
TRAUB GmbH.
Translated from the German by J. H. Hayes.
Hayes Engineering Services. GB WD3 3JZ.

205. Von Zeppelin, W. and Klauss, W.
'Availability increased by direct diagnosis on CNC machines'
TRAUB GmbH.

206. Von Zeppelin, W.
'Technical Information Link-up of an NC Machine Tool into Computer-assisted

Plant Organization'
TRAUB GmbH.

207. Hammer, H. and Viehweger, B.
'QTC Quick tool Change - A New Method for Fast and Selective Tool Changes in Machining Centres'
Werner und Kolb Werkzeugmaschinen GmbH, Berlin.

208. Anon.
'Control Station WERNER SCI for the Computer Control Workpiece and Tool Supply at Machining Centres and Flexible Manufacturing Systems'
Werner und Kolb Werkzeugmaschinen GmbH, Berlin.

209. Anon.
'Manufacturing Program - Compact and Flexible'
Werner und Kolb Werkzeugmaschinen GmbH, Berlin.
Publication No.: 1685E/N 3000 9/86.

210. Anon.
'Wickman 52/200 5-Axis CNC Lathe'
Wickman Bennett Machine Tool Company Ltd., Coventry, U.K.

211. Anon.
'Mazak European Factory'
Mazak Machine Tools, Yamazaki Machinery UK ltd.

212. Anon.
'Machine Tools'
State of the Art Technology
Yamazaki Mazak Corporation, 1987, M.T. 87.1.20,000.

213. Anon.
'QSH - 10 - Simultaneous 4-axis CNC Lathe'
Yamazaki Mazak Corporation, QSH - 10, 85.8.7500.

214. Anon.
'Quick Slant 20N 4-axis Chucker and Universal '

State of the Art Technology - MAZAK
Yamazaki Mazak Corporation, QS - 20N 86.3.7500.

215. Anon.
'Slant Turn 40N ATC - Mill Centre'
State of the Art Technology - MAZAK
Yamazaki Mazak Corporation, ST-40N ATC M/C 86.1.20,000.

216. Anon.
'MAZAK CAM-CNC System: MAZATROL CAM T-2; MAZATROL CAM T-3'
Yamazaki Mazak Corporation, CAM T-2, T-3, 86.1 15,000.

217. Anon.
'QUICK TURN 35 CHUCKER and UNIVERSAL'
Yamazaki Mazak Corporation, QT-35. 86.8.30.000.

218. Anon.
'Slant Turn 25&30 ATC Mill Centre'
Yamazaki Mazak Corporation, ST25.30 ATC M/C 86.1.20.000.

219. Anon.
'Quick Turn 8SP'
State of the Art Technology - Mazak
Yamazaki Mazak Corporation, QT-8SP 86.8.30.000.

220. Anon.
'State of the Art Technology - Mazak'
Yamazaki Mazak Corporation, MAZATECH-s 88.2 15000 R-1, 1988.

221. Anon.
'Mazatrol FMS'
Yamazaki Mazak Corporation, M-FMS 87.1.5000, 1987.

End of Manufacturers' Literature

222. Mason, G.
'Turning the Tables on Second Operation Work ...'

Machinery and Production Engineering, 4 January 1984, pp20 - 25.

223. McQueen, L. B.
Loughborough University of Technology, Private Communication, 1989.

224. Meister, A. E.
'Tooling in the CIM Environment'
Conf. Proc. Numerical Control Society, 1984, pp361 - 365.

225. Mills, R. L.
'Computer Simulation - A Feasibility and Planning Tool for FMS'
Intl. Trends in Manufacturing Technology Simulation - Application in Manufacturing, 1986, pp. 35-49.

226. Mojka, A.
'Optimal Design of Flexible Manufacturing Systems Using Simula'
Proc. of the XIV Simula User Conf. Stockholm, August 1986, pp. 37-46.

227. Moore, J. M.
'An n Job, One Machine Sequencing Algorithm for Minimizing the Late Jobs'
Management Science, Vol. 15, No. 1, September, 1968, pp.102 -109.

228. Nakamura, N. and Shingu, T.
'Scheduling of Flexible Manufacturing Systems'
Proc. of the 8th Intl. Conf. on the Production Res. and 5th Working Conf. of the Fraunhefer-Institute for the Industrial Engineering, Stuttgart, August 1985, pp. 147- 152.

229. Newman, S. T.
'An Integrated Approach to the Design and Evaluation of Flexible Machining Cells'
Ph.D Thesis, Loughborough University of Technology, 1989.

230. Nordstrom, C.
'The Complete Turning Cell for FMS'
Proc. of the 1st National Machine Tool Conf.,June 1984, Birmingham, pp.415 - 428.

231. O'Grady, P. J. and Harrison, C.
'A general search sequencing rule for job shop sequencing'
Intl. Journal of Production Research,1985, Vol. 23, No. 5, pp961 - 973.

232. O'Grady, P. J. and Menon, U.
'Loading a Flexible Manufacturing System'
Intl. Journal of Production Research, 1987, Vol. 25, No. 7, pp. 1053-1068.

233. Osabe, S.
'FMS Age and Cutting Tool Technologies'
Metalworking Engineering and Marketing, March 1984, pp40 - 44.

234. Papagiorcopulo, G. J.
'A Computer Simulation for Heuristic Scheduling and Management Control of Tools in a Flexible Manufacturing System'
Msc. Thesis, Cranfield Institute of Technology, Sep. 1984.

235. Pegden, C. D.
'Introduction to SIMAN'
System Modelling Co., State College, PA.

236. Perera, D. T. S. and Carrie, A. S.
'Simulation of Tool Flow within a Flexible Manufacturing System'
Proc. of the 6th Intl. Conf. on Flexible Manufacturing Systems, November 1987, pp. 211-222.

237. Perera, D. T. S.
'Solving Production Planning Problems of FMS with Computer Simulation'
Proc. of the 4th Conf. on Simulation in Manufacturing, Nov. 1988, pp. 127-135.

238. Perera, D. T. S. and Carrie, A. S.
'A Simulation Tool for Real Time Scheduling of FMS'
Advances in Manufacturing Technology , pp. 133-137.

239. Perera, D. T. S. '
The Development of Operational Strategies for an FMS Using Graphical Animation'

Advances in Manufacturing Technology, pp. 210-216.

240. Plute, M.
'Computerized Control Systems for the Tool Crib'
Modern Machine Shop, Feb. 1984, pp.50-58.

241. Pourbabai, B.
'Scheduling models for combining and splitting lots'
Production Management: Methods and Studies
Elsevier Science Publishers B. V. (North-Holland), 1986, pp113 - 122.

242. Pourbabai, B.
'An Operation Model for Automated Batch Manufacturing Systems'
Symposium on Information Control Problems in Manufacturing Technology, Yerevan USSR, 1986, pp. 117-121.

243. Pourbabai, B.
'A Production Planning and Scheduling Model for Flexible Manufacturing'
Proc. of the Second ORSA/TIMS Conf. on Flexible Manufacturing Systems: Operations Research Models and Applications, Amsterdam, 1986, pp. 533-543.

244. Purdom, P.B. and Palazzo, T.
'The CITROEN (CCM) Flexible Manufacturing Cell'
Proc. of the 1st Intl. Conf. on Flexible Manufacturing Systems, Brighton, U.K., Oct. 1982, pp151 - 169.

245. Pylkkanen, J.
'Tool Management System of an FMS of Prismatic Workpieces'
Proc. of the 5th Intl. Conf. on Flexible Manufacturing Systems, November 1986, pp265 - 274.

246. Rabinovich, N. G.
'Tool Assurance System for an Automated Flexible Section'
Soviet Engineering Research, Vol. 7, No. 3, pp. 51-52.

247. Radharamanan, R.
'A Heuristic Algorithm for Group Scheduling'
Proc. of the 8th Annual Conf. on Computers and Industrial Engineering.

Computers and Industrial Engineering, Vol. 11, No. 1-4, 1986, pp. 204-208.

248. Rajagopalan, S.
'Formulation and Heuristic Solutions for Parts Grouping and Tool Loading in Flexible Manufacturing Systems'
Proc. of the Second ORSA/TIMS Conf. on Flexible Manufacturing Systems: Operations Research Models and Applications, Amsterdam, 1986, pp. 311-320.

249. Raman, N., Talbot, F. B. and Rachamadugu, R. V.
'Simultaneous Scheduling of Machines and Material Handling Devices in Automated Manufacturing'
Proc. of the Second ORSA/TIMS Conf. on Flexible Manufacturing Systems: Operations Research Models and Applications, Amsterdam, 1986, pp. 455-465.

250. Ranky, P.
'Computer Integrated Manufacturing - An Introduction with Case Studies'
Prentice/Hall Intl..

251. Ranky, P. G.
'The Design and Application of Computer Integrated Manufacturing (CIM) Software'
Proc. of the 25th Intl. Machine Tool Design and Research Conf., Birmingham, 1985, pp.97-106.

252. Ranky, P.G.
'Integrated Software for Designing and Analysing FMS'
Proc. of the 3rd Intl. Conf. on Flexible Manufacturing Systems,Boeblingen, West Germany, Oct. 1983, pp.361-378.

253. Ranky, P. G.
'FMS Software: Data Structures of Distributed FMS Data Base'
Proc. of the 23rd Intl. Machine Tool Design and Research Conf.,Manchester, Sept. 1982, pp459-466.

254. Ranky, P. G.
The Design and Operation of FMS - Flexible Manufacturing Systems
IFS (Publications) Ltd, UK. North-Holland Publishing Company

255. Ranky, P. G.
'A Generic Tool Management System Architecture for Flexible Manufacturing Systems (FMS)'
Robotica (1988), Vol. 6, pp. 221-234.

256. Rathmill, K.
'Trends in the Application of Computer Simulation'
The FMS Magazine' July 1987, Vol. 5, No. 3, pp. 150 - 152.

257. Rembold, U., Blume, C., and Dillmann, R.
'Computer -Integrated Manufacturing Technology Systems'
Marcell Dekker, inc, New York and Basel, 1985.

258. Roberts, E. and Shires, N.
'The Application of Multi-processing to Simulation'
Proc. of the 1st Intl. Conf. on Simulation in Manufacturing, England, March 1985, pp. 85-96.

259. Sackett, P. J. and Cooper, D. J.
'Flexible Manufacture through Tool Management in a High Variety Environment'
Proc. of the 3rd Intl. Conf. on Flexible Manufacturing Systems,West Germany, Sept. 1984, pp. 185 - 194.

260. Salt, T.
'Rolls-Royce Aims High'
The FMS Magazine, Oct. 1982, p10.

261. Sarin, S. C. and Chen, C. S.
'The machine loading and tool allocation in a flexible manufacturing system'
Intl. Journal of Production Research,1987, Vol. 25, No. 7, pp1081-1094.

262. Schmidt, J.
'Flexible Manufacturing System Applied in Volume Production'
Proc. of the 3rd Intl. Conf. on Flexible Manufacturing Systems, Boeblingen, West Germany, Oct. 1983, pp.133-142.

263. Schriber, T. J. and Stecke, K. E.
'Machine Utilisation and Production Rates Achieved by Using Balanced Aggregate FMS Production Rations in a Simulated Setting'
Proc. of the 2nd ORSA/TIMS, pp.405 - 416.

264. Scudder, G. D. and Hoffmann, T. R.
'Composite cost-based rules for priority scheduling in a random routed job shop'
Intl. Journal of Production Research, 1985, Vol. 23, No. 6, pp1185 - 1195.

265. Seeger, W.
'Integrated Sizing Control on Automatic CNC Turning Machine Ensures Product Accuracy'
Reprinted from 'MM Machinery Market'
Vogel-Verlag Wurzburg, Germany, 29 March, 1983.
Translated from the German by J. H. Hayes.
Hayes Engineering Services. GB WD3 3JZ.

266. Seidmann. A. and Tenenbaum, A.
'Optimal Stochastic Scheduling of Flexible Manufacturing Systems with Finite Buffers'
Proc. of the Second ORSA/TIMS Conf. on Flexible Manufacturing Systems: Operations Research Models and Applications, Amsterdam, 1986, pp. 487-298.

267. Seliger, G., Viehweger, B. and Wieneke, B.
'Decision Support for Planning Flexible Manufacturing Systems'
Intl. Trends in Manufacturing Technology Simulation - Application in Manufacturing, 1986, pp. 149-162.

268. Shanker, K. and Tzen, Y. J.
'A loading and dispatching problem in a random flexible manufacturing system'
Intl. Journal of Production Research,1985, Vol. 23, No. 3, pp579 - 595.

269. Shaw, M.
'A Pattern-Directed Approach to FMS Scheduling'
Proc. of the Second ORSA/TIMS Conf. on Flexible Manufacturing Systems: Operations Research Models and Applications, Amsterdam, 1986, pp. 546-551.

270. Sheppard, M. H
'Step by Step into FMS'
15th ISATA Symposium on Automative Technology and Automation,
Flims, Swizerland, 6-10 Oct. 1986, Paper No. 86067.

271. Shires, N.
'The Distributed Simulation of Highly Automated Batch Manufacturing Systems'
Ph.D Thesis, Loughborough University of Technology, 1988.

272. Sinha, R. K. and Holler, R. H.
'A Review of Production Control Problems in Cellular Manufacture'
Intl. Journal of Production Research, 1984, Vol. 22, No. 5, pp. 773-789.

273. Solberg, J. J.
'A Mathematical Model of CMS'
Proc. of the 4th Intl. Conf. on Production Research, Tokyo, 1977.

274. Stecke, K. E.
'Formulation and solution of nonlinear integer production planning problems of flexible manufacturing systems.
Management Science, 29(3), pp. 273-288, 1983.

275. Stecke, K .E. and Kim, I.
'A Flexible Approach to Implementing the Short-term FMS Planning Function'
Proc. of the Second ORSA/TIMS Conf. on Flexible Manufacturing Systems: Operations Research Models and Applications, Amsterdam, 1986, pp. 283 - 295.

276. Stecke, K. E. and Morin, T. L.
'The Optimality of Balancing Workload in Certain Types of Flexible Manufacturing Systems'
European Journal of Operational Research, 20(1985), pp. 68 - 82.

277. Stecke, K. E.
'Design, Planning, Scheduling, and Control Problems of Flexible Manufacturing Systems'
Annals of Operations Research, 3(1985), pp. 3-12.

278. Stecke, K. E. and Solberg, J. J.
'Loading and Control Policies for a Flexible Manufacturing Systems'
Intl. Journal of Production Research, 1981, Vol. 19, No. 5, pp. 481-490.

279. Steiner, S.
'Production Planning and Control - A Review'
Production Planning and Control for Flexible Manufacturing, Coventry, Nov. 1986, pp. 14-31.

280. Stephens, A. P.
'Tool Management Within a Flexible Manufacturing System'
Intl. Conf. on the Development of Flexible Automation Systems
London, July 1984, pp.73-79.

281. Suri, R.
'An Overview of Evaluative Models for Flexible Manufacturing Systems'
Annals of Operations Research, 3(1985), pp. 13-21.

282. Sutton, G. P.
'Flexible Machining Systems'
Business intelligence Program, Research Report 664, August 1982.

283. Tarsuslugil, M. and Bloor, J.
'The use of similarity coefficients and cluster analysis in production flow analysis'
Proc. of the 20th Intl. Machine Tool Design and Research Conf., Birmingham
Sept. 1979, pp525-531.

284. Thomas, D.
'Automatic Tool Changing'
Proc. of the 2nd Intl. Conf. on Flexible Manufacturing Systems, London, Oct. 1983, pp431-449.

285. Thorneycroft, M.
'Advances in Manufacturing Technology II (Turning Systems)'
Numerical Engineering, July 1984, pp24 - 25.

286. Thorneycroft, M.
'Further British Developments in Automated Turning Cells'
Proc. of the First National Machine Tool Conf.June 1984,
Birmingham, U.K., pp573 - 581.

287. Tiernan, T.
'How to Place a Very Tall Order - And to Win'
Computers & Manufacturing Technology, June 1986
Reprinted by KTM Ltd., Brighton, U.K.

288. Timiryazev, V. A.
'Computer-Based System for Determining Cutting Tool State and Optimum Tool Change Rules'
Soviet Engineering Research, Vol. 5, No. 6, pp. 31-32.

289. Tomek, P.
'Tooling Strategies Related to FMS Management'
The FMS Magazine, April 1986, pp102-107.

290. Tomek, P.
'Tooling Concepts for FMS'
Proc. of the 5th Intl. Conf. on Flexible Manufacturing Systems, November 1986, pp315-326.

291. Tomek, P. and Zeleny, J.
'Machining Technology in Flexible Manufacturing Systems for Prismatic Parts with Automated Flow of Tools'
Proc. of the 2nd Intl. Conf. on Flexible Manufacturing Systems, London, pp.57-68.

292. Tonshoff, H. K. and Balbach, J.
'Increasing Economy by Re-organization the Field of Cutting Tools in Computer Aided Design, Planning And Manufacturing'
Proc. of the 23rd Intl. Machine Tool Design and Research Conf.,Manchester, Sept. 1982, pp429-436.

293. Tonshoff, H.K, Freist, C., Granow, R. and Bussmann, J.
'Use of the Cluster-analysis for Developing a Flexible Manufacturing System for Rotational Parts'
Proc. of the 23rd Intl. Machine Tool Design and Research Conf.,Manchester, Sept. 1982, pp.467 - 474.

294. Trajkovski, S.
'Automatic Tool Changes for NC Machining Centres'
Toward the Factory of the Future, Proc. of the 8th Intl. Conf. on the Production Research and the 5th Working conference of the
Fraunhofer Institute for Industrial Engineering (FHG-IAO), 20-22 August 1985, pp.95-100.

295. Valcada, A. and Aicardi, M.
'Comparison of Different Computerised Design Tools for FlexibleManufacturing'
Proc. of the 3rd Intl. Conf. on Flexible Manufacturing Systems,
Boeblingen, West Germany, Oct. 1983, pp.387-395.

296. Vil'son. A. L. and Samkharadze, G. V.
'Calculation of the Required Number of Tools (Replacement) for Multi-Tool Machining under Unmanned Operation'
Soviet Engineering Research, Vol. 5, No. 4, pp. 11-14.

297. Vil'son, A. L. and Samkharadze, G. V.
'Establishing the Requisite Level of Tool Duplication'
Soviet Engineering Research, Vol. 7, No. 3, pp. 33-34.

298. Vlasenkov, A. V.
'Optimization of Tool Location in a Machining Centre Magazine'
Soviet Engineering Research, Vol. 4, No. 1, pp. 61-63.

299. Voevodin, V. M. and Cherpakov, B. I.
'Flexible Automatic Lines (Classification, Principles of Construction)'
Soviet Engineering Research, Vol. 5, No. 10, pp. 44-48.

300. Von Zeppelin, W.
'In Stage Towards a Flexible Turning Cell'
Traub GmbH, Paper Given to the 19th NES Annual Technical Conf.:

Advances in Numerical Engineering, Wembly, May 1985,
Translated from the German by J. H. Hayes.
Hayes Engineering Services. GB WD3 3JZ.

301. Von Zeppelin, W. and Ganiyusufoglu, O, S.
'Developments Towards CIM by a Machine Tool Builder'
Robotics & Computer Integrated Manufacturing,
Vol. 3, No. 1, pp. 63 - 76, 1987.

302. Wang, W.
'A Knowledge Based Modelling System for the Design and Evaluation of Flexible Manufacturing Facilities'
Ph.D Thesis, Loughborough University of Technology, 1989.

303. Wang, W., Newman, S. T., and Bell, R.
'A Knowledge Based Multi-Level Approach to the Design of Flexible Machining Facilities Using Artificial Intelligence Techniques'
The 4th Intl. Conf. on Metal Cutting, Non- Conventional Machining and Their Automations, Beijing, China, April 1989.

304. Warnecke, H. J., Steinhilper, R. and Zeh, K. P.
'Simulation as an Integral Part of FMS Planning'
Intl. Trends in Manufacturing Technology Simulation - Application in Manufacturing, 1986, pp. 131-147.

305. Wassweiler, W. R.
'Tool Requirements Planning'
American Production and Inventory Control Society
1982 Conf. Proc., pp160 - 163.

306. Waterlow, G.
'Development and Application of Simulation Techniques'
Notes for ACME Directorate Research Portfolio, Nov. 1988.

307. Webb, S.
'User Project Management for Holset FMS'
Proc. of the 5th Intl. Conf. on Flexible Manufacturing Systems, November 1986,

pp135-144.

308. Weimer, G. A.
'Automatic Tool Selection Still Unfulfilled Promise'
Iron Age, 25 Nov. 1983, pp98-105.

309. West. J.
'Increasing NC Machine Tool Productivity through Improved Cutting Tool Management and Control'
NC/CAM - The New Industrial Revolution
Proc. of the 13rd Annual Meeting and Technical Conf. of the Numerical Control, Mar. 1976, Cincinnati, Ohio, pp363-370.

310. Whitney, C. K. and Gaul, T. S.
'Sequential Decision Procedures for Batching and Balancing in FMSs'
Annals of Operations Research, 3(1985), pp. 301-316.

311. Wilkerson, L. J., Irwin, J. D.
'An Improved Method for Scheduling Independent Tasks'
AIIE Transactions, September 1971, pp239-245.

312. Wilkins, A.
'SCAMP Comes on Modules'
The FMS Magazine, Oct. 1982, pp32-34.

313. Worrall, B. M.
' Job shop scheduling under resource constraints and varying order priorities'
Proc. of the 8th Annual Conf. on Computers and Industrial Engineering.
Computers and Industrial Engineering, Vol. 11, No 1-4, 1986, pp199 - 203.

314. Worsley, R.
'SCAMP FMS Goes on Show'
Metal working Production, Feb. 1983, pp56-59.

318. Worsley, R.
'Flexibility through Modular Design'
Metalworking Production, Sept. 1985

Reprinted by SMT Machine Company Ltd.

319. Yamamoto, M. and Nof, S. Y.
'Scheduling/Rescheduling in the Manufacturing Operating System Environment'
Intl. Journal of Production Research, 1985, Vol. 23, No. 4, pp. 705-722.

320. Yamazaki, K.
'The Forecast for Unmanned Factory Networking'
Metalworking Engineering and Marketing, March 1988, pp. 42- 47.

321. Young, A. R. and Murry, J.
'Performance and Evaluation of FMS'
Managing Advanced Manufacturing Technology,
Proc. of the UK Operations Management Association Conf., University of Warwick, Coventry,UK,January, 1986, pp291-301.

322. Yuan, Z. J., Cai, L. J., and Zhang, P.
'A New Type of Three-component Dynamometer with High Stiffness and High Natural Frequency'
Proc. of the 26th Intl. Machine Tool Design and Research Conf., Manchester, Sept. 1986.

323. Zeleny, J.
'Unmanned Technology and Control Strategies in Flexible Manufacturing Systems with Random Flow of Parts and Tools'
Annals of the CIRP, Vol. 34/1/1985, pp391 - 395.

324. Zhang, P. and Bell, R.
'Tool Management for Highly Automated Turning Systems'
The 3rd Intl. Conf. on Metal Cutting, Non- Conventional Machining and Their Automations, Nanking, China, April 1987.

325. Zhang, P., De Souza, R. B. R., and Bell, R.
'Tool Management for Highly Automated Turning Systems'
The 4th Intl. Conf. on Metal Cutting, Non- Conventional Machining and Their Automations, Beijing, China, April 1989.