TITLE A SYSTEMS APPROACH TO THE CONTROL OF CUTTING TOOLS WITHIN A LARGE-SCALE MANUFACTURING ENVIRONMENT

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A SYSTEMS APPROACH TO THE CONTROL OF CUTTING TOOLS WITHIN A LARGE-SCALE MANUFACTURING ENVIRONMENT

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My gratitude must also go to my wife Christine for her enduring patience and support, and to my children Victoria and Rebecca.

<u>THESIS DEDICATION</u>

To the memory of my Father.

MAJOR 'JIMMY' SUMMERFIELD

SYNOPSIS

The control of cutting tools within a large-scale manufacturing environment has been studied and a routing through a 'linked' tool control system designed and implemented.

Previous contributions in the field of cutting tool control have focused upon a number of specialist areas, and these can be divided into three broad categories:-

(a) At the point of application upon individual machine tools.

(b) The tool planning element within Process Planning systems.

(c) Tool material supply systems.

However, in terms of viewing the problem of tool control from a Manufacturing Systems perspective, i.e. the study of the 'whole' system, then this particular subject area has been neglected.

A claim to originality is made with respect to the contents of this thesis which consider the interactive nature of the essential control disciplines inherent in (a), (b) and (c) and these are then linked together within a single tool control system framework.

Applying this linked systems approach to one tooling family (indexable inserts) within a factory embracing jobbing, batch and flow line production systems resulted in the achievement of a package of economic benefits which included significant reductions in related inventory levels, expenditure, labour content, and through improvements in the utilisation and output of selected machine tools.

LIST OF ABBREVIATIONS

CAD	Computer Aided Design
CAM	Computer Aided Manufacture
NEB	National Enterprise Board
ATOMS	Automated Tool Management System
IMPS	Iterative Machine Parameter Selection
LINCS	Linked Inventory Control System
ARCLASS	Austin Rover Classification System
£m	£ Million
LMC	Light Medium Cars
PSF	Pressed Steel Fisher
P & MC	Production and Material Control
BLSL	British Leyland Systems Limited
£K	£ Thousand
NC	Numerical Control
PERA	Production Engineering Research Association
CNC	Computer Numerical Control
CAPPS	Computer Aided Process Planning System
APT	Automatically Programmed Tools
BS	British Standards
ISO	International Standards Organisation
ASM	American Society of Metals
CAE	Computer Aided Engineering
DOS	Disk Operating System
CMC	Computer Machinery Company

INTRODUCTION

In an ever-increasingly competitive world the need for a more efficient manufacturing sector within the national economy becomes of paramount importance. Economic recession and its impact on market shares encourages management to pursue rigorous short-term measures when faced with threats to business survival. Such measures impact upon all areas of the business activity and may range from aggressive marketing and purchasing policies to equally aggressive measures to achieve maximum utilisation from all existing resources which include employees as well as facilities. Such activities have been shown to generate considerable improvements in operational efficiency and can be seen to be long overdue, removing the shackles of many years of custom and practice within companies.

To maintain such improvements in business efficiency and generate confidence in medium-term viability will require the implementation of a package of measures underpinned by increased investment in new technology. However, it is important to recognise that such technology in itself is not a panacea, and criticism of under-utilisation of resources so frequently levelled in the 1970's could well be just as applicable in the 1980's unless management is educated to realise the true potential of their technological investment. Certainly thought processes and decision-making based on 'systems' concepts will play a major role in future business strategies.

Demands for a more visionary approach to management are not new, and the great milestones with respect to the traditional metal removal industries are undoubtedly the work of F W Taylor and M E Merchant.

In the first quarter of this century Taylor presented a totally new concept in management with the introduction of the far-reaching concepts embraced under the general heading of the 'Principles of Scientific Management'. Much of Taylor's management philosophy centred around a systematic approach to problem-solving utilising many analytical 'tools' in the process. In terms of metal removal his efforts to improve the efficiency at the cutting tool/workpiece interface were revolutionary and involved the study of many areas of manufacturing activity including such aspects as material supply systems, work measurement, tool classification and coding systems, and the introduction, with White in 1908, of High Speed Steel cutting tool materials.

Since the pioneering days of Taylor, metal removal practice and theory has attracted continuous attention although progress in many direct and indirectly related fields has not necessarily been in harmony. Centres of excellence have developed in specialist fields encouraging a narrow level of focus which can be to the detriment of understanding the interactive nature of related systems.

Another major step forward in offering a new level of vision to manufacturing management and related academic research came in the early 1960's with the work of Merchant [1] 1961, who recognsied the potential applications of systems theory within the manufacturing environment and this, combined with the advent of micro-chip based technologies, opened up new horizons in understanding the control mechanisms required to gain greater productivity at the cutting edge. This interrelated web of systems theory and general manufacturing technological advancement is providing greater momentum towards the optimisation of manufacturing systems and the conceptual ideals of the fully automated factory, a subject area with which Merchant's name has now become synonymous.

While Merchant offered direction in terms of studying the manufacturing system as a 'whole' other subsequent work has developed a more comprehensive understanding of the various sub-systems within the manufacturing system and their interactive nature. Of particular interest to the research work contained in this thesis is the study of one specific sub-system and that is the cutting tool control system.

The need for optimisation of this particular sub-system can vary from industry to industry. For example, where metal removal costs comprise only a small percentage of the total product cost then management control efforts may be directed elsewhere. However, in industries typified by motor vehicle manufacture, where significant economic investment in capital and/or manpower is made in the metal removal activity within the manufacturing process, then the control over the economics of tooling becomes critically important.

An awareness of the need for a more systematic approach to tool control has developed over the last fifteen years in the areas of CAD/CAM, although this tends to concentrate on batch production, utilising a limited number of cutting tools in the derivatives of relatively new numerically controlled machine tools. Transferring the philosophies of a systems approach to tool control within a large-scale manufacturing environment, where production processes can range from jobbing to flow line on dedicated manufacturing facilities comprising of predominantly conventional machine tools whose age span may vary from 0 - 50 years, with an average of 20 years, has been neglected in terms of academic research.

Such an environment is typified by the Power and Transmission manufacturing facility covered by the Birmingham Operations group of factories to be found within the Light Medium Cars Group of BL Limited which have been the focal point of this research.

In common with many other companies there has been a willingness to recognise the need for gaining control and effecting improvements to the manufacturing cost base, albeit management effort has been concentrated upon the control of direct costs (and understandably so, as this is the area of greatest short-term, visible, efficiency gains). In general, activity in the control of consumable items (i.e. non product-related) has attracted less activity at a Corporate level. Contributory factors to this lack of activity include:-

(a) A stream of Company structure organisational changes which have resulted in numerous changes in operational responsibility for the individual factories presently under the umbrella of 'Birmingham Operations' have discouraged any attempts to gain control over tooling related areas, allowing individual plants the freedom to pursue their own approaches to tool control. This situation has achieved limited functional/departmental requirements which often ignore the impact on other departments and result in the utilisation of dated cutting technology, duplication of effort particularly in the storage and maintenance of data, and poorly controlled inventory levels. This general lack of of control encourages custom and practice and results in general system abuse, both internally (by employees) and externally (by tool suppliers).

(b) A basic lack of awareness by management of the true potential of implementing a tool control system which initially questions, and then imposes necessary disciplines on all functions/activities involved in tool decision-making.

The financial problems encountered by BL Limited in the mid-1970's are now well documented enough to say that there was a dramatic deterioration in the Company's trading position with injection of large amounts of Government aid to ensure continuity of the mainstream business activity. In the NEB's submission to the Government in December, 1979 of the Company's performance and the 1980 Corporate Plan and Budget [2], the reduction of inventory levels and improvements in manufacturing productivity, both of which had significant implications with respect to cutting tools, were seen as essential to BL Limited's future survival and viability.

Following the NEB's submission, a comprehensive package of measures was implemented in order to achieve these Corporate objectives, and amongst them was the initiation of the research activity described in this thesis. Of major concern at the time was that the consumable tooling and related inventory for Birmingham Operations was estimated to be in excess of £7 million and only 'turning over' by value, i.e. £ inventory/£ annual expenditure, once every fifteen months.

Against this background the writer was given the opportunity to review in greater depth the problems being encountered in the control of metal removal tools within Birmingham Operations, and encouraged to initiate investigations. The content of this thesis is the direct result of that invitation and describes in detail the design, development and implementation of a routing through a 'linked' system which controls the application and supply of new cutting tools. The system was designed on the principle that tool control must begin with technological control at the point of application, thereafter, supportive tool material supply systems were developed. The system as described was implemented in one factory and, at the initiative of senior management within the Light Medium Cars Group of BL Limited, is to be expanded into three other factories.

From the onset the broad philosophies offered by Taylor (systematic approach to problem-solving) and Merchant (concepts of studying production systems as a 'whole'), have been adopted and the ability to analyse problems utilising varying levels of focus has proved invaluable; combining this approach with the communications potential offered by present-day low cost microprocessors, established the platform on which the tool control system to be described, was built.

Initial research work moved away from the highly sensitive problem of excessive tool inventories and concentrated on the tooling problems being encountered on a small bank of machine tools within a single machine shop working on the premise that the input requirements of the manufacturing system dictated the service required from supporting systems. This level of focus quickly identified two fundamental problems with respect to cutting tools, and these were:-

(a) The absence of any Company-wide tooling technology 'standards' encouraging personnel such as setters, foremen, process engineers, etc., to make personal decisions on the implementation of cutting tool type and machine tool operating conditions.

(b) The complete absence of tool material supply systems utilising flow control principles to service the needs of critical high component volume machine tools. Existing systems were seen to be extremely limited stock control systems which were either manually or partially computer system based.

Later work was to reveal many other tooling related problems, but at this early stage of research these two significant problems were apparent, namely the control and update of cutting technology and the physical supply of the tool material to the individual machine tool. Wishing to understand the interactive nature of the problem in greater depth the level of focus was changed to cover the, as then, three locations encompassed by Birmingham Operations, i.e. Longbridge, Drews Lane and Coventry Engine Plants, with a fourth factory, Triumph Radford Plant joining the Group during 1980. At this level it quickly became apparent that the problems encountered, typified by the absence of machining standards, ineffective multiple tool classification systems, inadequate inventory control systems, etc., were common to all locations and research effort was being diluted by the spread of geographical activity. For this reason the research activity concentrated upon one location only, namely Coventry Engine Plant, which by virtue of the mixed nature of its manufacturing activity was considered to be a reasonable reflection of the operational environment to be found elsewhere within Birmingham Operations. In principle the objective was to establish a tool control system routing at a single Plant, prove the benefits, and subsequently expand the system locally and establish the capability of transferring the control mechanisms to other manufacturing locations as an operational Company 'standard' system.

The main body of the following thesis describes the research work programme at Coventry Engine Plant, from the initial system design concept through to the implementation of the full system routing and its resulting economic benefits. The system principle is to optimise tool control at the factory level and to achieve this objective the span of control activity ranges from ensuring the correct technological application at the level of individual machine tools through to rigid procurement disciplines, resulting in the external tool suppliers actually being considered to be an integral part of the overall system. The total system is known as ATOMS, an acronym for Automated Tool Management System and was initially designed to establish control over high volume, fast moving tools, typified by indexible inserts as in the case of this thesis, but potentially including such tooling families as twist drills, reamers, taps, dies, grinding wheels. The system was designed on a modular basis to facilitate progressive in-house expansion as well as geographic expansion. In addition, vision has been given to the potential integration of the system into broader based CAD/CAM systems.

ATOMS comprises two main sub-systems and these are:

(a) IMPS (Iterative Machine Parameter Selection), which is a semi-generative system for establishing technological control and up-date of the machining parameters at the level of the individual process operation.

(b) LINCS (Linked Inventory Control System), which is a component-volume related tool material supply system utilising the principles of flow control.

The essential link between the two sections is a significant character classification and coding system known as ARCLASS (Austin Rover Classification System).

The IMPS sub-system is considered to be at the heart of the overall tool control system (ATOMS) and having established control at the point of application within the manufacturing system, establishing similar levels of control within the tool material supply systems became considerably easier. In principle IMPS generates the individual operation process standard which includes the tool material type/geometry required and machining parameters at which it is to be operated, ARCLASS provides the mechanisms for establishing the tool type families that are available for consideration by the Process Planner and LINCS ensures the supply of the chosen cutting tool to the manufacturing system and subsequently monitors the variance from the established tool standard performance, hence the terminology of 'linked systems'.

The first routing through ATOMS was established for indexable inserts with selected areas of the system, notably the inventory control section, being expanded to cover other tooling families during the period of research.

CHAPTER ONE

1.0 COMPANY PROFILE

BL Limited at home and overseas is engaged in the automotive industry, providing an extensive range of vehicles, from private cars to heavy commercial trucks and buses. It also supplies automotive, industrial and marine engines, carburettors, axles and transmission units to other manufacturers. The Company plays a strategic role in the economy of the UK with an annual turnover of £2,869 million (1981), 30% of which was exported to some 170 countries, and employs 94,000 people within the UK with a further 23,000 employed overseas.

1.1 BL LIMITED - AN HISTORICAL PERSPECTIVE

Although elements of the Company can be traced back to 1890 in the form of the Lancashire Steam Company (which became Leyland Motors in 1907) and the formation of the Standard Motor Company in 1903, the modern-day structure has evolved from the merger between Leyland and British Motor Holdings in 1968. The new Company, the British Leyland Motor Corporation (BLMC) brought together many of the famous names from the history of motor manufacture; from the Leyland wing, Rover, Alvis, Standard Triumph, AEC, Scammell and Albion and from BMH, Austin, Morris, MG, Riley, Wolsley, Jaguar, Daimler and Guy.

This rather unsteady alliance came together during a period of rapid change and uncertainty, which included such factors as:-

(a) Expansion decisions taken during the boom years of the 1950's and early 1960's by the traditional motor vehicle manufacturers in the UK and the USA which resulted in over-capacity and declining profitability.

(b) The restructuring of the European and Japanese motor vehicle industry had taken place which offered a potential threat to existing markets.

(c) The early 1970's saw a cut-back in the economic growth amongst the industrialised nations, sparked off by the accelerating cost of oil relative to other goods. This heralded the beginning of an economic recession in 1973 and the demand for vehicles world-wide dropped dramatically.

This sets the business environment in which the newly formed BLMC had to operate, and despite a profit before tax of £68 million in 1973/74, a loss was reported for the first half of the 1974 financial year of £16 million. During the ensuing months BLMC's financial position continued to deteriorate, overdraft limits had been reached and major investment programmes cancelled. As a result of the pending crisis a Government enquiry was initiated to investigate the Company's affairs and was led by Sir Donald Ryder. The 'Ryder Report' was published in April 1975 [3] and the main recommendations covering a ten-year forward plan included:-

(a) The need for substantial Government investment.

(b) Restructuring of the Company with a particular emphasis on the centralisation of key functions.

(c) Rationalisation of the product range.

As a result of Ryder, the business interests of BLMC were vested in a new Holding Company, BL Limited, in which a majority shareholding was transferred to the NEB in February, 1976 and then transferred back to the Secretary of State for Industry in March, 1981.

The foundations established by Ryder and the subsequent arrival of Sir Michael Edwardes in 1978 set the scene for significant changes to the structure and direction of the Company. A summary of the main areas of activity is as follows.

1.2 COMPANY STRUCTURE

Reference to Figure 1 will show that the BL Company structure as at April, 1981 was sub-divided into four distinct business groups:

(a) Unipart

(b) Cars

(c) Land Rover

(d) Leyland (Trucks and Buses)

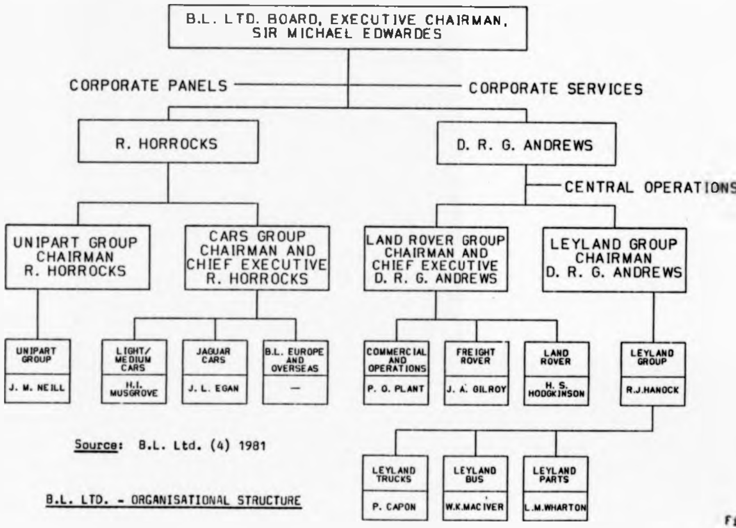
1.3 TRADING POSITION OF BL LIMITED

Reference to Figure 2 details the BL Limited Profit and Loss Account 1980-81 revealing a static sales figures for the consecutive years, but with a marginal reduction in trading loss, i.e. from £293.9 to £244.6 millions. Reference to Figure 3 shows a two-year trading summary, and although not totally clear from the figures, the majority of the loss burden as identified in the Profit and Loss Account rests with the Cars Operations.

As with many other companies significant external factors impacted on the Company's trading position, and include:-

(a) The strength of sterling combined with high interest and inflation rates.

(b) The sharp fall in world-wide demand for cars and vehicles in general.



<u>Source</u>: B.L. Ltd. (4) 1981

<u>B.L. LTD. - ORGANISATIONAL STRUCTURE</u>

Figure 1

	Year ended December 31	
	1980	1981
Sales	2,877.1	2,868.7
Trading Loss	293.9	244.6
Interest Payable Less Interest Receivable	93.6	88.3
Loss before Taxation	387.5	332.9
Taxation Charges	3.2	6.3
Loss after Taxation	390.7	339.2
Minority share of Profits of Subsidiaries	5.8	5.8
Loss before Extraordinary items	396.5	345.0
Extraordinary items	139.0	152.0
Loss after Extraordinary items	535.5	497.0

N.B. Figures in £ Millions

<u>Source</u>: B.L. Ltd. (4) 1981

<u>B.L. LTD. - PROFIT AND LOSS ACCOUNT 1980-81</u>

Figure 2

YEAR	CARS/ UNIPART		LAND ROVER		LEYLAND	
	Sales £M	Profit £M	Sales £M	Profit £M	Sales £M	Profit £M
1980	1,769	L283*	452	27	629	L30
1981	1,849	L168*	438	17	666	L74

YEAR	OTHER ACTIVITIES		INTRA GROUP SALES	TOTAL	
	Sales £M	Profit £M	Sales £M	Sales £M	Profit £M
1980	247	1	220	2,877	L285*
1981	164	L8	248	2,869	L233*

* Identifies that the majority of the loss burden was attributable to the cars operations

<u>Source</u>: Extel Statistical Services (5) 1982

B.L. LTD. - ANALYSIS OF SALES AND PROFIT BEFORE TAX

Figure 3

In addition, the high level of imported vehicles into the UK market, as shown in Figure 4, has obviously had a significant impact on the Company's trading position.

Clearly the Cars Group operates in an extremely competitive business environment and continual emphasis on greater productivity, cost containment, and efficient manufacturing witnessed considerable operational improvements during 1980/81 and these include:-

(a) A 30% reduction in manpower during 1980

(b) A 35% reduction in inventory levels

(c) The ratio of cars produced per employee per year, rose from 10 to 14

1.4 LIGHT MEDIUM CARS GROUP

The subsidiaries of the LMC Group are:

(a) Austin Morris which provided the locations for the research activity contained in this thesis.

(b) Rover Triumph

(c) Pressed Steel Fisher (PSF)

(d) Parts of BL Components

1.4.1 Product Range

In line with the recommendations of the Ryder Report the Company is rationalising its range of vehicles with the objective of offering a product range which by the mid-1980's will revolve around the derivative of three basic families of cars, two from the LMC Group and one from Jaguar. These are as follows:-

	1980 ACTUAL	1981 ESTIMATED	1982 FORECAST	% CHANGE 82/83
Total New Registrations	1,513,761	1,460,000	1,500,000	2.7
Domestic	655,442	650,000	675,000	3.8
% of Total	43.3	44.5	45	0.5
Imported	858,319	810,000	825,000	1.9
% of Total	56.7	55.5	55	-0.5

Estimated B.L. % of New Registrations - 17-20%

Source: E.I.U. Forecasts (6)

FORECAST OF NEW REGISTRATIONS
OF PASSENGER CARS IN THE U.K.

Figure 4

(a) Metro based at Longbridge.

(b) LM10, which is a new 'light medium' car family with an engine range of 1600 to 2000 c.c. to be assembled at Cowley. The potential derivatives include:-

(i) LM10, hatch back

(ii) LM11, booted version of the LM10

(iii) LM12, possibly a fastback produced under the Rover marque.

(c) The third car family will be a re-styled Jaguar range, code named XJ40, which will be far lighter in weight than the existing range and consistent with world-wide trends towards energy conservation.

Collaboration with other manufacturers is increasingly playing a more prominent role in new product development and examples include:-

(a) The Triumph Acclaim, a 1300 c.c. saloon car currently being assembled at Cowley, is the result of a joint venture between BL Limited and Honda (Japan). The car involved a £70 million investment by BL Limited and was launched in October, 1981.

(b) During 1982 a second major concept study was agreed in collaboration with Honda to design, develop and manufacture a new range of executive cars, code named project X-X. Production of the new vehicle is due in 1985.

(c) In March, 1981 the LMC Group signed a component purchasing agreement with Vokswagen for the supply of VW gearboxes for certain models in the LM10 range.

1.4.2 Birmingham Operations

The Light Medium Cars Group is divided into three broad areas of operational responsibility and these are as follows:-

(a) Midlands and North - comprising the Rover (Solihull) and Triumph (Liverpool, Speke) factories.

(b) Southern region - which embraces the Body Plant at Swindon and Vehicle Assembly at Cowley.

(c) Birmingham Operations - which covers the Power Train and Vehicle Assembly at Longbridge and the additional Power Train facilities at Drews Lane (Birmingham), Coventry Engine Plant, and Triumph Radford (Coventry).

The initial project work was centred at Coventry Engine Plant and, subsequently, at the Company's initiative the tool control system developed is currently being implemented into the remaining three factories comprising Birmingham Operations. Unfortunately, at the time of writing the closure of the Coventry Engine Plant was announced, and as with other locations such as Rover (Solihull) and Triumph (Liverpool) the closures are due for completion by year end 1982.

1.4.3 <u>Coventry Engine Plant</u>

A brief profile of Coventry Engine Plant taken at the commencement of the research work during 1979 was as follows:-

- Built during the 1930's and formally opened in 1938.

- Plant capability to produce a mix of 4,000 motor vehicles, industrial and marine engines per week.

- Self-contained facility embracing a foundry, machine shops and engine/gearbox assembly groups.

- 2,500 employees.

- 39,000 standard hours generated per week.

- 2,280 components are contained in the machining register, being classified into current (live), spares and non-current spares.

- 4,130 machine tools ranging from jobbing machines to 'in-line' transfer machines. Reference to Appendix (A) details the age profile of the machine tools.

- 16,000 varieties of cutting tools and related accessories, i.e. toolholder, clamps, shims etc., are held in stock with an inventory value in excess of £900K.

- 52 different component material specifications in a variety of material forms and metallurgical process conditions are machined. 36 of these specifications are ferrous based and represent the main part of the machining activity.

CHAPTER TWO

2.0 COMPANY APPROACH TO TOOL CONTROL

The requirement to gain control over the supply and application of cutting tools is obviously not a new phenomenon within the individual Plants now comprising 'Birmingham Operations' and the following Chapter summarises historical and present-day management contributions within this specific area of activity.

2.1 AN HISTORICAL PERSPECTIVE

Clearly the two names that are at the historical heart of Birmingham Operations are Herbert Austin (Longbridge) and William Morris (Coventry Engine Plant). As the bulk of the project research activity was concentrated at Coventry Engine Plant (formerly Morris Motors) it is appropriate that this historical review begins with William Morris.

Early history of the Morris concern commenced with the building of cycles and motor-cycles in a garage in Long Wall, Oxford, and with the profits accumulated the foundations of Morris Motors were established. By 1921 the Company was producing 400 vehicles per week and although during the war years normal activities ceased, in common with most engineering establishments facilities being utilised for the production of war materials, the immediate post war years saw a gradual return to normality and increase in vehicle production. By 1912 volumes had increased to 1000 cars per week and to 1200 per week by 1924, at which stage Morris Motors was responsible for more than one-third of the total volume of motor cars produced annually in the United Kingdom.

From these early days William Morris pursued a policy of decentralised manufacture and from 1923 Morris Motors' Power Train activity has been centred at Coventry. The initial operational activity began with the purchase of the Hotchkiss Engines factory which, with further expansion, housed all the manufacturing facilities needed to meet the accelerating demand for power train units. Despite this acquisition further expansion plans emerged, and in 1928 the 45 acre site of the present-day Coventry Engine Plant was acquired. During the following years a purpose-designed factory was built on the site at a cost of £2,000,000 offering three times the floor space of the Hotchkiss factory and a production capability of up to 4000 units per week. From 1938 onwards the new Morris Engines Plant became the main supplier of the engines and gearboxes for Morris Motors Limited.

An interesting insight into William Morris' philosophies regarding the engineering requirement to meet the upsurge in demand and at the same time control costs is seen in the following quotes [7]:-

(a) "A question naturally arises by which process has such meteroric progress been possible? To this there can be only one reply, and that is by an appreciation of - and an aptitude on the part of the management to apply - a very advanced policy of standardisation."

(b) "The most conspicuous economics are in respect of the number of machine tools and employees used in the construction of each unit and the most important item is the reduction of employees."

To achieve the aspirations of (a) and (b), William Morris introduced a Production Planning Standards Manual in 1925 entitled 'Morris Production Methods' which deployed many of the analytical techniques embraced in Taylor's "Scientific Approach to Management" [7], 1925.

Although the standards concentrated predominantly upon machine tool design, reference is made to the use of standard stock tooling which were mounted on quick change tool blocks. Similarly, simple guidelines are given in terms of cutting speeds and feeds.

The manual clearly shows the importance given to machine tool design during the period and the innovation in installing some of the earliest metal working 'in-line' transfer machines in 1924 for the machining of flywheels and gearbox cases.

Conversation with personnel employed at Morris Motors during the late 1920's and 1930's, reveals that the foremen and chargehands had the greatest influence on actually determining machining parameters and the process planning departments concentrated more on machine tool/jig and tool design and 'rate fixing'. This theme of machining from experience rather than by the adoption of machining standards has remained to this day.

A positive approach was made by the Austin Motor Company during the immediate pre and post World War II years with the introduction of 'Austin Tooling Standards'. These standards are the most comprehensive tooling standards to be found in the present-day Company and were aimed at introducing a standard range of small metal removal tools into the Austin Morris factories and were part of a series of general engineering standards covering machine tool, jig and tool design, component material specifications, etc. However, in common with the earlier 'Morris' standards they neglected machinability data.

The formation of the BMC in November, 1951 with the union between Nuffield (Morris) and Austin, brought together two Companies built on strong engineering traditions and raised the now common problem of bringing together various sets of engineering standards under one umbrella. BMC rose to the challenge by developing a series of parts standards which cross-referenced those of Morris and Austin, but these did not include a revision of the Austin tooling standards.

Advancement in machine tool technology continued with the introduction of the first standardised unit head transfer line for the Austin A40 in the early 1950's. This period also saw BMC building their own machine tools.

As the BMC standards evolved during the late 1950's they appeared to be directed more towards vehicle assembly and less towards metal removal technology. The absence of up-to-date tooling standards and associated machinability data continued with process planning engineers being allowed a great deal of autonomy in the setting of machining parameters.

The merger between Leyland Motor Vehicles and British Motor Holdings (which became known as the British Motor Corporation - BMC) in 1968 amplified the problems, in terms of tooling standards and control, of the Austin/Morris merger in 1951 by the bringing together of a large number of Companies with differing standards and coding systems.

The development and subsequent maintenance of Company-wide engineering standards has continued, but in the manufacturing arena are heavily biased towards industrial engineering and vehicle assembly. Present-day tooling standards date back to 1978 and act only as a general guideline to preferred suppliers.

This neglect of machinability and tooling standards over many years within the Power Train Divisions has resulted in a fragmented approach to tool control encouraging numerous individual departments to become involved in influencing tooling related decisions. The net result of this erosion of process planning based control, namely wide-ranging tool varieties being held in stock and in use in the machine shops combined with inadequate coding and stock control systems, is discussed in the following sub-sections.

2.2 Present Levels of Control

Senior management within the Company were aware for some time of the lack of adequate tool control systems, but the business requirement to gain a greater level of control over direct materials has assumed a greater managerial priority. To understand their concern it is necessary to take an overview of the tooling activity within Birmingham Operations and this can be shown by an analysis of the tooling related inventories at a point in time and the annual expenditure for the same commodity groups for factories involved.

This analysis is as follows:-

	Inventory Jan. 1982 (£ million)	Annual Expenditure 1981 (£ million)
Longbridge	4.9	3.53
Drews Lane	0.75	0.85
Coventry Radford	0.10	0.09
Coventry Engines	0.68*	0.81*
	6.43	5.28

NB: Figures achieved after the implementation of the system routing as described in this thesis.

Observations within Chapter Nine will show that in the case of Coventry Engine Plant the inventory movement by total value was minimal over a twelve-month period and based on this a similar assumption has been made, with justification, for the three remaining factories within Birmingham Operations. Therefore, from this it is possible to gain a simple, global, indicator of the present levels of control by establishing an inventory/expenditure ratio for Birmingham Operations as follows:-

$$\frac{6.43}{5.28} = 1.22$$

which shows that there is in excess of fourteen months (1.22 x 12) of tooling inventory by value held in stock at any one point in time. Realistically, this should not exceed three to four months if average internal and external lead times for tool procurement are to be taken as a guide.

From this simple analysis no individual Plant has established an acceptable level of control and an insight into existing practices may help to understand why.

From a Birmingham Operations' viewpoint the following items are common to all four Plants:-

(a) Company machinability standards do not exist.

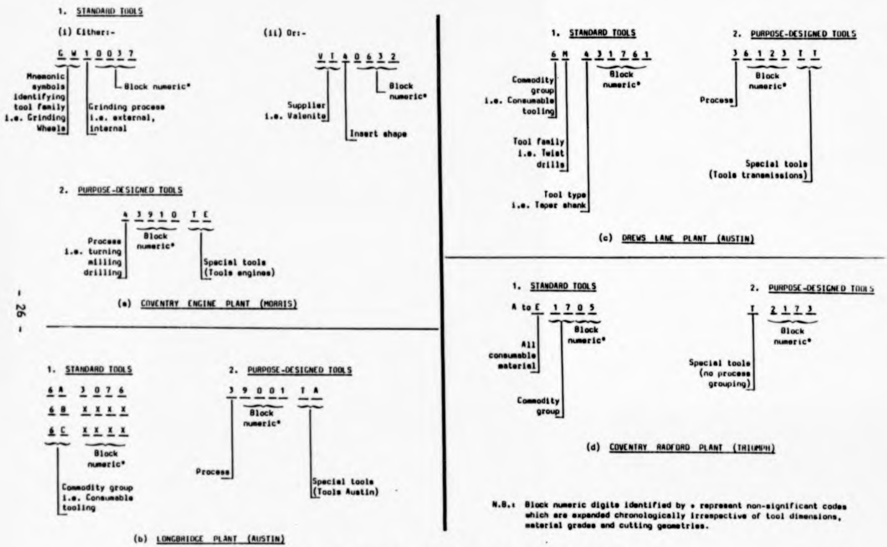
(b) Only very limited Austin tooling standards are in use which are based on the cutting tool materials and metal removal technology of the 1950's/60's.

(c) Reference to Figure 5 will show that each Plant has its own unique classification/coding system for cutting tools. In principle all of the systems used are based on simple commodity definition followed by block numeric codes which are expanded chronologically irrespective of tool dimensions, material grades and geometric definition. This approach results in an identical cutting tool being held in stock against a minimum of four different classification/code numbers within Birmingham Operations.

Further disturbing features with respect to classification/coding systems include:-

(i) The custodians of the coding systems for standard tools were clerically graded P and MC staff with little awareness of the requirements for technological control.

(ii) Confusion prevailed in the case of special tools, i.e. purpose-designed, where jig and tool personnel allocated a unique number which was then given a further number for the purposes of stock control. A purpose-designed tool could, therefore, be recognised by numerous codes within the Plant.



* **BIRMINGHAM OPERATIONS - INDIVIDUAL PLANT CODING SYSTEMS**

Figure 5

(d) Individual Plants have been slow to move from labour intensive inventory control systems, and recent activity in this area has been fragmented with little 'central' guidance.

(e) Cutting tools may be held in any one of 16 consumable material stores located throughout Birmingham Operations, thereby compounding excessive inventory levels.

(f) Inter-Plant and inter-departmental communication with respect to tooling is extremely poor. This is particularly evident in the area of technological planning where rigid demarcation lines exist between Product Design, Divisional Process Planning and local Plant Process Planning Departments.

(g) The net result of items (a) to (f) is that custom and practice prevails and as Figure 6 depicts, numerous personnel from a whole host of functions can either directly or indirectly influence tooling related decisions.

A brief historical summary of the actions pursued by individual Plants to gain control over tooling is as follows.

2.2.1 Longbridge Plant

Although Longbridge was the home of the Austin Tooling Standards these have eroded with time and today formal control mechanisms are minimal. A major effort to gain control was instigated by the Tooling Engineers' Department in 1977 who raised a project proposal to implement a Ford Motor Company style 'tool block system' in selected areas of Longbridge. This approach to tool control is aimed at reducing machine down-time due to non-availability of tools ready and waiting at the point of predetermined tool change. The scheme was partially implemented in the East Works Factory but additional inventory requirements and the cost of supportive facilities prevented any further expansion.

<u>INFLUENCES AFFECTING TOOLING RELATED DECISION-MAKING</u>

Figure 6

Another attempt by management to gain local control is typified by a joint exercise conducted with a major tool supplier who carried out a survey of the North Works Automatics Factory (127 machines, mainly six spindle bar automatics and a catalogue of 350 live components), to study the economics of implementing a range of standard tooling and necessary supportive systems. The tool supplier involved submitted a project cost of £57,000 which was rejected by the Company.

Up until 1981 Longbridge management had no mechanism for identifying the exact inventory level for cutting tools and related accessories, apart from a manual stock-take across twelve tool stores. Clearly action had to be taken and a decision was made to use the services of an external time sharing agency. In principle the agency provisioned a mainframe based, turnkey, consumable material stock control system and at the time of writing the system was under implementation within Longbridge.

The profile of this package is as follows:

Number of stores covered	12
Number of items covered (includes all consumables)	120,000
Monthly transactions	45,000
Cost - external charge	£80K per annum

2.2.2 Drews Lane Plant

Of all the Austin Morris Plants in recent years, Drews Lane has been the most active in attempting to solve the problems of tool control. Initiatives have included:-

(a) October 1976 to June 1977

Extensive efforts were concentrated on the problems of controlling the inventories of new and reground tools, but despite the volume of work committed the project floundered on the industrial relations problems faced by storekeepers refusing to accommodate additional duties.

(b) January 1978

Again with respect to inventory control, BLSL (the computer systems division of BL Limited) undertook a review of the existing problems which endorsed many of the observations of the previous exercise.

(c) 1979

A decision was taken by local management to implement a BLSL sponsored non-productive material control system known as '041'. This system, which was stock control based, was by then over ten years' old and despite numerous software modifications due to implementation problems at other BL Limited sites, including Cowley, Swindon, and Llannelli, has achieved little recognised success. Again the system is mainframe based, and some three years' later, has proven to be cumbersome and expensive to run. Line managers were quick to criticise the system's hard copy reporting features, an argument that the local Systems Department accept.

Although the decision to implement the 041 system was taken as long ago as February 1979 its implementation progress has been little more than chaotic. The main reason for this was that a decision was taken to completely re-code all of the consumable items before committing them to the system. This decision led to numerous problems in that while stores record cards were altered to accommodate the new coding systems, the process planning operation sheets were not. The problems caused by the coding exercise were magnified by the weak framework of the coding system itself and the failure to technologically categorise tools prior to the exercise which led to some tools being given several 041 code numbers. As a result of this it has taken over two years to load the records of 8,000 different items to the system with a further 6,000 still remaining.

A profile of the system is as follows:

Number of stores covered	2
Number of consumable items to be loaded to the system	14,000
Existing monthly transactions	4,500
Cost (In-house charge from BLSL to Operations Management)	£40K per annum

2.2.3 <u>Coventry Engine Plant</u>

Coventry Engine Plant has generally lagged behind in attempts to establish control over tooling (prior to this research work). The two main initiatives have been:-

(a) In 1976 the Plant Industrial Engineering Department designed an addition to the existing manual inventory control system, which in theory, generated a bill of tooling material against a forward manufacturing programme for selected components, but this was rejected due to the increased labour content requirement.

(b) In 1977 a new classification and coding system was implemented in parallel with Drews Lane, but the absence of any central maintenance mechanism resulted in the system eroding very quickly.

2.2.4 Triumph Radford Plant

The position at Triumph Radford was nearly identical to that of Coventry Engine Plant with little action taken in terms of tool control systems, and a heavy reliance on custom and practice.

Therefore, in summary the key factors underpinning the inadequate tool control systems within Birmingham Operations are as follows:-

(a) The absence of central control and direction.

(b) General lack of management commitment and understanding of the control mechanism required.

(c) Present financial control practices discourage any major initiative in the area of establishing control over consumable materials. Currently the practice prevails whereby Financial Controllers set forward operational budget tasks based on an historical analysis. Therefore, in the case of tooling inventory the local management are given an annual inventory reduction task, generally in the order of 10 to 15% of the total inventory by value, a nominal target established against the previous year's known/assumed inventory value.

Achievement of this task discourages local management from pursuing any initiative to reduce the respective inventories by considerably larger amounts, or indeed, questioning the requirement for inventories at all.

All of these problems were not helped by the dynamic nature of the Company's business organisational structure, which on occasions has resulted in all four Plants being under the responsibility of individual Operations Directors.

CHAPTER THREE

3.0 LITERATURE SURVEY (GENERAL)

Publications under the general heading of 'Tool Control' concentrate predominantly upon stock control systems and offer little in terms of vision of the problem area in its broader sense. For this reason early research effort was directed towards developing an overview of the tool control problems being faced by Birmingham Operations Management, the results of which were discussed in the previous Chapter. Having established this level of understanding it became apparent that the eventual resolution of the problems encountered would require a multi-disciplinary approach utilising knowledge and expertise from several key areas, which included:-

(a) General systems theory.

(b) The application of general systems theory within a manufacturing environment.

(c) The interactive nature of sub-systems.

(d) Classification and coding systems.

(e) The disciplines required to establish control in such areas as:-

(i) The correct application of metal removal technologies.

(ii) The efficient supply of tool material to the machine tools.

(f) Machine tool design and operational capability.

(g) The evaluation and potential application of computer-aided engineering systems.

Before embarking upon the subject related literature survey it is, however, appropriate to review the significant events in terms of technological development with respect to metalworking industry in general.

3.1 METALWORKING - AN HISTORICAL PERSPECTIVE

Manufacturing industry as we would recognise it today, only dates back to the mid-Eighteenth Century and the onset of the Industrial Revolution. The achievements of this period have been well documented by Cardwell [8] 1971, Russell [9] 1972, Riggs [10] 1976, and Buffa [11] 1980, and a summary of their work in terms of benchmarks of the progression of manufacturing technology, with particular emphasis towards metal removal, offers fundamental lessons for this and future years.

Advancements in manufacturing technology have resulted, in many cases, from the demands from other disciplines and notable examples include:-

(a) The pioneering work of Watt in the introduction of the steam engine created demands from machine tools in terms of the generation of surfaces, forms and maintenance of component tolerances that existing metal cutting techniques were incapable of meeting. From this the machine tool industry was born.

(b) The production of mild steel by Bessemer and alloy steels by Siemens towards the end of the Nineteenth Century exposed the serious limitations of the predominant metal cutting material of the day, hardened carbon steel. The demands for cutting volume steel production were met by Taylor and White in 1908 with the introduction of High Speed Steel resulting in a five-fold increase in cutting speeds. This work also had the impact of directing attention towards the cutting edge in terms of increased productivity.

(c) The introduction of the model 'T' Ford by Henry Ford in 1903 and flow-line production in 1913 heralded the age of mass production technology. In the motor vehicle industries in Europe and the United States machine tools were designed specifically for mass production and many supportive analytical systems were introduced by such people as Gantt, Emerson, Parsons, the Gilbreths, Shewhart and Tippet, following in the path of Taylor's Principles of Scientific Management.

(d) A combination of new industries such as aerospace with its non-ferrous alloys and increasing competitiveness in existing industries placed a greater emphasis on cutting tool performance and notable developments in this field have included:-

.	1914	Stellite - Haynes
.	1926	Tungsten Carbides - Widier
.	1938	Large Grain Ceramics - Osenberg
.	1955	High Density Low Grade Ceramics and Synthetic Diamonds - GEC/Russia
.	1965	Cubic Boron Nitride - GEC/Russia
.	Late 1960's	Coated Tungsten Carbide Tools - Wimet UK
.	1980	Syalons - Lucas Industries UK

(e) The Second World War accelerated technological development and the immediate post-war years established the foundations for much of the advanced technology of today including computer science, genetic engineering, fibre optics/opto electronics, supersonic and space travel. Many of these developments either individually or combined have had a major impact in the field of manufacturing.

Before any system design takes place it is necessary to understand the problem in question and develop a perspective in terms of its relationship with the overall business activity. To achieve this level of understanding the most appropriate start point is the field of general systems theory.

3.2 SYSTEMS THEORY

The word 'system' is commonly found throughout standard management and scientific text with the result that in many cases its meaning has become confused and almost valueless. During the 1960's terms such as productive, production and manufacturing systems grew in popularity and similarly the range extended to include flexible, integrated and linked manufacturing systems all serving to confuse rather than clarify.

Because of this potential for misapplication of terminology there is a need to revert back to first principles, establish definitions and develop an historical perspective with respect to systems theory and its application within manufacturing industry.

3.2.1 Systems - A Definition

Systems definitions abound ranging from the simple (Oxford Dictionary) to extremely complex (Modern Control Theory); however, for the purposes of uniformity throughout this thesis a system is defined as, Wendler [12] 1966:-

> "........ an orderly arrangement of interdependent activities and related procedures which implements and facilitates the performance of the major activity of an organisation".

Wendler states further that a system may at times encompass such a wide range of activities that it becomes difficult to handle in its entirety. In such cases, the system should be divided into sub-systems, and the sub-systems brought together to form an integrated whole.

3.2.2 Systems Engineering

The systems engineering method recognises each system as a whole even though composed of diverse, specialised structures and sub-functions.

It further recognises that any system has a number of objectives and that a balance must be achieved in optimising the overall system function according to the weighted objectives and achieving compatibility of its parts, Chestnut [13] 1966.

This concept provides a methodology which enables known and new scientific methods to be represented in a schematic form so that they can be employed in gaining knowledge of complex facts. It enables problems to be broken down into individual component parts in a logical manner to investigate each element without losing the interrelationship to the overall problem, Buffa [14] 1977.

Systems engineering is often referred to as the 'exact doctrine of the whole' and it utilises the analytical techniques from many disciplines, e.g. Control Engineering Theory, Operational Research, Management Science, Cybernetics, Topology, Communications, Information and General Systems theories to help understand system design and control and to study behaviour and performance.

3.2.3 Systems Theory - An Historical Perspective

It would be misleading to imply that the concept of studying the system as a whole is attributable to engineers. There is little doubt that the mechanical engineers of the Industrial Revolution and more notably the later electrical engineers such as Edison and Ferranti were heavily involved in systems considerations, but the original study of the total system belongs to the Behavioural Sciences. Psychologists have consciously used systems concepts since the early 1930's and Angyal (1941 and 1965) provided a forceful statement that the key concepts used to describe the organisation of living systems required a new logic. Both of his major works are focused upon the individual biosphere (man in his environment) and expose the general dynamics involved in system change, Emery [15] 1970.

In 1947 Bertalanffy proposed the concept of general systems theory as a mechanism for the unification of the science. This theory asserts that there are properties of systems that do not derive directly from the individual components themselves, but from the unique combination of components that make up the whole. Furthermore, these properties make the value of the whole (the system) worth more than the simple sum of its parts, Buffa [14] 1977.

The introduction of this conceptual thinking by Bertalanffy broadened the vision of many scientists and engineers who had been working within the traditional mechanistic framework which had dominated Nineteenth and early Twentieth Century thought.

The development of general systems theory coincided with what is now known as the classical period of control theory. The emphasis was directed towards frequency response methods with single loop systems which found mainly industrial application. Random disturbances and the effects of parameter changes were taken into account implicitly, but not usually quantified. Optimisation was usually confined to a choice of parameters in a fixed structure and not widely used.

These methods had some important advantages for industrial application in that they gave a great deal of insight to a problem, showed when a single solution existed, and allowed practical constraints to be taken into account although the mathematical foundations were infirm, Rosenbrock [16] 1975.

The analytical tools grouped together under the umbrella of 'Systems Engineering' enable the construction of system simulation models and the ability to measure performance before implementation. The major limitation of this approach is that the practical situation is much less 'tidy' than the theoretical one, resulting in the following situations:-

(a) It is not always possible to specify exact requirements.

(b) Very often the solution is a compromise of what can be achieved compared to what would be desired.

(c) Manufacturing problems often admit to more than one satisfactory solution.

(d) As in many other disciplines, engineering contains an element of experience and intuitive judgment which cannot be reduced to a mathematical form.

3.2.4 System Control

One of the prime purposes in developing systems knowledge is to help achieve satisfactory control. Control as a steering mechanism rather than the political/economic implications of a suppressive mechanism is essential if organisations are to remain viable and achieve some, if not all, of its objectives.

Control Engineering theory is playing a rapidly increasing role in studying whole and sub-systems. In particular the concepts of feedback and adaptive control offer significant benefits and the information generated is the basis for management control. The order of element of a system can range from:-

(a) First order systems which are capable of maintaining levels of state during changing exogenous stimuli.

(b) Second order systems which rely upon a feedback mechanism which anticipate and seek goals.

(c) Third order systems which have the capability of reflective decision-making.

Practical applications of control theory concepts within manufacturing industry abound within the field of CAD/CAM.

3.3 SYSTEMS - LEVELS OF FOCUS

A further potential area of confusion is the term 'whole' or 'total' system. We all live and function within recognised systems, for instance they may be family, community, social, economic, political, etc., and understanding system hierarchy is helped by adjusting levels of focus; for example, the universe can be taken as a total system comprising two major sub-systems, natural and man-made. Although this simplified illustration of a total system neglects the essential aspect of sub-system interaction it does help to illustrate the concept of hierarchy and establishes a perspective to one of the lesser systems which is of particular interest, and that is the business system.

3.3.1 The Business System

A business system can be defined as a motivated force (owner) obtaining prime resources (raw materials) and subjecting them to regulated activity (the business activity) performed by producer resources (premises, staff, machines, etc.), to provide goods or services for consumers (society's needs and satisfactions) and thus provide profit, (the owner's needs and satisfactions), Kilgannon [17] 1979.

The business exists in an extremely complex environment consisting of numerous other systems. The prime consideration of the business environment is time and space. Time reflects political/economic stability, availability of skilled labour and resources, etc., while space is concerned with the physical location of the business; town, county, country, and continent. Its location within any one of the major power blocks will influence the nature of trade, customers, suppliers, etc.

The main functional sub-systems within the business system are those of marketing, financial and production systems, all of which are supported by a communications system. By way of an example the marketing system comprises the following sub-systems:-

- Market research, analysis and assessment
- Advertising and sales promotion
- Publicity
- Customer contact and advice
- Customer order and acceptance
- Sales inventory and storage
- Distribution
- Customer billing and payment handling
- Customer relations, queries and complaints

The complexities of the business resource/financial management system go well beyond the boundaries of this thesis, but its importance cannot be overvalued. Resource management is concerned with the survival of the business, with its day-to-day efficient running and with its future growth and development. It is concerned with locating and obtaining resources and with their maintenance, security and replacement. A broad classification of resources would be as follows:-

(a) Real Resources

Location:	Land, premises, floor space, etc.
Materials:	Animal, vegetable and mineral matter.
Energy:	Wind, gravity, magnetism, etc.
Machines:	Tools and equipment, aids to, or substitutes for manpower.
Information:	Cumulative or stored useful knowledge.
Goods and Services:	The processed prime resources.

(b) Token Resources

Token resources are considered as money and credit requesting the value of the real resources. As such token resources have no value in themselves, but are used as a medium of exchange, a measure of value and store of value.

Of prime interest is the production system as a sub-system within the total business activity.

3.3.2 The Production System

Again the question of focus is important; Buffa [11] 1980, defines a productive system by which we transform resource inputs to create useful goods and services, in other words it is a process of transformation or conversion. This very general definition highlights an important feature which is that discussion of production systems is usually weighted towards machine shop activity where, as with systems engineering, the concepts are applicable to many other areas where the emphasis may be social, economic or political where resource inputs would vary considerably.

McPherson [18] 1971 and Spur [19] 1971, help to narrow our vision to manufacturing industries by the following definitions:

(a) McPherson

(i) Production system - the general process whereby the utility (or value added) of raw material, objects, services is increased overall.

(ii) Manufacturing system - the process within a production system whereby raw materials or piece parts are converted into completed products and for assemblies and adding value to the raw materials.

(b) Spur

Spur pursues an even narrower level of focus by limiting his definitions to the level of the machine tool.

(i) Production system - comprises a plant of machines, devices, etc., for the production of certain goods.

(ii) Manufacturing system - consists of a machine tool for transforming a blank workpiece into the shape required by means of a manufacturing process.

3.4 MANUFACTURING SYSTEMS

The linking of manufacturing facilities is not a new phenomenon and early systems included manually operated conventional machine tools fed by automatic means from a common source, combined with a limited number of machining centres coupled by a palletised loading and unloading. Such a system was implemented by the Hughes Aircraft Corporation in the mid-1950's where three Kearney and Trecker machining centres were linked to a common feed conveyor, Collins [20] 1980. However, the real breakthrough in the theory and practice of manufacturing systems came in the late 1950's with the introduction of micro chip technology and the subsequent design of reliable, comparatively low cost control systems.

In 1961 Merchant [1] recognised the impact that a combination of general systems theories and the recently developed micro chip technology would have within Production Engineering and identified the need for a 'guide pattern' for future research by recognising two key points:-

(a) Employment of the scientific engineering rather than empirical approach as the effective way to produce major advancement in production process and methods.

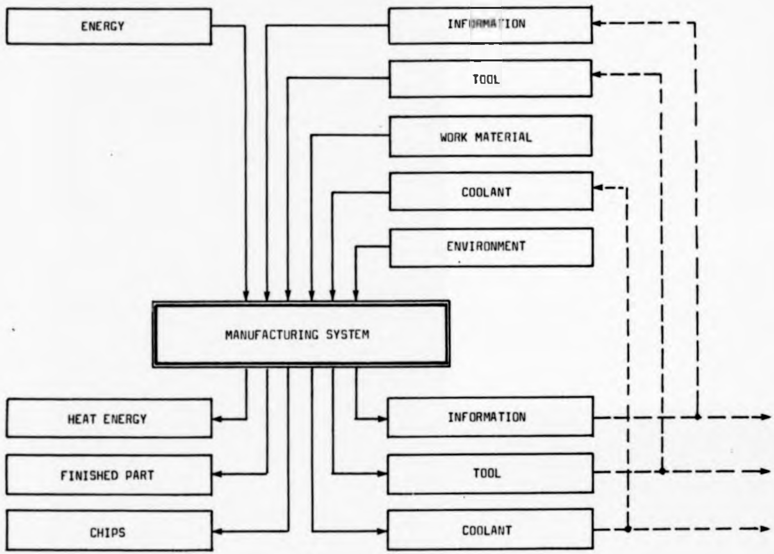
(b) Direction of this scientific engineering effort at the problem of freeing men from routine tasks of production, thus allowing them to set their hands and minds to activities which use and develop their creative activities.

Merchant's concept of manufacturing systems integrated the new manufacturing technology in a single system of production and in subsequent years his name became synonymous with the development and implementation of manufacturing systems theory.

An early development within the United Kingdom of this new approach to manufacturing was the implementation of the Molins System 24, Williamson [21] 1967. The Molins Machine Company Limited produced tobacco processing and packaging machinery and developed a high output machinery arrangement based on the use of NC machines, light alloys, automatic work loading and tool changing over a 24 hour period.

Further advances in the field of manufacturing systems research followed with the work of Peklenik [22] 1971 and Spur [19] 1971. Although the level of focus is limited to machine tools, both applied the principle of feed-back theory to the manufacturing system. Peklenik pursued the logic of having two major units within a manufacturing closed loop system, namely the integration of the manufacturing process (m-process) in the forward loop with the machine tool in the return loop for surface generation. It was recognised that it was impossible to analyse and optimise the manufacture of components without considering the interactive nature of both units.

As Figure 7 shows Spur [19] 1971, identified the inputs and outputs of the manufacturing system and this includes tooling as a sub-system. However, there are inherent dangers in the 'black box' approach of control systems theory as it can discourage appreciation of sub-system interaction. Riggs [10] 1976 dispelled the concept of a common approach to manufacturing systems theory by stating that each company in its own way was a unique manufacturing system with its own sets of problems. Singhal [23] 1978 summarises previous work on the importance of synthesis in production decisions and illustrates how in cases where there is a low degree of sub-system interdependence then isolated study may be possible but, in general, sub-system interdependence is the norm. Hammond and Oh [24] 1973, and Alford [25] 1973, stress the importance of gaining



Source: Spur (19) 1971.

THE INPUTS AND OUTPUTS OF THE MANUFACTURING SYSTEM — Figure 7 visibility in manufacturing systems as a prerequisite to developing the ability to respond to external disturbances; a quality essential to the assurance of future business survival.

In order to respond effectively to a changing external environment there is a need to up-date the elements within the manufacturing system; notable recent developments of such are as given below.

3.4.1 Advancement of Technological Aspects within the Manufacturing System

The evolution of manufacturing systems practice and theory embraces technological advancement in many separate, yet interrelated disciplines, and areas of specific interest relating to the research work undertaken include:-

(a) Machine tool design and operational capability

(b) Metal removal technology.

(c) Computer aided engineering systems.

Each subject area is discussed in the following sub-sections.

3.4.1.1 Machine Tool Design

Koenigsberger [26] 1974 and Merchant [27] 1977, indicate that advances will include greater power enabling higher speeds, but with reduced noise levels, improved rigidity and bearing/slideway design, utilising composite materials such as concrete, plastics and carbon fibres. The greatest impact, however, will undoubtedly be in the field of control systems based on computer technology with particular emphasis on fault diagnosis. This will be complemented by greater machine tool accuracy resulting from the incorporation of laser technology.

Both abrasive and a combination of conventional cutting processes with fully self optimising adaptive control systems will be in widespread use during the 1980's continuing to displace many of the conventional machining processes. Such machines will have a stand alone application, but will be part of a versatile manufacturing system, featuring automatic parts handling between stations, controlled by a central processor.

3.4.1.2 Metal Removal Technology

Despite the increased efforts to improve metal forming techniques spurred on by the 'economics of waste', the application of metal removal technology will still have a significant role to play in the manufacturing industries of the future. Once again, the subject area covers a wide span of activity, König [28] 1980 reviews the advances in conventional metal removal techniques such as single point and abrasive machining, including the increasing role of abrasive machining techniques.

Bellows [29] 1976 reviews the technological advancement with respect to 'non traditional' material removal processes which can be grouped together under the general headings of:-

- Predominantly non-mechanical
- Layless
- Involving new energy modes

Examples of such processes include:-

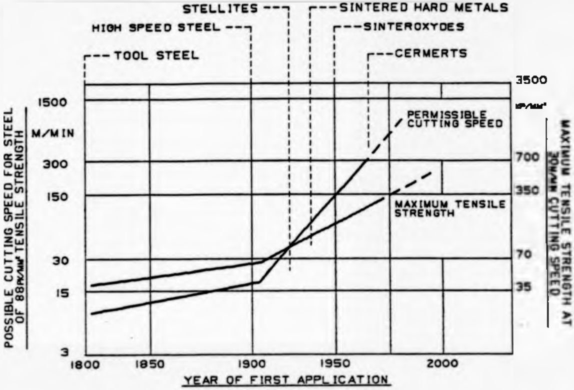
(a) Abrasive flow machining
(b) Ultrasonic machining
(c) Electrochemical grinding
(d) Electrochemical turning
(e) Electrical discharge machining
(f) Electron beam machining
(g) Photochemical machining
(h) Thermochemical machining

Bellows discusses the advantages and disadvantages of twenty-six non-traditional machining processes, and presents an argument for a more wide-spread application of such technology throughout manufacturing industry in general.

Of specific interest to the research activity covered by this thesis are the technological advancements related to single point machining. The general thrust of such advancement is in the direction of developing tool materials capable of retaining hot hardness and chemical inertness when cutting at ever-higher cutting speeds and feed rates whilst achieving longer, more predictable tool life. The increased cutting speed capabilities of tool materials over a period of time is shown clearly in Figure 8, Koenigsberger [26] 1974, and the relative speed operating regions for various tool materials is as depicted in Figure 9. A summary of the progress made in developing single point cutting tool materials is given below:-

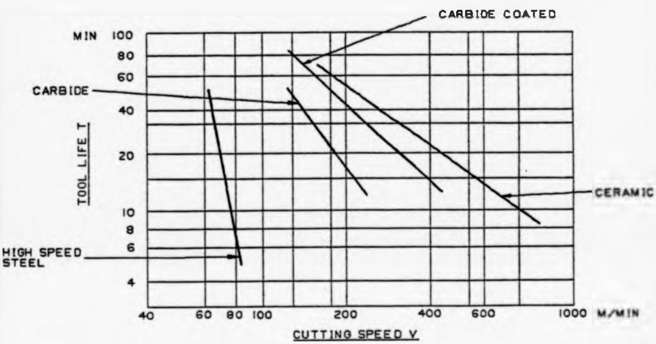
(a) Although widely superseded, High Speed Steel tooling still finds use in specific applications, mainly those requiring maximum tool toughness. Recent endeavours to improve tool life characteristics have included:-

- 'Bulk transformation' methods which are mainly cryogenic in nature and seek to transform residual Austenite to the harder Martensite.
- The introduction of powder technology to enable the manufacture of sintered high speed steel tools offering the potential of a far more homogeneous material structure when compared to the conventional wrought material.
- Methods of coating the steel material with more wear resistant materials by Chemical Vapour Deposition (CVD) and through ion implantation.



Source: Koenigsberger (26) 1974

CUTTING SPEEDS 1800 TO 1970 Figure 8



Source: Koenigsberger (26) 1974

RELATIVE SPEED OPERATING REGIONS Figure 9

(b) Tungsten carbide tooling has been improved in terms of its toughness by ensuring greater degrees of purity of the raw materials and exerting better control over the sintering process to promote reduced variation in grain size and improved evenness of distribution of the mixed Carbide phase, König [28] 1980. This improved degree of control has meant that benefits in terms of tool toughness have been achieved without commensurate loss of tool hardness. A warning note to be struck here, however, is the increasing scarcity and vulnerability of raw Tungsten material which had led already to the re-cycling of used carbide tools for subsequent re-use. Potential detrimental effects of such action in terms of material purity must be closely monitored.

(c) 'Coated Carbide' tool materials continue to be developed at an enormous rate to add to the profusion already existing in the market place, Brookes [30] 1979. Such tools combine the relative toughness of conventional carbides with the superior wear resistance properties at elevated temperatures of engineering ceramics (particularly Aluminium Oxide) or Carbonitrides and Oxycarbides. The CVD process enables the production of such combination tools which comprise a number of discrete layers to ensure compatibility of coefficients of thermal expansion between successive coatings to prevent layer separation due to thermal reversed loading. Such tools out-perform straight carbide tools in suitably rigid set-ups by virtue of their superior resistance to diffusive wear mechanisms.

(d) Ceramic materials are now being used on an increasingly wide basis due to the increased toughness being achieved by improved process control in the production of 'conventional' engineering ceramics leading to finer grained structures which are more securely bonded due to the use of Hot Isostatic Pressing (HIP) techniques.

New materials are also being developed for metal removal purposes the most notable of which are the Si-Al-O-N materials. This material family could only previously be produced by hot pressing techniques with additives to enable liquid phase sintering, a process which left as a residue secondary crystalline or vitreous phases which impaired material strength. Fully dense Si-Al-O-N's can now, however, be achieved by pressureless sintering with Ytteria and offer significant potential for improvements in cutting tool performance particularly in the areas of machining grey cast iron and upon exotic aerospace materials, a subject discussed further by Bhattacharyya [31] 1981.

(e) 'Polycrystalline' tool materials fall into two categories, polycrystalline diamond and polycrystalline cubic boron nitride. Tools produced from such materials typically comprise a 0.5 mm thick layer of synthetically produced diamond or CBN of particle size 10 - 100 micrometres in diameter, bonded under high temperature and pressure (1300 - 2000°C and 50 - 125 KBar) to a tungsten carbide substrate for toughness. Although such tool materials require care in use to avoid edge chipping which leads to rapid crack propagation and tool failure, their potential for operating at elevated operating parameters is considerable. Polycrystalline diamond which has a hardness similar to that of single crystal natural diamond at 8000 - 12000 kg/mm^2 is best suited due to its hardness and chemical inertness to machining abrasive non-ferrous and non-metallic materials such as high Silicon Aluminium alloys, Brasses, Bronzes, Fibreglass materials and epoxy resins; cutting of Aluminium alloys is economically performed at cutting speeds of 1600 m/min and feed rates of 0.2 mm/rev. The tendency for diamond material to become soluble in Austenite at temperatures in excess of 700°C however, precludes its use in the machining of ferrous materials which generate interfacial tool temperatures in excess of 1000°C. Cubic Boron

Nitride, however, can be utilised and although its hardness is less (typically 3000 - 35000 kg/mm^2) it will economically cut ferrous materials of 60 HR_c at 100 - 200 m/min at a feed rate of 0.2 mm/rev.

The continually improving capabilities of tool materials, however, raises important questions as to whether their true potential can be exploited including:-

(a) Workpiece configuration and its ability to withstand increased metal removal rates without deformation.

(b) The age and condition of machines available.

(c) Machine tool 'peripheral' design (i.e. the ability of jigs and fixtures, etc., to withstand high torques).

(d) Commitment to capital investment where process capabilities are specified through custom and practice combined with an extremely cautious approach to the implementation of new technology.

3.4.1.3 Computer Aided Engineering

Early systems emphasis within manufacturing industry was directed towards the achievement of management control over such areas as inventory, goods despatched/received, payroll, etc., but in the subsequent years the impact of computer based systems is to be seen in all aspects of the business system activity. This widespread application has been accelerated by a combination of ongoing reduction in hardware costs and a similar trend in improvements in system processing capability. Such technological advancements supported by the increasing availability in applications orientated software offers the potential for continuing improvements in management control capability.

Of particular interest is the impact of computer based systems within manufacturing industries, and reference to Figure 10 indicates that developments have taken place in three broad areas, namely:-

(a) Design and drafting - (CAD)

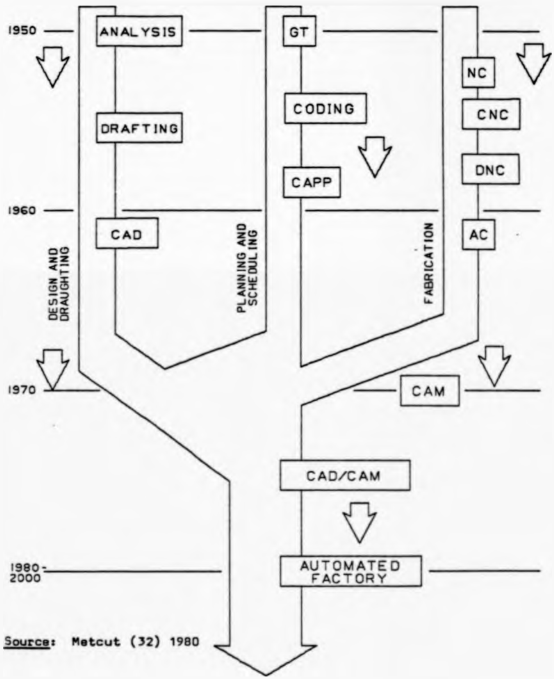
(b) Process planning and scheduling - (CAM)

(c) Fabrication - (CAM)

Evolution in these three related areas has seen the emergence of linked CAD/CAM systems with further rapid advancement towards the horizons of the automated factory. Technological development with respect to computer aided engineering systems have been well publicised describing advancements in countries such as the USA, Japan, East and West Germany, Czechoslovakia, Sweden, Norway and in addition, numerous examples describing CAD and CAM installations can be quoted within the United Kingdom, although the recent tendency has been to give more wide-spread publicity to the recent installation of flexible manufacturing systems (FMS) which link several computer aided systems together. Examples of this trend include:-

(a)	Baker Perkins	[33] 1980
(b)	Dowty Fuel Systems	[34] 1981
(c)	Normalair Garrett	[35] 1981
(d)	Babcock Power	[36] 1982
(e)	British Aerospace	[37] 1982

Within the CAD/CAM environment computer based systems applications can range from corporate mainframe systems through to individual production process control.



Source: Metcut (32) 1980

HISTORICAL DEVELOPMENT OF CAD/CAM SOFTWARE CONCEPTS

Figure 10

3.5 TOOL CONTROL SYSTEMS

Despite the wealth of information available on metal removal technology and its related aspects, the subject of a systems approach to the control of cutting tools has, in terms of published literature, been neglected. As a result of his work into the analysis of families of turned parts, Phillip's Ph.D. thesis [38] 1972, recognised this neglect and recommended that future research into the requirements and designs of 'complete' tooling systems would be invaluable. However, while this recognition is important his use of the word 'complete' is rather misleading and is directed more towards the achievement of technological control over the metal removal activities within a cell of machine tools, and apart from general observations on the ideals of composite tooling and the benefits of efficient information retrieval systems, offers little guidance in terms of the possible development of a 'complete' system embracing total managerial and technological control.

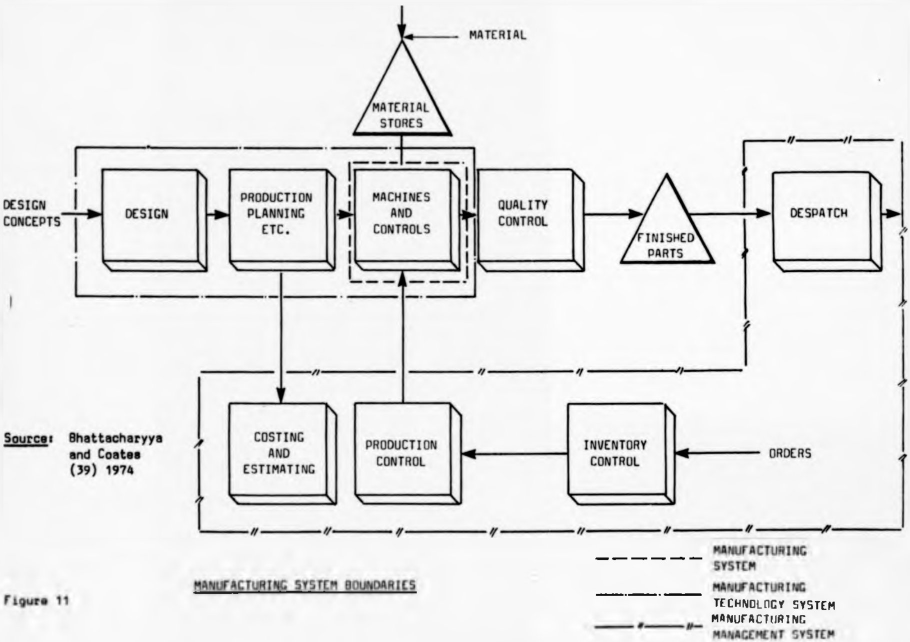
Although not specially directed towards the problems of tool control, observations by Bhattacharyya and Coates [39] 1974, when commenting on the work of Peklenik [22] 1971, help to establish a framework for the study of the subject area by identifying three major sub-systems within the overall production system (reference to Figure 11) and these are:-

(a) The manufacturing system

(b) The manufacturing technology system

(c) The manufacturing management system

Publications that are available consider the tool control implications within the individual sub-systems, but rarely consider the implications of system interaction. The exception to this is in the area of CAD/CAM where consideration is given to the links between the manufacturing and technology systems. However, while the concepts of



Source: Bhattacharyya and Coates (39) 1974

MANUFACTURING SYSTEM BOUNDARIES

Figure 11

linking systems is certainly of interest, research efforts in CAD/CAM systems are usually aimed at the control of a limited number of computer controlled machine tools, often in a green field site situation, and do not reflect the problems encountered in implementing similar concepts into an established mass production environment utilising, in the main, a wide range, by type and age, of conventional machine tools and labour intensive design/planning/manufacturing control systems.

Contributions in the field of tool control within the three sub-systems as discussed by Bhattacharyya and Coates are as follows:-

(a) <u>Manufacturing System</u>

Areas of physical control covered at the tool/component interface include:-

(i) Sensing probes for setting and measuring

(ii) Automatic tool wear compensation

(iii) Simplified tool changing leading towards automatic tool changing, i.e. block change tooling

(b) <u>Manufacturing Technology System</u>

There are tooling implications throughout the technology planning system and key areas include:-

(i) Tool design

(ii) Tool development and evaluation

(iii) Various levels of process planning, including:-

- Total process routing
- Individual operation specification
- Tool paths

(c) <u>Manufacturing Management System</u>

Such systems are required to ensure financial control of the production systems and in terms of tool control cover such areas as:-

(i) Inventory control procedures covering the procurement and supply of tooling and related items to the machine tool and monitor tool material usage variance.

(ii) Industrial Engineering procedures which establish tooling related man-assignment standards and subsequent variance from the standard, i.e. tool setting, refurbishment, etc.

The degree to which any of the preceding areas are investigated depends upon the level of focus adopted in the research work; for the purpose of this research work this is set at achieving the control of tooling at factory level and not at the level of the individual machine tool. As later discussion will reveal, the achievement of this criterion required the setting of a system boundary that went beyond the factory, and included the external tool suppliers as an integral part of the overall ATOMS concept. Therefore, whilst an appreciation of the topics covered in (a) is useful, the main area of attention will be to review literature which falls into the categories of manufacturing technology/ management systems, i.e. (b) and (c).

3.6 TOOLING TECHNOLOGY SYSTEMS

Spur [19] 1971, pinpoints the heart of the problem by showing the tool control system as a sub-system of the manufacturing system and identifies the important technological aspects as being:-

(a) Properties of the tool material
(b) Tool geometry
(c) Toolholders and their placement

In addition, Spur recognised that as a general point manufacturing sub-systems had yet to be evaluated and considered this to be an important task for future research.

If this direction offered by Spur is to be pursued then tool control must begin by ensuring the application of the correct technological specification at the cutting edge, i.e. the achievement of technological control. The operating efficiency of the machine tool exerts a predominant influence upon manufacturing costs and the ability to move towards optimising the manufacturing system begins with the efficiency of the process planning system. The advent of computer aided engineering systems has, and will continue to offer, significant contributions in terms of process planning systems and the two key areas of advancement are:-

(a) The structuring of technology data bases.
(b) Automated process planning systems.

It is recognised that CAD systems will play an influencial role with respect to special purpose tool design, but for the purposes of this literature survey, the emphasis will be towards items (a) and (b) as stated above, and discussion on each area is contained in the following sub-sections.

3.6.1 <u>Technological Databases</u>

In a further paper Bhattacharyya and Coates [40] 1976 take an overview with respect to such databases and identify the need for companies to structure them to incorporate all the manufacturing technology related information requirements of the production sub-systems described in the preceding section. Essential characteristics of such a database would include information relating to:-

(a) Machinability
(b) Component material specifications

(c) Tooling

(d) Machine tools

(e) Coolant, etc.

Arn [41] 1975 pursues a similar theme for the storage of group technology related data and Merchant [27] 1975, visualises that while such databases may evolve from machinability type data banks they will cover a wider span of activity and are a prerequisite for providing the manufacturing information base for CAD/CAM implementation. It is apparent that as companies strive to compete technologically in the market place then the structuring and maintenance of such databases will become a prerequisite for business survival.

It would be misleading to imply that the collection storage and retrieval of technical information is a new phenomenon. Every engineering company will have some form of technical data recording system to support its manufacturing operations. At present most of these are not computerised and in many cases base data, albeit lacking in consistency and quality, can be found in non-technology planning departments, e.g.:-

- Finance - assets register
- Purchasing - tool costs
- Industrial Engineering - tool change frequencies

The evolution of computerisation and communications technology has made the ideals of such databases possible and enables many of the difficulties traditionally associated with maintaining integrity of data to be overcome. The information becomes more accessible and as the system develops the database will be able to serve company-specific needs and furnish more detailed information than would be found by searching international/national data bank files, or by that offered by commercial technical data software packages.

If the analysis given by Spur [19] 1971 is to be taken as a starting point, viz. that tool control begins with the correct technological specification at the cutting edge/component interface then certain areas of the proposed technology databases assume priority status, particularly those relating to machinability data. Because of its importance in a potential tool control system the subject area is discussed in greater detail in the following sub-section.

3.6.2 Machinability Databases

Although the term 'machinability' is commonly used throughout published literature it is difficult to establish a precise definition of its meaning. The Machining Data Handbook [42] 1972 defines the machinability characteristic of a component material in terms of:-

(a) Surface integrity

(b) Tool life

(c) Power or force required

Where tool life is generally defined as the cutting time (in minutes) required to produce a given wear land upon a given tool material when cutting a given component material at defined machining parameters.

It should be recognised that while the above definition has been given as a general guideline it does omit comment upon chip form which will always be a key area for discussion with respect to machinability.

However, using this definition as a starting point it is now possible to review the subject area of machinability databases. Once again this can be considered from differing levels of perspective, ranging from the much publicised national data bases to purpose-designed 'in-house' machining information which can be unique to individual companies.

At the national level the majority of the machinability data centres were formed during the late 1960's and early 1970's, many at the instigation of respective governments. Typically they offer a wide-ranging machinability based service to their subscribers and include such activities as:-

(a) Recommendations of cutting conditions

(b) Laboratory data

(c) Workshop data

(d) Literature service

(e) Specialised machining consultancy

Some of the more notable data centres include:-

(a) UK - PERA Machining Data Club, Moore [43] 1974

As the result of a Ministry of Technology feasibility study in 1969 momentum was given to the formation of the PERA machinability data centre in 1972. The 'club', as PERA prefer to call it, offers two main services to its subscribers:-

(i) Regular supplies of machining data bulletins which build up into volumes of the machining data manual.

(ii) Limited free access to PERA's machining data service whereby companies can request specific machining information not covered in the machining data manual.

(b) Japan - National Machining Data Centre (NMDC), Sata et al [44] 1974

Early research by the Japan Society for the promotion of the Machine Tool Industry recognised the role that a centralised computer based machinability data bank would play in CAD and CAM. This led to the formation of the NMDC in 1974 with its heavy bias towards a NC/CNC-related technical information service.

(c) USA - Machining Data Centre (MDC), Kahles and Field [45] 1974

This government financed body became operational in 1965, and unlike the Japanese centre, offers a broad-based machinability data service to many engineering related industries, e.g.

Automotive and farm equipment

Aerospace

Instrument and precision engineering

Machine tools

Shipbuilding

Screw machine production

Foundry

Steel mills

MDC are also responsible for producing and publishing the well known Machining Data Handbook.

The original thinking behind such centres was sound in that they accumulated vast stores of information readily available to subscribers. However, in practice, various factors including economic and psychological mitigate the benefit of such data to industry.

Specific problems encountered by MDC and PERA include:-

(a) Cost recovery has been an on-going problem in that while members are usually willing to pay for data to be generated to provide solutions for individual machining problems, there is a resistance to charges for searching or retrieving data that already exists. This resistance is probably due to an unwillingness to recognise machining data as a commodity combined with a lack of awareness of the costs involved in data collection, storage and retrieval.

A fundamental problem here is the inability to quantify the value to an individual company of a national information service. Internal finance procedures may well approve the purchasing of a machining data handbook, but not the initial registration fees and on-going access costs to an external data bank; thus technological updating, an aspect of ever increasing importance to company survival is foregone.

(b) The lack of accurate data which stems from excessively large grouping of workpiece and tooling materials when industry really needs smaller groupings with accurate data on specific tool material/ workpiece material combinations.

(c) Individual companies may not be truly representative of their industry class and generated machinability data may bear little relevance.

(d) Many companies are not concerned with the optimisation of individual machine tools, but rather with the optimisation of costs of production for an entire job or production.

Clearly, any refinements required to improve the limitations imposed by (b), (c) and (d) would further compound the cost recovery problem of (a).

Moving away from the national level of data banks it is becoming increasingly common for cutting tool suppliers to offer a restricted machinability data service relating to their own products. A prime example of this is the time sharing facility offered by Carboloy (GE - USA) to subscribers relating to tungsten carbide and ceramics. Similar data is now available in hard copy form from the majority of the larger tool suppliers in the UK market.

Weill and others [46] offer a positive direction in rectifying many of the weaknesses as identified in this sub-section by stating:-

"The development of the automatic manufacturing system has stressed the need for a rapid access to 'proven' data in the technological field. This need should be satisfied by simple and cheap data bank systems."

Waill stresses the difficulty in collecting reliable data from industrial sources and proposes ways to overcome certain of the difficulties encountered. The methodology pursued shows how available data can be used to determine optimum machining conditions and compares the results obtained with the results of current data handbooks, notably the second edition of the Machining Data Handbook [42] 1972. The results of such comparisons indicated a high degree of overlapping with METCUT data with respect to feed rate, speed and depth of cut, but compared to the manuals the data bank offered a more precise evaluation of the machining conditions, particularly with respect to time and cost involved. An additional benefit identified was that the data bank had a high potential for updating and optimising improvements, the information for which was not always available in handbooks.

3.6.3 Computerised Process Planning Systems

An expansion of the machinability data banks has been to link them to computerised process planning systems. The growth in this area is directly linked with the development of CAD/CAM systems and begins to set a base to ensure consistency in a function which has traditionally been vulnerable to the non-standardisation of process application caused by the labour intensity and preponderance of personal preference in the process planning function. The achievement of improved levels of consistency is essential for two main reasons and these are:-

(a) Process planning is the first stage in the manufacturing process and is a major determining factor with respect to manufacturing costs.

(b) As later chapters will show a broader approach to tool control will be based on disciplined control over metal removal technological specification and application.

At the highest level of differentiation computer aided process planning systems (CAPPS) can be classified into one of two categories:-

(a) Retrieval type systems which are Group Technology orientated and rely heavily on effective data file organisation and component classification systems.

(b) Generative type systems which pursue a decision-making process structured by the use of alogrithms which manipulate engineering logic through the use of mathematical equations. In principle truly generative systems are still very much in the conceptual stage and the present systems generally classified into this category still require a high proportion of interactive user dialogue to generate the required decisions.

While the generative systems avoid much of the data storage problems of the retrieval systems they do require a thorough understanding of metal removal processes and the use of mathematical models.

Against this background it is helpful to understand the function of the more well known systems and to do so it is necessary to establish a second level of differentiation, and a broadly defined classification would be as follows:-

(a) Tool motion plan
(b) Process operation plan
(c) Process plan including time and cost estimates
(d) Machine shop scheduling

Referring back to the three system definition as given initially by Peklenik followed by Bhattacharyya and Coates, items (a), (b) and the majority of (c) are considered to be embraced by the management technology planning system, while item (d) is identified as part of the manufacturing management control system.

Discussion of the CAM element of CAD/CAM during the 1960's and early 1970's usually centred on the part programming for NC machine tools. With hindsight this perspective can appear to be very narrow as the activity under attention really only covered the detailing of the cutter path and operational process plan for specific machine tools. However, part programming has become recognised as one of the earliest developments in the field of computerised process planning systems and the programming language known as APT (Automatically Programmed Tools) has become synonymous with the evolution of CAD/CAM systems.

APT was developed by MIT during the years 1955-60 and subsequently enhanced by several engineering centres in Europe during the 1960's. Notable work includes the development of specific APT based NC machining modules by the Engineering Institutions in Aachen, Berlin and Stuttgart, resulting in:-

EXAPT 1	Drilling
EXAPT 2	Turning
EXAPT 3	Milling

During the 1970's a second popular part programming language emerged known as COMPACT II which is a proprietary system of MDSI (Manufacturing Data Systems Incorporated). The majority of the present-day commercially available systems utilise either APT or COMPACT II based languages for NC tool path generation.

Systems which go beyond the absolute detail of the motion plan and consider other elements of the process such as cutting conditions, power required, etc., are typified by the TNO (Netherlands) MITURN turning module [47] 1971. An interesting feature of MITURN is that it was an early attempt to generate process detail for either NC or conventional machine tools.

Having established the process operation parameters the next step is to compile the overall process plan. Typically such systems have the capability, through system/user interactive dialogue, of producing operation sequences after having given due consideration to such aspects as machine tool selection, cutting conditions, machining times, etc. System classification at this level becomes difficult as the majority of commercially available systems combine generative and retrieval capabilities. Bearing this 'greyness' in mind examples of computerised process planning systems include:-

(a) Systems based predominantly on the generative approach include the derivations of the AUTAPP System, Eversheim and others [48] 1980, and CAPSY (Computer Aided Process Planning System), Spur [49] 1978, both of which were initially designed for NC turning applications but have now been expanded to cover other machining processes for both NC and conventional machine tools.

(b) Information retrieval systems MIPLAN, Schaffer [50] 1981, and LOCAM, Gibbs [51] 1980. The MIPLAN system is attributable to the work of TNO (Netherlands) and is the process planning support system to Computervision Limited's CAD Systems and can be classed as a process plan 'assembler' system working on the principle of planning by variance, i.e. the standard process plan is generated allowing the process engineer to concentrate on items which may vary from standard. The associated component classification system which is the cornerstone of the MIPLAN system, is known as MICLASS and is discussed further in Chapter Four.

LOCAM is based upon a structured information storage, retrieval and manipulation process whereby manufacturing related information can be stored at various levels of applicability, ranging from the high level 'macros' which contain common generalised data, through to the more process specific data patterns, and finally to tables of discrete data. The system allows the user to specify engineering logic through interactive dialogue to enable the compilation of the process plan. A brief insight into both systems in the form of system routing demonstrations suggests that MIPLAN adopts a more mechanistic approach to planning whereas LOCAM encourages flexibility with a greater emphasis on the achievement of engineering logic through user input.

Systems which pursue a much broader span of activity including machine shop scheduling are typified by PEFAC, Challis [52] 1981, H Walton Technical Systems Limited, Rassam [53] 1980 and the National Engineering Laboratories CAPE System [54] 1980. There are similarities between these systems and the LOCAM system as discussed in the previous paragraph in that all three rely on data files being established relating to individual company's manufacturing information, i.e. machine tool specifications, cutting parameters, component material specifications, work element times, etc. However, the emphasis is more towards the development of time/cost estimates, work scheduling, etc., albeit experience to-date appears to have been limited to small batch work environments. In summary, common features linking the systems discussed under the general heading of CAPPS include:-

(a) The concept of fully automated process planning systems are still very much in their development phase despite dialogue with respect to fully integrated CAD/CAM systems from national and international commercial turnkey system suppliers. Kotler [95] 1979, gives a further insight into the subject area by stating that the practical limitations on implementing such systems is due to the lack of three dimensional computer aided design modules and the absence of comprehensive manufacturing data bases which are difficult to achieve given the great number of product types being designed and the countless additions to technology.

(b) Systems are designed to reduce costs associated with the generation and maintenance of the process plan.

(c) In principle they are logic orientated plans designed to take full advantage of computing facilities.

(d) Experience is showing that these systems are unique to their operational environment.

(e) The vast majority have been specifically designed for application to small batch environments although publications are now available discussing more far-reaching systems under development within the aerospace and related environments. Kotler [55] 1979, discusses a computerised production process planning system under development for the US Army Missile Command, based on an information retrieval variance approach, and at the time of publication covering a limited number of machining processes.

Hermann [56] 1979, presents an overview of the ICAM (Integrated Computer Aided Manufacturing) program which is an ambitious project, initiated by the US Air Force, to develop a completely integrated system covering all the computer aids in manufacturing in the aerospace industry. Little detail is given with respect to the approach to be pursued in terms of process planning although the requirement to link such files of information as cutter selection, speed and feed selection, form tool design, etc., is identified.

(f) The majority of the systems require files of manufacturing related data unique to specific companies to be established before the systems can become operational. This raises serious concerns because of the quality and relevance of such data, much of which may contain inherent custom and practice, then assumes a significant level of importance within the functioning of the system. Too often the system specifications assume that items such as up-to-date tooling and machinability operational standards are already in existence, giving little consideration to the realities of having to initially establish, and then maintain the relevant information.

Clearly the correct application of metal removal process planning technological standards will play an important role in an eventual tool control system and it is now necessary to undertake a similar review within the manufacturing management control system where the control of the tool material supply to the machine tool and subsequent control over tool usage are major factors.

3.7 INVENTORY CONTROL

Inventory control is the discipline with which tool control has traditionally been associated. A literature search under the general heading of 'Tool Control' will produce encouraging titles but are, in the main, directed towards small to medium batch work production environments and either discuss good housekeeping practices (i.e. "tool crib management"), e.g. Wood [57] 1958, the Tool Engineer's Handbook [58] 1959 and Burnett-Hughes [59] 1962 which are based in the pre-computer age of the 1950's or on the experience of several individual companies/management consultants in the installation of computer based stock/flow control systems for consumable tools in general, e.g. Mittal [60] 1976, Hebber and Brani [61] 1976, Kellock [62] and Galgut [63].

To clarify the terminology used the term 'inventory control' is taken to include stock and flow control systems, with the following respective definitions taken from Burbidge [64] 1980.

(a) Stock control systems maintain supplies of materials and parts, but ordering a new batch every time stocks of an item drop to a predetermined level.

(b) Flow control systems determine the quantities to order and their due dates by calculation from production programmes which are based on sales forecasts. Both Period Batch Control (PBC) and Material Requirements Planning (MRP) are derivatives of flow systems.

The importance attached to tool classification and coding systems does emerge, but as they are inventory control based, their level of sophistication rarely goes beyond that of simple alpha/numeric block class codes, the objective being purely and simply to apply a unique code number to each individual commodity item. Classification and coding systems have, however, received microscopic attention in the field of component statistical analysis for the application of the principles of Group Technology, and more recently CAD.

In addition to the literature survey several visits to non BL Limited companies were undertaken to review 'in-house' tool control systems. Reference to Figure 12 indicates that as with many of the publications on the subject the emphasis within these companies was very much towards limited manual orientation/computerised stock control systems utilising simple block numeric codes. In every instance no action had been taken, or indeed was planned, in terms of company based machinability and formal control over tooling standards was minimal. The reasons for this situation were as follows:-

(a) It was easier to quantify the justification for an inventory control system than one that controls metal removal technology. Dialogue suggested that there was a lack of understanding as to the real benefits to be achieved through technological control reflecting

COMPANY		1. MACHINABILITY STANDARDS		2. TOOLING STANDARDS		3. CLASSIFICATION & CODING SYSTEMS		4. 'WHERE USED' (SPECIFIC)		5. INVENTORY CONTROL				COMMENTS
										Stock Control		Flow Control		
Name	* Product Range	Manual	Automated	Manual	Automated	Block Alpha Numeric	Significant	Manual	Automated	Manual	Automated	Manual	Automated	
1. Coventry Climax Ltd. (Formerly part of BL Ltd)	Material Handling Equipment	x	x	x	x	✓	x	Process Planning Sheets	x	✓	Planned	x	x	Opitz Classification and Coding System used for Component Material Specification
2. Automotive Products Ltd.	Auto Industry Parts	x	x	Limited Range	x	✓	x	Process Planning Sheets	x	x	✓	Selected items in Bar Auto Shop	x	Effective use of Tool Trolleys to anticipate tool changeovers in the Bar Auto Shop
3. Hopkinsons Ltd.	Process Control Systems ie Valves	x	x	Wide Range	x	x	Opitz Based	Process Planning Sheets	x	x	✓	x	x	The principles of the Opitz System have been implemented extensively (including product specification)
4. R.H.P. Ltd.	Bearings	x	x	Limited Range	Limited Range of Purpose Designed Tools	✓	x	Process Planning Sheets	Established for selected high cost special tools	x	✓	x	x	The very strict planning control over the design of purpose designed tools is of interest
5. W.G.L. Ltd.	Aero-Space	x	Wide range of industrial engineering aids. Incorporate a limited amount of machinability data in the form of tables of discrete data (ie retrieval system)	x	x	✓	x	Process Planning Sheets	x	x	✓	x	x	The tooling impact on industrial engineering planning standards is of interest here
6. Perkins (Diesels) Ltd.	Diesel Engines	x	x	Wide Range	x	✓	x	Specific 'Where Used' file in operation	x	✓	Planned	Limited application to certain families of brazed tools	x	. Opitz utilised for selected component families . Manual tooling/component 'Where Used' file of interest . Comprehensive reground tools throughout the machine shops
7. Davy Loewy Ltd.	Heavy Eng.	x	Limited machining data in APT based NC planning modules	x	x	✓	x	Process Planning Sheets	x	✓	Planned	x	x	Several years experience in APT based process planning NC modules (ie cutter path plotting)
8. McEvoy (Oilfield Equipment Ltd)	Medium/ Heavy Eng.	x	Limited machining data in APT based NC planning modules	x	Wide Range	Purpose Designed	x	Process Planning Sheets	x	✓	Planned	x	x	Heavy emphasis towards computer aided engineering systems but not specifically related to tool control

NB: 1. All visits made during 1981/82.
2. For the purposes of respective Company confidentiality a detailed insight into any of the specific topics presented here is not given.

AN OVERVIEW OF NON B.L. LTD. APPROACHES TO TOOL CONTROL

Figure 12

very much attitudes of custom and practice - the hallmark of traditional process planning environments.

(b) In general inventory control procedures had proven to be successful in the control of direct materials resulting in the application of similar control mechanisms for indirect (consumable) materials. This approach resulted in tool inventory levels and rate of turnover, being taken as the simple indicator as to the efficiency of the management of tools within the factory.

(c) Standard, off the shelf, software packages are now readily available headed by IBM's COPICS (Communications Oriented Production Information and Control System), Walko [65] 1980, modules which service the requirements of the Manufacturing Management Control Systems, but offer little more than a data base storage facility for the basic information required within the Manufacturing Technology Control System. Typically tool control is discussed in some length within the COPICS manuals [66] 1981, but control is directed towards the benefits of tool material requirements planning with minimal vision and consideration being given to the control and update of the application of metal removal technology.

Three papers which go marginally beyond the inventory control based approach to tool control are those by Justice and Gaio [67] 1966, Gay and Moffatt [68] 1974 and Galligan and Mokris [69] 1981.

The interesting features of the work by Justice and Gaio, which describes the implementation of a computerised tool control system at IBM's manufacturing division (Rochester, USA), includes the principle of a tool 'tracking system' for reground tools to enable a complete new/reground tool inventory status to be generated and the implementation of a significant character tool classification and coding system. As Figure 13 shows the system comprises of nine significant characters which represent

7 6 3 0 1 6 3 8 1 - R B 0 3 - _ _ _ _ _ _ _ _ _ _

Significant Digit Code -
Represents the Basic Tool:-

½" Dia., HSS, RH, Standard Twist,
Jobber Length Drill

Tool Geometry Required:-

R - Red (Steel)
W - White (Aluminium)
B - Blue (Cast Iron)
X - No Colour
(No Geometry
Variation Available)

Tool Condition:-

A - Tool Tolerance Equal to New
B - Average Reground Tool
C - Reground Tool, nearing the
end of Productive Life
D - No Class Variation Available

Quantity of Tools
Required for Machine
Set-up

Modification to Tool Detail

Source: Justice and Gaio (67) 1966

IBM LTD. - TOOL CLASSIFICATION AND CODING SYSTEM

Figure 13

the basic tool shape and material grade followed by characters for tool geometry condition, number of tools required for a specific machine tool set up, and finally eleven 'end of code' characters for detailing tool modifications etc.

This paper is a good example of the author attempting to go beyond the traditional stock control based systems, but recent communication with the Company in question reveals that since the paper was published in 1966 the system has not progressed much further, since in terms of possible linking the tooling definition based classification and coding system to a more comprehensive machinability standards data base. The present day system covers 5,000 cutting tools and related spares in total.

Gay and Moffatt concentrate predominantly on the financial control of tooling through improved P and MC/Finance based systems and make only passing reference to the need to up-date tooling technology with ongoing tool trials to compare the products of alternative suppliers against existing manufacturing data.

Galligan and Mokris offer an interesting paper on tool control recognising the advances towards fully integrated manufacturing systems software and describe in their terminology a 'complete' tool control system which had recently been implemented at Braun Engineering, a major steel extruder in the USA. This system addressed three areas in terms of control:-

- Tool inventory control, adopting the principles of flow control with the generation of tooling bills of material.
- Tool consumption and control.
- Engineering change and control.

Certainly from a tool material supply point of view this paper was the most comprehensive on the subject area found while undertaking the literature survey, but their use of the term 'complete system' is rather misleading as the emphasis is still very much on the traditional approach of inventory control and what initially appears to be an extremely interesting area of the system, namely, engineering change and control refers purely to monitoring tooling stock implications when introducing new work to the machine shops.

From the contents of the paper it is apparent that the system has been developed along similar lines of IBM's COPICS 'communications' approach to establish closer control over existing inventories and tool usage. Fundamental limitations with this approach include:-

(a) Such systems control the existing situation, but discourage thought as to the actual need for tooling inventory, i.e. the potential for a 'nil inventory' situation.

(b) The economics of tool usage are directly linked to improvements in cutting tool performance, the control and update of which were not discussed and therefore by implication are not recognised as a prerequisite to overall tool control.

Other papers which offer interesting points relating to specific aspects of tool control include:-

(a) Zeleny [70] 1981, discusses tool flow and transportation implications with respect to supporting the requirements of flexible manufacturing systems.

(b) Taylor [71] 1968, discusses the benefits of tool store centralisation and the need to establish formal control over reground tools within a mass production environment (Pontiac Motor Division of General Motors).

In summary, while the papers discussed in this section address the problem of tool control their level of focus is directed towards the requirements of tool material supply systems to the neglect of achieving the same level of control over the technological parameters of metal removal.

3.7.1 Tool Usage

The two key factors that emerge in terms of tool usage are:-

(a) Tool re-usability - whereby tools can be returned to the stores, after regrind, in the same form as which they were issued. This is particularly applicable to purpose-designed tools such as broaches, hobbs, shaving cutters, etc., and therefore, there is a requirement to establish the number of tool lives available per individual tool.

(b) Tool life - is applicable to recyclible and disposable (indexable inserts, grinding wheels, etc.) tooling and is usually measured in terms of:-

(i) The number of components that will be produced until one of the following limiting factors is reached:

1. Tool deterioration (roughing operations) to a point immediately prior to catastrophic failure.
2. A pre-defined tool wear limit is reached, i.e. flank/crater wear as established by the relevant ISO or British Standard. However, it should be recognised that the adoption of this discipline would require accurate control at the cutting edge/component interface, which is typified by CNC based activities, and would prove more difficult to implement and control within a labour intensive, conventional machine shop environment.
3. Component deterioration (finishing operations) to a point immediately prior to the excession of component design tolerances. This category tends to be applicable to high component volume transfer lines.

(ii) Tool life can also be stated in terms of the number of hours in use before a tool change is required, irrespective of tool or component condition. This approach tends to be used on purpose-designed, multi-spindle machines, such as chucking/bar automatics, whereby total banks of tools are changed at convenient break points during the shift to maximise machine productive availability.

All of the items discussed in (a) and (b) should be subject to Industrial Engineering disciplines where tool change frequencies/tool regrinds are accurately measured and built into the standard time from which point variance from standard can be monitored on an ongoing basis.

Again, for this procedure to work effectively, the Industrial Engineer requires the support of machinability/tooling standards. If such standards are not available the engineers resort to custom and practice with little awareness of the true operational potential of the cutting tool. This can build in constraints to the overall business efficiency by allowing non-management personnel, i.e. machine tool setters/operators, to have a major influence on the efficiency of tool utilisation.

Once again the question of consistency arises at the process planning stage and an extension of CAPPS has been the development of MTM (Method Time Measurement) oriented software packages. A typical example of such a system is AUTOMAT and COMPUTE, Schofield [72] 1980. AUTOMAT (Automatic Measurement and Times) is the system name for a suite of programs which can assist the Industrial Engineer in the design and evaluation of work tasks covering the two main areas of time and method study. COMPUTE is a similar package aimed specifically at machine shop based work. As with the CAPPS survey discussed in sub-section 3.6.3 the effectiveness of MTM systems will require access to accurate and relevant machinability data and tooling standards.

CHAPTER FOUR

4.0 LITERATURE SURVEY - CLASSIFICATION AND CODING SYSTEMS

From the onset it is important to recognise the broad division between the roles of classification and coding systems, and these are as follows:-

(a) Classification

In classification each commodity is allocated to a specific class of commodities; the classes themselves are clearly defined, and are ordered into a structure - commonly hierarchic - showing the relationship of one class of commodities to another. The structure may be anything from a highly organised complex structure down to a simple list of groups, NCC [73] 1968.

(b) Coding

A code is one or more symbols to which an arbitrarily assigned meaning and/or arrangement has been given which, when deciphered, communicates specific information or intelligence, Hyde [74] 1976.

4.1 AN HISTORICAL PERSPECTIVE

Classification and coding systems have received varying levels of attention over a long period of time with early notable advances including the hierarchical classification of flora and fauna by the Swedish botanist Linne (1707-1778) and the Dewey numerical classification systems (1876) which provided 1,000 book classes and relative index.

The importance that F W Taylor attached to the role of classification systems within his philosophy of 'Scientific Management' is shown by H K Hatheway, a colleague of Taylor at Tabar Manufacturing in 1904, when addressing the Taylor Society in 1920 quoted Taylor as saying, Hyde [74] 1976:-

"Classification is essential to an orderly arrangement of the facts relating to a business and to the orderly conduct of its activities. During the period of development and installation of a system of scientific management is is especially helpful to a proper visualisation and understanding of the business and its problems as well as the conduct of the work".

4.2 INDUSTRIAL CLASSIFICATION AND CODING

Hyde [74] 1976, defines industrial classification as:-

"A technique for arranging the individual items comprising any aspect of a business in a logical and systematical hierarchy whereby like things are brought together by virtue of their similarities, and then separated by their essential differences".

The importance attached by Taylor to classification systems has since been endorsed by many observers including Drucker [75] 1954, who although directing his attention to organisation theory said, to quote:-

"Get the facts, is the first commandment in most texts on decision-making. But this cannot be done until the problem has first been defined and classified. Until then, no-one can know the facts; one can only know data. Definition and classification determine which data is relevant; that is, the facts. They enable the manager to say what is misleading".

Drucker's observations were well-timed because the immediate post-war years witnessed considerable advances in the use of industrial classification systems for information retrieval particularly in the fields or Group Technology with the early work of Sokolovsky (1939) followed by Mitrofanow and Opitz in later years, gave momentum to advances in the design of 'component statistic' classification systems utilising hierarchic meaningful character systems as against the more generally open-ended approach to be found in other areas of statistical analysis.

Houtzeel [76] 1976 summarises the two broad categories of classification systems to be found within the disciplines covered by the general heading 'Group Technology', and these are:-

(a) Hierarchical (Monocode) systems

(b) Chain-structured (Polycode) systems

A brief description of each category is as follows:-

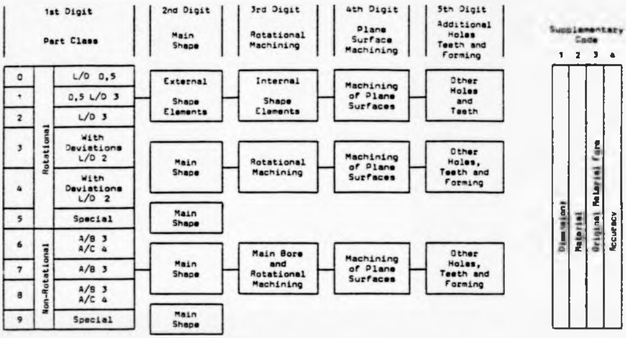
4.2.1 Hierarchical Systems

Hierarchical systems are designed primarily for design or engineering departments. Using a numeric code (typically from six to twelve characters), these systems provide a means of coding and classifying drawings to facilitate the retrieval and eliminate unnecessary duplications. In a hierarchical system, the meaning of an individual character in the part classification number is dependent on the previous character in the classification number, and does not represent a discrete bit of independent information. The first character of the number thus defines a type of part 'shaft', for example, the second defines a type of shaft, the third defines a further refinement of the second character, etc. The Opitz system is a typical example of this category and is shown in Figure 14.

4.2.2 Chain-Structured Systems

Chain-structured classification systems are structured in a different way. Every character in the part classification number represents a distinct bit of information, without regard for the previous character. Every character in the classification number thus represents a "small building block" of the total part. One character may be used to define form, for example, the next dimension, etc. By chaining these blocks together, a complete part can be described in a manner which is internally consistent with the description

(A) THE STRUCTURE OF THE MAIN FORM CODE AND SUPPLEMENTARY CODE



(B) AN EXAMPLE OF SECONDARY CODES FOR OPERATION TYPE AND SEQUENCE

Designation	Form Code	Supplementary Code	Sawing	Boring, Rough	Turning, Centre Lathe	Turning, Turret	Inspection	Milling Keyway	Heat Treatment	Grinding, Cylindrical	Grinding, Surface	Turning, Centre Lathe	Turning, Turret	Inspection	Hobbing, Teeth	Shaping, Teeth	Milling Keyway		Deburring	Inspection	Hobbing, Teeth	Grinding, Cylindrical	Grinding, Surface	Grinding, Teeth	Inspection
Spur Gear			28	41	01	11	25	54	66	31	33	01	11	25	25	53	54		73	25	25	31	33	34	25
	04166	2409	x	x	x			x	x			x		x		x			x			x	x	x	
	01106	2409	x	x		x			x				x	x		x						x	x	x	
	14166	2409	x	x	x		x	x		x	x				x		x		x	x				x	x
	01166	2408	x	x		x	x	x		x	x				x				x						
	14166	2408	x	x		x	x								x		x		x			x	x		
	04106	2408	x	x		x	x								x							x	x		
	01106	3478		x	x		x								x							x	x		
	14166	3409	x	x	x		x			x	x						x				x			x	

Source: Remmersweal and Schilperoot (79) 1971

THE OPITZ CLASSIFICATION SYSTEM

Figure 14

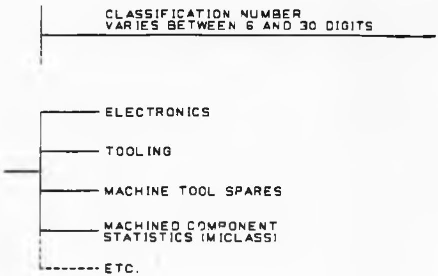
of all other parts in the system. The MICLASS system developed by TNO during the mid-1970's is a typical example of a chain-structured system, and although difficulty was encountered in obtaining specific information due to commercial implications, a general overview of the commodity categories to be covered by the system, and the more well known component statistical routings are given in Figures 15a and 15b respectively.

Rose [77] 1977 states that there are in excess of 120 varieties of Group Technology orientated component classification and coding systems, the more prominent of which are reviewed by Knight [78] 1972 and system comparisons are given by Remmerswaal and Schilperoot [79] 1971.

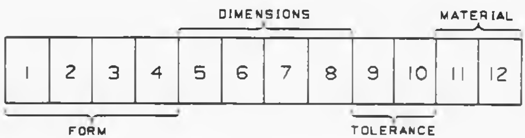
Two systems which have a broader, commercial, applicability are those of NATO and Brisch, both of which are discussed in the following sub-section.

4.2.3 NATO System (General)

The classification and coding systems mentioned in the previous sub-sections are orientated towards establishing control within a manufacturing environment. A system which goes well beyond the requirements of manufacturing and into a much broader field of management control is the NATO equipment codification system which is reviewed at length by Mitchell [80] 1972. Based on the US 'Federal Catalogue System' it was adopted as a NATO standard in 1957 and has inbuilt its own classification, naming and hierarchies of coding systems. Its main attributes are the grouping of interchangeable products and commodity specifications. Its limitations for general use include its reliance on a large confidential data base, the extensive system maintenance required, and as it is based on non-significant characters may create compatibility problems with other in-house technological classification systems.



(a) Multiclass Categories



(b) MICLASS - Machined Component Statistics

MICLASS SYSTEM

Figure 15

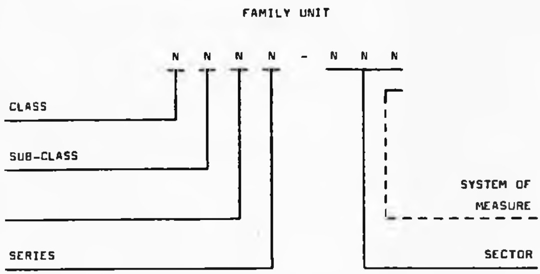
4.2.4 <u>Brisch System (General)</u>

There are two types of classification/coding systems generally associated with the Management Consultants, Brisch Birn & Partners Limited. The first system is the well-known 'monocode' which is a typical example of a significant character hierarchical structure whereby each code character is qualified by the preceding code and, in turn, qualifies the succeeding code. In principle the monocodes are used as the universal code recognised by all functions as the base identification for a component.

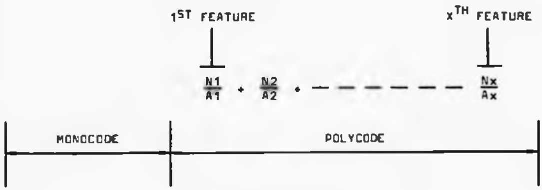
The second system, referred to as 'polycodes' are essentially open-ended strings of significant characters which contain specific information which is of interest to only a limited number of system users. In practice the polycodes act as 'trailer' codes to the main monocode, and an overview of each system is given in Figure 16.

Astrop [81] 1978, expands on the question of system flexibility by discussing the experiences of several companies in implementing the broad approach of a concept known as the 'Brisch Wheel' which classifies a company's business activities into ten main classes, reference to Figure 17. This simple principle provides a classification structure which can be moulded to individual company's requirements and part explains the claim by Brisch-Birn that there is no such thing as a Brisch Classification System as no two systems are alike.

Houtzeel [76] 1976 argues that systems such as Brisch, Opitz, etc., which are based on product functions have a number of shortcomings. For example, changes in products require that produce dependent systems be overhauled. Additionally, visits to certain companies discussed previously in section 3.7, such as Hopkinsons, Coventry Climax and Aveling Barford where Brisch based systems are operated across selected commodity groupings, revealed extremely cumbersome classification/coding manuals which are error prone to manually orientated paperwork maintenance systems.



(a) Brisch Monocode

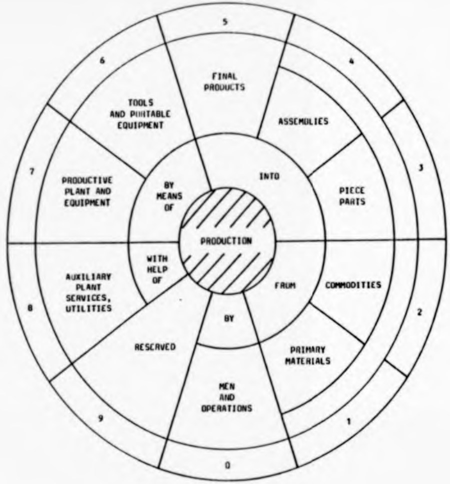


(b) Brisch Polycode

Source: Hyde (74) 1976

BRISCH MONO AND POLYCODES

Figure 16



Source: Astrop (81) 1978

BRISCH CLASSIFICATION PLAN

Figure 17

4.3 CUTTING TOOL CLASSIFICATION AND CODING SYSTEMS

A review of the application of classification and coding systems with respect to cutting tools is contained in the following sub-sections.

4.3.1 Mnemonic Codes

The visits to the companies referred to in section 3.7 revealed that the majority had implemented Mnemonic based coding systems. This is not, perhaps, surprising as the most well known mnemonic system is F W Taylor's tool code which formed the basis of Twist Drill Manufacturers' Association code for perishable tools and was implemented during World War I and was in continuous use up until World War II when it began to break down due to an increasing number of varieties. Typical examples of a general mnemonic code and, more specifically, Taylor's mnemonic code are given in Figures 18a and 18b respectively.

4.3.2 Commodity Classification

Again a commonly used system quoted in the Tool Engineers' Handbook [58] 1959. As Figure 18c shows, the system is based on successive sub-classifications, but with the mnemonic system, is prone to erosion with the introduction of new tooling families.

4.3.3 Brisch (Cutting Tools)

Reference to Figure 19 gives an example of the Brisch (monocode) system as applied to a specific family of cutting tools, i.e. hard metal tipped brazed tools.

4.3.4 PERA - Sequence Technology

As part of the work undertaken under the general heading 'Sequence Technology' PERA pursued a vector analysis approach to the classification of turning tools, reference to Figure 20a. While this work offers areas

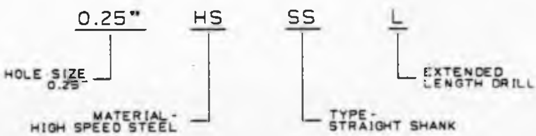
D — BORING, DRILLING, REAMING AND TAPPING TOOLS

DD — DRILLING

DDT — TWIST DRILLS (TWO FLUTES)

DDTS — STRAIGHT SHANK TWIST DRILL, STANDARD LENGTH

(a) General Mnemonic Code



(b) Taylor's Mnemonic Code

T - 10 (MAIN CLASS) - CUTTING TOOLS

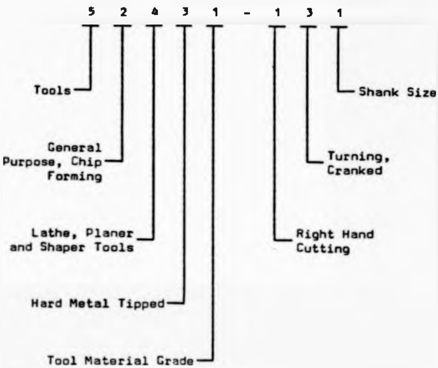
T - 11 (SECONDARY CLASS) - DRILLS

T - 11 - 015 (SUBDIVISION) - 1/64"DIA. (.015") DRILL

(c) Commodity Classification

GENERAL TOOL CLASSIFICATION AND CODING SYSTEMS

Figure 18



5 - Class

2 - Sub-Class

4 - Group

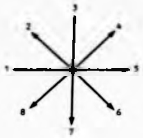
3, 1 - Series

1, 3, 1 - Sector

Source: Hyde (74) 1976

BRISCH MONOCODE : HARD TIPPED TOOLING

Figure 19



Element types expressed as a 'Vector Star'

E.g. Part-off and Chamfer Tool - 686

SHAPE VECTOR PARAMETERS					
Shape Vectors	Tool Material Grade	Size	X	Length	Z

<u>Source</u>: PERA (82)

(a) <u>PERA - Sequence Technology</u>

A - Tool Material Type

B - ISO Grade (Application)

C - Tool Manufacturer

D - Manufacturers Code

E - Special Features

<u>Source</u>: PERA (83) 1976

(b) <u>PERA - Machinability Data Bank</u>

<u>PERA - TOOL CLASSIFICATION AND CODING SYSTEMS</u>

Figure 20

of interest the concept is limited to tool/component statistics and does not offer a practical approach for developing an overall classification structure for the wide ranges of cutting tools and related accessories likely to be in use in mass production industries.

4.3.5 PERA - Machinability Data Bank

The most comprehensive cutting tool classification and coding system encountered in terms of technological specification/definition was that used by PERA for their in-house machinability data bank [83] 1976. Reference to Figure 20b reveals a chain-structured system which is purpose-designed to achieve technological control at the cutting edge and contains significant characters relating to tool material type, material grade, special features and cutting geometry.

However, as with the previous sub-section this approach has several weaknesses in terms of practical implementation in industry and these include:-

(a) The system is clearly purpose-designed and omits such important features as tool shape, chip breaker styles, etc.

(b) It does not present an overall classification structure for all cutting tools and accessories.

(c) The number of characters utilised is far too great for day-to-day industrial operations.

(d) The chain-structured, polycode approach could be confusing for less technically orientated personnel, i.e. storekeepers, commercial clerks, etc.

4.3.6 The Hal System

Halevi [84] 1980 discusses the role played by cutting tool classification and coding with the Hal (Hal meaning all-embracing in

Hebrew) computer orientated manufacturing philosophy. Figures 21a and 21b identify the system in use which is, yet again, a hierarchical significant character system.

Halevi recognises the high cost of installing such systems and the requirement for continuous maintenance:-

> "New technologies are introduced into the plant, hence creating a need for new types and groups of materials. Moreover, this system does not last forever. Reorganisation and changes in the classification and codes have to be made every six to ten years. The limitation of the code length also limits the extent to which the desired secondary objectives are achieved".

4.3.7 National and Universal Systems

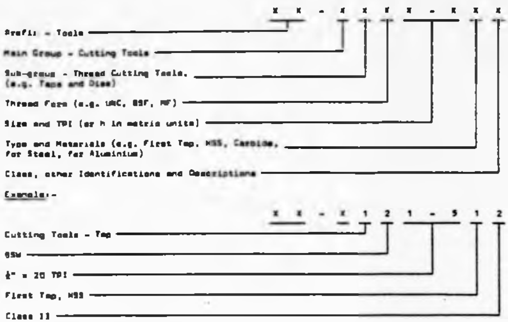
In terms of cutting tools there are three broad areas of interest:-

(a) The NATO equipment codification system (initially discussed in sub-section 4.2.3). Reference to Figure 22a.

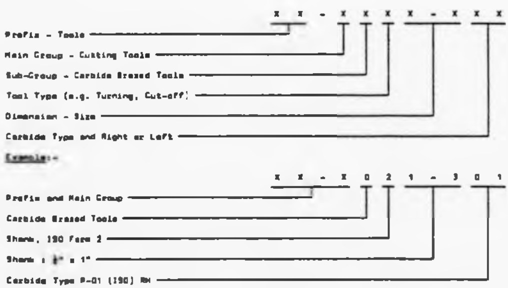
(b) British Standards. Reference to Figure 22b.

(c) International Standards Organisation (ISO). Reference to Figure 22c.

All three are comprehensive systems which provide the opportunity of linking tool shape, dimensional and material specifications. However, the weakness in (b) and (c) is that they do not offer a classification structure for the wide range of cutting tools and accessories to be found in a machine shop and because of this no individual system can be as the working 'in-house' classification and coding system.



(a) Thread Cutting Tools

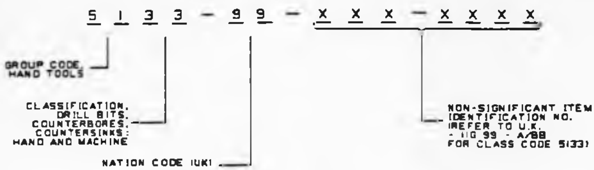


(b) Tools - Cutting - Carbide Brazed

Source: Malawi (84) 1980

THE HAL TOOL CLASSIFICATION AND CODING SYSTEM

Figure 21

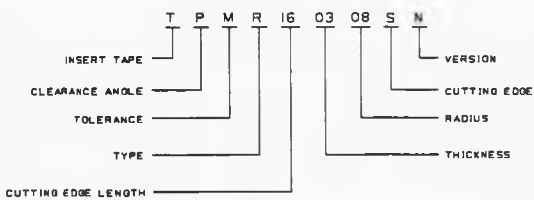


(a) The NATO Stock Code

ORDER OF MARKING	0	1	2	3	4	5	6
	TYPE OF ABRASIVE	NATURE OF ABRASIVE	GRAIN SIZE	GRADE	STRUC-TURE	NATURE OF BOND	TYPE OF BOND,ETC
EXAMPLE	51	A	363	L	5	V	23

(b) British Standards

An example of the complete designation of a grinding wheel specification



(c) International Standards Organisation (ISO)

The designation of an indexable insert

NATIONAL AND UNIVERSAL - TOOL CLASSIFICATION AND CODING SYSTEMS

Figure 22

CHAPTER FIVE

5.0 A SYSTEMS APPROACH TO TOOL CONTROL

Chapter Two has shown that previous attempts to gain control over consumable tooling within the Company have lacked direction, which has been underpinned by the absence of any in-depth understanding of the problem, and as a result has attracted little attention in terms of senior management priority. Equally the work of others has concentrated on areas of specialist activity within the subject area and a systems approach, i.e. the study of the 'whole' problem to help management achieve control over tooling at an operations level, has been neglected.

Despite these shortcomings important lessons can be learnt from an historical analysis as to why the Company has failed to gain control over such a vital area of its business activity, and certainly direction offered by others can be utilised in structuring a sound platform from which the problem of tool control can be analysed and the necessary control mechanisms developed.

5.1 PROBLEM DEFINITION

The highest level of problem definition is taken from the NEB's submission to the Government in December 1979 of the Company's 1980 Corporate Plan/Budget [2] in which the reduction of inventory levels and improvements in manufacturing productivity were seen to be essential in terms of BL Limited's future survival and viability.

Clearly the control of cutting tools would have a significant role to play with respect to inventory levels and productivity and to help begin to understand the problem in contributing to the achievement of the objectives, as set by the NEB, the level of research focus was adjusted to concentrate on the four factories which comprise the Birmingham Operations Division of the Light Medium Cars Group of Companies.

The problems being faced by senior management within Birmingham Operations require quantitative and qualitative statements and these are given as follows:-

5.1.1 Quantified Statement

The main features of the Birmingham Operations tooling activity profile are:-

(a) The number of tool records, i.e. individual tool code numbers, is estimated to be in excess of 75,000 items being stocked in 16 individual tool stores located throughout Birmingham Operations.

(b) Total inventory £6.43 million.

(c) Annual expenditure £5.28 million.

(d) Inventory turnover ratio = $\frac{6.43}{5.28}$ = 1.22 years, or 14.6 months.

(e) Productivity in terms of metal removal activity is extremely difficult to measure, but later discussion with respect to Coventry Engine Plant established a simple index of monitoring weekly standard hours generated by the Power Train cost centres at the Plant compared to the cutting tool and related accessories inventory.

Therefore, to contribute to the objectives as established by the NEB the proposed tool control system should be seen to be reducing the total inventory and subsequent expenditure against the number of standard hours generated.

5.1.2 Qualitative Statement

A summary of the underlying reasons for the general lack of control to be found with respect to tooling is as follows:-

(a) An absence of Corporate standards relating to cutting parameters resulting in widespread disparity in levels of productivity between work areas.

(b) The lack of a Group-wide tool classification and coding system.

(c) Inadequate stock control systems.

The net results of the inherent inefficiencies contained in (a), (b) and (c) were:-

(i) Custom and practice prevailing throughout all areas connected with tooling decision-making.

(ii) Excessive tool stocks.

(iii) Inefficient tool procurement mechanisms due to the prevention of the potential for Group-wide bulk purchasing.

(iv) The fragmented approach to tooling decision-making was reflected in the minimal control over the introduction of new tool types leading to large ranges of tool type varieties being held in stock.

(v) Duplication of effort in indirect hourly paid and staff functions, i.e. tool setters, storekeepers, process planning and purchasing.

Simply, the situation was semi-chaotic.

5.2 SYSTEM OVERVIEW

It would be misleading to imply that a system was initially designed and subsequently implemented. In reality the research began against a background of extremely broad objectives, namely to achieve reductions in tooling inventories and to contribute to general increases in productivity within the Birmingham Operations Group of factories. Additionally, while certain system design prerequisites were in mind from the onset of the research work, notably the role and early development of IMPS, much of the interactive nature of ATOMS only became clear when faced with the practicalities of system implementation into the receiving factory, and the ensuing management expectation of positive results.

5.2.1 Research Location

From the onset of the research programme a fundamental principle was adopted which was that the manufacturing requirements of the individual machine tool dictated the service required from such supportive systems as tool material supply and control. In other words, the priority was to achieve efficient 'spindle management'.

Therefore, to begin to understand the requirements of the manufacturing system, initial research activity moved away from the extremely sensitive area of excessive tooling inventories and concentrated on the tooling problems being encountered on a small bank of machine tools within a single machine shop, i.e. the single- and multi-spindle bar automatics shop at the Longbridge Plant. This quickly identified two base problems with respect to cutting tools and these were:-

(a) The absence of any Company-wide tooling technology 'standards' encouraging personnel such as setters, foremen, process engineers, etc., to make personal decisions on the implementation of cutting tool type and machine tool operating conditions. In this environment formal process planning documentation rapidly became out-of-date, and in many cases improvements in cutting parameters were as a result of personal initiative by the local personnel, and were not recorded for the benefits of other machining locations.

(b) The absence of formal tool material supply systems to service the requirements of high component volume machine tools which were critically linked to car assembly demands.

A number of extremely disturbing features came to light in this area and include:-

(i) The considerable influence that a storekeeper had in terms of determining stock levels and tool re-order quantities.

(ii) The high level of dialogue that took place between the storekeeper and the machine tool setters in determining alternative tool choice.

(iii) The informal working relationships that developed between foremen, tool setters and the representatives of tool supply companies, resulting in the latter having full access to the machine shops, a major contributory factor to the wide ranges of tool varieties held in stock.

At this early stage, a series of tool trials took place on the machine tools under observation, and by a series of very simple technological changes an annual saving of £4.5K in direct tool costs was achieved.

Having achieved this limited level of success local management were keen to maintain the research work activity at the level of the bar automatics shop, but it was recognised that this direction would achieve little in understanding the interactive nature of the problems of tool control, particularly when viewed from an operational level. Wishing to understand the problem at a different level of focus, the research activity was then changed to cover the four factories within Birmingham Operations, i.e. Longbridge, Drews Lane, Coventry Engines and Triumph Radford. After a short period of time the range of problems quickly became apparent, typified by the absence of machining standards, ineffective multiple tool classification systems, inadequate inventory control systems, etc., were common to all four locations and research time was being diluted by the spread of geographical activity. Because of this the decision was taken to concentrate the research activity at one plant, develop a routing through a tool control system, validate the benefits, and subsequently expand the control mechanisms to the remaining locations. Coventry Engine Plant was chosen as the centre of the research activity for the following reasons:-

(a) The manufacturing activity at the Plant ranged from jobbing type work through to flow line production on major dedicated machining facilities. In addition to this only one of the 4,130 machine tools at the Plant was NC based with the remainder being of conventional design, a situation which typified the Power Train activity throughout Austin Morris at the time of writing.

(b) Because the Plant was responsible for machining a high level of component spare parts as well as high volume components, it provided an opportunity of studying the machinability of the vast majority of component material specifications to be found within BL Limited.

(c) Because of the mix of components, the range of material specifications, the age/range and conventional nature of the machine tools, high tooling inventory levels and a complete absence of computerised systems in tooling related areas, it was considered that, as a whole, the Coventry Engine Plant was a fair reflection of the tool control problems likely to be encountered elsewhere within Birmingham Operations.

5.2.2 Linked Systems

Previous chapters have discussed in some detail the tool control problems being faced by senior management across Birmingham Operations at the commencement of this research work, and the key factors to emerge were:-

(a) Design criteria for a tool control system should recognise the requirement to achieve technological control as well as control over tool material supply.

(b) Custom and practice prevailed.

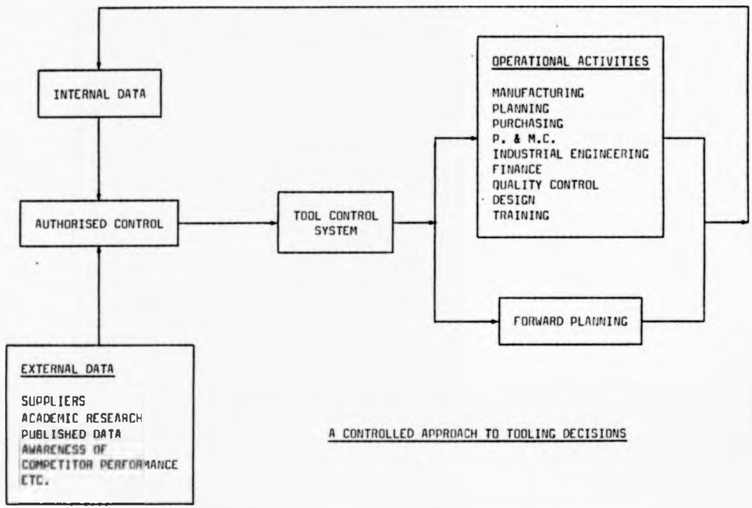
(c) Attempts to gain control over tooling-related areas had failed because of parochial attitudes and blinkered vision in terms of problem definition and understanding.

Against this background a routing through a tool control system was developed and implemented at Coventry Engine Plant which accommodated the requirements of item (a), removed the inherent inefficiencies of item (b) and did not repeat the mistakes of item (c).

5.2.2.1 Authorised Control

Reference to Figure 23 shows a conceptual system design produced during the early stages of research. A prerequisite to any future system had to be a recognised authorised in-house control mechanism for tooling related information and tool material supply, which controlled the tooling requirements for operational and forward planning activities. Such a mechanism would act as a system input filter with respect to external, i.e. non-company related sources, typified by tool suppliers' literature, academic publications, etc., and likewise internally generated information, e.g. variance in practice from identified company tooling technology related standards.

An overview of the development of such a system is contained in the following sub-sections.



A CONTROLLED APPROACH TO TOOLING DECISIONS

Figure 23

5.2.2.2 <u>Inputs and Outputs of the Manufacturing System</u>

Section 5.2.1 gave a brief resumé of initial observations with respect to tool control when studying a small bank of machine tools within the Longbridge Bar Automatics Machine Shop.

Discussion by Spur [19] 1971, helps to put these initial observations into a system context with an analysis of the inputs and outputs of the manufacturing system, reference to Figure 7, page 45. While Spur identifies the tool control system as a sub-system of the manufacturing system, it is clear that as a sub-system it cannot be studied in isolation. The efficiency of the tooling input into the manufacturing system will require control over the following tooling related aspects:-

(a) Correct technological application.

(b) Optimal tool material supply.

(c) Environmental control.

Therefore, while the 'black box' approach to manufacturing systems is of help as a starting point, it can detract from understanding the complexities of sub-system interaction which is a prerequisite to achieving the eventual optimisation of the manufacturing system.

Having identified in systems terms the areas of prioritised control and the implications of sub-system interaction, it is now possible to turn to others for further direction in system development.

5.2.2.3 <u>Manufacturing Sub-Systems</u>

Section 3.5 made reference to the work of Bhattacharyya and Coates [39], and Peklenik [22]. Their observations have been utilised as the platform from which the tool control system to be described in later sections has been established. Their analysis identifies three main sub-systems as being critical to establishing overall control which were identified in the previous section as:-

(a) Technological control - Manufacturing technology system.

(b) Tool material supply - Manufacturing Management system.

(c) Environmental control - The setting and maintenance of environmental control standards would require inputs from both the technology and management systems.

5.2.2.4 System Design Concept

The major influences on the initial tool control system criteria were:-

(a) System Requirement

To achieve:-

(i) Control over the application of metal removal technology.

(ii) Tool material supply.

(iii) The installation of necessary disciplines to achieve control over tooling related aspects within the manufacturing systems environment.

(b) System Design

(i) To avoid replicated data.

(ii) To install a system input control which facilitated systematic and dynamic update of the data base.

(iii) Capability for system expansion in terms of:-

1. Geographic mobility, i.e. to be installed at several manufacturing locations and to have the flexibility to accommodate problems unique to the receiving plant.

2. The provision for technological expansion in terms of new metal removal processes and techniques.

3. To be mindful of potential expansion links into larger CAD/CAM systems.

(c) <u>System Management</u>

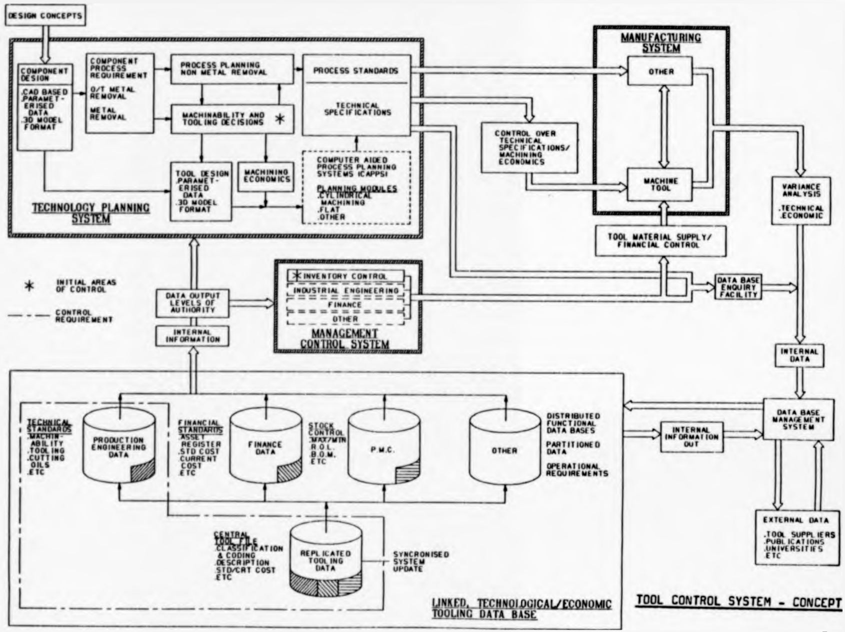
(i) To utilise the full potential of microprocessor based technology.

(ii) To establish a hierarchy of control whereby certain critical features became the responsibility of a small number of selected, highly trained personnel within Birmingham Operations.

Reference to Figure 24 shows the eventual system concept which superimposes the principles of control as identified by Spur, Peklenik, Bhattacharyya and Coates, onto additional systems requirements of restricted authorised control and a Birmingham Operations technological/ economical tooling data base. In principle the data base supports the requirements of the technology planning and management control systems and system update can be through either internal feedback in the form of variance analysis reports from the manufacturing system, or through the incorporation of external data. An important feature of the concept is that while the initial system boundaries are shown to be in-house the external data links are considered to be an essential link in the dynamic update of the system and, therefore, external bodies such as tool suppliers, research institutions, etc., are considered to be part of the system although their input is strictly controlled. Indeed if the "universal level" of focus as described by Kilgannon [17] 1980, was to be adopted a 'total' tool control system would question the supply of raw materials utilised by the tool suppliers, review their internal manufacturing facilities and their ability to meet the commercial and technical requirements of the receiving company's business system.

At this stage genuine practical problems as described in the following items have been given a lesser priority than the achievement of a tool control system routing. Such aspects include:-

(a) Multiple tool stores and their impact on tool stock levels.



TOOL CONTROL SYSTEM - CONCEPT

Figure 24

(b) The absence of any formal work schedule control within the Tool Rooms, with its subsequent impact on tool regrind costs.

An insight into the concept of the tool control system is as follows:-

(a) Technology Planning System

The two broad areas of activity within this sub-system are:-

(i) Design - which includes, components, tools, jigs/fixtures, etc., and to a degree can include such aspects as factory layout.

(ii) Process planning - which includes metal removal and non-metal removal activities.

The prime activity of this sub-system is to control technically and economically the operational standards of the manufacturing system. In a Power Train environment there are tooling implications throughout the technology planning system ranging from the metal removal implications at the component design stage, through to selecting alternative tools for a unique problem that may occur within the manufacturing system.

Against this background a decision was made to develop a control mechanism which concentrated on establishing technological disciplines at the point of metal removal, i.e. machinability and tooling standards. Therefore, the initial decision was to gain control over the operational requirements for individual process operations. Having gained this level of control the philosophy would be to expand the system to combine the individual process operations to generate process plans, and further expansion would potentially include machining economics, and the linking in to Industrial Engineering standards to facilitate process estimating packages.

Special purpose form tool design requirements were not considered at this stage apart from the machinability implications of tool material type and respective tool geometry.

(b) Management Control System

Of prime importance within this sub-system was considered to be the control of tool material supply combined with a facility to monitor Industrial Engineering and Finance Departments' 'variance from operational standards' reports to facilitate formal disciplines within the Manufacturing System. Other benefits, particularly in terms of tool procurement, were not given an immediate priority in the early stages of the system development as it was felt that having achieved control within the Manufacturing System, the adherence to the resulting process operational standards would provide a sound platform from which the Purchasing Department could take advantage.

(c) System Management

Having established a platform for developing the necessary control over tooling technology, tool material supply and environmental control, the ongoing maintenance of the control mechanisms were then considered.

In this area the two key features to be incorporated were:-

(i) Restricted and authorised control of the system.

(ii) Efficient information storage, retrieval and update.

Further reference to Figure 24 shows that the conceptual system has the required input/output control in the form of the data base management system, a term used at this stage in its broadest sense. In addition, recognition is given to the syncronised update of replicated tooling related data whereby any data used by more than one functional department is held in a central tool file. Typical examples of such data and their originating departments include:-

(i) Classification and coding (Production Engineering)

(ii) Technological specification (Production Engineering)

(iii) Part description (Production Engineering)

(iv) Standard/current cost (Finance)

The originating departments, as shown in brackets, would maintain responsibility for supplying the update of the specified data, known as partitioned data, within the central tool file. Additionally, the respective departments would also have the facility to update its own local tooling related data. Examples of such data would include:-

(i) Production Engineering

1. Tool trial evaluations
2. Alternative tool choice

(ii) Finance Department

1. Off-standard reports

(iii) Purchasing Department

1. Supplier evaluation/address
2. Levels of discount

(d) System Operation

The tooling data base would provide and monitor, through feedback, the operational standards of the manufacturing systems with respect to tooling related activities. The data would be accessible through levels of authority by user areas within the technology planning and management systems, but dynamic update would only be through a formal control mechanism with, again, levels of authority for system update.

Conceptually the implementation of such a system would eliminate the problems discussed in Chapter Two.

The following sub-sections present an overview of the stages involved in moving from such a design concept to the eventual tool control system implemented at Coventry Engine Plant.

5.3 TOOL CONTROL SYSTEM (ATOMS)

The system routing which was implemented at Coventry Engine Plant is known as ATOMS, an acronym for Automated Tool Management System. Reference to Figure 25 presents an overview of the ATOMS system which is divided into two clearly defined sub-systems; firstly the 'Technological Control and Update' system which is essentially a process planning aid, selecting appropriate cutting tool materials and cutting parameters for given component material/machine tool combinations; and secondly the 'Management Control' system which comprises four main control features, and these are:-

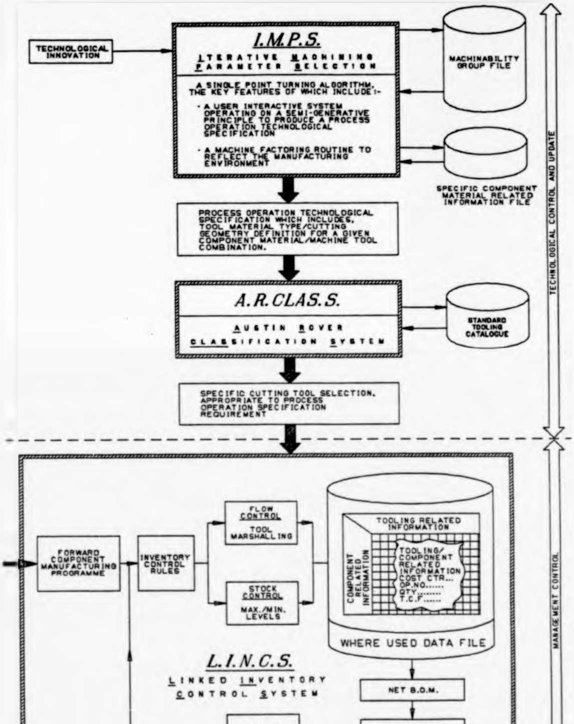
(a) Inventory control

(b) Order tracking

(c) Material receiving

(d) Inventory accounting

The essential 'link' between the Technological control/update and management control sections was the requirement for an effective tool classification and coding system, the design and development of which attracted a large proportion of research time. A further insight into the two main control sub-systems of ATOMS, and the classification/coding system, are given in the following sub-sections to help the reader establish a routing through the system philosophy before commencing the details of system design, development and implementation strategy contained in the following chapters.



A.T.O.M.S. (AUTOMATED TOOL MANAGEMENT SYSTEM) CONCEPT

Figure 25

5.3.1 Technological Control and Update

The technological control and update sub-system is known as IMPS (Iterative Machining Parameter Selection). IMPS is an interactive system designed to act as an aid to process planning engineers working in a conventional machine tool environment. The system was initially developed for single point turning, and given component design specifications (including tolerances and material type) and machine tool selection, IMPS offers the facility to generate the following balanced outputs, aimed specifically at achieving technological control at the level of the individual machining process operation:-

- Surface cutting speed
- Rotational speed
- Feed rate
- Depth of cut
- Specific cutting force
- Power requirement
- Tool life
- Standard time
- Tool change frequency
- Recommended tool grade

Key features of the IMPS sub-system include:-

(a) Initial algorithms were designed to capture process planning decision-making procedures, adopting the philosophy of minimising user input wherever possible.

(b) System output is based on semi-generative principles utilising a combination of mathematical equations and tables of discrete data.

(c) The system comprises two main files of information and these are:-

(i) Component material machinability groupings and recommended tool material types.

(ii) Specific component material data.

With respect to items (i) and (ii) above the data has been established as a result of in-house tool trials thereby reflecting unique, local operating conditions. Similarly the final IMPS process operation specifications have been validated within the machine shops of the receiving factory.

The achievement of the system output validation was established through the implementation of 'factoring routines' which were used to down-rate predicted 'ideal' spindle speeds, and to adjust depth of cuts, to compensate for machine tool age, condition, structural design, fixturing arrangements, etc., and for variations in component surface finish with respect to pre-machined conditions and hardness.

(d) The system contains interactive sub-routines where if an individual element of the final system process operation specification is either unachievable, e.g. spindle speed, or is undesirable because of other imposed limitations, e.g. balancing tool lives in multi-tool set-ups; the user has the facility to set an individual element as the limiting factor and then reproduce a 'rebalanced' final process specification through user/system dialogue and the inbuilt interactive sub-routine.

5.3.2 Management Control

The main emphasis in the management control system was directed towards tool material supply/usage control and these disciplines are covered by a system referred to as LINCS (Linked Inventory Control System). The key area of control within LINCS is a file of information known as the tool/component 'where-used' file. Base information within this file includes:-

- Cost centre details.
- Process routings which identify tooling by operation and machine tool.
- Quantity of tools per operation and respective tool change frequencies.

The 'where used' file, comprising these simple tables of discrete information, can be accessed at a primary level by either a tool type or component type enquiry. The tool type enquiry generates a summary listing the part identification numbers of all the components upon which the specific cutting tool is used. Likewise the component type enquiry is structured in a single level explosion format which generates a tool parts list for a specific component number.

The base information for the 'where used' file resulted from a major data collection exercise within the machine shops at Coventry Engine Plant followed by IMPS assisted cutting tool trials. However, having completed this task an essential area with respect to tool control had been established from which a series of applications programs were written, i.e. tool material issue/receipt, and for the generation of bills of tooling material support the manufacturing programme by cost centre.

An overview of the inventory control rules adopted reveals that the cutting tools and related accessories are classified into three broad categories, these being:-

(a) Standard, 'off the shelf', tools linked to high volume components.

(b) Slow-moving standard tools and low cost special tools.

(c) High unit cost tool e.g. broaches, gear cutters, large grinding wheels.

For the purpose of the ATOMS routing category (a) received the highest level of attention and the main part of the tool material supply system was based upon the principles of 'semi-flow control' whereby knowing the forward manufacturing programme for all high tool usage components it was possible to input this data, supported by applications programs, into the tool/component 'where used' data files to generate a gross bill of tooling material. This material quantity was then adjusted by comparing the gross requirement to the existing stock level held in the tool stores and pending deliveries to generate a net bill of material.

Traditional stock control procedures of setting max/min levels and re-order levels against historical usage patterns were implemented for category (b) items. Category (c) did not receive any detailed attention during the research work from a systems point of view and control was undertaken on a manual basis monitoring the forward requirement against existing stocks and tool regrind lives left in the system against lengthy procurement lead times.

Tool procurement control concentrated on monitoring purchase requisitions and tool deliveries. In selected areas, notably category (a) items, the manually intensive purchase requisition system was abolished in favour of placing an annual contract with the tool suppliers from which specific quantities of tools were called off on a weekly basis and invoiced against the receiving tool stores. Again by establishing an estimate for a twelve month forward manufacturing programme it was possible to combine this data with the tool/component 'where used' files to generate an annual tooling requirement for major volume components. Clearly, system feedback is always necessary with this approach for system update and this was initiated at various levels throughout the overall ATOMS concept.

Towards the end of the research work a further tool material supply initiative was taken and this was to develop the routing through a system concept whereby a tooling bill of material was generated for a specific cost centre against the following week's manufacturing programme. This requirement was then delivered in the form of a package of tools by each of the main tool suppliers servicing the needs of the Plant. The system was referred to as 'Tool Marshalling' and its mechanisms questioned the need to hold more than seven days' buffer stock of indexable inserts at any one moment in time within the Tool Stores at Coventry Engine Plant.

5.3.3 <u>Tool Classification and Coding System</u>

From the onset of the research programme it was recognised that a common tool classification and coding system would have to be developed, but its importance did not become apparent until faced with the practicalities of system implementation. The system developed is known as ARCLASS (Austin Rover Classification System), and is the vital link between the technological control and update system (IMPS) and the management control system (LINCS). ARCLASS is a semi-significant classification/coding system and its structure can be broken down into three main elements, and these are:-

(a) Commodity definition

(b) Technological specification

(c) Tool type family specified by dimensional variation

The commodity definition is based on the well-established hierarchical approach to classification and this element comprises five, fixed numerically assigned significant characters. The technological specification is based on a 'chain-linked' approach to classification and comprises a variable number of alpha/numeric assigned characters. It was found for system routing purposes that the technological definition could be accommodated with four fixed significant characters, but logic would maintain that certain tools not covered by the system routing may require a greater number of characters to classify individual technological specifications, and therefore as a concept the number in this element could be variable.

The final element, tool type family, was based on a simple block number system, comprising two fixed non-significant characters. At this final stage of the classification/coding system, the only classification variance is the dimensional characteristics of the specific tool and the simple block numbers are allocated accordingly.

5.3.4 System Operation

The full system (ATOMS) routing is divided into three key elements:-

(a) IMPS determines the technological standard for each individual process operation, and part of this specification includes recommended tool material/geometry for a specified component/machine tool combination.

(b) ARCLASS offers an information retrieval facility whereby an enquiry can be made relating to the families of tools held in stock with respect to the IMPS generated tool material/geometry specification.

(c) Having chosen a specific tool, LINCS then identifies the current component demand for the tool in question and adjusts accordingly to accommodate the new requirement.

Therefore, ATOMS controls the tool decision-making process from the planning stage through to the point of application. Adjustments to each element with the introduction of new tools, or deletion of old, becomes a mechanical procedures of system maintenance and update.

5.4 RESEARCH METHODOLOGY

While the concept of a system routing based upon a single tool family seemed ideal in theory, the practicalities of system implementation demanded that in certain sections consideration should be given to other tool families/related spares to accommodate the problems of medium-term system expansion. For this reason later sections will show that while IMPS was based primarily on single point turning, other sections, notably ARCLASS and LINCS, were expanded to establish control over several other tooling families.

Throughout the main body of the research programme the development of ATOMS was based on a 64k, core memory, microcomputer with associated peripheral storage.

CHAPTER SIX

6.0 TECHNOLOGICAL CONTROL AND UPDATE (IMPS)

All references relate to the IMPS single point turning module which was the first machining process to be developed, albeit the logic employed is similar for the majority of machining processes.

6.1 DATA CAPTURE AND ANALYSIS

In accepting that the construction of a generative type process planning module necessitates a degree of generalisation of data in order to minimise the volume being held, it was clear that the range of component material specifications being machined within the workshops at Coventry Engine Plant needed to be grouped together. The criterion used to establish similarity of materials and thus facilitate grouping was machinability.

The term machinability is in many ways a nebulous one, but the definition given by the Metcut Research Associates Inc [42] 1972 suggests that materials of like machinability should have similar surface integrity, tool life and power or force requirements when machined under similar machining conditions. This definition is the one that is accepted for this thesis with similarity of tool life being the predominant feature.

An analysis conducted upon a Pareto basis (ranked by the product of production volume and standard production hours per item) of the component materials being machined at the Plant revealed that a total of 36 ferrous material specifications predominated. This figure allowed for the confusing situation which prevailed whereby an identical component material specification could be quoted on process planning documentation by any one of three designations:-

(a) British Standard reference

(b) BL's own internal designation

(c) EN numbers which were still the most commonly used reference throughout the Plant despite the system's obsolescence.

On the basis of machinability groupings utilised in various publications (notably the Machining Data Handbook) and the experience of the tooling manufacturers, the materials were divided into six machinability groups for turning, the details of which are given in Figure 26.

It should be noted that non-ferrous machining activity at Coventry Engine Plant was minimal with a high percentage of aluminium based processes being outsourced to SU Butec Limited (part of the BL organisation) and the majority of brass/bronze based components being machined in the main multi-spindle bar automatics factories at Longbridge and Drews Lane.

Initially it was considered that the recommended machining parameter data provided by the Metcut Machining Data Handbook would form the basis of the IMPS machinability standards. Endeavour to implement the Metcut recommendations in the shop floor environment proved fruitless, however, because when applied to similar operations (i.e. similar component materials, tool material, machining parameters, etc.), disparities in tool life achieved were noted. It was a point of major concern that Metcut gave a range of tool lives achieved using their parameters (30-60 minutes), and no objective criterion given to signify end of tool life; it must, therefore, be assumed that the effects of the custom and practice surrounding tool changing in industry was implicitly included within the tool life range quoted. The problem of Metcut data generalisation caused by the wide range of data supply sources and the use of 'judgment' to interpolate and extrapolate beyond known data points was proving to be a major impediment.

MATERIAL GROUP	BRITISH STANDARD REFERENCE	EXISTING B.L. LTD. MATERIAL SPECIFICATION	AISI GROUPING (METCUT)	IMPS GROUPING	BRINELL HARDNESS
Free machining Carbon Steels Wrought	BS970(220 M07)	None	1116	1	170/200BH
	BS970(216M36/R)	FS6, FS6R	1132, 37, 39	3	201/255
	BS970(212M14)	HS12	1117 ·	1	170/200
Carbon Steels (Wrought)	BS970(070M20)	MS2	1015-1025 inclusive	1	170/200
	BS970(070M20)	None	1005-1025 inclusive	1	170/200
	BS970(070M26) BS970(080M30)	None	1009, 11, 13, 16, 18, 19, 20, 21 to 40	2	160/207
	BS970(080M40) BS970(080M401)	None	1035, 37, 38, 39, 40, 42, 43, 45	2	152/207
	BS970(080M40/R)	FS6, FS6R	1035, 37, 38, 39, 40, 42, 43, 45	2	201/255
	BS970(216M36)	None	1536	3	223/277
	BS970(120M36)	AS17, AS17T (FS6R - AS176T)	1536	3	248/302
	BS970(045M10)	None	1008, 9, 10, 12, 13, 15	3	170/200
	BS970(080M15)	HS12	1011, 13, 15, 16, 18	3	170/200
Free machining Alloy Steels (Wrought)	BS970(709M40/W)	AS23	4140	3	311/375
Alloy Steels (Wrought)	BS970(530M40/T)	AS17, AS17T (FS6R - AS176T)	5135	3	248/302
	BS970(805M17)	HS13R	4118	4	149/197
	BS970(637M17)	HS14T	8620, 8615	4	149/197
	BS970(805M20)	None	8620	4	156/207
Alloy Steels (Cast)	BS970(608M38/T)	None	8430, 8440	4	248/302
	BS970(605M36/T)	AS17, AS17T (FS6R - AS176T)	8430, 8440	4	248/302
Grey Cast Irons	BS1452 10/4 & 12	None	ASTM A48 Classes 25, 30, 35, 40 SAE G2500, G3000	6 6	163/207
	BS1452 14 & 17	None	ASTM A48 Classes 30, 35, 40, 45, 50 SAE G3000, G3500, G4000	5	187/241
	BS1452 or C560)) BS1452/220)	BLS 21 FC01)) FC05) FC01 +) 0.5% MO) FC55 + FC56	ASTM A48 Classes 25, 30, 35, 40 SAE G2500, G3000 ASTM A48 Classes 25, 30, 35, 40 SAE G2500, G3000 ASTM A48 Classes 30, 35, 40 SAE G3000	6 6 6	182/229
Carbon Steels (Wrought)	BS4360/40C BS1449/P/1 - 4P or 4GP 45/25P	HR15 CSA 128R	1005 - 1022 inclusive 1005, 6, 8, 9, 10, 12 1005 - 1020 (excl. 1010) 1005 - 1025 (excl. 1010 & 1020)	1	Approx. 100/140
Malleable Cast Irons	BS3333 - P33/34 BS310 B20/10 BS310 B20/10MC1 BS310 B340/12MC	None	40010, 43010, 45006, 45008, 48005, 50005 32510, 35018 32510, 35018 32510, 35018	6 6 6 6	170/220
Ductile Cast Irons (SG Iron)	BS2789	SNG 37/2	Ferritic - Pearlitic	5	192/269

COMPONENT MATERIAL MACHINABILITY GROUPINGS Figure 26

To overcome such limitations it was decided to collect the machining standards data from in-house trials conducted within the machine shops at Coventry Engine Plant. However, after a short period of time two fundamental problems were encountered, these being:-

(a) The increased specificity of data caused an inordinate increase in data volume which began to contradict the philosophy of a generative type system.

(b) The ability to establish an objective criterion to signify end of tool life. The heart of this particular problem lay in the long established custom and practice of machine tool setters/machine operators changing tools at 'convenient' times, such as the commencement of shifts, regardless of flank or crater wear evident upon the tool, or tool indexing in preference to manual slide adjustment to compensate for tool wear, etc. Also in the case of finish turning operations end of tool life is dictated by loss of component conformity to design tolerances rather than exceeding a predefined single tool wear limit.

Both of the above approaches seemed, therefore, to suffer inherent drawbacks and a new approach to the problem was required. There was clearly a need to establish a criterion for end of tool life upon an objective basis rather than the ad-hoc methods used upon the shop floor, and also a need to accommodate (and predict) the variability in that life which appeared to be strongly influenced by machine tool related characteristics without descending to a level of detail which would necessitate the storage of large volumes of data. It was, therefore, decided that machining data should be obtained under ideal operating conditions and then validated, utilising a factoring routine, to reflect the actual operating conditions of the range of production machine tools upon which the cutting tools under consideration were used. An attendant advantage gained by adopting this approach is that the data may be used in a predictive sense to support machine tool performance capacity stipulations made at the time of purchase and thereby overcome the problem of perpetuating mediocre machine tool design features.

Returning to the problem at hand of gathering reference machinability data, an obvious source appeared to be the tooling vendors responsible for supplying the cutting tools to Coventry Engine Plant. Of the, as then, twelve companies supplying indexable inserts to the factory only three were prepared to be involved in such an exercise:-

(a) Sandvik (UK) Limited - tungsten carbide machining in general.

(b) Seco Tools Limited - tungsten carbide and ceramic machining in general.

(c) SPK Feldmuehle - specialist ceramic machining.

The problem was discussed in greater depth with the three Companies involved and a request made to supply comprehensive cutting data for their respective standard ranges of tools against, in the case of Sandvik and Seco, the six machinability component materials as discussed earlier, and in the case of SPK, selected materials from within the groupings. With respect to the complete range of machinability groupings neither of the main Companies involved could supply the full range of data, but both requested further time to run additional in-house tool trials to complete the data packages as requested.

Therefore, against this background a series of tool trials were undertaken with the tool suppliers in question, under idealised operating conditions (within their own respective workshops), upon a range of machine tools of high static rigidity and dynamic stability, to establish the tool life for a range of cutting tool materials from within each machinability group. The criterion adopted to establish end of tool life conformed, by request, with the recommendations of British Standard 5623 [85] 1979, the limits adopted as signifying end of tool life for sintered carbide tools being as follows (reference to Figure 27):-

Flank wear - Average land width of 0.3 mm for regular wear in zone B

or

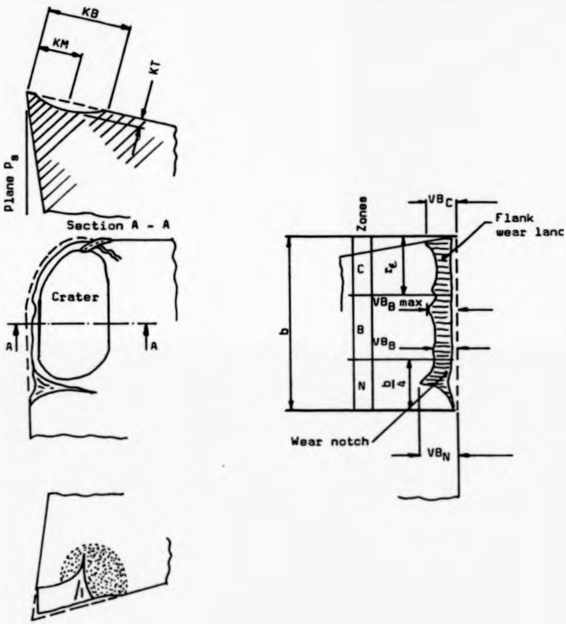
- Maximum land width of 0.6 mm for irregular wear in zone B.

NOTE:- This flank wear limit should be reached during the secondary, linear stage of tool wear characteristics, (reference to Figure 28).

For ceramic tooling materials the flank wear life-end criteria are identical to the above; cratering wear is replaced, however, by catastrophic failure.

It will be noted that the criterion used to determine end of tool life by flank wear (generally the more predominant tool wear mechanism within the automotive environment) is a fixed limit. In the shop-floor situation, however, the amount of wear achieved on a tool prior to its removal/indexing is related to component tolerance, particularly upon finishing operations.

Using the above criteria to signify end of tool life and conducting single point cutting tests according to the recommendations of BS 5623 to achieve that amount of wear after fifteen minutes continuous cutting time, the following mean results were achieved for materials within machinability group 1 from one supplier (Sandvik) using three grades of Tungsten Carbide cutting tool material of differing application ranges from within the ISO grading system (reference to Figures 29 and 30). These results are mean values of a spread of data distributed within 10% of the mean.

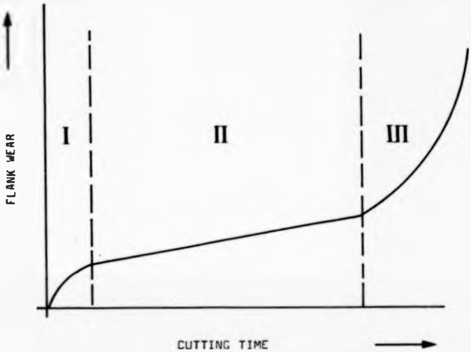


KB = Crater width
KM = Crater centre distance
KT = Crater depth

__Source:__ BS 5623 (85) 1979

__TOOL WEAR CHARACTERISTICS__

Figure 27



PHASE I - INITIAL WEARING AWAY OF 'SHARP' TOOL FEATURES

PHASE II - LINEAR, REGULAR WEAR STAGE OF TOOL LIFE

PHASE III - IMPENDING CATASTROPHIC FAILURE

Source: Radford and Richardson (86) 1974

FLANK WEAR CHARACTERISTICS

Figure 28

Feed Rate (mm/rev)	CUTTING SPEED (METRES/MIN) (Tool life = 15 mins) Mean Material Hardness = 110 HB		
	'Hard' Tool Grade ISO P10-30	'Standard' Tool Grade ISO P15-35	'Tough' Tool Grade ISO P20-40
0.15	460	450	320
0.25	385	370	265
0.40	335	320	230
0.50	300	285	205
0.60	280	265	190
0.80	240	230	165

*

Reference to Appendix B gives further detail based on Sandvik results for the remaining 5 machinability groups although it should be added that those shown for groups 3 and 4 reflect an approximate increase in the cutting parameters equivalent to 50% in spindle speed as the result of further tool trials undertaken at Coventry Engine Plant, a finding discussed in greater detail within Chapter Nine. In terms of the remaining two suppliers, Seco and SPK, it was found at this early stage of system development that the results obtained from the independent cutting tool trials indicated comparability of tool material grades, i.e. results were obviously not identical, but were sufficiently close to allow mediation to give equivalence of data without exceeding the limits of experimental error. However, the proving of true interchangeability of tooling in the manufacturing machine shop environment requires a more detailed discussion.

*Data given with the kind permission of Sandvik UK Limited

MAIN GROUPS OF CHIP REMOVAL			GROUPS OF APPLICATION			DIRECTION OF INCREASE IN CHARACTERISTIC	
Symbol	Broad Categories of Material To Be Machined	Distinguishing Colors	Designation	Material To Be Machined	Use and Working Conditions	Of Cut	Of Carbide
P	Ferrous metals with long chips	Blue	P 01	Steel, steel castings	Finish turning and boring; high cutting speeds, small chip section, accuracy of dimensions and fine finish, vibration-free operation.	Increasing feed	Toughness
			P 10	Steel, steel castings	Turning, copying, threading and milling, high cutting speeds, small or medium chip sections.		
			P 20	Steel, steel castings Malleable cast iron with long chips	Turning, copying, milling, medium cutting speeds and chip sections, planing with small chip sections.		
			P 30	Steel, steel castings Malleable cast iron with long chips	Turning, milling, planing, medium or low cutting speeds, medium or large chip sections, and machining in unfavorable conditions.*		
			P 40	Steel Steel castings with sand inclusion and cavities	Turning, planing, slotting, low cutting speeds, large chip sections with the possibility of large cutting angles for machining in unfavorable conditions* and work on automatic machines.		
			P 50	Steel Steel castings of medium or low tensile strength, with sand inclusion and cavities	For operations demanding very tough carbide: turning, planing, slotting, low cutting speeds, large chip sections, with the possibility of large cutting angles for machining in unfavorable conditions* and work on automatic machines.	Increasing speed	Wear resistance
M	Ferrous metals with long or short chips and nonferrous metals	Yellow	M 10	Steel, steel castings, manganese steel Gray cast iron, alloy cast iron	Turning, medium or high cutting speeds. Small or medium chip sections.	Increasing feed	Toughness
			M 20	Steel, steel castings, austenitic or manganese steel, gray cast iron	Turning, milling. Medium cutting speeds and chip sections.		
			M 30	Steel, steel castings, austenitic steel, gray cast iron, high temperature resistant alloys	Turning, milling, planing. Medium cutting speeds, medium or large chip sections.		
			M 40	Mild free cutting steel, low tensile steel Nonferrous metals and light alloys	Turning, parting off, particularly on automatic machines.	Increasing speed	Wear resistance

MAIN GROUPS OF CHIP REMOVAL			GROUPS OF APPLICATION			DIRECTION OF INCREASE IN CHARACTERISTIC	
Symbol	Broad Categories of Material To Be Machined	Distinguishing Colors	Designation	Material To Be Machined	Use and Working Conditions	Of Cut	Of Carbide
K	Ferrous metals with short chips, nonferrous metals and nonmetallic materials	Red	K 01	Very hard gray cast iron, chilled castings of over 85 Shore, high silicon aluminum alloys, hardened steel, highly abrasive plastics, hard cardboard, ceramics.	Turning, finish turning, boring, milling, scraping.	Increasing feed	Toughness
			K 10	Gray cast iron over 220 Brinell, malleable cast iron with short chips, hardened steel, silicon aluminum alloys, copper alloys, plastics, glass, hard rubber, hard cardboard, porcelain, stone.	Turning, milling, drilling, boring, broaching, scraping.		
			K 20	Gray cast iron up to 220 Brinell, nonferrous metals: copper, brass, aluminum	Turning, milling, planing, boring, broaching, demanding very tough carbide.		
			K 30	Low hardness gray cast iron, low tensile steel, compressed wood	Turning, milling, planing, slotting, for machining in unfavorable conditions* and with the possibility of large cutting angles		
			K 40	Soft wood or hard wood Nonferrous metals	Turning, milling, planing, slotting, for machining in unfavorable conditions* and with the possibility of large cutting angles.	Increasing speed	Wear resistance

<u>Source</u>: Brookes (30) 1979

<u>ISO INDEXABLE INSERT GRADING SYSTEM</u>

Figure 29

Typical* carbide grades for machining

Designations			Compositions						Properties		
ISO application code	U.S. industry code	BHMA properties code	WC	TiC	Ta(Nb)C	Co	Ni	Mo	Density g/cm^3	Hardness HV	Transverse rupture strength N/mm^2
P01	C8	919	-	80	-	-	10	10	5.8	1900	850
P01	C8	919	50	35	7	8			8.5	1900	1100
P05	C7	926	78	16	-	6			11.4	1820	1300
P10	C7	727	69	15	8	8			11.5	1740	1400
P15	C6	635	78	12	3	7			11.7	1660	1500
P20	C6	444	79	8	5	8			12.1	1580	1600
P25	C6	344	82	6	4	8			12.9	1530	1700
P30	C5	353	84	5	2	9			13.3	1490	1850
P40	C5	263	85	5	-	10			13.4	1420	1950
P50	-	182	78	3	3	16			13.1	1250	2300
M10	-	453	85	5	4	6			13.4	1590	1800
M20	-	363	82	5	5	8			13.3	1540	1900
M30	-	263	86	4	-	10			13.6	1440	2000
M40	-	273	84	4	2	10			14.0	1380	2100
K01	C4	930	97	-	-	3			15.2	1850	1450
K05	C4	830	95	-	1	4			15.0	1780	1550
K10	C3	741	92	-	2	6			14.9	1730	1700
K20	C2	580	94	-	-	6			14.8	1650	1950
K30	C1	280	91	-	-	9			14.4	1400	2250
K40	C1	290	89	-	-	11			14.1	1320	2500

* Very considerable variation between the products of different manufacturers is possible.

Historical development
WC-base sintered carbides

1923-25	WC-Co
1929-31	WC-TiC-Co
1930-31	WC-TaC(VC, NbC)-Co
1932	WC-TiC-TaC(NbC)-Co
1938	WC-Cr_3C_2-Co
1956	WC-TiC-Ta(Nb)C-Cr_3C_2-Co
1959	WC-TiC-HfC-Co
1968-69	WC-TiC-TaC(NbC)-HfC-Co
1968-69	WC-TiC-NbC(TaC)-HfC-Co
1965-78	TiC, TiN, Ti(C,N), HfC, HfN and Al_2O_3 coatings on WC-base alloys
1967-70	Sub-micron WC/Co
1965-75	Hot isostatic pressing
1969-71	Thermochemical surface hardening
1974-77	Polycrystalline diamond layers on WC-base hardmetal
1973-78	Multi-carbide, carbonitride/nitride and multiple carbide/carbonitride/nitride/oxide coatings
1976-79	Complex hardmetals with Ru additions
1981	Many thin coatings with AlON (aluminium oxynitride) surface layer

Historical development
WC-free sintered carbides

1929-31	TiC-Mo_2C-Ni, Cr, Mo
1930-31	TaC-Ni
1931	TiC-TaC-Co
1931	TiC-Cr, Mo, W, Ni, Co
1938	TiC-VC-Ni, Fe
1944	TiC-NbC-Ni, Co
1949	TiC-VC-NbC-Mo_2C-Ni
1950	TiC(Mo_2C, TaC)-Ni, Co-Cr
1952-66	TiC - heat-treatable steels and alloys
1957	TiC-TiB_2
1965-70	TiC-Mo_2C (mixtures)-Ni, Mo
1968-70	(Ti, Mo)C(solid solution)-Ni, Mo, Cr
1969-70	TiC-TiN-Ni
1968-73	TiC-Al_2O_3
1972-75	TiC-TaN-Ni
1979	TiC-TaC-Mo_2C-Ni alloy
1980	Ti(C,N) with precipitation-hardened superalloy binder

<u>Source</u>: Brookes (30) 1979

<u>TYPICAL CARBIDE GRADES FOR MACHINING</u>

Figure 30

Returning to the initial discussion on machinability group 1 results, it is clear that a process planning engineer would not wish to be restricted to selecting feed rates only from a given table and, therefore, the facility to interpolate was required. Therefore, the possibility of utilising an extended Taylor's tool life equation of the form generally quoted in related text [83] 1976 was considered, i.e.:-

$$\text{Tool life (minutes)} = KV^{x}\ S^{y}\ a^{z}\ (HV)^{w}\ (VB)$$

where,

V	=	Cutting speed
S	=	Feed rate
a	=	Depth of cut
HV	=	Component material hardness
VB	=	Flank wear
K	=	Constant for component/tool material combination
w,x,y,z	=	Exponents (generally negative)

A computer program was then written to plot the logarithm of cutting speed values on the abcissa and the logarithm of corresponding feed rates upon the ordinate axis, deduce the best fit straight line by the method of least squares and calculate the non-parametric coefficient of correlation. A listing of the program is given in Appendix C.

In conducting the analysis upon the data relating to machinability group 1, given previously, it was found that the plotting of logarithm of feed rate against the logarithm of relative speeds (i.e. the cutting speed at a given rate divided by the cutting speed to achieve a 15 minute tool life at a feed rate of 0.8 mm/rev) provided a relationship which yielded a very high degree of correlation for all three tool material grades across all machinability groups. The results of analysis for machinability group 1 for the tool materials of one supplier are given below, the comparable results for machinability groups 2 to 6 given as Appendix B.

Feed Rate (mm/rev)	CUTTING SPEED DETAILS (TOOL LIFE = 15 MINUTES) (MEAN MATERIAL HARDNESS = 110 HB)					
	Hard Tool		Standard Tool		Tough Tool	
	Actual (m/min)	Relative*	Actual (m/min)	Relative*	Actual (m/min)	Relative*
0.15	460	1.916	450	1.957	320	1.939
0.25	385	1.604	370	1.609	265	1.606
0.40	335	1.396	320	1.391	230	1.394
0.50	300	1.250	285	1.239	205	1.242
0.60	280	1.166	265	1.152	190	1.152
0.80	240	1	230	1	165	1
Gradient	-2.616		-2.526		-2.557	
Intercept	-0.138		-0.166		-0.159	
Correlation	0.994		0.997		0.996	

* (viz. Actual cutting speed divided by cutting speed at datum feed rate of 0.8 mm/rev)

It should be noted that as previously stated the values of speed corresponding to various feed rates to produce a given tool life are mean values obtained from experiments which produced a scatter of data to which a best straight line would have been fitted. Based on this, a very high correlation of results to a straight line formula would be expected.

In practice, tool life other than 15 minutes may be required (for example to achieve balanced tool lives upon a multi-tool machine to minimise down-time due to tool changing) the incorporation of a tool life 'modifier' was needed to enable the amendment of the predicted cutting speed to produce the desired tool life. This relationship is again logarithmic in nature (see expression given previously) and is often referred to as the Taylor tool life equation after F W Taylor who first accurately monitored the relationship after conducting cutting tests which generated graphs of the type shown in Figure 31 which, when logarithmically inverted, appear as shown in Figure 32. The multiplicative index by which cutting speed should be downrated to achieve a tool life other than 15 minutes for each of the machinability groupings (one value being taken as applicable to all tool material grades within the group) is as given below:-

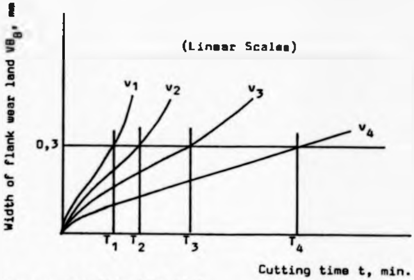
		Machinability Group Number					
		1	2	3	4	5	6
Tool	15 (datum)	1	1	1	1	1	1
Life	30	0.87	0.87	0.87	0.84	0.85	0.87
(Minutes)	60	0.76	0.76	0.76	0.71	0.73	0.76
		SPEED MODIFIER (Multiplicative)					

Again, as with the initial machinability data the speed modifiers quoted resulted as a joint initiative between the writer and the tool material suppliers involved in the exercise.

The logarithmic relationship known to exist between tool life and speed modifier was analysed, using the program as given in Appendix C, and the results obtained were as follows:

		SPEED MODIFIER (Multiplicative)					
Machinability Group		Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
Tool Life (mins)	15	1	1	1	1	1	1
	30	0.87	0.87	0.87	0.84	0.85	0.87
	60	0.76	0.76	0.76	0.71	0.73	0.76
Slope		-0.198	-0.198	-0.198	-0.247	-0.227	-0.198
Intercept		0.54	0.54	0.54	0.67	0.613	0.54
Correlation		0.99	0.99	0.99	0.99	0.99	0.99

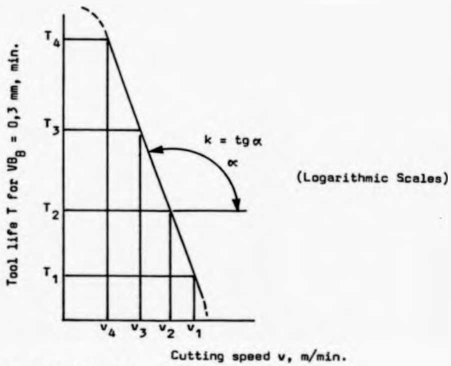
It has been found in practice ASM [87] 1979 that although the value calculated for the gradient tends to hold true in all conditions, the



Source: BS 5263 (85) 1979

DEVELOPMENT OF FLANK WEAR FOR DIFFERENT CUTTING SPEEDS

Figure 31



Source: BS 5263 (85) 1979

LOGARITHMIC INVERSION OF v-T CURVE

Figure 32

intercept is subject to a degree of fluctuation from one machine tool to another and should be used with a degree of caution.

It was therefore possible, by combining the known relationship in terms of graph gradient and intercept between feed rate and cutting speed and then between cutting speed and tool life for a given component machinability group, and knowing the base cutting speed at 0.8 mm/rev feed rate datum point to give a fifteen minutes tool life to generate a cutting speed appropriate to any tool life and feed rate by interpolation and, if used with a certain degree of caution, extrapolation beyond known limits may be used for guidance.

6.2 INITIAL DATA ORGANISATION WITHIN THE IMPS DATA BASE

The parameters derived from the analysis of tool trials conducted were arranged into the following format within IMPS, all data being held in sequentially organised floppy diskette text files to maximise storage potential. Figure 33 depicts graphically the data organisation and variable names allocated to each item of data, the values shown relating to materials within machinability group 4. This particular arrangement permits the identification of the appropriate tungsten carbide tool clearance angle(s) and generation of the correct cutting speed for a given input of feed rate and tool life for three grades of cutting tool material from two tooling suppliers (i.e. Sandvik and Seco) by means of following formulae which form the cornerstone of the IMPS algorithm written in the Applesoft BASIC programming language:

```
S =   [B11S  * (EXP ((LOG (F) - I1/S1)))
             *  EXP (IL + (SL * (LOG (T))))]
```

The expression yields the correct cutting speed S (m/min) for a selected feed rate F (mm/rev) to achieve a tool life T (minutes for the

MAX. D.O.C. (mm)	MAX. FEED (mm/rev)	TWO W.C. CLEARANCE ANGLES		HARD GRADE	BASE SPEED (at 0.8 mm/rev)	FEED RATE MODIFIER		STANDARD GRADE	BASE SPEED (at 0.8 mm/rev)	FEED RATE MODIFIER		TOUGH GRADE	BASE SPEED (at 0.8 mm/rev)	FEED RATE MODIFIER		TOOL LIFE MODIFIER FOR ALL GRADES OF W.C.	
						SLOPE	INTER-CEPT			SLOPE	INTER-CEPT			SLOPE	INTER-CEPT	SLOPE	INTER-CEPT
12	0.8	N	P	GC 015	157	-2.722	-0.148	GC 1025	128	-2.808	-0.166	GC 135	83	-2.451	-0.242	-0.247	-0.668
MDOC	MFEED	W1CCØ	W2CCØ	H1SØ	B11S	S1	I1	N1SØ	B21S	S2	I2	T1SØ	B31S	S3	I3	SL	IL

IMPS INITIAL DATA ORGANISATION FORMAT

Figure 33

'hard' tool material. Obviously to obtain the cutting speed appropriate to either of the other two 'classes' to tool material (viz. 'standard' and 'tough') the variables B21S and B31S would respectively replace B11S in the above expression, and S2, I2, S3 and T3 included also as shown below:-

'Standard' Tool Class:

```
S = [B21S  * (EXP ((LOG (F) -I2/S2)))
             *  EXP (IL + (SL * (LOG (T)))]
```

'Tough' Tool Class:

```
S = [B31S  *  (EXP ((LOG (F) - I3/S3)))
             *   EXP (IL + (SL * (LOG (T)))]
```

It will be noted that since the same base speed, slope and intercept apply to tool grades within the same class from both suppliers, interchangeability is an inherent assumption. However, as stated in the previous section the proving of true interchangeability of tooling within a manufacturing machine shop environment requires a more detailed study, a subject area which is discussed later.

The first two items of data held in each machinability group files are virtually self-explanatory; in order to set realistic limits upon the parameters to be selected by any user of the IMPS system upper boundaries, established from workshop practice, were set for maximum depth of cut and maximum feed rate in the form of the variable MDOC and MFEED respectively.

The subsequent two variables relate to the tungsten carbide tool clearance angles recommended for use in conjunction with component materials which comprises the machinability groups. Standard tungsten carbide inserts are produced in a limited range of clearance angles each of which is designated by a letter according to the ISO convention as depicted in Figure 34. Variables W1CC$ and W2CC$ correspond to two such appropriate letters.

6.3 INITIAL APPLICATION WITHIN THE SHOP-FLOOR ENVIRONMENT

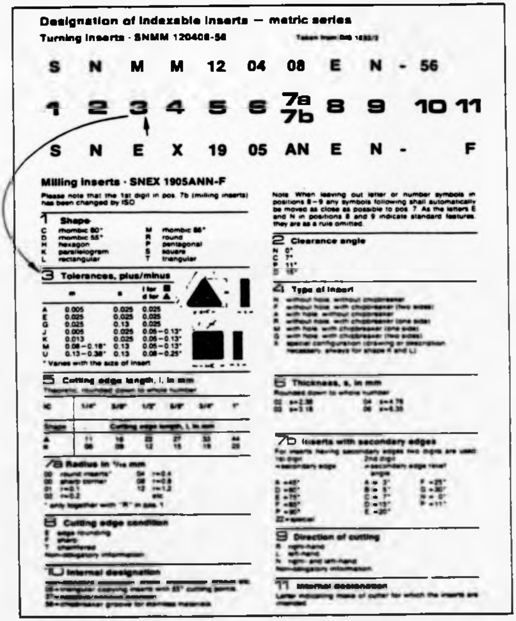
As a result of the initial contribution of, in the main Sandvik and Seco in the form 'core data', a maximum of three grades of tungsten carbide cutting tool material were identified against each material machinability grouping, the difference between grades being increased hardness at the expense of toughness. Clearly the advantage gained from using the harder tool material is that higher cutting speeds may be operated at, provided the machine tool is not susceptible to vibration which could cause catastrophic failure, in which case the utilisation of 'hard' tools is obviated and it becomes permissible to use only a tougher (and, therefore, less hard) tool material which would withstand the adverse operating conditions, but would necessitate a reduction in cutting speed to maintain tool life. Having limited the choice of tool materials to three grades per component machinability grouping, and as later discussion will reveal, an even more limited choice in terms of ceramic based tool materials, the final choice was very much dependent on a series of interrelated factors which included:-

(a) Component and fixture rigidity

(b) Tool set up rigidity

(c) Component material surface condition

Recognising the potential complexity of the problem being faced a decision was made to build a factoring routine into the IMPS algorithm which made allowances for machining parameters to be encountered, typified by (a), (b) and (c) above, but including many others as well, in making



Source: Seco Ltd. (95) 1980

DESIGNATION OF INDEXABLE INSERTS

Figure 34

the final tool choice decision. While the recognition of the problem was relatively simple, in hindsight, the achievement of a practical solution was not.

The very early factoring routines were based on qualitative assessments of the machining parameters being encountered and the determination of the appropriate tool grade was dependent upon the rating given to each condition encountered. In this initial form a rudimentary handbook was produced which served to guide the system user, in an albeit somewhat subjective manner, towards the determination of which classification a given shop floor set-up belonged to.

Equipped, therefore, with a procedure for determining the tool material class most appropriate to a given component/machine tool combination complete with the necessary logarithmic equations previously derived, in theory, the correct surface cutting speed for a given feed rate and tool life was calculable. However, during the course of implementing the system into the production environment it was found that there were wide discrepancies in the machining parameters generated by IMPS compared to the operational standards encountered. Of particular concern were the tool life predictions which far exceeded those achieved in practice; for example, extremes of twenty times tool life (predicted) in certain cases. As a generalisation such extremes predicted/actual variances could have been due to:

(a) An irrelevant factoring routine.

(b) Invalid core machinability data from the tool suppliers.

(c) Operational custom and practice.

Wishing to understand the complexities contained in (a), (b) and (c) above a decision was made that for the time being the core machinability data would be held as correct with further attention to be given to the factoring routine followed by machine tool operator custom and practice.

With respect to the factoring routine the decision was made to extend the concept of rating or factoring from its qualitative base to become quantitative by allocating numeric values to each of the three aforementioned machine and tool features and, initially, downrating the cutting speed accordingly.

A multiplicative arrangement was the obvious method of achieving the downrating or factoring and was based upon the premise that if all three criteria were rated at maximum (i.e. good component and fixture rigidity, good tool set-up rigidity and bright and true component material pre-machining condition) then the tool life obtained should approximate closely to the results obtained in the ideal cutting tests, each feature was thus accorded the value of unity and the following expression developed:-

Cutting speed to give required tool life

= Predicted tool life from logarithmic equations

* Rating for component/fixture rigidity

* Rating for material surface pre-machining condition

Descending values were then given for each subsequent rating for each factor.

The combination of the handbook guide to support the adoption of this factoring approach led to an improvement in correlation between predicted and actual tool life data. Continual feedback from shop-floor tests refined still further the values accorded to each rating of each factor.

A further important additional feature noted during the IMPS validation shop-floor exercises was the tool life variation caused by component batch-to-batch machinability differences. Although there are a variety of features related to material composition which will affect machinability the most easily measured is material hardness. The IMPS data base was thus extended to incorporate the facility to amend cutting speed to compensate for the difference between the workpiece batch hardness and the mean datum hardness figure of the materials machined under idealised operating conditions to yield initial data for each machinability group. In the case of machinability group 1 it will be seen from Section 6.1 that all data relates to a mean component hardness of 110 HB. The compensating factor applied is of the form:-

Index by which to multiply speed to compensate for deviation of batch hardness from machinability group mean hardness = (1 + ((Batch hardness - Mean Datum) x .04*))

*Compensating figure obtained from tests conducted in conjunction with cutting tool suppliers.

The cutting speed appropriate to a known batch hardness is the product of the above index and that speed previously generated from the IMPS data.

The compensating figures for each machinability group are as follows:

Machinability Group Number	1	2	3	4	5	6
Compensating Figure	0.04	0.04	0.05	0.02	0.04	0.02
Nominal Hardness (HB)	110	150	180	345	200	200

Despite the successful incorporation of the above compensating figures into the IMPS data base arrangement, it was still felt necessary to refine further the factoring methodology, therefore, a far more detailed and objective method of downrating or factoring was subsequently developed in an endeavour to reduce still further the variance between predicted and actual tool life. Of fundamental importance was the need to determine what proportion of the discrepancy between predicted and actual data was due to substantive reasons (machine age/condition, tool overhang, etc.) and how much was due to traditional restrictive shop floor custom and practice. The former was to be accommodated within the factoring routine, the latter to be eradicated by means of a tightening of the standards applied to the job.

The use of this very detailed, approach, although far too comprehensive for day-to-day use, at least forced greater attention to certain problem areas. In an endeavour to improve still further the correlation between predicted and actual and also use IMPS as the vehicle for introducing standardised tooling onto the shop floor in order to rationalise the proliferation of grades in use, the following two-part decision was made:-

(a) Rather than pursue the somewhat random approach of attempting to validate the IMPS core data across a variety of machine tools the decision was made to concentrate on a single family of machine tools, i.e. copy lathes, using the IMPS algorithm in the form detailed in Section 6.5.

(b) A practical balance was required between the two rather extreme approaches pursued up until this stage for the factoring routines.

6.3.1 <u>Dedicated Cutting Tool Trials</u>

The decision to concentrate the IMPS core data validation on this particular family of machine tools was made for the following reasons:-

(a) Although the two main suppliers involved were extremely cooperative in terms of supplying machinability data and supportive information they were both very cautious in releasing comprehensive details of the machine tools used in the formulation of the data in question, enough to say that assurances were given that all tests were carried out on single point turning machines against the experimental test conditions as stipulated in Section 6.1.

Because of this level of uncertainty the decision was made to pursue comparable 'in-house' tool trials on single point turning machines which would meet the power, rigidity, stability, etc., requirements to exploit the true potential of the cutting tools under consideration. Of the considerable range of turning machines available to choose, it was considered that a specific family of copy lathes would be the best suited to the task at hand.

(b) The machine tools in question, twelve in all, had an age span of 0 to 20 years and were used to machine a variety of components from within the six machinability groupings already established, albeit current activity in groups 5 and 6 was minimal.

(c) Permission was given by local management to use the twelve machines as a 'test cell' allowing alterations to machining parameters for the purposes of data validation.

This facility was particularly useful for two key reasons:-

(i) Such a dedicated tool trial facility allowed close observation of machine tool setter/operator custom and practice.

(ii) With the total cooperation shown from management and machine shop personnel alike it was possible to monitor accurately flank wear for a given tool life under specified operating conditions.

Against this background a total of twenty-one tool trials were undertaken covering a period of several weeks, the results of which, combined with the improvements in the modified factoring routine contained in the following sub-section established a firm platform from which the

IMPS system could be developed. The results of this work and their impact with respect to the tool supplier's initial machinability data are discussed fully in Chapter Nine.

6.4 MACHINE TOOL FACTORING ROUTINE

Previous discussion has indicated that while recognition was given at an early stage of the research work to the requirement for a machine tool factoring routine within the IMPS module the final solution was only arrived at after attempting several routings through the problem. Initial attempts were based, in the main, upon the subjective opinion of the system user, and this was considered to be a far from satisfactory solution. Logically the factoring routine needed to be structured in a framework governed by quantifiable rules, rather than the existing approach of utilising qualitative statements with the inherent danger of inconsistency.

Whenever discussing the subject of machinability data emphasis is usually placed upon such quantifiable areas as component material specification/surface condition, cutting tool grade/geometry, spindle/surface speed, depth of cut, feed rate and other parameters contributing to the actual 'cut'. In studying these items in isolation it is possible to set up a number of similar machine tools with apparently similar machining parameters, and yet in practice achieve significantly differing levels of performance. Clearly a further variable to be taken into account is the machine itself in that such aspects as machine type, condition and tool set up mechanisms can radically affect the data at which it is possible to achieve consistent optimum machine tool performance.

This problem was particularly apparent at Coventry Engine Plant where, unlike many metal removal research facilities, the average age of the plant machine tools used in component production was twenty years (reference to Appendix A for further details), and in many cases have been subjected to continuous heavy use. Therefore, in attempting to structure core machinability data which would have relevance to the factory in question it was recognised that a machine tool factoring routine would be required to act as a machinability data 'modifying mechanism' for the machine tool under observation.

6.4.1 Initial Development

As IMPS was initially developed for single point turning operations so the subsequent machine tool factoring routine was based upon the key design/set-up features inherent within single point turning machines, although it is considered that many of the fundamental principles contained are applicable to rather more complex machine tools.

In terms of adopting a quantifiably based solution to the problem, initial work began by considering the basic machine tool design, and the key features which affect the achievement of optimum machinability conditions, and at the highest level of focus these were:-

(a) Stiffness

(b) Damping

(c) Forced vibrations

This initial analysis generated a list of 24 factors for consideration ranging from method of construction and stiffness of the machine tool elements when reviewing items (a) and (b), to consideration of unbalanced rotating masses and machine tool age and condition in (c).

Having established this list of factors the first direction pursued was to weight each factor with respect to its impact upon cutting tool life with guidance being taken from such sources as:-

(i) Machining Data Handbook, Vol 2, [32] 1980

(ii) Koenigsberger [26] 1974

Conceptually, the summation of all the factor weightings equated to one for a machine tool in theoretically 'perfect' condition and other machine tools in poor relative condition would yield factors as low as 0.5. These factors were then used as machinability modifiers within the IMPS module in order to reflect operational conditions.

In principle a machine tool factoring routine had been developed which improved the correlation between the IMPS predicted and actual results. This was based in the main upon quantifiable factors the evaluation of which were governed by rules within a system user's handbook. Additionally, the information required for the factor evaluations was readily available to the system user from such sources as:-

(a) Factory records
(b) Machine tool catalogues
(c) The machine tool itself

However, despite this apparent progress the in-house practical application of system was met with a high level of user resistance due to the time taken in collecting the data required for establishing the overall machine tool factor. Because of this the procedure had to be reviewed once again.

6.4.2 Machine Tool Factoring Routine as Implemented

The key requirements to emerge through the first stages of development were:-

(a) To maintain the improved levels of correlation between the IMPS predicted, and actual results.

(b) To reduce the level of system detail, and time taken to establish the factor, without departing from a quantifiable approach to the problem.

(c) Move towards a more system/user interactive approach.

With these basic requirements in mind research work progressed, resulting in the following machine tool factoring routine.

The routine divides the machine and respective set-ups into four main categories, and these are listed below with the IMPS program variable name assigned to them shown in brackets:-

Machine Structure	(MST)
Component Rigidity	(RR)
Tool Rigidity	(TT)
Machine Condition	(MC)

Each of the categories has an effect upon the suitability of the machine tool to perform a specific operation(s), and each is examined separately. Unlike the simple accumulative approach discussed in the previous section, the results are brought together using the following relationship:-

F(machine tool factor) = A - B

where A = f(MST, RR, TT)

and B = f(MC)

(A) comprises the first three categories which are all machine condition independent, while (B) is a function of the machine condition and is machine type/set-up independent.

The above relationship ensures that the condition of the machine has the same net effect upon the factor irrespective of the machine type and set-up. This requirement was identified by observations at Coventry Engine Plant where three machines were used to support one component operation, i.e. machining axle shafts. Although all three machines were of similar design, utilising similar tooling and component set-up arrangements, one of the machines was in a poor state of repair when compared with the remaining two. Under these circumstances all three machines had similar values for A but in the case of the machine in poor condition its resulting value for B had a greater impact in terms of reducing the overall machine factor value.

As with the system described in the previous section, the machine factor is a real number rounded to two decimal places with a maximum value of one (which assumes a 'perfect' machine), and a slightly reduced minimum value of 0.43. In practice, whenever using IMPS any provisional machine factor established at 0.65 is automatically declared as 'very low' by the system and the user is given the opportunity to change the machine and/or the tooling set-up.

The following sections give the actual questions as seen by the user upon the microcomputer screen when operating the factoring routine, combined with their adjusted weightings and a brief explanation for their relative importance.

The four categories as listed previously are examined separately during the factoring routine, and in total there are eight questions relating to the machine and its set-up. These are divided between the four categories as follows:-

Category Number	No of Questions	Subjects	Variable IMPS Program Names
1. Machine Structure	3	M/C body material M/C construction M/C mounting	MM CC WW
2. Component Rigidity	1	Component rigidity	RR
3. Tool Rigidity	1	Tool Rigidity	TT
4. Machine Condition	3	M/C age Past usage Running condition	AA PP OO

Each question is dealt with separately, and is shown along with all of the possible answers and their adjusted weightings, commencing with the best condition.

1. Question: What is the machine body made from?

   Answers: 1. Predominantly cast iron (1.0)

   2. Predominantly steel (0.975)

   3. Other (0.94)

   The weightings reflect the fact that iron is a good damping medium, i.e. having less than half of the modulus of elasticity of steel. Although the potential damping properties of such materials as concrete and synthetic granite are recognised, and accordingly would be given a weighting of 1.0 (i.e. option 1) neither material was found to be in use at Coventry Engine Plant. Finally the third category, i.e. other, was added to the factor listings as more of a cautionary 'safety net' for machine tool structures not falling into the (a) or (b) category and as such would possibly warrant further investigation.

2. Question: How is the machine constructed?

   Answers: 1. All separate parts (1.0)

   2. Separate bed only (0.985)

   3. One piece cast body (0.97)

   Again this is concerned with damping characteristics, i.e. joint damping occurs when mating surfaces move in relation to each other. This is a linear relationship, the joint damping characteristic being directly proportional to the number of major parts from which the machine is constructed. Note that this is considered to be less critical than internal damping from the machine body material, therefore, explaining why there is a difference in the weightings for the worst condition in questions 1 and 2, i.e. 0.94 compared to 0.97. These observations have been taken from the Machining Data Handbook [32] 1980.

3. <u>Question</u>: How is the machine mounted?

<u>Answers</u>: 1. Bolted and grouted (1.0)

2. Bolted only (0.987)

3. Grouted only (0.975)

4. Free standing (0.96)

The machine mounting affects the machine's susceptibility to vibration transmitted through the floor and also the rigidity of the machine structure. The weightings are based upon the subjective assessments, established during the initial work described in the previous sub-section, with a level of adjustment resulting from subsequent shop floor experience. Again this factor is not considered to be as critical as damping.

4. <u>Question</u>: Describe unsupported lengths/diameters of the component.

<u>Answers</u>: 1. Small and solid (1.0)

2. Large and flexible (0.825)

3. Between these (0.92)

The degree of component rigidity is determined by the geometry of the unsupported parts of the component. The structural stiffness of a beam or disc is a function of its cross-sectional area and overhang:-

i.e. standard mechanical engineering formulae

$$d = \frac{64(PL^3)}{3\pi(ED^4)} \qquad \text{or} \qquad d = f\,\frac{L^3}{D^4}$$

where d = deflection

P = force on the end of beam

L = length of overhang

D = beam diameter

E = modulus of elasticity

k = constant for unit of measure

The answers given previously are quantified in a users guide to the factoring routine. The relationships are non-linear and are based upon the above relationship, specifically that between length and diameter.

5. Question: Describe tooling rigidity.

This is dealt with in a similar way to component rigidity in that a long boring bar is more inclined to deflect under load than a short copy tool. The three descriptions of the tooling set-up and their respective weightings are (TT):-

(i) Long overhang/diameter ratio (0.825)

(ii) Short overhang/diameter ratio (1.00)

(iii) Between the two (0.92)

Again, the definition for items (i) to (iii) was given in a user's guide.

6. Question: How old is the machine?

Answers: 1. ≤ 5 years (2.24)

2. 6-10 years (2.17)

3. 11-25 years (2.09)

4. > 25 years (2.00)

With respect to this question the machine age could be either actual age, or age since last major recondition if applicable. The weightings in this category assume that deterioration of a machine tool is fairly linear with age although machines over 25 years of age tend to have their condition compounded by gradual wear, rust and neglect.

7. Question: Describe the past usage of the machine.

Answers: 1. Light (2.24)

2. Moderate (2.15)

3. Heavy (2.00)

These descriptions were quantified in a user's guide in terms of feed rate and depth of cut. The relationship between the weightings is based upon the average rate of metal removal corresponding to each of the three answers. In addition, note that the overall factor calculation, age and past usage are multiplied together to give an indication of the rigours it has been subjected to.

8. Question: Describe running condition of the machine.

Answers: 1. Normal (0.5)

2. Reasonable (0.43)

3. Poor (0.35)

This is a subjective assessment of the condition of the machine covering such aspects as bearings, slides, lead screws, motor, toolpost rigidity etc.

6.4.2.1 Factor Calculation

After answering the eight questions the IMPS program contains values for each variable from which the machine factor calculation takes place. Therefore, a routing through the system would be as follows:-

$$F(\text{machine factor}) = A - B$$

$$\text{where } A = f_1(MST, RR, TT)$$

$$\text{and } B = f_2(MC)$$

Element A (machine condition independent factors) comprises:-

Questions:				
	1.	M/C body material	(MM)	Machine structure (MST)
	2.	M/C construction	(CC)	Machine structure (MST)
	3.	M/C mounting	(WW)	Machine structure (MST)
	4.	Component rigidity	(RR)	
	5.	Tool rigidity	(TT)	

Element B (machine type/set-up independent factors) comprises:-

Questions:				
	6.	M/C age	(AA)	Machine condition (MC)
	7.	Past usage	(PP)	Machine condition (MC)
	8.	Running condition	(OO)	Machine condition (MC)

MST (Machine structure) $= f_1(MM, CC, WW)$

<u>let MST = MM x CC x WW</u>

With the weighting ranges assigned to each variable the value of MST within the overall machine factor equation will be 1.0.

MC (Machine condition) $= f_2(AA, PP, OO)$

let AP = (AA x PP)/10

With the weighting ranges assigned to AA and PP the value of AP will be 0.5, i.e. maximum value of AP 0 (2.24 x 2.24)/10 = 0.5 to one decimal place.

let AO = AP + OO

As OO (machine running condition) has a weighting value 0.5 then the value of AO will equate to 1.0

<u>let MC = (1 - AO) x 0.65</u>

In principle, the impact of the machine condition element of the overall machine factor equation will be nil for a machine tool in 'perfect' condition, i.e. where AO = 1. Likewise as the value of AO decreases, i.e. f_2(AA,PP,OO)<1 then the impact of MC upon the overall machine factor equation increases.

The machine condition equation is downrated by a constant 0.65 to reflect the impact of the variable MC (of a machine in less than perfect condition) in the overall machine factor equation.

YY (machine factor) = f(A, B)

let YY = (MST x RR x TT) - MC

As mentioned previously the maximum weighting value of each question is already predetermined by the maximum possible factor, i.e. 1.0 and the structure of the overall equation for YY. Likewise the minimum weighting value is determined by the minimum possible factor, i.e. 0.43, the structure of the overall equation, and by the relative overall importance of each question. Therefore, in the case of the machine condition independent questions the wider the weighting range, the greater the impact of the specific factor upon the overall equation, i.e.

Question Number	Weighting Range
1. M/C body material	1.0 to 0.94
2. M/C construction	1.0 to 0.97
3. M/C mounting	1.0 to 0.96
4. Unsupported lengths	1.0 to 0.825
5. Tool rigidity	1.0 to 0.825

Within Element A of the equation items (4) and (5) are considered to have the greatest impact upon spindle speed in practice. It is recognised that while this may be true for re-tooling existing facilities, which the factoring routine is directed towards, a different approach may be required for decision-making procedures relating to the purchase of new, technologically advanced machine tools, where the factor weighting criteria may alter.

Likewise a similar analysis of Element B questions will reveal:-

Question Number	Weighting Range
6. M/C age	2.24 to 2.00
7. Past usage	2.24 to 2.00
8. Running condition	0.50 to 0.35

Therefore question 8, Running Condition, is considered to have the greatest impact upon the machine condition (MC) calculation.

6.5 IMPS ALGORITHM

Previous sections have explained the methodology employed in obtaining, analysing and organising into data files the component material related machining information, i.e. recommended tool materials and associated cutting speed parameters, etc. Attention is now focused upon the IMPS algorithm which utilises the data held in the machining files to identify the tool grades appropriate to the component material being machined, generates the associated cutting parameters calculating basic machining times, tool change frequency, etc., and finally ascertains by means of inspecting the Company Standard Tooling Catalogue via the ARCLASS system whether suitable tooling is already a standard item within the Company. The detail of the file layouts referred to hereafter are depicted in Figures 35 and 36. It will be noted that the file named 'Machinability Group 4' is an extended version of Figure 33, the additional data held relating to the hardness speed modification referred to in Section 6.3, details of the specific force constant (or k_s value) which facilitates the calculation of power required to remove a volume of

1. FILENAME: 'MATERIALS INDEX COUNTER'

Description	NUMBER OF MATERIAL TYPES IN THE MATERIALS INDEX FILE
Data	MAX. NO. 100
Variable Names	KK

This File is created by the Program 'Materials Index Creator' Automatically

2. FILENAME: 'MATERIALS INDEX'

	MATERIAL NAME	CONSTITUENT POSITION (REF: 'CONSTITUENT LEVELS' FILE)	APPROPRIATE MACHINABILITY GROUP NO.	MEAN HARDNESS (HB)	HARDNESS TOLERANCE ABOUT THE MEAN ± (HB)
(1)	BS970 220M07	1	1	120	20
(I)	MN$(I)	P(I)	MG(I)	MH(I)	HT(I)
(KK)					

This File Created by the Program 'Materials Index Creator'

To amend use 'File Amender'

ETC.
Dimensioned in accordance with the KK items in the File

3. FILENAME: 'CONSTITUENT LEVELS'
(RA FILE, RECORD LENGTH = 150 BYTES)

RECORD NO.	13 MATERIAL CONSTITUENT LIMIT LEVELS (UPPER AND LOWER)	
1		
2		
I	X(1)	X(26)
KK		

IMPS - DATAFILE STRUCTURES

Figure 35

4. FILENAME: 'MACHINABILITY GROUP 4*' (* VARIABLE)

MAX. D.O.C. (MM)	MAX. FEED (MM/REV)	TWO W.C. CLEARANCE ANGLES		HARD GRADE	BASE SPD (AT 0.8 MM/REV)	FEED RATE MODIFIER		STD GRADE	BASE SPD (AT 0.8 MM/REV)	FEED RATE MODIFIER		TGH GRADE	BASE SPD (AT 0.8 MM/REV)	FEED RATE MODIFIER		TOOL LIFE MODIFIER FOR ALL GRADES OF W.C.		MEAN HARDNESS (HB)	HARDNESS MODIFIER (SPEED MULTIPLIER PER 10 HB FROM MEAN)
						SLO-PE	INTER-CEPT			SLO-PE	INTER-CEPT			SLO-PE	INTER-CEPT	SLO-PE	INTER-CEPT		
12	0.8	N	P	GC 015	157	-2.722	-0.148	GC 1025	128	-2.808	-0.166	GC 135	83	-2.451	-0.242	-0.247	-0.668	345	0.02
MDOC	MF-EED	WICC$	W2CC$	✦ HIS$	# BIS$	S1	I1	NIS$	B2IS	S2	I2	TIS$	B3IS	S3	I3	SL	IL	H	HM

✦ SIGNIFIES 'HARD GRADE, FIRST SUPPLIER'

\# SIGNIFIES 'BASE SPEED, FIRST TOOL, FIRST SUPPLIER'

FINISHING ROUTINE

BASE KS VALUE (KG/MM) AT 0.8 MM/REV FEED AND 90 DEG. APPROACH ANGLE	HARDNESS MOD.	FEED RATE MULTIPLIER FOR KS MOD.		LINEAR QUANTITY, ADD TO GIVE KS AT 75 DEG. APPROACH ANGLE	1ST INTERVAL			2ND INTERVAL			3RD INTERVAL			4TH INTERVAL		
		SLO-PE	INTER-CEPT		SIZE TOL. ON FINISHED PART (LINKED)	SURF. FIN. ON FIN. PART	MAX. D.O.C TO ACHIEVE EITHER	SIZE TOL. ON FINISHED PART (LINKED)	SURF. FIN. ON FIN. PART	MAX. D.O.C TO ACHIEVE EITHER	SIZE TOL. ON FINISHED PART (LINKED)	SURF. FIN. ON FIN. PART	MAX. D.O.C TO ACHIEVE EITHER	SIZE TOL. ON FINISHED PART (LINKED)	SURF. FIN. ON FIN. PART	MAX. D.O.C TO ACHIEVE EITHER
225	0.06	-3.232	-.2715	5	0.03	1	0.6	0.07	2	2	0.1	3	2.5	0.15	4	3
KS	HK	S4	I4	KD	ST(1)	FT(1)	DC(1)	ST(2)	FT(2)	DC(2)	ST(3)	FT(3)	DC(3)	ST(4)	FT(4)	DC(4)

INCREASING TOLERANCE ⇒

H.S.S. AND CERAMIC DATA ⇒

SET FILES UP USING 'MACHINABILITY GROUP CREATOR'

TO AMEND USE 'FILE AMENDER'

IMPS MACHINABILITY GROUP - DATA FORMATS

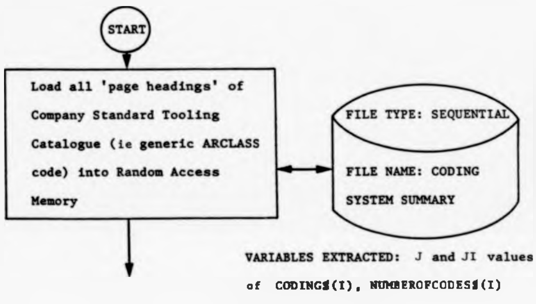
Figure 36

component material (and its variation with varying component hardness values), and finally data related to the maximum depth of cut recommended to achieve a related final component size and surface finish tolerance.

A full printout of the IMPS program in APPLESOFT BASIC, utilising the Apple disk operating system DOS 3.3 is given in Appendix D. In addition, a complete routing through the IMPS flowchart is given in Appendix E and the materials index creator, machinability group creator and file amender programs referred to in the following figures and text are contained within Appendices F, G, and H respectively.

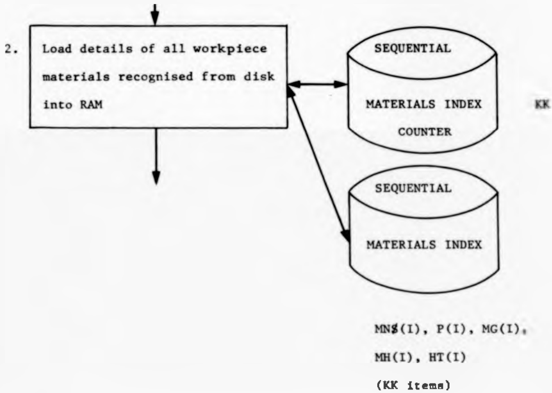
A flowchart to represent the first type of situation to be considered is contained in the remainder of this section and details a routing through the system with a component which requires one 'pass' of the tool to remove the required amount of stock to produce the final component shape to within specified limits of size and surface finish. The items of data being manipulated at each point and the floppy diskette based data file from which they were extracted are given in the following step by step breakdown of the IMPS flowchart combined with reference to the appropriate lines of the IMPS algorithm BASIC program.

1.

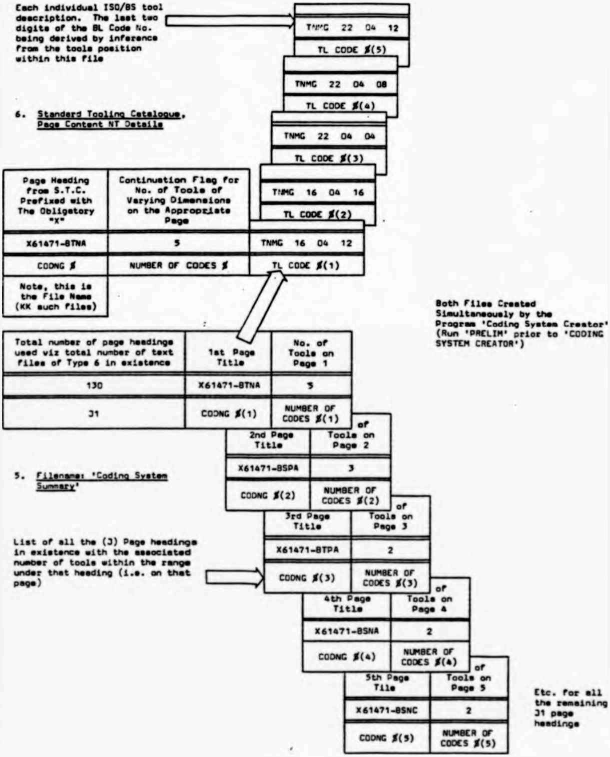


At this point of the algorithm all 'page headings' of the Company Standard Tool Catalogue are loaded from disk into the microcomputer Random Access Memory (RAM). The data files in question are created by initially running the program 'Prelim', reference to Appendix I, followed by the program 'Coding System Creator', reference to Appendix J.

The lines of program 16530 to 16690 are those which enable the tranferences of data from disk to RAM and the variable names referred to are those used in Figure 37.



Following on from the previous actions, details of all the workpiece materials recognised are loaded from disk to RAM. The file 'Materials Index Counter' which is accessed first gives details of the number of materials recognised; this amount of data is then loaded from the file 'Material Index' which contains each material name, the positional point P which is used in Segment 4 of this algorithm, the material group number, the mean hardness of this workpiece material, and finally the anticipated

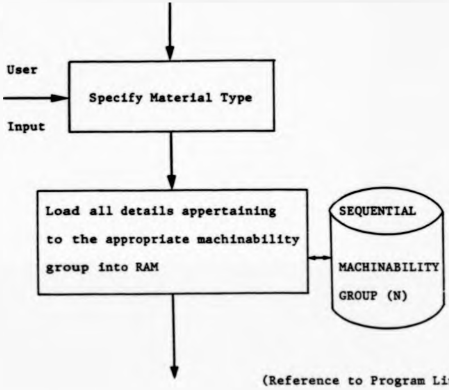


VARIABLE NAMES USED THROUGHOUT IMPS PROGRAMS

Figure 37

range of hardness for the material (reference to program line number 24561 to 24690).

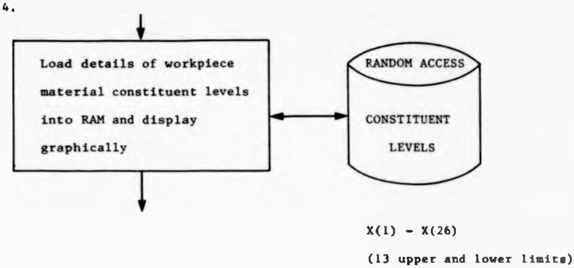
3.



(Reference to Program Line Numbers 16694 to 17025)

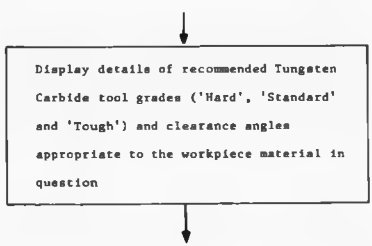
At this point in the algorithm the system user specifies the workpiece material to be machined. A check is then made to verify whether this material is contained within the specifications recognised by the 'Materials Index' file. Upon finding reference to the material, the machinability group to which it belongs is determined via the variable MG previously loaded. The entire contents of the appropriate 'Machinability Group' file as depicted in Figure 36 are then loaded into RAM for subsequent manipulation.

4.



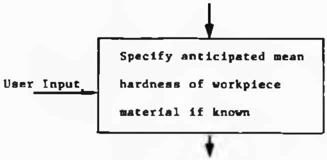
As shown, details of the allowable levels of workpiece material constituent elements are loaded into RAM from the Random Access file 'Constituent Levels', the appropriate record position being denoted by the Variable P previously extracted in Segment 2 from the file 'Materials Index'. The display is in the bar chart form and utilises the low resolution graphics capability of the microcomputer. Although it would appear logical to incorporate such details in the file 'Materials Index', the loading of this complete file, which takes place in Section 2 of the algorithm would needlessly consume 11.2 kilobytes of RAM storage. (Reference to Program Line Numbers 25010 to 25240).

5.



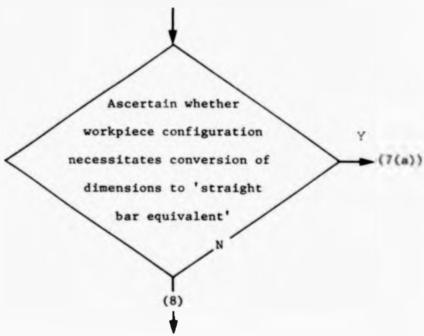
As stated, this very short section serves to visually display details of recommended tool grades and clearance angles (according to ISO convention) appropriate to the workpiece material. (Reference to Program Line Numbers 17100 to 17190).

6.



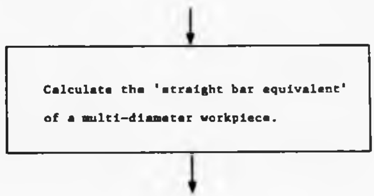
This segment enables the system user to input details of the mean hardness of the workpiece material if it is known. Such is often the case, and if input is made, the value entered overrides the value of MH already held in RAM as extracted from the file 'Materials Index' in Segment 2. (Reference to Program Line Numbers 810 to 850).

7.



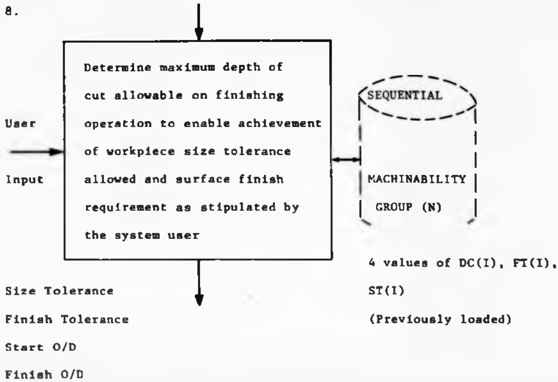
It was soon realised during the development of the IMPS algorithm that in many instances a number operations would be carried out upon one machine operating at a fixed spindle speed across a number of diameters (a prime example being the production, in one pass of the tool, of a multi-diameter component upon a copy lathe operating at a single rotational speed). This situation caused problems for the IMPS system in that since IMPS generated a single recommended peripheral cutting speed from which a rotational speed could be deduced from component dimensions, clearly it would recommend different rotational speeds for each component diameter; this situation was not acceptable, and thus in such cases the complex component would have to be translated into a straight bar requiring the same amount of work content. The procedure for achieving such a conversion is given below as Segment 7a. In the case of single diameter components or where a multi-diameter component is to be produced upon a machine with variable speed capability, Segment 7a is clearly not required. (Reference to Program Line Numbers 860 to 880 which relate to Segment 7.)

7a.



The basis used to obtain the 'straight bar equivalent' of a multi-diameter workpiece is to ensure that the turning and facing content of the multi-diameter bar is carried out in the form of turning only upon the 'straight bar'. A detailed explanation of the logic underpinning this translation is given in sub-section 6.5.3. (Reference to Program Line Numbers 13000 to 13310 which relate to this segment).

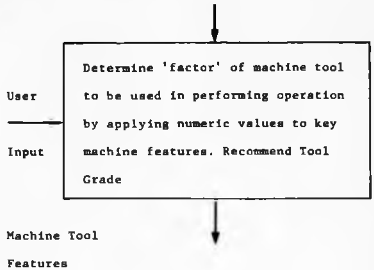
8.



The allowable maximum depth of cut is obtained here by examining the values of the variables ST and FT previously loaded and comparing them with the surface finish FSF and size tolerance TSF required of the workpiece as stipulated by the system user; a recommended depth of cut likely to enable achievement of firstly the surface finish is calculated and then the depth of cut to enable achievement of the size tolerance is identified; the smaller of these two depths of cut is selected as appropriate.

Although productivity maximisation should always be sought in preceding operations, the objective of the final operation is the production of a quality component - production of scrap in the final instance destroys all value added up to that point and is thus economically highly undesirable. (Reference to Program Line Numbers 890 to 1290).

9.



The IMPS program line numbers with respect to the individual elements of the machine tool factoring routine as discussed in section 6.4 are:-

(a) Program Line Numbers 1380 to 1520 recommend the tool material grade considered to be the most appropriate on the basis of a known machine tool factor, i.e. factor established on a previous occasion.

If the factor is unknown then the system user is directed into the following interactive sub-routines.

(b) Machine structure section, program line numbers 11250 to 11650.

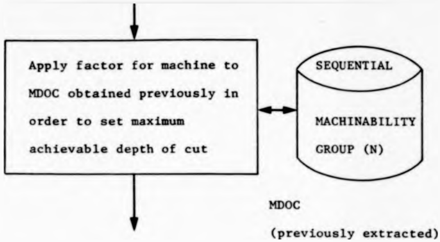
(c) Machine condition section, program line numbers 12020 to 12410.

(d) Component rigidity section, program line numbers 11660 to 11850.

(e) Tool rigidity, program line numbers 11860 to 11990.

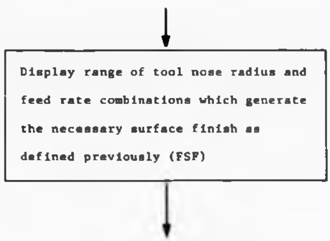
Finally, reference to section 6.4.2 will show that the calculation for the machine tool factor (YY) to be used with IMPS is given in lines 12420 to 12580 where YY = f(machine structure, component rigidity, tool rigidity and machine tool condition).

10.



This section serves to determine whether the depth of cut requested/ recommended previously in section 8 is achievable upon the machine selected based upon the factor generated. MDOC, the maximum depth of cut possible under ideal conditions is consequently downrated by the factor FA$ and the resulting value checked against the depth of cut requested D(CNTR). (Reference to Program Line Numbers 1530 to 1600). It is clear from the above that if the depth of cut requested is unlikely to be able to be achieved upon the machine selected, the option is offered to either change the depth of cut or, alternatively, select a machine of a higher factor. The latter option necessitates repeating segment 9, i.e. the factoring routine for the new machine.

11.



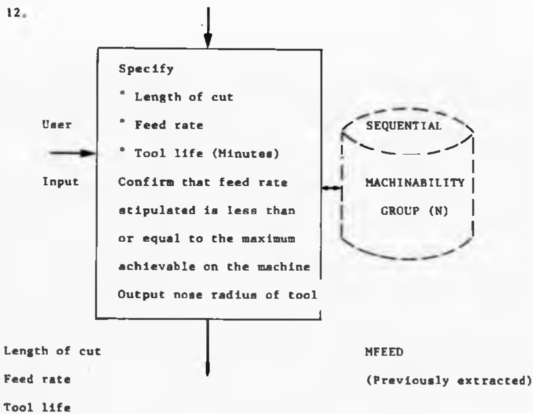
Provided the feed rate per revolution does not exceed tool nose radius, the formulae

$$\text{Feed rate} = \sqrt{18\sqrt{3} * R * \frac{\text{surface finish}}{1000}}$$

provides a relationship between feed rate, tool nose radius (R) and surface finish.

The lines of program 10005 to 10105 hold surface finish constant and generate feed rates associated with standard tool nose radii which generate the desired surface finish.

12.



In addition to facilitating the input of the length of cut, feed rate and tool life in minutes by the system user, the lines of program 1850 to 1950 check that the feed rate selected is less than MFEED, i.e. that feed rate achievable under ideal conditions, multiplied by the factor derived from the factoring routine.

Based upon the relationship given in section 11, the tool nose radius which will enable the achievement of the stipulated surface finish requirement is output.

13.

Using the values of the variables for feed rate and depth of cut previously inputted, the appropriate tool chip-breaker style is determined.

As outlined in sub-section 6.5.4 a relationship exists between feed rate and depth of cut, and the style of chipbreaker which will produce 'acceptable' swarf. The program lines 7610 to 9170 contain the logic required to generate the appropriate BL chipbreaker reference for position within the ARCLASS code, i.e. 16-61471-BTNA-01 (reference to Figure 46 for the ARCLASS system routing).

14.

Generate recommended peripheral cutting speed appropriate to the tool material grade recommended from relationship between speed and feed rate

SEQUENTIAL

MACHINABILITY

GROUP (N)

B11S, I1, S1,

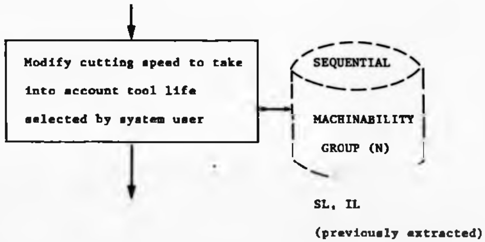
B21S, I2, S2,

B31S, I3, S3

(previously loaded)

This operation is the cornerstone of the IMPS algorithm. As outlined in Section 6.1, the cutting speed may be generated to give a fifteen minute tool life for a material of the mean group hardness by the expression given in the lines of program 13900 to 14100. The tool material grade recommended was of course, generated in segment 9 above. The cutting speed generated is that associated with an 'ideal' machine tool and component arrangement.

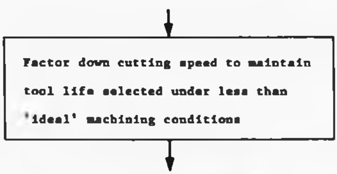
15.



With reference to Figure 36, SL is the slope of the Taylor tool life curve, and IL the intercept.

As described in Section 6.1 there is a relationship between cutting speed and tool life as determined by Taylor. This particular portion of the IMPS algorithm, i.e. program line numbers 14110 to 14160, serves to modify the cutting speed previously generated to accommodate any difference between the standard fifteen minute tool life around which all file based data is originated and the user's stipulation of tool life desired.

16.

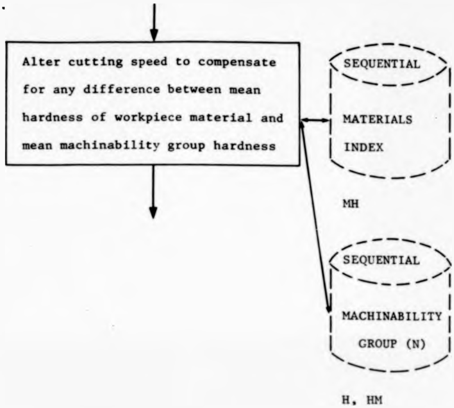


The purpose of the factoring routine is twofold; firstly, it serves to recommend the most suitable tooling grade appropriate to the machining set-up and secondly, it is used to downrate the predicted cutting speed (which is derived from data obtained from cutting trials under ideal machining conditions) to maintain the selected tool life.

This secondary purpose may be considered to be a refinement of the Taylor tool life equations used within the IMPS algorithm an approach supported by the findings of Mayer [87] 1979 - "To optimise a machining operation, of course, you must know what conditions to select to get the maximum output, minimum cost, or whatever is desired. Of course, the main objective is to maximise profits. In order to do this, some of the relationship is needed, such as speed-tool life curves, to predict new results once a change is made. While one cannot ever exactly predict what tool life in the plant will be, based on laboratory results, relative changes can be determined. One of the reasons for this is that the constant in the Taylor equation varies with plant conditions. In a study of nine different laboratories using the same workpiece and tool materials, a family of nine separate Taylor curves with similar slopes were obtained. This shows that the constant in the equations is dependent upon the machine. Machines in a production plant will, of course, behave in a similar manner".

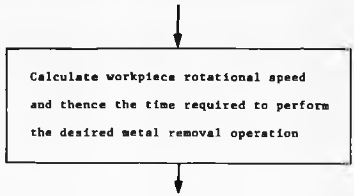
The program line numbers 14170 to 14190 are used to factor down the initial idealised cutting data to compensate for the detrimental effect that a machining set-up, which is less than ideal, will have upon tool life.

17.



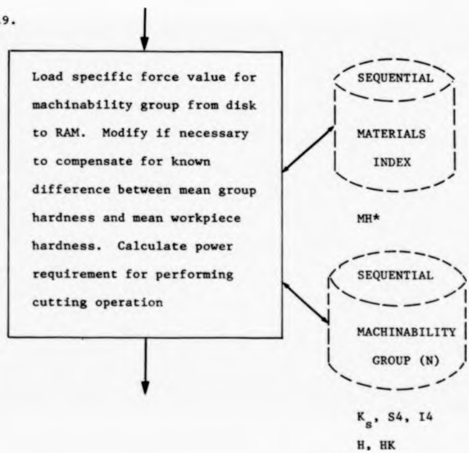
The final adjustment to be made to the cutting speed is the modification required to account for the difference between the mean hardness of the machinability group (around which all file-based data is centred) and the mean hardness of the workpiece material (either as extracted from the diskette file 'Materials Index' or as input by the system user as discussed in Segment 6). Clearly a 'harder than mean' workpiece material would require the downrating of cutting speed to produce the tool life desired, and conversely a 'softer than mean' workpiece would enable an increase to be made upon cutting speed without having a detrimental effect upon the tool life selected. (Reference to Program Line Numbers 14200 to 14260).

18.



The conversion of peripheral speed to rotational speed is a simple geometric relationship and program line numbers 14270 to 14280 establish the time required for the tool to traverse a bar of length L when rotating at N rpm at a feed rate of F mln/rev.

19.



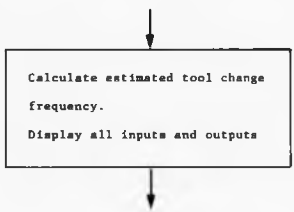
*Or overriding manual input

As shown below, the power required to remove the stipulated amount of material is given by the formula

Power = Depth of cut * Feed rate * Cutting Speed
(peripheral) * Specific cutting force

The final variable, specific cutting force is defined as that amount of power required to remove a unit amount of material from a workpiece and a value specific to each machinability group, that value being appropriate to a nominal group hardness. It is clear that any difference between workpiece hardness and mean group hardness will influence the specific force or K_s value, and consequently a facility is provided within the IMPS algorithm (i.e. line numbers 14285 to 14310) to perform such a compensation. Details of the logarithmic relationship found to exist between feed rate and K_s value are given in Figure 38.

20.



Tool change frequency is simply calculated by dividing the tool life selected in minutes (T) by the cutting time (ST$) to give an indication of expected TCF.

The lines of program 14320 to 14560 also enable the screen display of all values calculated.

K_S (SPECIFIC FORCE) CUTTING VALUES AT 90° APPROACH ANGLE

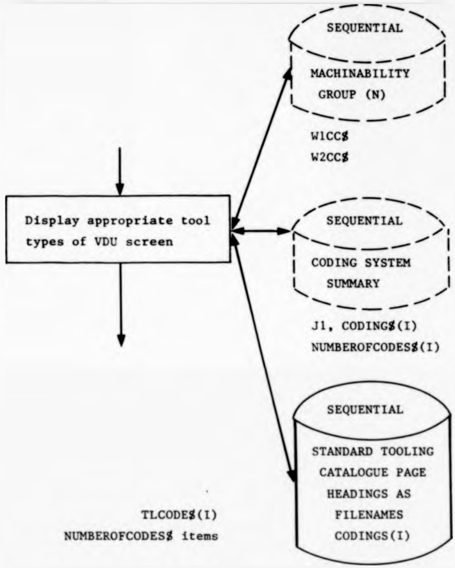
Material Group Number	Mean Hardness (HB)	Feed Rate (mm/rev.) : (F)						Slope	Intercept	Correlation
		0.8*	0.6	0.5	0.4	0.25	0.15			
1	110	155	170	180	195	220	260	-3.272	-0.208	0.99
2	150	170	185	195	210	245	285	-3.202	-0.236	0.99
3	180	170	185	195	210	240	280	-3.351	-0.225	0.99
4	345	225	240	255	275	315	375	-3.232	-0.271	0.99
5	200	105	110	120	125	150	180	-2.990	-0.315	0.99
6	200	80	84	88	97	108	124	-3.67	-0.28	0.99
		Specific Cutting Force (K_S) (kg/mm)								

* Datum value for any feed rate may thus be predicted from K_S = Datum * ((LOG(F) * Slope) + Intercept)

(Base data given with kind permission of Sandvik U.K. Ltd.)

Figure 38

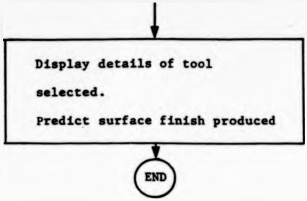
21.



The function of Program Line Numbers 18490 to 19080 is to identify all tools of the appropriate material grade and clearance angles suitable for performing the operation in question. It is this segment of the algorithm that effects the link between the Standard Tooling Catalogue and the stipulated tool grade requirements, using the ARCLASS coding system as the vehicle for linking.

If no selection is made following examination of all appropriate pages, the option is offered to review all such pages again; additions of new items to the rationalised range will only be allowed through recognised authorised personnel.

22.



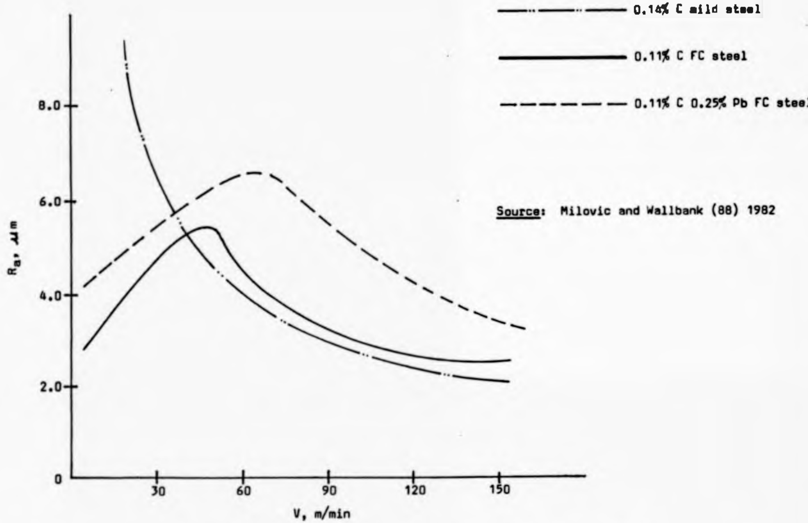
A prediction is now made within Program Line Number 19110 to 19220 of the expected surface finish to be produced upon the component according to the previously used formulae

$$\text{Surface finish} = \frac{\text{Feed rate}^2}{18\sqrt{3} \times \text{Nose Radius}}$$

Nose radius of the tool is obtained by positional inference from within the variable TLCODE$ which is the ISO description of the indexable insert. It should, however, be noted that the prediction of surface finish should be used for guidance only, as the formula above is true only as cutting speed becomes very high (reference to Figure 39).

Essentially the algorithm converts the recommended tool grade into the letter by which it is designated within the ARCLASS system and is given a positional reference within the variable CODING$. Reference to Figure 46, page 217, will help the reader understand the overall ARCLASS structure and the character position for the tool grade and other technological features. Likewise, a positional reference within the same variable is also given to the recommended clearance angles as previously extracted from the appropriate 'Machinability Group' file notably W1CC$ and W2CC$, and also for the recommended chipbreaker style, again as denoted within Figure 46.

Therefore at this stage the various characters within the ARCLASS system which will have been defined are 61477-B7NA which indicates that the tool



Source: Milovic and Wallbank (88) 1982

VARIATION OF ARITHMETIC AVERAGE ROUGHNESS (Ra) WITH CUTTING SPEED (V)

Figure 39

selected is an indexable insert, i.e. 6147 - with a category B tool material grade, N type clearance angle, and category A chipbreaker style. The only remaining decisions are:-

1. Tool supplier which will be an automatic system output.
2. Tool style and size which will be selected from the standard tooling catalogue file.

To activate the process to enable decision (2) to be made a search is then made of the total contents of the 'Coding System Summary' file which was previously loaded to RAM from disk in Segment 1 of the algorithm, inspecting each 'page heading' in turn to establish whether it conforms with the above code number restrictions; a case in the affirmative causes a branch to a loop of the program to open up the appropriate file, such as X61471-BTNA, and extract the entire contents, viz. the tools of different sizes which all conform to this generic loading - a page from the Standard Tooling Catalogue - and display them on screen. A negative result of the investigation, however, simply causes the investigation of the next 'page heading' with the 'Coding System Summary' file.

Upon finding a suitable tool on a displayed page, such as that shown below:

X61471 - BTNA

-1 TNMG 16 04 12

-2 TNMG 16 04 16

-3 TNMG 22 04 04

The reference number as shown on the extreme left is input by the system user, and progression may be made onto the next segment of the algorithm.

The previous 22 program segments are sufficient to enable the selection of recommended tool types from within the Company Standard Tooling Catalogue and generate associated machining parameters for a component requiring one pass of the tool for component manufacture.

It is, in practice, rare for sufficient machining to produce a final finished component from the 'rough state' in one operation, thus the IMPS program was extended to enable the total removal of the desired amount of stock, so that a final Operation Summary Sheet of the type shown in Figures 40 and 41 could be produced for the convenience of the Process Planning Engineers. The ability to accommodate up to ten machining operations is achieved within the algorithm by the use of the subscript (CNTR) which is an abbreviation for 'counter' and was used throughout the program segments as listed previously. For non-finishing operations there are minor amendments to the IMPS algorithm as depicted graphically in Appendix E, the major differences being due to the fact that since iteration occurs between Segments 9 and 22 this eliminates the need to input again such details as workpiece material specification, workpiece hardness, etc. Segment 11 is also circumvented and is replaced by what is effectively an inversion of it which is inserted between Segments 20 and 21 and lists for a constant feed rate (previously stipulated prior to this point in the program) an indicated surface finish for varying tool nose radius.

It will be noted that the option planning sequence does not begin at the component start diameter and progressively remove annuli of material with the final operation being the finishing one as in the matching sequence in practice; but rather deals with the finishing operation first and then reverts back to the rough outer diameter working progressively down to the penultimate operation. The reasoning underpinning this logic is that the final operation warrants extra attention over and above the preceding operations due to the fact that the value added to the component up to that point makes the objective of the operation the production of a component, within the established design criteria, rather than the maximisation of productivity levels which is the case for all other operations. A pictorial representation of the machining

ITERATIVE MACHINING PARAMETER SELECTION

COMPT NO. DAM 0168 COMPT DESCRIPTION MAINSHAFT

INITIAL RESULTS

SPEED FROM FEED	(M/MIN):-	154
SPEED FROM TOOL LIFE	(M/MIN):-	143
SPEED FROM MACHINE FACTOR	(M/MIN):-	110
SPEED FROM COMPONENT HARDNESS	(M/MIN):-	150

****

SURFACE CUTTING SPEED	(M/MIN):-	150
ROTATIONAL SPEED	(R.P.M):-	1232
FEED RATE	(MM/REV):-	.5
DEPTH OF CUT	(MM):-	2
SPECIFIC CUTTING FORCE 'KS'	(KG/MM):-	-21
POWER REQUIREMENT	(KW):-	-.51
TOOL LIFE	(MINUTES):-	20
STANDARD TIME	(MINUTES):-	.371
TOOL CHANGE FREQUENCY	(COMPTS):-	53
RECOMMENDED TOOL GRADE	:-	GC1025

(a) Roughing Operation

ITERATIVE MACHINING PARAMETER SELECTION

COMPT NO. DAM 0168 COMPT DESCRIPTION MAINSHAFT

INITIAL RESULTS

SPEED FROM FEED	(M/MIN):-	160
SPEED FROM TOOL LIFE	(M/MIN):-	113
SPEED FROM MACHINE FACTOR	(M/MIN):-	87
SPEED FROM COMPONENT HARDNESS	(M/MIN):-	119

****

SURFACE CUTTING SPEED	(M/MIN):-	119
ROTATIONAL SPEED	(R.P.M):-	1090
FEED RATE	(MM/REV):-	.45
DEPTH OF CUT	(MM):-	1
SPECIFIC CUTTING FORCE 'KS'	(KG/MM):-	-22
POWER REQUIREMENT	(KW):-	-.19
TOOL LIFE	(MINUTES):-	60
STANDARD TIME	(MINUTES):-	.466
TOOL CHANGE FREQUENCY	(COMPTS):-	128
RECOMMENDED TOOL GRADE	:-	GC1025

(b) Finishing Operation

IMPS - SYSTEM OUTPUT

Figure 40

COMPT.NO. DAM 0168

COMPT.DESCRIPTION- MAINSHAFT

MATERIAL GROUP:- 4

OPERATION SUMMARY SHEET

OP.NO.	LENGTH (MM)	START OD (MM)	D.O.C. (MM)	SPEED (M/MIN)	R.P.M.	FEED (MM)	STD.TIME (MINS)	T.C.F. (CPTS)
10	228.89	38.74	2	150	1232	.5	.371	53
20	228.89	34.74	1	119	1090	.45	.466	128

TOOLING

OP.NO.	TOOL SPECIFICATION	GRADE	CLASSIFICATION
10	SNUN 120408	GC1025	61471-CSND-01
20	TPGN 160304	GC1025	61471-CTPD-01

IMPS - PROCESS SUMMARY SHEETS

Figure 41

sequence and the variable names used within the IMPS program are given in Figure 42.

Of more importance than the extension of the algorithm to accommodate multiple operations was the addition of two subroutines that constitute the 'iterative' element of the IMPS acronym, that is a subroutine to rebalance all outputs such as standard time, tool life, tool change frequency, etc., for inadequate machine spindle speed, and a second routine to rebalance these same outputs for a limited machine power capability. The need for such routines was of fundamental importance as it was often the case that the spindle speed generated by the algorithm was in excess of that achievable upon the production machine tool actually to be employed in performing the turning operation, thus the following two subroutines were designed and implemented.

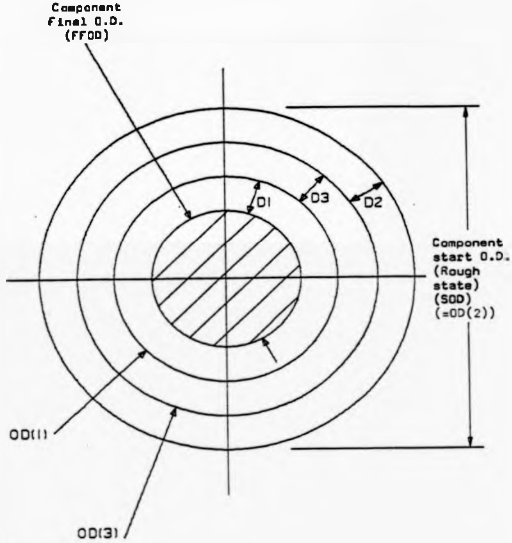
6.5.1 Power Constraint Subroutine

The purpose of the subroutine (reference to Program Line Numbers 18010 to 18160) is to make amendments to machining parameters selected and/or generated to accommodate the fact that insufficient power was available at the machine to perform the operation being planned. It is recognised that there are one of two options available to reduce the power requirement, and these are:-

(a) Reduce depth of cut.

(b) Reduce the feed rate to the maximum allowable without exceeding the power required.

It is clear from the power calculating formulae that depth of cut has a linear relationship with power, therefore, the percentage difference in achievable power and power predicted will be the percentage reduction applied to the input depth of cut to calculate the maximum allowable depth of cut.



D(I) represents the sequence of depths of cut used within the IMPS program

A SCHEMATIC REPRESENTATION OF THE IMPS SEQUENCE FOR A THREE-OPERATION TASK

Figure 42

It was assumed that since depth of cut has relatively little influence upon tool life that no change other than predicted outputs would occur.

The alternative to simply reducing the depth of cut is to 'optimise' the machining parameters within the power constraint. Given the complex interrelationships that exist between feed rate, tool life, cutting speeds, etc., it was decided to maximise feed rate and the iterative process for this is contained in Program Line Numbers 18170 to 18420.

The routine simply reduces feed rate from the user input value by 0.01 mm/rev and re-calculates all outputs, checking to see if the resulting power falls within the constraint power level and speed level input. If this is not the case then a reiteration takes place, reducing the feed rate by the decremental amount. When the power value generated meets with the maximum limit, all standard time and tool change frequency data, etc., are re-calculated in the normal way. This iterative routine resulted in acceptable correlation between predicted outputs and actual results achieved in terms of tool change frequency, standard times, etc., as did the 'uniterated' main IMPS program.

6.5.2 Speed Constraint Subroutine

Of far more frequent importance was the need to rebalance IMPS outputs to take account of the fact that the predicted output value of cutting speed was greater than that achievable on a machine, or even for between the finite speeds that could be selected (only a limited number of the production machines had infinitely variable speed selections). The routine in Program Line Numbers 1600 to 16075 was the first approach towards resolving the problem enabling the system user to input the maximum speed achievable, and this value was taken to be the final output of the IMPS algorithm. There then followed what was effectively an inversion of the sequence and arrangement of the generating lines of the main IMPS program to determine the new tool life and thus re-calculate the tool change frequency and standard time.

The major, and wholly unforeseen, problem encountered was that the resulting increase in tool life appeared to be grossly out of proportion with the decrease in cutting speed, and large deviations between predicted and actual tool life ensued. Since this subroutine was regularly used by process planning engineers a solution to the problem was required albeit the logic being pursued appeared to be correct. A further consideration of the problem guidance was taken from general discussion contained in the ASM proceedings [87] 1979 which identified the fickle nature of the intercept within the Taylor tool life equation. The elimination of the intercept from the equation used in the subroutine could not be logically justified, and so, therefore, a relative position was adopted which simply calculated the new tool life associated with the lower than originally predicted cutting speed on a percentage basis linked to the Taylor equation. For example, it is clear from the data given in Section 6.1 that for group (1) materials, a doubling in tool life requires a 13% reduction in cutting speed, thus within this speed constraint subroutine, the inverse of that was adopted, as follows:-

- Predicted speed = 100 m/min at tool life T_1
- Achievable speed = 25 m/min
- Differential index = 2 'doublings' (25 x 2 x 2)

  New tool life = $T_1 \times (1 - (2 \times .13))$

Although this methodology is not as rigorous as the former approach, it was responsible for improving the degree of correlation between predicted and actual results.

Other key subroutines contained within the overall IMPS program include:-

i) Conversion of multi-diameter workpieces to 'straight bar' equivalents.

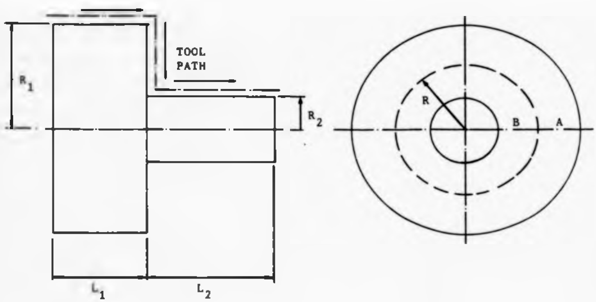
ii) Chipbreaker style selection.

The function of both are discussed in the following sub-sections.

6.5.3 Conversion of Multi-diameter Workpieces to 'Straight Bar' Equivalent

A further area for consideration that emerged during the initial tool trials was a requirement for converting multi-diameter workpieces to 'straight bar' equivalents in order to accommodate the fact that the IMPS module generates a single recommended peripheral cutting speed which, with multi-diameter workpieces, necessitates the operation of the machine tool at different rotational speeds for each diameter, a facility not generally available upon the majority of the existing turning machines at Coventry Engine Plant.

The resolution to this problem was the development of a small sub-routine within the main IMPS program, i.e. line numbers 12900 - 13310 which have been derived from the following logic:-



The total equivalent length of cut is obviously:

$$L_1 + (R_1 - R_2) + L_2$$

The average diameter of the component must, however, be calculated on the basis of:-

$$\frac{\sum_{i=1}^{i=n} \text{length x diameter}}{\text{total length}}$$

The numerator will ensure that the greater the length over which the diameter exists, the more influential will be its weighting. Therefore, the problem existing is to determine the mean diameter of the 'face' being machined between R_1 and R_2. R was selected as the mean radius value, and it is defined as being that radius value which makes area A equate to area B. R may thus be calculated from the following expression:-

For area A to equal area B,

$$\pi R_1^2 - \pi R^2 = \pi R^2 - \pi R_2^2$$

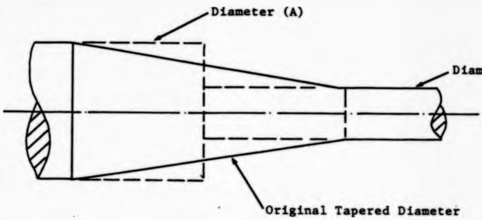
$$\therefore \; 2R^2 = R_1^2 + R_2^2$$

$$\therefore \; R = \sqrt{\frac{R_1^2 + R_2^2}{2}}$$

Therefore the average diameter of a multi-diameter component may be calculated from the expression:-

$$\text{Average Diameter} = \frac{\sum_{i=1}^{i=n} (2Ri \times Li) + \sum_{i=1}^{i=n-1} \left| Ri - (Ri + 1) \right| \times 2\sqrt{\frac{Ri^2 + R(i+1)^2}{2}}}{\sum_{i=1}^{i=n} Li + \sum_{i=1}^{i=n-1} \left| Ri - (Ri + 1) \right|}$$

Obviously tapered component features are not catered for by the above expression, and so these must be approximated to 2 diameters each operating for half the taper length as shown below:

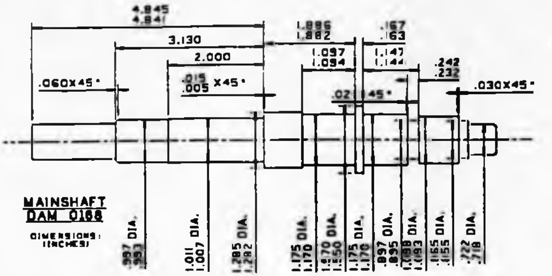


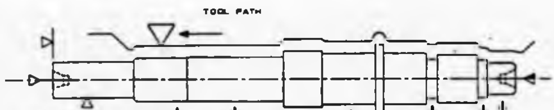
The requirement for this equivalent length/diameter facility emerged during the period of factor proving IMPS upon the bank of twelve copy lathes, and was predominantly used thereafter by the Process Planning Engineers at Coventry Engine Plant for process estimating. A typical example of the resultant equivalent length/diameter for a mainshaft is given in Figure 43.

For the more widespread IMPS assisted tool trial programme component complexity demanded a somewhat simple approach, and there was a preference to adopting the IMPS 'pilot diameter' methodology as discussed within Chapter Nine for establishing machinability benchmarks.

6.5.4 <u>Chipbreaker Style Selection</u>

When selecting an indexable insert for a potential application the user is faced with decisions relating to such factors as tool geometry, size, material/surface coating and chipbreaker style. Previous sections have shown that the ISO designations for insert geometry and size, have, in the main, been adopted as standard design criteria by the major tool





MEAN LENGTH (IN.)	MEAN DIA. (IN.)
1.130	0.995
2.000	1.009
0.010	1.141
0.789	1.283
1.095	1.172
0.165	1.960
0.908	1.172
0.237	0.896
0.876	1.095
0.202	0.860
0.587	0.720

Equivalent length = 9.012 in. (228.89 mm)

Equivalent diameter = 1.289 in. (32.74 mm + 6 mm to allow for roughing D.O.C. = 2 mm and finishing D.O.C. = 1 mm)

COMPONENT - EQUIVALENT LENGTH/DIAMETER

Figure 43

suppliers. In terms of tool material and surface coatings ISO guidelines do exist in the form of the general P, M and K categories and their respective sub-divisions, but discussion in later sections will show that tool supplier grade interchangeability cannot be assumed, and should be validated through 'in-house' cutting tool trials. However there is one remaining critical area, with respect to indexable inserts, which is not supported by ISO guidelines and that is chipbreaker styles. Recent years have witnessed the evolution from the traditional top clamp, 'loose' chipbreakers, for which there is still a limited specialised applications requirement, through to increasingly complex designs which are now formed as an integral feature of the base insert during the manufacturing process.

Chapter Seven will show that for the purposes of ARCLASS designation, and subsequent IMPS selection, both tool material grade/coating and chipbreaker styles have been placed into broad character defined selection matrices which accommodate tools from several suppliers on an interchangeability basis. However, it must be repeated at this stage that comprehensive, tool interchangeability validation was not established during the period of research work covered by this thesis, and the ARCLASS classifications are offered initially as user guidelines, albeit future research work will confirm, or otherwise, these assumptions.

The grouping of like chipbreaker styles proved to be rather difficult as many of the geometric definitions were relatively new to the market place and it was not possible to find, neutral, published literature which offered any subjective comparisons. Against this background a variety of chipbreaker styles were taken from the main tool suppliers and classified in terms of similar geometric features. General validation of these broad classifications was then undertaken as part of the overall tool trials discussed in previous sections. The importance attached to chipbreaker styles and their impact upon cutting conditions, particularly with respect to swarf control, is shown in the reference sheet of the documentation used to monitor the in-house tool trials, reference to Figure 62, page 257, in that the form of chip which may be produced in a machining operation has been categorised into one of eighteen general varieties. Some such as the loose arc chips (type code 1.3) are likely to foul around the tool post and/or component with potentially dire consequences for the machine operator. In addition to the machining benefits achievable in terms of correct chipbreaker style selection, manufacturing managers are controlled by Health and Safety legislation which dictates the avoidance of dangerous machining practices typified by the generation of the loose arc chip.

Experience has shown that three factors exert the major influence over the type of chip form produced by any workpiece material, and these are:-

(a) Depth of cut

(b) Feed rate

(c) Style of chipbreaker

The conventional way of determining suitable combinations is to select one chipbreaker style, cut a bar of material using varying combinations of feed rate and depth of cut, and denote upon a 2-D matrix of feed rate versus depth of cut the type of chip form produced, reference to Figure 44a. From this the decision may be taken that chip form types 4.2 and 5.2 are acceptable, therefore, enabling an 'acceptability' frame to be constructed as shown.

Likewise, by conducting similar trials using different chipbreaker forms and superimposing 'acceptability' regions onto one matrix, as depicted in Figure 44b, begins to establish the ground rules for chipbreaker style selection. From this it will be appreciated that

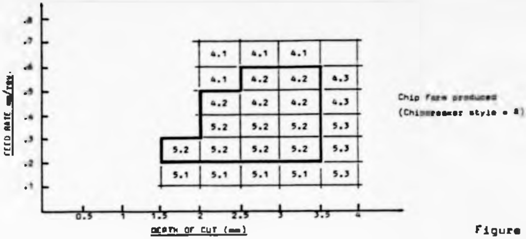


Figure 44(a)

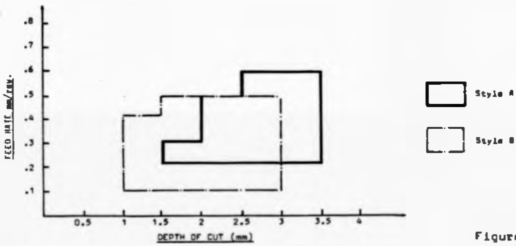


Figure 44(b)

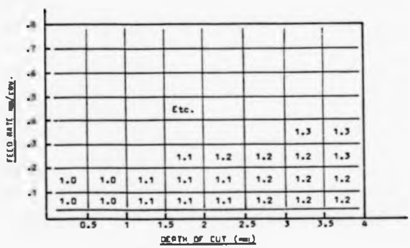


Figure 44(c)

Where 1.0 = Chipbreaker Style A
1.1 = Chipbreaker Style C
1.2 = Chipbreaker Style C Alternative Type B
1.3 = Chipbreaker Style B Alternative Type C
Etc.

IMPS - CHIPBREAKER STYLE SELECTION

Figure 44

suitable chipbreaker styles are available to cover virtually the whole of such a matrix, which gives rise to a situation in which any point on the matrix will have one, two or even three suitable chipbreaker types for any given combination of feed rate and depth of cut.

The IMPS algorithm, as written, stores details of appropriate chipbreaker styles in the format as depicted in Figure 44c. Therefore, by converting feed rate and depth of cut to an x and y co-ordinate the appropriate preferred chipbreaker styles may be determined.

6.6 IMPS ASSISTED TOOL STANDARDISATION PROGRAMME

Having established an acceptable level of confidence in the predictive ability of IMPS, combined with further confidence generated by the tool material grade control mechanisms of the system, the potential for a factory-wide 'IMPS driven' indexable insert (initially turning) standardisation exercise had been created. To help understand the problem being faced a simple profile was established, which is as follows:-

(a) The tool range of indexable inserts held within the tool stores totalled 785 different varieties, a breakdown of which revealed:-

(i) 572 varieties were turning related.
128 varieties were milling related.
75 varieties were related to other processes, i.e. boring, threading, part off, etc.
10 varieties for which it was impossible to identify a positive end use.

(ii) The variety range of 785 indexable insert types resulted in approximately 38,000 individual inserts being held in stock with a total inventory value of £93.5K, based on current cost.

(iii) Annual expenditure up to year end 1980 had been £112K.

(iv) For the existing range of indexable inserts the number of tool suppliers totalled 12, and the number of individual tool material specifications equated to 83.

(b) The number of current (live) components being machined was 1150, albeit the top 200 components accounted for 90% of the standard hours generated by the Power Train machining activities within the Plant.

(c) An examination of process sheets revealed a high level of inaccuracy, with the updating of the manually based process planning system being recognised as a serious problem area.

(d) A variety range of 4,360 tooling related accessories were held in stock, a high percentage of which were identified as supporting items, i.e. toolholders, shims, clamps, etc., for the existing range of indexable inserts.

At the commencement of the research work at Coventry Engine Plant a strong argument was presented by process planning and tool stores related personnel justifying the existing range/value of the tooling stocks in general, but simple indicators suggested considerable improvements in control could be achieved, examples of which included:-

(a) The inventory/annual expenditure ratio of (£93.5K/£112K) 0.84 indicated that the inventory was being turned over by value once every ten months for a range of tools, a vast proportion of which were standard off-the-shelf tools.

(b) The analysis of indexable inserts held in stock indicated that 73% of the variety range were related to turning operations suggesting that the predictive ability of IMPS combined with inherent tool material rationalisation mechanisms would have a significant role to play in terms of establishing control. In addition to these points the very early benefits established within the Longbridge Bar

Automatics Factory (reference to Section 5.4) were again 'turning' related, therefore, helping to establish a level of confidence for the task ahead.

6.6.1 Tool Supplier Involvement

It was recognised at an early stage that the tool suppliers, particularly those involved in the high volume supply of tooling, would be an integral part of the overall tool control system. An initial problem revealed by a simple analysis of the tool stocks was that five suppliers of indexable inserts were directly responsible for 77% of the existing range. This number of suppliers was considered to be a contributory factor for the wide range of tools and the decision was taken to reduce this number from five to two suppliers for the purposes of tool standardisation, these being Sandvik (UK) Limited and Seco Tools Limited. In addition, the research project was supported in terms of technical advice by a third Company (SPK Feldmuehle Limited) with respect to low volume specialist tools.

The two mainstream Companies (Sandvik and Seco) indicated a willingness to be involved in an exercise lasting for a minimum of twelve months, and against allocated tool trial areas within the factory each committed a tooling engineer on a part-time basis to the project to assist with tool trials. Therefore, in summary, the full project team was:-

(a) The writer

(b) One plant-based process planning engineer on a full time basis.

(c) The equivalent of one full-time tooling engineer if the input of Sandvik and Seco is combined.

6.6.2 Project Work Presentation

The next stage was to generate an awareness throughout the factory of the requirement for a more effective tool control system and the work involved to meet this objective. Much of the eventual success of the ATOMS routine is attributable to regular communications at all levels within the Company detailing project objectives and progress against timing plans.

6.6.3 Data Collection

Three fundamental decisions were taken at the commencement of the exercise:-

(a) Although IMPS could only make a direct contribution in terms of turning based machining operations the decision was taken to include all indexable insert based machining applications in terms of developing overall Plant tooling standards. Therefore, for assessing the machinability aspects of such processes as milling, boring, threading, etc., the more conventional sources would be utilised, i.e. Metcut, tool supplier's data, University research links, etc. However, the one main advantage that was gained through the IMPS (turning) development work was that much of the inherent logic, (i.e. tool control begins with technological control at the cutting edge supported by the mechanistic, generative logic, etc.), was applicable to all metal removal processes. Further IMPS machinability modules were started during this research work, however for the purposes of describing the ATOMS routing any reference to other such work will be minimal.

(b) It was considered that there was only one way to validate all of the existing indexable inserts standards and supply requirements and that was, in theory, to visit every machine tool throughout the factory and physically record the data. In practice such an idea would have taken several months for 1-2 people to complete. The task, and the research project timescale precluded such a commitment. However, after discussing the problem with the Manufacturing Manager an apparent solution emerged, and that was the formation of a task force comprising the part-time involvement of all of the machine shop foremen and machine tool setters in establishing the data base required. Again, communications were important and a series of half-day training sessions were given to all members of the task force, and as a result the way ahead had been prepared to make a very positive step forward. Under the direct supervision of the writer, the data collection exercise required three weeks to complete, using the foremen and setters wherever possible.

(c) Having established the above data base which reflected the Plant indexable insert requirement profile, the subsequent validation of a new rationalised range of standard tools was recognised as the next major task. After further consideration the resolution to this particular problem was to limit the tool trial activity to the top 200 machined components within the Plant, which as stated earlier, represented 90% of the standard hours generated for the machining based Power Train activities.

Hence, the standards generated from the top 200 components would then be used for the remaining 900 plus current components. Subsequent work, however, did impose minor alterations to this strategy for specialist low volume machining operations.

With the rules as established in (a), (b) and (c) the necessary information relating to existing indexable insert requirements was established. From this base data a simple file of information was committed onto the APPLE microcomputer, hereafter known as the 'where-used' file. An enhancement of the 'where-used' related files plays a very prominent role within the tool material supply module, LINCS, and for this reason the respective file organisations and supportive programs are discussed in greater detail in Chapter Eight.

The very first 'where-used' file was component orientated, and enabled an automatic access to current component tooling related details. Further work enabled a tool orientated access to the data base, and thereafter, the 'where-used' file could be accessed in terms of component or tooling related information. This extremely simple data file proved to be the cornerstone of further work with respect to the tool material supply element of ATOMS, and at the time was considered to be a useful aid to functional areas within the factory.

The component/tooling 'where-used' file highlighted two significant problems which Plant Management had been unable to quantify previously, and these were:-

(a) Of the 785 individual varieties of indexable inserts held in the tool stores only 436, i.e. 56% had an identifiable end use.

(b) A random comparison between the tool/component 'where-used' data and the process planning sheets revealed a 27% mismatch between what had been planned (process sheets) and what was actually happening in practice ('where-used').

As a further step towards establishing control the following actions were taken:-

(a) A hard copy of the 'where-used' information was given to every cost centre supervisor and a request made that the tools as indicated were to become the local areas 'authorised standards', irrespective of process sheet data, until IMPS based (if turning) tool validation trials could take place.

(b) In the tool stores all indexable inserts without an identifiable end use as per the 'where-used' file were bonded and subsequent issue against them restricted to all but emergency situations.

6.6.4 <u>IMPS Assisted Tool Trials</u>

Tool trials then commenced across all of the top 200 components utilising IMPS generated machinability/tool material grade standards for selected 'pilot' operations upon each component for all turning based activities, and Metcut/tool supplier data, etc., for the remaining processes. The philosophy pursued was relatively simple, with the following guidelines being adhered to:-

(a) If the IMPS predicted standards, validated by tool trials were seen to be offering the potential of economic improvements then the revised standard was run on a trial basis for four weeks.

(b) If the IMPS predicted standard only matched the existing machining parameters, but the existing tooling was not part of the new proposed standard range of tools, then the tool in question was replaced with the equivalent IMPS standard tool. Again, this revised condition was run on a trial basis for four weeks.

(c) If the existing machining parameters indicated an economic advantage when compared to the IMPS data then those conditions remained unaltered and the IMPS data base/tool material range was extended accordingly to reflect the improved situation.

(d) With respect to the remaining indexable insert related processes, i.e. milling, boring, threading, etc., similar IMPS type standards emerged allowing the simple measures in (a), (b) and (c) to be implemented and, in addition, the respective IMPS type system frameworks were established, albeit the new machinability modules were still in their embryonic phase and required a considerable period of dedicated research time on system development and refinement to meet the IMPS (turning) operational specification.

(e) Having completed whichever measure was appropriate from (a) to (d) above each production foreman and local process planning engineer was then asked to 'sign off' their respective cost centre to the standards as determined by the tooling validation trials.

(f) As all of the individual cost centres were 'signed off' at foreman level the local production superintendents were then asked to audit their areas of responsibility, and this time 'sign off' complete machine shops, which comprises all of the individual cost centres.

Upon the completion of the exercise incorporating items (a) to (f) a factory profile was established to reflect the new standard range of tools and machining parameters. An overview of the situation revealed:-

(a) The range of indexable inserts actually in use had been reduced from 436 to 120.

(b) While physical changes in machining parameters had been limited in consideration to the number of tool trials undertaken, IMPS had imposed a radical change in one specific area, that of tool change frequencies, resulting in a considerable economic advantage to the Company.

The next logical step towards the objective of establishing overall control was the formation of a standard tooling catalogue in which ARCLASS (Austin Rover Classification System) was to play a major role. The development of ARCLASS, and subsequently the standard tooling catalogue are discussed in the following Chapter.

CHAPTER SEVEN

7.0 CLASSIFICATION AND CODING SYSTEMS (ARCLASS)

The prime objective of the ARCLASS classification and coding system is to act as the technological information link between the IMPS data base and other supportive systems which initially includes the tool material supply system (LINCS). Gombinski [89] 1969 highlighted the difficulties of having a common system for servicing the requirements of design and production orientated tasks, and proposed the use of separate purpose-designed systems for the Product Design and Production Planning Departments which are complementary to, and interface with each other. This approach may be desirable to establish control within the confines of the manufacturing technology planning system, but when the requirements of achieving similar levels of control within the manufacturing management and manufacturing systems as defined by Bhattacharyya and Coates [39] 1974 are considered then the concept of departmentalised, purpose-designed, classification/ coding systems presents significant medium-term maintenance problems and potential user difficulties in non-technical areas. In addition, this local approach to control can distract management attention from the requirement to understand sub-system interaction, and their contribution towards improving the efficiency of the overall business system.

However, as the Tool Management System (ATOMS) as described in Chapter Five, is underpinned by the achievement of technological control at the cutting edge then clearly the operational classification/coding system should utilise a metal removal based technological classification structure and, where possible, accommodate a compromise of user needs from within the overall business system. Conceptually, such a system would act as a 'common language' throughout the Company/Business and have provision for secondary 'end of code' characters to be utilised for specific individual department's local requirements.

7.1 PRINCIPLES OF SYSTEM DESIGN

Having established a broad system objective and direction it is then necessary to understand the essential design features of classification and coding systems, and these are given in the following two sub-sections.

7.1.1 Classification

(a) The essential needs of the system users must be established and the best compromise between such requirements achieved.

(b) Only the permanent characteristics, i.e. those which are meant to last and are not subject to change, contained within the information, data, or components should be selected and used in designing the classification system.

(c) The definition of the classification categories must be precise and unambiguous.

(d) The classification must be comprehensive, i.e. the categories are capable of including all that which comes within the scope of classification.

7.1.2 Coding

After the classification plan has been completed and the data items identified within that plan the coding method should be selected. As with the previous sub-section the basic requirements to be satisfied are as follows, IBM [90]:-

(a) Expandable - the code must provide space for additional entries within each classification for new items. There must also be capacity to expand existing classifications and add new ones to take care of future changes.

Although difficult to quantify this possible rate of change, Halevi [84] 1980, indicates with the introduction of new technologies into the plant create an ongoing need to classify and control new types and groups of materials. Hence, reorganisation and changes in the classification and codes have to be made every six to ten years. Additionally, the limitation on code length also limits the extent to which the desired secondary objectives can be achieved.

(b) Precise - the codes structures must be such that only one code may be correctly applied to a given time.

(c) Concise - the code should require the least number of characters to adequately describe each item.

(d) Convenient - the code must be easily understood by each user and simple to apply, whether encoding or decoding.

(e) Meaningful - if possible, the code itself should indicate some of the characteristics of the items.

(f) Operable - the code should be adequate for present and anticipated data processing machine methods, as well as for manual reference.

7.2 SYSTEM SELECTION AND DESIGN

In selecting a potential system the following aspects, in addition to the features discussed in sub-sections 7.1.1 and 7.1.2 above, were considered to assume particular importance:-

(a) The nature of the business environment into which the system will be implemented.

(b) Establishing the system cost/benefit profile.

(c) Implementation timescale.

These key features were used as the benchmarks when assessing the suitability of the existing systems as discussed in Chapter Four and based on this accepted cautious approach, the main concerns to emerge were:-

(a) The majority of the systems were orientated towards component statistics in a batch work environment, with the underlying theme of achieving control within the manufacturing technology planning system and not directly in the production business system as a whole.

(b) In committing a major Company to a complete restructuring of its consumable category materials classification/coding system serious consideration must be given to:-

(i) Experience in terms of system maintenance and its vulnerability to medium-term erosion.

(ii) The system's ability to function within a dynamic environment with particular emphasis on flexibility and ease of update.

(iii) The quantification of system cost/benefit and implementation timescale.

An exception to this appeared to be the Brisch Mono-Code System and exploratory discussions began with Brisch-Birn Limited, the licensees of the system in question. However, after a short period of time the following concerns emerged:-

(a) The concept of the Mono-Code was far too rigid and committed the user from the onset to a classification structure which remained constant irrespective of the technological complexity of the cutting involved.

(b) Despite the move by Brisch into component statistical analysis during the 1960's/70's and the more recent move into the field of CAD/CAM, Hyde [91] 1981, the roots of the system design are embedded in commercial areas such as inventory control and purchasing, utilising manual rather than computer based systems, and much of this hereditary design is not suited towards the achievement of technological control within a manufacturing systems environment.

(c) Apart from the technical limitations the system implementation cost was considered to be excessive and a profile of the quotation received based on the part requirements of Coventry Engine Plant was as follows:-

(i) For the classification/coding of 9250 tools, 28 man weeks of consultants' time was required at a standing charge of £1000 per week.

(ii) Additional costs included:

- Consultants' expenses (unknown)
- £2500 for a computer program which structured the new classification/coding system.
- Approximately two man years' input to the project from BL Limited personnel.

The forecasted benefits from such an investment were given as:-

(iii) A 15% reduction in current inventory by the end of year one representing an inventory reduction of £150K based on a total estimated inventory value of £1 million.

Against the known expenditure and estimated savings the pay back would be in the region of twelve months, but the proposal was rejected by local management on the basis that the implementation of the ATOMS routing would provide a platform from which similar savings could be achieved without having to make the financial investment as identified by Brisch-Birn Limited.

Despite not pursuing the Brisch proposal the system offered two important guidelines which were incorporated into the eventual classification/coding system and these were:-

(a) The Brisch 'classification wheel' as discussed by Astrop [81] 1978 offers a starting point for developing a system which would embrace any of the items involved within the business operational activity, i.e. employees, productive/non-productive materials, machines, etc.

(b) Hyde [74] 1976 discusses in relation to classification systems the principles of arranging individual items into a logical and systematic hierarchy whereby like things are brought together by virtue of their similarities and then separated by their essential differences.

A further influence on the eventual system came from the work of Houtzeel [76] 1976 when commenting on the MICLASS system which classifies workpieces by their characteristics (such as shape, dimensions, tolerance requirements and machinability) and not by their functions. Although the chain structured approach of MICLASS cuts across many of the principles of Brisch, and the following section will show that a constructive use can be made of utilising features from both approaches.

7.3 ARCLASS - A SYSTEM PROFILE

It would be misleading to give the impression that the classification/coding system (ARCLASS) was designed and implemented over a short period of time. The service and disciplines required from the system only became apparent when the IMPS and LINCS modules were well into their development and implementation phases. In addition to this before committing the final ARCLASS classification plan provisional research work was carried out into the requirements of several machining processes and related tooling requirements, i.e. abrasive machining, drilling, tapping, reaming, etc., to ensure the proposed plan was suitable for servicing medium-term requirements.

An additional feature which was 'kept in mind' during this development phase was a further medium-term systems requirement in that the eventual system design should be capable of being integrated into an automatic classification/coding system by the application of suitable software. The concept would revolve around automatically generating a new tool code number by utilising an approach of interactive computing whereby the user would be automatically guided through the classification system by a series of prompts. It was recognised at this early stage in system design that the initial classification plan, i.e. hierarchical, network, logical, etc., would have a significant influence on the data base design requirements to facilitate such a self-generating system.

Reference to Figure 45(a) presents a profile of the eventual classification system. The operational system (as implemented at Coventry Engine Plant) consists of four main elements, separated by hyphens which are shown as A, B, C, and D, the functions of which are:-

(a) Element 'A' allocated consumable items, such as cutting tools, into financial control account categories.

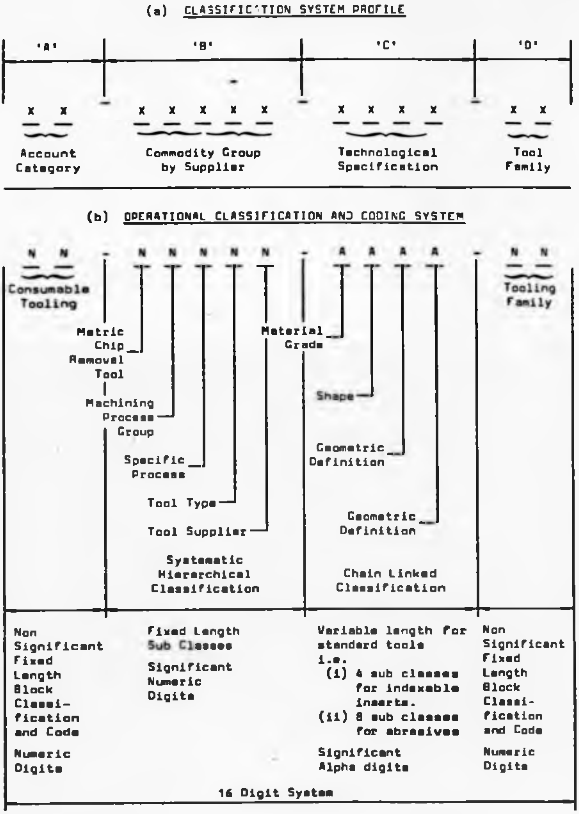
(b) Element 'B' classifies cutting tools and related items into machining process defined commodity groups.

(c) Element 'C' facilitates the critical technological control required for linking the IMPS data base to the LINCS tool material supply system.

(d) Element 'D' classifies specific tool families whereby the only variance between the items is dimensional.

7.3.1 Classification

Reference to Figure 45(b) gives an overview of the system routing with the key features being as follows:-



ARCLASS - SYSTEM ROUTING

Figure 45

(a) The basic system is 16 characters in length (including hyphens) although the number of characters is not considered to be a limiting feature.

(b) Element 'A' (characters (1) and (2)) sets the level of focus for the entire system and comprises a simple, non-significant, block classification plan of fixed character length. Chapter Four has shown that the level of focus can vary from the all embracing business approach of the Brisch Wheel [81] to the specific technological control disciplines of the PERA machinability data bank system [83].

Clearly the starting point must be somewhere between the two and indeed this was dictated by the existing BL Limited financial control procedures which identify consumable materials, of which tooling is a major element, under a unique account code.

(c) Element 'B' (characters (4) to (8)) is a systematic, significant character hierarchical classification plan, again of predetermined length. The principles of formatted matrices typified by the Brisch and Opitz systems have been adopted for this element.

An insight into the successive sub-classes contained within Element 'B', which conceptually will remain constant for all cutting tools and related spares to be classified, will reveal an attempt has been made to install manufacturing logic related to the decision-making process normally pursued by the production/process planning engineer, the flow of which is as follows:-

(i) Character (4) establishes the consumable tooling related item, as identified by Element 'A', into the following categories:

- Imperial (measurement system) consumable cutting/forming tools other than hand tools.
- Imperial tool holders and related spares.

- Metric consumable cutting forming tools other than hand tools.
- Metric tool holders and related spares.

The following sub-classifications will be directed towards cutting tools rather than spares albeit the classification plans are very similar, i.e. for a tool relating to a particular process category read tool holder.

(ii) Character (5) establishes the tool by the manufacturing process category.

(iii) Character (6) classifies the specific machining proces group, i.e. milling, turning, grinding, etc.

(iv) Character (7) identifies tool type within a defined machining process family, i.e. single point machining, turning, brazed tool or indexable insert.

(v) The requirements for the fifth sub-classification, i.e. Character (8) commodity by supplier, is perhaps less self-explanatory. For BL Limited to gain commercial benefit in terms of purchasing discount rates, etc., then the ideal situation particularly with high usage 'off the shelf' standard tooling is to have supplier interchangeability once the respective IMPS machinability standards have been established.

In the case of single and multi point machining this was found to be difficult to achieve in practice and despite apparent comparability against ISO tool material grade charts a wide range of tool performance was encountered as the result of conducting supplier interchangeability tool trials. Because of this variance further research work would be required to enable the desired situation of interchangeable standard composite tooling.

Therefore, at the time of writing both the IMPS machinability data and subsequent identification were linked to specific tool suppliers although provision has been made within the classification plan to eliminate the supplier classification once interchangeability has been established.

(d) Element 'C' (characters (10) to (13)) was found to be the heart of the system and a level of flexibility was required to accommodate various technological features. Because of this a decision was made to move away from the rigid, interdependent hierarchical approach of Element 'B' and adopt the flexibility of a chain-linked, variable significant character length, classification plan typified by the principles contained in the MICLASS system.

The successive sub-classifications contained within Element 'C' are dictated by the technological requirements of the IMPS machinability standards and are not intended to accommodate purpose-designed cutting tool features as to be found with form tools, etc. In principle the basic system would comprise four successive sub-classifications, utilising ISO/BS system definitions wherever possible. However, if additional technological features required definition within the overall classification plan then further sub-classifications would be allowed.

The basic classification plan is:-

(i) Character (10) identifies tool material specification, i.e. high speed steel, tungsten carbide (uncoated), hot pressed ceramics, etc.

(ii) Character (11) identifies the basic tool shape/style, i.e. rhomboid (indexable inserts), quick helix (twist drills), etc.

(iii) Characters (12) and (13) refer to the basic tool cutting geometry, i.e. clearance angles, chip breaker styles (indexable inserts), twist drill point angles etc.

With respect to all of the sub-classifications within element 'C' standard nomenclature, i.e. BS/ISO etc., have been utilised wherever possible.

(e) Element 'D' (characters (15) and (16)) consists of a further classification to group the tools now defined by specific common technological features into dimensional families. A simple non-significant fixed character length block classification plan has been utilised.

The tool family matrices of this element were then used to form a standard tooling catalogue, a subject discussed in more detail in Section 7.6.

(f) The overall design of the classification plan provisions for an 'end of code' open-ended data recording facility for local departmental requirements and this is discussed further in sub-section 7.5.2.

7.3.2 Coding

Initially the principle of utilising numeric based characters throughout Elements 'A', 'B', 'C', and 'D' was adopted, but this became very cumbersome when attempting to accommodate well-established ISO and BS systems, which are predominantly character based codes, within Element 'C'. Therefore, as Figure 45 indicates a clear division was made whereby Elements 'A', 'B' and 'D' with their fixed number of sub-classifications were identified by numeric characters (excluding 0) and Element 'C', which is the only variable element, comprises sub-classifications identified wherever possible by characters (excluding the letters I, O and Q).

Reference to Figure 46 shows a detailed routing through the combined classification/coding system known by the acronym ARCLASS. The example given for a specific tool family within the general classification of indexable inserts, has been taken from the standard tooling catalogue as implemented as part of the overall ATOMS approach to tool control at Coventry Engine Plant, and is a typical example of the ARCLASS style, i.e.

16-61471-ATNB-01

The hyphens were used for better system visibility and offer a distinctive breakdown between the main classification elements, with the key variable Element 'C', i.e. technological control, particularly well highlighted.

7.4 ARCLASS - SYSTEM ROUTING

Further reference to Figure 46 summarises many of the key features as discussed in the previous sections. Items of particular interest include the following.

7.4.1 Account Code

The classification within Element 'A' designates the appropriate financial accounting code from which all Plant-wide financial reports are generated.

Typical examples of the two character account codes which are common to all Birmingham Operations factories are:-

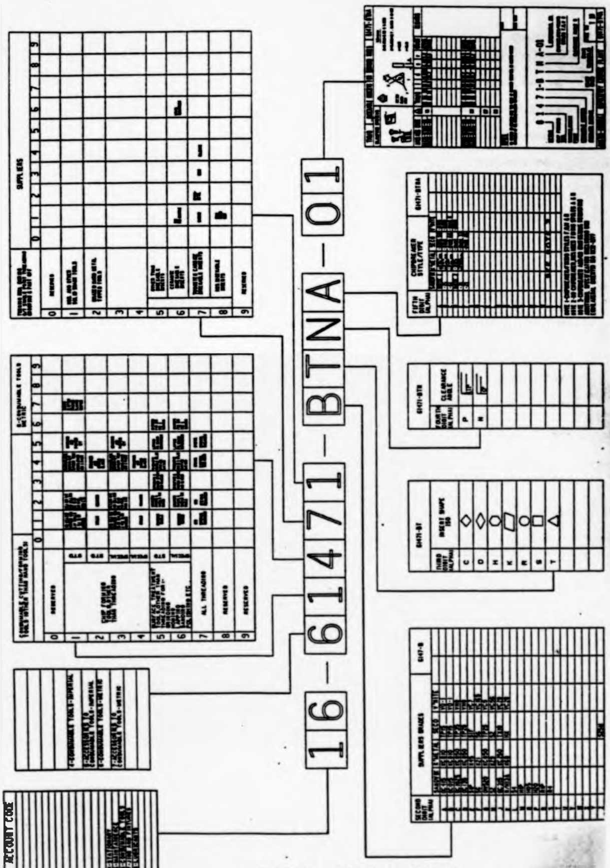
14 Stationery stores

15 Maintenance items

16 Consumable tooling

17 Jigs and fixtures

18 Oil



ARCLASS - SYSTEM DEFINITION

Figure 46

7.4.2 Commodity Group

The distinctive characteristic of Element 'B' is the initial use of two dimensional formats for establishing the classification plan and the subsequent coding system, reflecting the influence of Brisch and Opitz. It should be noted that to avoid user misunderstanding with respect to interpretation a dictionary of terms and definitions used throughout ARCLASS is provided as a section within the standard tooling catalogue (to be discussed in greater detail in Section 7.6)

7.4.3 Technological Specification

The detail contained in the classification categories identified by the individual characters (10) and (13) highlight a basic problem encountered while implementing ATOMS and that was the interchangeability of tools by supplier. In the case of indexable inserts this problem was compounded by the combined interchangeability requirement of chip breaker styles as well as tool materials.

The classification plan shown against the respective characters establishes the framework for possible supplier interchangeability albeit the following problems would have to be overcome before this objective could be fully implemented:-

(a) Tool material (character (10)) - this matrix has been provisionally structured on the potential for supplier interchangeability based on information taken from ISO tool material grade profile charts, and discussions with a limited number of tool suppliers. The tool material grades shown against each alpha character are theoretically interchangeable, i.e. similar metal removal performance standards can be expected from any of the individual suppliers material grades quoted. Non-acceptable variations in performance were encountered during interchangeability tool trials and at the time of writing acceptable interchangeability criteria has yet to be established.

(b) Chip breaker styles (character (13)) - the problems of supplier tool interchangeability were compounded by the proliferations of chip breaker styles now commercially available for which there are no ISO/BS specifications available. In an attempt to establish a level of control in this area an analysis was undertaken whereby similar chip breaker styles, by geometric definition, were classified into specific families and these are identified by the characters as shown in the matrix.

It may appear to the reader that undue caution is being expressed to this particular problem area, but in a mass production industry, typified by motor vehicle manufacture, the significant commercial advantage of bulk tool purchase from any chosen tool supplier world-wide, combined with the requirements of optimum tool performance against a predefined operational standard are fundamental factors in the optimisation of the manufacturing, production and business systems.

The remaining characters in Element 'C' allow for the classification of tool shape and basic cutting geometry. In the example chosen the indexable insert styles and clearance angles are based on ISO nomenclature.

7.4.4 Tool Families

Having pursued the individual cutting tool through the filtering process of the financial accounting, commodity grouping definition and technological specification elements, the only remaining classification is that by dimensional variance, and the net result of this is shown by a page from the standard tooling catalogue which represents a unique tooling family, reference to Figure 50, page 226.

7.5 SYSTEM EXPANSION

To ensure medium-term system expansion capability a review was undertaken of several tooling families (including tool spare parts) in order to anticipate potential system limitations. The families investigated were:-

(i) Drills

(ii) Reamers

(iii) Taps

(iv) Dressing diamonds

(v) All abrasives

From this review the following observations were made:-

(a) In all cases the format of Elements 'A', 'B' and 'D' were found to be acceptable, i.e. fixed length classification categories identified by numeric characters.

(b) The control mechanisms of Element 'C' were expanded by the requirements of the ISO [92] specifications for grinding wheels due to:-

(i) The number of characters utilised by the ISO system.

(ii) The utilisation of alpha and numeric characters for technological specification.

The net result of items (i) and (ii) are shown in Figure 47 where Element 'C' has a character length of eight and contains a mix of alpha and numerics. Neither point is considered to be detrimental to the overall ARCLASS mechanism in that the system boundaries have been set between a minimum of 16 characters to a maximum of 20.

7.5.1. Additional System Design Features

Clearly, the difficulty in developing a system routing is to anticipate all medium-term requirements, and two possible examples could

1. TWIST DRILLS

6 2 1 1 3 - A R N A - 1 4

- 6 — METRIC
- 2 — CHIP FORMING TOOL
- 1 — DRILL
- 1 — STRAIGHT SHANK
- 3 — LONG SERIES
- A — MATERIAL, HIGH SPEED STEEL
- R — CUTTING, RH
- N — HELIX, NORMAL
- A — TANGED?, YES:- ASA STANDARD
- 1 — SEQUENTIAL NO. (DESCRIBES DIMENSIONS)
- 4 — SEQUENTIAL NO. (DESCRIBES DIMENSIONS)

EXAMPLE (A)

A STRAIGHT SHANK, LONG SERIES, TANGED, HSS DRILL, RH CUTTING, 6 DIA.X 93 O/ALL X 57 FLUTE LENGTH STANDARD 118 DEG. POINT ANGLE, NORMAL HELIX

6 2 1 3 1 - A R F 2 - 0 8

- 6 — METRIC
- 2 — CHIP FORMING TOOL
- 1 — DRILL
- 3 — TAPERSHANK
- 1 — STANDARD LENGTH
- A — MATERIAL, HIGH SPEED STEEL
- R — CUTTING, RH
- F — HELIX, FAST
- 2 — TAPER, NO. 2 MORSE
- 0 — SEQUENTIAL NO. (DESCRIBES DIMENSIONS)
- 8 — SEQUENTIAL NO. (DESCRIBES DIMENSIONS)

EXAMPLE (B)

A TAPERSHANK, STANDARD LENGTH, NO.2 MT, HSS DRILL, RH CUTTING, 15 DIA.X 212 O/ALL X 114 FLUTE LENGTH, STANDARD 118 DEG. POINT ANGLE, FAST HELIX

2. GRINDING WHEELS

6 5 1 4 1 - A H K 1 K 6 V C - 0 3

- 6 — METRIC
- 5 — SURFACE TREATMENT TOOL
- 1 — GRINDING WHEEL
- 4 — RECESSED SIDES (ISO 5, 6, 7 AND 9)
- 1 — SUPPLIER 'UNIVERSAL'
- A — SINGLE RECESS (ISO 5)
- H — ABRASIVE, 47A
- K — BASIC GRIT SIZE, 46
- 1 — GRIT COMBINATION, 1
- K — GRADE, 3
- 6 — STRUCTURE, 6
- V — BOND TYPE, VIYRIFIED
- C — MANUFACTURING INDEX, MRAA
- 0 — SEQUENTIAL NO. (DESCRIBES DIMENSIONS)
- 3 — SEQUENTIAL NO. (DESCRIBES DIMENSIONS)

EXAMPLE (A)

A GRINDING WHEEL 250X25X101.6 REC O/S 175X8, IN SPECIFICATION 47A46136VMRAA, WITH A M.O.S. OF 2500 REV./MIN, PLAIN PERIPHERAL SHAPE, SUPPLIED BY UNIVERSAL GRINDING WHEEL LTD.

6 5 3 3 1 - A G 1 E B B A - 0 3

- 6 — METRIC
- 5 — SURFACE TREATMENT TOOL
- 3 — TOOL FOR FLAT SURFACE MACHINING
- 3 — NUT INSERTED CYLINDER WHEEL (BS/ISO 37)
- 1 — SUPPLIER GEO. JEWITT
- A — ABRASIVE, WHITE REFINED AL OXIDE
- G — BASIC GRIT, 30
- 1 — GRIT COMBINATION, 1
- E — GRADE, E
- B — STRUCTURE, 12
- B — BOND TYPE, RESINOID
- A — MANUFACTURING INDEX, Z
- 0 — SEQUENTIAL NO. (DESCRIBES DIMENSIONS)
- 3 — SEQUENTIAL NO. (DESCRIBES DIMENSIONS)

EXAMPLE (B)

A 'CYLINDRICAL' GRINDING WHEEL, 457X127X63.5 WITH 8 M10 THREADED INSERTS SPACED ON A 406.4 P.C.D., IN SPECIFICATION WA 30EBZ, M.O.S. 600 REV./MIN, SUPPLIED BY GEO. JOWITT LTD.

ARCLASS - SYSTEM EXPANSION

Figure 47

include local departmental requirements and facilities for classifying purpose-designed tools. Comments on each are as follows:-

7.5.2 End of Code Facility

Reference to Figure 48(a) will show that a further Element 'E' has been added to the operational system and allows for the local requirements of individual functions to hold specific information against the code number identified. This provision is open-ended and is restricted only by the file address capability of the processor being used and typical examples of its use include:-

(a) Regrind characters to show the number of expected regrinds remaining in a cutting tool.

(b) Additional geometric definition as shown in Figure 48(b).

7.5.3 Purpose-Designed Tools

Reference to Figure 49 shows that a provision has been made for purpose-designed tools which is not an avenue pursued in this research activity. However, a modified ARCLASS structure could be designed along the following lines:-

(a) Element 'A', account category to remain the same.

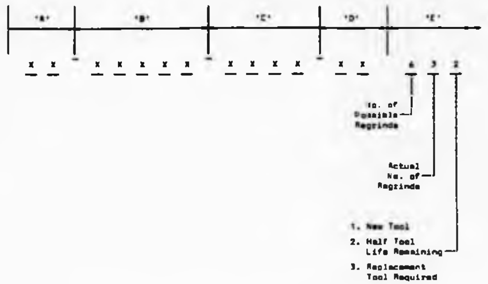
(b) Element 'B', identifies the special tool type by machining process.

(c) Element 'C', would be reduced to accommodate technological definition only, thereby removing the tool shape classifications.

(d) Element 'D', would now become the tool form/shape category definition by possibly pursuing a modified chain linked component type statistical analysis approach to the classification structure.

(e) Again the final element, in this case 'E', for tool family designation would remain fixed at two characters.

(a) Predicting Tool Life Remaining - Inventory Control



(b) Additional Technological Features For a Single Point Cutting Tool

Where:

γ = Side Rake

α = Clearance Angle

λ = Back Rake

ψ = Approach Angle

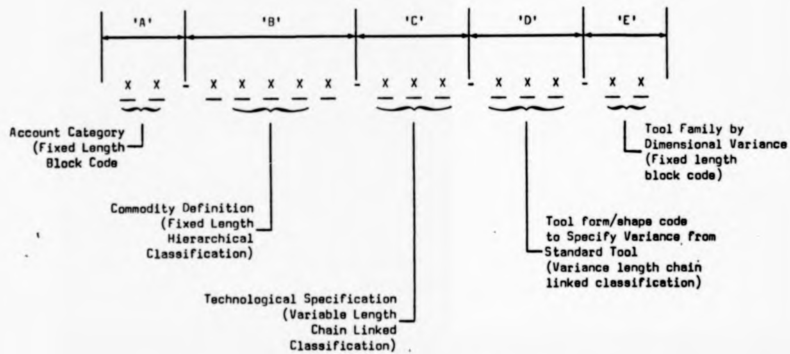
ε = Included Angle

r = Nose Radius

X, Y, Z = Specific Features, i.e. Edge Preparation

EXAMPLES OF INDIVIDUAL DEPARTMENTAL USE OF END OF CODE CHARACTERS

Figure 48



N.B. (i) Elements A, B, C, and E constant for all tools.

(ii) Element D additional for purpose-designed tools only.

<u>ARCLASS POTENTIAL APPLICATION - PURPOSE-DESIGNED TOOLS</u>

Figure 49

7.6 STANDARD TOOLING CATALOGUE

Chapter Six has shown that the result of the IMPS assisted indexable insert standardisation programme was to reduce the range of tools actually in use throughout the machine shops from 436 to 120 varieties. The next logical stage was to allocate an ARCLASS derived code number to each individual tool and then amend the 'where used' files to reflect the revised tool designations. Having completed this task an additional system benefit became apparent and that was the development of a standard tooling catalogue, initially to reflect the new standard range of indexable inserts, followed by the subsequent addition of other tooling families typified by twist drills and grinding wheels. A typical page from the standard tooling catalouge, as implemented, is given in Figure 50.

The main role of the catalogue was to act as an operational standard to which everyone at the factory was committed. From this point onwards only one individual, the Process Planner associated with the project, was allowed to amend the catalogue.

In addition to this main theme of control the catalogue was also intended as an educational aid, containing general discussion and advice relating to experiences gained during the tool standardisation programme. Typical sections included:-

(a) A full description of the ARCLASS control principles

(b) Tool wear diagnosis

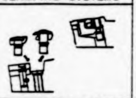
(c) Swarf control

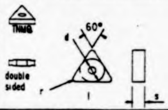
(d) Tool style equivalents

The issue of the catalogue was particularly well received within the user areas and for many it was considered to be a tangible result for tool trial activities which had taken place in the preceding months. Although the importance of such a catalogue was always recognised in terms of system implementation, its ready acceptance was a significant factor in creating a positive working environment for further ATOMS based initiatives.

TNMG	INDEXABLE INSERTS FOR TURNING TOOLS	61471-BTNA

CLAMPING SYSTEMS





tolerances

d=±0.05(d=6.35 & 9.525)

d=±0.08(d=12.7 , 15.875 & 19.05)

s=±0.13

r=±0.10

ARCLASS CODE	△	TNMG	l	d	s	r	GRADE	REMARKS
61471-BTNA-01	16	16 04 12	16.5	9.525	4.76	1.2	GC015	
61471-BTNA-02		16 04 16	16.5	12.7	4.76	1.6	GC015	
61471-BTNA-05	22	22 04 04	22.0	12.7	4.76	0.4	GC015	
61471-BTNA-06		22 04 08	22.0	12.7	4.76	0.8	GC015	
61471-BTNA-07		22 04 12	22.0	12.7	4.76	1.2	GC015	
	27							
	33							

NOTES

NO ADDITION OR DELETION FROM THIS RANGE OF STANDARD TOOLS WILL BE ALLOWED UNLESS AUTHORISED BY THE PROCESS PLANNING DEPARTMENT

ISSUE

ISSUE DATE

6 1 4 7 1-B T N A-01

- 6 — METRIC
- 1 — CHIP FORMING TOOL
- 4 — TURNING, SINGLE POINT
- 7 — INDEXABLE INSERTS
- 1 — SUPPLIER SANDVIK
- B — GRADE GC015
- T — SHAPE TRIANGULAR
- N — CLEARANCE ANGLE 0
- A — CHIPBREAKER/FIXING STYLES F.G.M R
- 01 — SEQUENTIAL NO

PAGE NO T 10

AUSTIN-MORRIS	COVENTRY ENGINE PLANT	61471-BTNA

STANDARD TOOLING CATALOGUE PAGE

Figure 50

7.7 SYSTEM LINKING

Reference to Section 6.5 and Figure 46 will begin to highlight the links between ARCLASS and the machinability grouping data files which the IMPS algorithm manipulates. For example, Figure 36, page 159, shows that the component machinability group (4) is best machined with tools with clearance angles N and P, and an appropriate tool grade is (i.e. GC 015) supplied by Sandvik, thus all tools with the code format:-

$$61471\text{-}B?^{N}_{P}?\text{-}??$$

would be eligible choices. The approach pursed within the IMPS algorithm is to search the entire floppy diskette-based Company Standard Tooling Catalogue to identify the appropriate tooling available, as described in Section 6.5, along with the methodology which facilitates the nomination of the most suitable chip breaker style based upon the feed rate and depth of cut specified for the machining operation.

CHAPTER EIGHT

8.0 TOOL MATERIAL SUPPLY SYSTEM (LINCS)

Having pursued the system routing this far the next logical step is to establish the factory supply mechanisms for the standard range of tools in question.

This particular aspect of the research work initially raised a point of concern in that there appeared to be a danger of apparently 're-inventing the wheel', because unlike the purpose-designed requirements of the IMPS and ARCLASS stages of the overall tool control concept, standard material supply software packages were readily available from the majority of the main hardware suppliers, as a purchasable commodity. However, rather like the initial appeal of the Brisch monocode as discussed in Chapter Four a limited investigation revealed the following problems:-

(a) As Chapter Two has shown existing 'in-house' systems were extremely expensive, with system running costs alone ranging from £40K to £80K per annum. To avoid any apparent confusion to the reader due to BL Limited's business organisation, each Plant would still have to pay similar system operational costs irrespective of the fact that the system may already be in use elsewhere within the Organisation.

(b) Experience from reviewing software packages that were commercially available revealed an emphasis towards direct material control, and minimal activity in terms of indirect/consumable materials.

(c) The foundation of the research work was based upon designing and implementing a routing through a linked systems approach to tool control, and involvement with other functions, departments, companies, etc., at the critical tool material supply stage imposed totally unacceptable constraints, examples of which include:-

(i) Access to hardware within any of the factories comprising Birmingham Operations for the purposes of system development was limited.

(ii) Access to software packages for the purposes of system modification/enhancement was discouraged at all times.

(iii) Existing systems within Birmingham Operations had restrictions with respect to the number of characters allowed within the tool code format. This ranged from a maximum of 8 characters with the Drews Lane system to 12 with the Longbridge system; thus effectively preventing utilisation of the variable length control features inherent within ARCLASS.

(iv) Involvement with others at any stage of the ATOMS development imposed constraints in terms of timescale, system design, flexibility, and a general reluctance to identify and rectify recognisable operational limitations.

Against this uncertain background the decision was taken to develop a tool material supply module, hereafter referred to as LINCS (Linked Inventory Control System), which services the manufacturing management control systems element of the overall ATOMS concept.

LINCS was developed at two distinct levels, and these were:-

(a) In any sizeable manufacturing concern it is necessary to have 'good housekeeping' disciplines to facilitate control. One such discipline is the operation of a stock transaction recording system, i.e. some method of recording to an acceptable level of accuracy, the flow of, in this instance, tool material and related information to and from the manufacturing system.

The three key areas of control established within LINCS are:-

(i) Tool material issue against the bona fide user area as identified by the data within the 'where used' files.

(ii) Tool material receipt.

(iii) A simplified purchase order tracking facility, although as later discussion will reveal this element of the system was replaced with a vastly improved tool procurement mechanism.

(b) Having established the more conventional stock control procedures as described in (a) a further initiative was taken to make greater use of the tool/component 'where used' files and develop the routing through a flow control based material supply system whereby the tools would be delivered directly to the machine shops against a forecasted weekly requirement thereby eliminating the need for certain categories of tools to be held in stock.

This concept is a derivation of the much publicised Japanese 'just in time' method of material supply, known universally as KANBAN, McElroy [93] 1982, albeit more generally identified with the supply of direct materials and not consumable/indirect materials typified by cutting tools and their related spares. However, a successful departure was made from the traditional approach to tool material supply and the routing for a KANBAN based flow control system was designed, and implemented, in two areas and these were:-

(i) A dedicated transfer line.

(ii) A single cost centre containing a mix of conventional machine tools.

The following sub-sections give an overview of the existing stock control system encountered at Coventry Engine Plant followed by further discussions on the various elements of the LINCS module as implemented at the Plant.

8.1 STOCK RECORDING - THE EXISTING SITUATION

The existing system was manually based and inherent problems stemmed from the allocation of duplicate tool code numbers, and a general lack of discipline in the recording of transaction data, resulting in little correlation between recorded stock levels and actual shelf stock. Enlargement of these problem areas is as follows:-

(a) Numerous codes have been allocated to one item of tooling due to the weak design, and operation, of the coding system used within the tool stores. The existing coding system which was discussed in some detail within Chapter Two was installed at the instigation of the local Production and Material Control and Financial Control Departments, was simply sequential, and served merely to allocate a unique code number to each item; since, however, it had no structure to facilitate technological grouping of like items, it failed to achieve this simple objective, thus one tool was held under several different code numbers at differing locations (bins) within the tool stores leading to considerable problems in terms of updating incorrect documentation.

To compound this problem, shop floor supervisors were totally oblivious to the existence of any coding system, and requested tools according to the description given by the tool supplier, or occasionally, by a British Standard (BS) or International Standards Organisation (ISO) technologically orientated description.

(b) Lack of instantaneous updating of stock card records following delivery of tooling by suppliers and/or issue to the production areas. This led to an accumulation of unrecorded transaction data which was updated periodically, the timing of which was dependent upon the department work load. Decisions taken regarding the requirement to re-order based upon the evidence of stock card records was clearly being made upon an infirm basis.

8.2 INVENTORY CONTROL

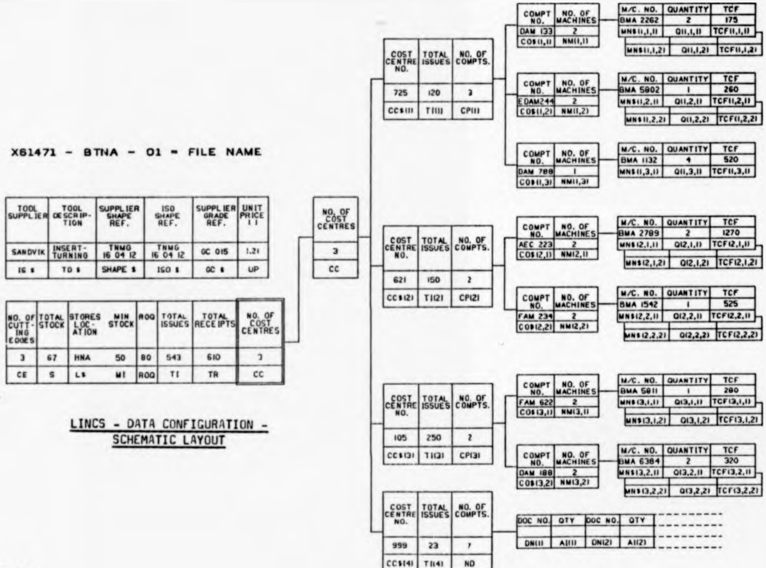
Following rationalisation of the indexable insert tooling range the facility to store, update and interrogate the records of 120 tooling items was required. This presented two initial problems, and these were:-

(a) The data base configuration.

(b) Data storage mechanisms.

Figure 51 presents a schematic layout of the eventual data configuration which is based on an ARCLASS designated file address, which for the routing shown is 61471-BTNA-01, followed by a hierarchically structured set of related data records. Examination of the individual records will reveal that the data base comprises an enhanced version of the original tool/component 'where used' file, and enables storage of data required to achieve management control, i.e. finance, stores, industrial engineering related as well as core information from the IMPS derived technology data base, i.e. cutting tool geometric and material grade parameters, etc. As the following sub-sections will show that all of the stock/flow control mechanisms have been developed by writing applications programs to interrogate this dynamic data base from various levels of focus to achieve the desired management control reporting features.

Because of the relative simplicity of this approach, it is not the intention to pursue the detailed, step by step, analytical procedure contained in the IMPS Chapter, but rather to give an overview of the



LINCS - DATA CONFIGURATION - SCHEMATIC LAYOUT

Figure 51

methodology pursued to establish control over tool material supplies and then refer to relevant appendices for details contained in the applicable applications program.

The second problem relating to data storage mechanisms centred around limiting the number of diskettes the system user was being asked to handle. In hindsight, and with the parallel technological development in terms of data storage, i.e. Winchester disk drives, this would no longer be a problem, but during the period of research the APPLE Disk Operating System (DOS) arranged the diskette directory in a format restricting the number of possible files to a maximum of 84 in sequential text form, when in fact the indexable insert tooling LINCS data base required a minimum of 120 file addresses. This problem was resolved by writing the program detailed in Appendix K which expanded the diskette potential to 175 files, therefore, resulting in all of the LINCS based data for the tooling family in question being held on a single density 5 1/4" floppy diskette.

As discussed in Chapter Three the term 'inventory control' is taken to include stock and flow control systems, and as the following sections will reveal, both approaches to material control played prominent roles in the evolution of the LINCS module.

8.3 STOCK CONTROL

The initial activity in terms of establishing control over tool material supply was to concentrate on three key areas of the tool stores activity, and these were:-

(a) Material issue

(b) Material receipt

(c) Re-order procedures

Further comment relating to each aspect is contained in the following sub-sections.

8.3.1 Tool Material Issue

A greater control over the recording of issues of indexable inserts was achieved by:-

(a) Disciplined use of the ARCLASS classification and coding system.

(b) Use of the tool/component 'where-used' data to restrict tool issue to recognised and user departments only.

At the conclusion of the IMPS assisted plant-wide rationalisation programme it was ensured that each indexable insert was identified by one unique code number and duplications had been eliminated. All production supervisors were given details of such tooling related to component machining under their control in the form of their local 'where-used' data, usually by cost centre designation. This represented a marked departure from past custom and practice, resulting in storekeepers no longer being required to cross-reference tool descriptions with code numbers as had previously been the case; hence the elimination of a serious source of confusion was achieved.

In addition to this a positive use was made of the 'where used' data to restrict the issue of tooling only to the bona fide end users as identified by the rationalisation exercise. It was considered that having completed the IMPS assisted tool rationalisation exercise the only reasons for tools being withdrawn by unrecognised user cost centres would be due to:-

(a) An alternative tool was required due to stock-out of the recommended standard.

(b) Shop floor personnel, i.e. setters, operators, etc., were using license to experiment still further with alternative tool types.

The first possibility should not have arisen following the introduction of the well established procedures of component volume linked max/min levels combined with supportive guarantees from the tool suppliers to hold adequate stocks of the recognised standard tools within their own stores. With reference to the second point, in practice it is unrealistic to suggest that tools should be automatically refused at the point of issue owing to the technicality that the requesting department is an unrecognised end user; instead tools were issued provided an authorised level of Production and Material Control signatory was willing to concur the issue. All such issues were recorded by the system and a weekly summary was presented to the Production Engineering Department for subsequent investigation to identify the existence, or otherwise, of any recurrent machining problems. Following this investigation the respective production engineer would then concur, or otherwise, the continued use of the non-authorised tool.

8.3.2 <u>Tool Procurement</u>

The first move towards applying control over the inventories held of the rationalised range of indexable insert tooling came by endeavouring to set maximum and minimum stock levels. This exercise highlighted a fundamental problem experienced within the Company and common to virtually all large commercial enterprises with labour intensive clerical systems and that is the time delay in processing paperwork. It was discovered that in the case of such standard tools as indexable inserts which are 'off the shelf' items, it took the Company eight weeks from the inception of a request to purchase tooling (by the local stores personnel) to the placement of a confirmed order by the central purchasing function with the tooling supplier; this concurrence route was clearly unacceptable. It then required a further week for the nominated supplier to complete their own internal procedures before tools were eventually delivered. The initial reaction was to include a purchase requisition 'tracking' facility within LINCS to monitor internal and external lead times as an anticipatory mechanism to enable stores personnel to check for any impending deliveries prior to the raising of new requisitions. This tracking facility was initially implemented, but despite its apparent usefulness and its general acceptance in the user areas the resource invested seemed to be accommodating a problem rather than seeking to overcome it. The decision was made, therefore, to eliminate this highly labour intensive approach to tool procurement and adopt a much more simplified solution to the problem. To this end, an agreement was reached between Production and Material Control, Finance, and Purchasing functions to the effect that a 'blanket order' arrangement should exist between various suppliers and Coventry Engine Plant such that at the local tool stores level a request for delivery of a given number of tools from within the new rationalised range would not require central concurrence and would be placed directly upon the supplier who would in turn, invoice the Company on a regular basis.

The net result of this action was to decrease the tool procurement time from eight weeks to one week and in doing so it was then possible to establish more realistic max/min levels for the 120 tools in question. This was based on a semi-flow control approach whereby data held in the 'where-used' files provided a link between components a tool was used to produce, the quantity in use at any one time and an approximate consumption rate by number of components produced (i.e. utilising validated tool change frequencies); receipt of monthly manufacturing programmes enabled the generation of appropriate tool quantities required to support that production level. Net order quantities were simply the result of the following equation:-

Net order quantity = Gross requirement + minimum buffer stock - stock on hand

8.3.3 Tool Material Receipt

Following on from improvements in tool issue and procurement then the remaining discipline of tool receipt from the suppliers following the direct placement of orders simply required mechanising to facilitate on-line real time (OLRT) updating to ensure accuracy of records.

Finally, examples of key reporting/control features and supportive applications programs are as follows:-

(a) Reporting/control features:-

(i) Tool issue/receipt - reference to Figure 52.

(ii) Tool/component 'where used' data - reference to Figure 53.

(b) Likewise, the main applications programs utilised are given in the following Appendices:-

(i) Tool data file creation program - Appendix L

(ii) Tool issue/receipt - Appendix M

(iii) Tool component 'where used' data - Appendix N

(iv) Tool bill of material generator - Appendix O

8.4 FLOW CONTROL

After a period of consolidation thereby allowing the initial issue, procurement, and receipt mechanisms to become established, further consideration was given to the problem, particularly in terms of tool procurement and supply. Upon reflection the approach pursued in the previous section still revolved around the in-house maintenance of tooling inventory with its obvious detrimental effect on the Company's cash flow position. Attention was therefore focused on developing the

```
]RUN


PLEASE KEY IN THE TOOL NAME

:-?61471-BTNA-01



ARCLASS CODE       *
=X61471-BTNA-01    *COST CENTRE   ISSUES
TOOL SUPPLIER      *    725          120
  =SANDVIK         *    621          150
SUPPLIER REF       *    105          250
  =TNMG160412      *    999           23
STORES LOC'N       *
  =HNA             *
CURRENT STOCK      *
  =67              *
MIN.STOCK          *
  =50              *
RE-ORDER Q'TITY    *
  =80              *
TOTAL ISSUES       *
  =543             *
TOTAL RECEIPTS     *
  =610             *


?
COST CENTRE999
AUTHORISED ISSUE DOCUMENTS
==========================
DOCUMENT NO.     NO. OF ISSUES
  10               2
  53               4
  72               1
  156              6
  159              6
  220              2
  300              2
PRESS(RETURN) TO CONTINUE
```

<u>LINCS - TOOL ISSUE/RECEIPT (SCREEN DISPLAY)</u>

Figure 52

```
?CCOST CENTRE725
COMPONENT NO. M/C NO.  QUANTITY T.C.F.

  DAM133
             BMA 2262  2          175
             BMA 2661  2          200
----------------------------------------

  EDAM 244
             BMA5802   1          260
             BMA5803   1          320
----------------------------------------

  DAM788
             BMA1132   4          520
----------------------------------------
PRESS (RETURN) TO CONTINUE

?COST CENTRE621
COMPONENT NO. M/C NO.  QUANTITY T.C.F.

  AEC223
             BMA2789   2          1270
             BMA2790   2          1270
----------------------------------------

  FAM234
             BMA1542   1          525
             BMA1543   1          525
----------------------------------------
PRESS (RETURN) TO CONTINUE

?COST CENTRE105
COMPONENT NO. M/C NO.  QUANTITY T.C.F.

  FAM 622
             BMA5811   1          280
             BMA5812   1          280
----------------------------------------

  DAM 188
             BMA6384   2          320
             BMA6385   2          320
----------------------------------------
PRESS (RETURN) TO CONTINUE
```

LINCS - TOOL/COMPONENT 'WHERE USED' DATA (SCREEN DISPLAY)

Figure 53

routing through a material supply system which had the objective of having tools delivered by suppliers on a weekly basis in 'packages' specific to a cost centre and/or dedicated machining facility in sufficient quantity to support the following week's production. The subsequent system routing which was developed to accommodate this new approach to tool material supply was known as 'Tool Marshalling'. Discussion in the following sub-section will reveal that the system takes its name from the physical procedure, as carried out by the local storekeeper, of marshalling the appropriate tool packages as delivered by different tool suppliers for specific cost centres.

8.4.1. Tool Marshalling

While the routing for a direct material supply system could be developed on an APPLE Microcomputer all of the Plant's cost centre details and forward manufacturing plans were generated from a Plant based (BLSL owned) CMC Sovereigr minicomputer to which access was finally made available for the purpose of developing the line side supply of standard indexable inserts. For the purposes of the initial system routing two distinct levels of activity were established, the details of which are:-

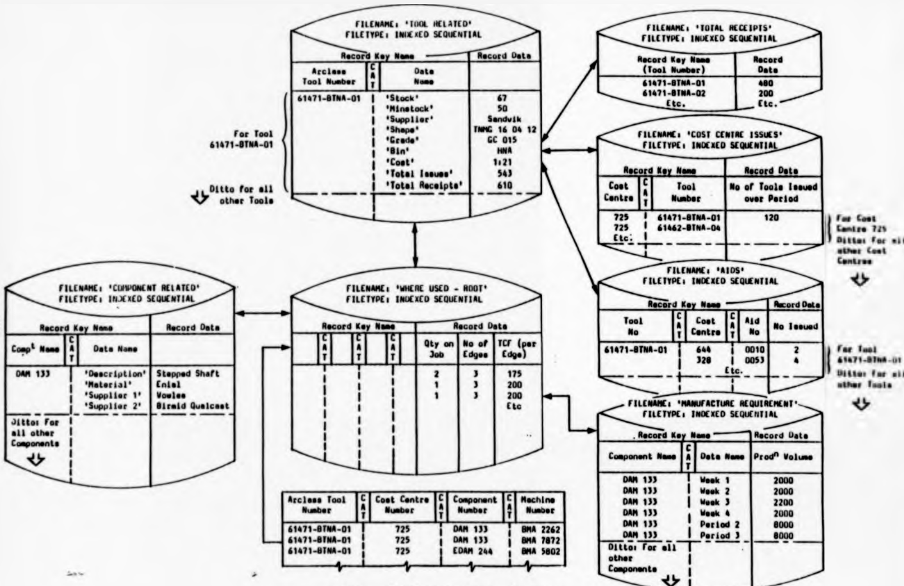
(a) It was considered that the most sophisticated and detailed supply situation supportable in both computerised system and personnel organisation terms was a level of control which enabled a cost centre to receive its tools in packages specific to each component containing sufficient quantity to support the following week's production requirement. Such a method of control was found to be applicable to cost centres producing a relatively small range of components in high volume and was referred to as Level 1 control.

(b) For cost centres having a larger range of components, usually being produced in commensurately smaller quantities, Level 1 control proved difficult to support because of a number of major difficulties, the primary one being that since Level 1 control called for the delivery of one tooling package for each componet in the cost centre, a multiplicity of components necessitated the delivery of a large number of containers which were simply too cumbersome to transport and, because of the generally lower production figures, contained few tools. For this reason a less detailed, but more appropriate level 2 control was devised for such cost centres. Level 2 control provided for the delivery of tools specific to the cost centre as a whole (i.e. not component specific) on a weekly basis.

When considered in conjunction with the above two levels of control, the net bill of materials supply system introduced earlier is thus a still less refined method of control and was, therefore, designated as level 3 control since it worked upon the premise that although tooling requirements were generated from the 'where used' matrix, tools were held in the central tool stores and not delivered by the vendor in cost centre or component-related packages. It is important to understand, however, that for all three levels of control, the bills of material were generated on a weekly basis from the same core data held in indexed sequential form upon the CMC Sovereign computer as shown in Figure 54, the level of control to be applied for each cost centre being discerned from the setting of a flag included for that specific purpose.

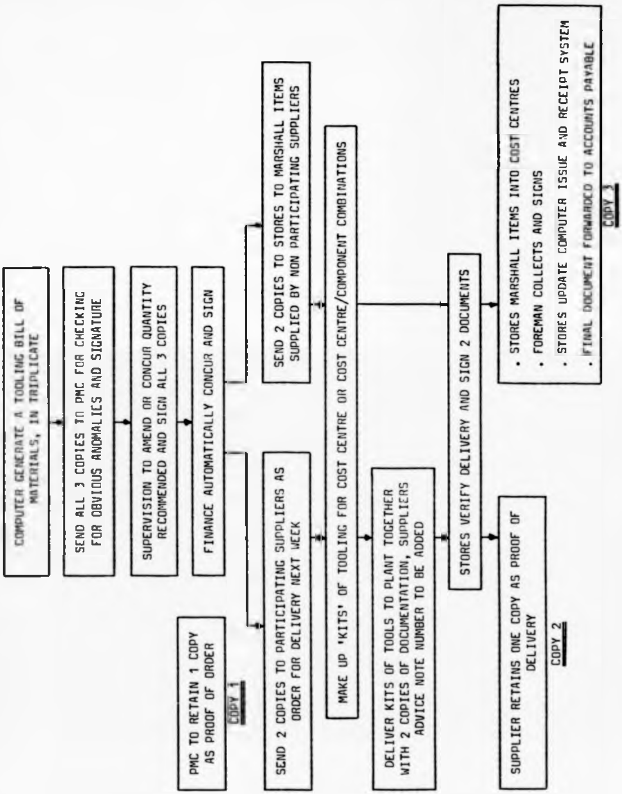
The detailed mechanism of system operation was as follows and reference should be made to Figure 55 in association with the text.

Documentation is computer-generated in triplicate from the CMC Sovereign 'where used' file base (component volume data being extracted from the Plant Production and Material Control files) upon the Tuesday of week one with all columns completed up to, and including the 'quantity required' column which for level 1 is the gross quantity (based upon component volume and tool consumption rate details) rounded to the nearest even number and for level 2 is the gross quantity rounded to the nearest 10 to simplify packaging considerations; examples of documentation



LINCS - (CMC) BASED FILE STRUCTURE

Figure 54



TOOL 'MARSHALLING' - OUTLINE OF DOCUMENTATION FLOW FOR LEVELS (1) AND (2) CONTROL PROCEDURES

Figure 55

generated for Level 1 control is given as Figure 56 for cost centre 738, component number FAM 9433 for suppliers Sandvik and Seco. Following vetting for anomalies by Production and Material Control the area supervisor either concurs the computer generated figure as being appropriate or alternatively amends it to accommodate movements in his section's tooling buffer stock levels in the 'quantity ordered' column; two copies are collected on the following day by the supplier and are retained by the Plant as proof of placement of order. Upon the Friday of the following week delivery of the tooling to fulfil the order is made and the two copies of documentation returned by the supplier to the stores personnel to verify the delivery, acknowledge such in the 'quantity received' column, and sign the appropr'ate box; one copy is returned to the supplier as his proof of delivery for invoicing purposes. The one remaining copy is signed by the production supervisor upon collection of his package from the tool stores as proof of issue, thus on one document a full list of signatories signifying concurrence of order, acknowledgement of receipt and acknowledgement of issue is achieved.

It will be appreciated that this method of delivery entailed far greater effort on the part of the supplier than was normally the case in satisfying 'conventional' orders and thus those vendors with only a minority interest in BL's activities could not justify such involvement on a cost-benefit basis, such suppliers were thus dealt with in the conventional ordering manner and for Levels 1 and 2 control, their two copies of documentation were sent instead of the tool stores keeper who withdrew the appropriate 'order quantity' from stores' stock and marshalled this with the Sandvik and Seco deliveries.

It should be noted that this 'marshalling' approach was only implemented towards the end of the project research activity and, therefore, it was not possible to quantify the full benefit to the Company in terms of

738 PAGE 1 12:17:52

COMP.NO.	MACHINE NO.	C/CTP.	I.S.O.CODE	GRADE	SUPP.NO.	T.C.F.	NO.EDG.	NO.MAC.	OP.D.	OP.NO.	FCT.
FAM9432	BMW4383	738	SPGN 120308	S6	S02301	825	4	10	TURN	050	1
FAM9432	BMW4384	738	SNMA 120408	GC015	S02301	550	8	1	TURN	050	1
FAM9432	BMW4384	738	SPGN 120308	S6	S02301	825	4	10	TURN	050	1
FAM9432	BMW4384	738	SPUN 090308	GC015	S02301	275	4	1	TURN	050	1
FAM9432	BMW4384	738	TPUN 160308	GC015	S02301	550	3	2	TURN	050	1
FAM9432	BMW4384	738	TNMA 220412	GC015	S02301	825	6	3	TURN	050	1
FAM9432	BMW4384	738	TNMA 160408	GC015	S02301	550	6	4	TURN	050	1
FAM9432	BMW4385	738	SNMA 090308	GC015	S02301	550	8	2	TURN	050	1
FAM9432	BMW4385	738	DCMA 110404	K10HTM	K12610	550	2	2	TURN	050	1
FAM9432	BMW4385	738	SPGN 090308	KC210	K04076	550	4	4	TURN	050	1
FAM9432	BMW4385	738	SPGN 050204	VC2	V00372	10000	4	1	TURN	050	1
FAM9432	BMW4386	738	SPGN 120308	S6	S02301	825	4	10	TURN	050	1
FAM9432	BMW4387	738	SNMA 120408	GC015	S02301	550	8	1	TURN	050	1
FAM9432	BMW4387	738	SPGN 120308	S6	S02301	825	4	10	TURN	050	1
FAM9432	BMW4387	738	SPUN 090308	GC015	S02301	275	4	1	TURN	050	1
FAM9432	BMW4387	738	SNUN 090308	GC315	S02301	550	8	2	TURN	050	1
FAM9432	BMW4387	738	TPUN 160308	GC015	S02301	550	3	2	TURN	050	1
FAM9432	BMW4387	738	TNMA 220412	GC015	S02301	825	6	3	TURN	050	1
FAM9432	BMW4387	738	TNMA 160408	GC015	S02301	550	6	4	TURN	050	1
FAM9432	BMW4388	738	SPGN 090308	KC210	S02301	550	4	4	TURN	050	1
FAM9433	BMW4383	738	SPGN 120308	S6	S02301	825	4	10	TURN	050	1
FAM9433	BMW4384	738	SNMA 120408	GC015	S02301	550	8	1	TURN	050	1
FAM9433	BMW4384	738	SPGN 120308	S6	S02301	825	4	10	TURN	050	1
FAM9433	BMW4384	738	SPUN 090308	GC015	S02301	275	4	1	TURN	050	1
FAM9433	BMW4384	738	TPUN 160308	GC015	S02301	550	3	2	TURN	050	1
FAM9433	BMW4384	738	TNMA 220412	GC015	S02301	825	6	3	TURN	050	1
FAM9433	BMW4384	738	TNMA 160408	GC015	S02301	550	6	4	TURN	050	1
FAM9433	BMW4385	738	SNUN 090308	GC315	S02301	550	8	2	TURN	050	1
FAM9433	BMW4385	738	DCMA 110404	K10HMT	K12610	550	2	2	TURN	050	1
FAM9433	BMW4385	738	SPGN 090308	KC210	K04076	550	4	4	TURN	050	1
FAM9433	BMW4385	738	SPGN 050204	VC2	V00372	10000	4	1	TURN	050	1
FAM9433	BMW4386	738	SPGN 120308	S6	S02301	825	4	10	TURN	050	1
FAM9433	BMW4387	738	SNMA 090308	GC015	S02301	550	8	2	TURN	050	1
FAM9433	BMW4387	738	SNMA 120408	GC015	S02301	550	8	1	TURN	050	1
FAM9433	BMW4387	738	SPGN 120308	S6	S02301	825	4	10	TURN	050	1
FAM9433	BMW4387	738	SPUN 090308	GC015	S02301	275	4	1	TURN	050	1
FAM9433	BMW4387	738	TPUN 160308	GC015	S02301	550	3	2	TURN	050	1
FAM9433	BMW4387	738	TNMA 220412	GC015	S02301	825	6	3	TURN	050	1
FAM9433	BMW4387	738	TNMA 160408	GC015	S02301	550	6	4	TURN	050	1
FAM9433	BMW4388	738	SPGN 090308	KC210	K04076	550	4	4	TURN	050	1

RECORDS SORTED 40

Base data utilised from tool/component 'where used' file for cost centre 738 to generate weekly tooling bill of material

PROGRAM DLTC0060/IN RUN AT 15: 05: 45 ON 09 SEP 81 PAGE 1

COST CENTRE REQUIREMENTS REPORT INSERTS

* SUPPLIER - SANDVIK U K LTD

COST CENTRE - 738

ARCLASS CODE	I.S.O. CODE & GRADE		GROSS QTY	RECM'D QTY	ORDER QTY	QTY REC'D
61471-BSND-02	SNMA 090308	GC015	3	4	-----	-----
61471-BSND-04	SNMA 120408	GC015	3	4	-----	-----
61471-FSPD-05	SPGN 120308	S6	94	94	-----	-----
61471-BSPD-02	SPUN 090308	GC015	14	14	-----	-----
61471-JSND-02	SNUN 090308	GC315	3	4	-----	-----
61471-BTPD-04	TPUN 160308	GC015	18	18	-----	-----
61471-BTND-10	TNMA 220412	GC015	9	10	-----	-----
61471-BTND-05	TNMA 160408	GC015	18	18	-----	-----

COST CENTRE REQUIREMENTS REPORT INSERTS

* SUPPLIER - KENNAMETAL LTD

COST CENTRE - 738

ARCLASS CODE	I.S.O. CODE & GRADE		GROSS QTY	RECM'D QTY	ORDER QTY	QTY REC'D
61472-LSPA-01	SPGN 090308	KC210	28	28	-----	-----

COST CENTRE REQUIREMENTS REPORT INSERTS

* SUPPLIER - VALENITE MODCO (UK)

COST CENTRE - 738

ARCLASS CODE	I.S.O. CODE & GRADE		GROSS QTY	RECM'D QTY	ORDER QTY	QTY REC'D
61471-LSPD-01	SPGN 050204	VC2	0	1	-----	-----

P.M.C. DATE	SUPERVISOR DATE	FINANCE DATE	STORES DATE	SUPERVISOR DATE

DUE DELIVERY DATE:- ORDER NO:- RELEASE NO:- ADVICE NO:-

TOOL 'MARSHALLING' - SYSTEM OUTPUT

Figure 56

reduced inventory levels, the near elimination of paperwork systems, etc. The majority of the benefits to be discussed in the tool material supply section of the following Chapter are due mainly to the more conventional stock control mechanisms within IMPS as detailed in the earlier stages of this Chapter.

Finally, it was always recognised that for LINCS in general (including the concepts of 'tool marshalling') the update of the tool/component 'where used' data base was critical to the overall functioning of the system, and reference to Figure 57 shows the documentation implemented to achieve this task.

LINCS (WHERE USED)-FILE MAINTENANCE

1. TICK THE BOX(ES) CORRESPONDING TO THE MODIFICATION DESCRIPTION
2. FILL IN THE DETAILS IN THE APPROPRIATE SECTION(S)
3. SIGN AND FORWARD TO TOOL CONTROL

MODIFICATION DESCRIPTION

1. COST CENTRE RENUMBERING ☐	6. TOOLING ALTERATION ☐
2. COST CENTRE REDEFINITION ☐	7. TOOL CODE ALTERATION ☐
3. COMPONENT INTRODUCTION ☐	8. SUPPLIER CODE ALTERATION ☐
4. COMPONENT OBSOLESCENCE ☐	9. ORDER NO. ALTERATION ☐
5. COMPONENT RENUMBERING ☐	

1. COST CENTRE RENUMBERING

OLD NO.	NEW NO.	EFFECTIVE DATES:

2. COST CENTRE REDEFINITION

CURRENT DEFINITION	
NEW DEFINITION	EFFECTIVE DATES:

ENTER DETAILS OVERLEAD, INCLUDING COMPONENTS AFFECTED

3. COMPONENT INTRODUCTION

PART NO.	DESCRIPTION:	
COST CENTRE:	MODEL:	EFFECTIVE DATES:

4. COMPONENT OBSOLESCENCE

PART NO.	DESCRIPTION:	
COST CENTRE:	MODEL:	EFFECTIVE DATES:

5. COMPONENT RENUMBERING

OLD PART NO.	NEW PART NO.	DESCRIPTION:
COST CENTRE:	MODEL:	EFFECTIVE DATES:

6. TOOLING ALTERATION

PART NO.	DESCRIPTION:	
COST CENTRE:	MODEL:	MACHINE NO.

ENTER BELOW FULL DETAILS OF NEW TOOLING AND TOOLING REPLACED INCLUDING TOOL CHANGE FREQUENCIES.

7. TOOL CODE ALTERATION

OLD CODE NO.	TOOL DESCRIPTION:
NEW CODE NO.	EFFECTIVE DATE:

8. SUPPLIER CODE ALTERATION

OLD CODE NO.	SUPPLIER
NEW CODE NO.	EFFECTIVE DATE:

9. ORDER NUMBER ALTERATION

OLD ORDER NO.	SUPPLIER	COST CENTRE:
NEW ORDER NO.	DURATION: FROM: TO:	

ADDITIONAL INFORMATION.

ATTACH SEPARATE SHEET IF NECESSARY

SIGNATURE:	DEPARTMENT:	DATE:
TOOL CONTROL	ACTIONED BY:	DATE:

<u>LINCS 'WHERE USED' FILE MAINTENANCE</u>

Figure 57

CHAPTER NINE

9.0 RESULTS OF SYSTEM IMPLEMENTATION

The system results can be viewed from three levels of focus:-

(a) Initial IMPS core data validation upon the 'test cell' of twelve copy lathes.

(b) The factory-wide IMPS-'driven' tool standardisation programme.

(c) Tool material supply and control.

Discussion with respect to each area is as follows:-

9.1 IMPS CORE DATA VALIDATION

At first sight the tool range in use upon the twelve machines lacked any coherent control in terms of standardisation and application, and because of this a series of cutting tool trials took place to:-

(a) Reduce the number of tool manufacturers supplying tools to the machines from six to two.

(b) To implement a reduced range of tools upon the machines with the intention of improving the machining economics wherever possible.

(c) Following (a) and (b) to then establish a set of machinability standards that were considered to be acceptable to the Plant's Process Planning, Industrial Engineering, and Financial Control Departments.

The net result of this initial action was to establish control over the cell of machine tools and effect a number of desired economic improvements. The next logical step was to evaluate IMPS' predictive ability against a series of accepted machining standards. This was possible by linking together the IMPS turning program and the first compilation of the standard tooling catalogue. This early validation exercise required the writing of an inverted form of the IMPS program (reference to Appendix P), which enabled the user to specify a particular grade at the start of the program rather than obtain a grade recommendation output midway through the algorithm as is the case with IMPS. This inverted program, referred to as Factor Proving IMPS, also enabled base speeds to be modified with the objective of establishing machinability data which accurately reflected shop floor performance capabilities. Reference to Figure 58 summarises the overall results from twenty-one machine tool trials, and reference to Figure 59 gives the results of a routing through the Factor Proving IMPS routine adopted.

As has already been explained in Chapter Six, an increase of 50% in the datum speeds for machinability groups (3) and (4) was considered to be necessary following these initial core data validation trials. In analysing the results obtained from this detailed study, such an increase may be considered to have been too great, since the predictors for cutting speed and tool change frequency exceeded the actual values by some 11.63% and 17.19% respectively. It was felt, however, to be appropriate from a management control perspective to leave the data at these higher levels in order to produce a high target standard value for speed, tool change frequency, and standard time rather than to generate data which would be easily achievable in practice, and would thus not encourage the exploration of the opportunity to extend tool life, etc.

In 12 of the 21 examples presented tool flank wear normally achieved in practice was considerably less than the 0.3 mm taken as the criterion used to designate end of tool life in the cutting tool trials performed by the individual suppliers which formed the basis of the initial IMPS core data hence the reference to 'normalised' tool life within the results table. This 'premature' tool changing was found to be due to two aspects:-

TEST REF. NO.	MACHINE NO.	MACHINE FACTOR	MATERIAL MACHIN-ABILITY GROUP NO.	MATERIAL HARD'S (HB)	TOOL GRADE IN USE	NORMALISED TOOL LIFE (MINS.)	FEED RATE MM PER REV.	ROTATIONAL CUTTING SPEED (R.P.M.)			TOOL CHANGE FREQUENCY (COMPONENTS/EDGE)			STANDARD TIME (SECONDS)		
								ACTUAL	PREDICTED	VARIANCE %	ACTUAL	PREDICTED	VARIANCE %	ACTUAL	PREDICTED	VARIANCE %
1	22866	0.73	4	160	TP 35	64	.457	1400	1260	11.1	160	166	3.6	24	23	-4.2
2	37364	0.86	4	275	GC 415	110	.381	927	1080	14.2	276	371	25.6	24	18	-33.3
3	37363	0.86	4	275	GC 415	134	.381	927	1020	9.1	336	429	21.7	24	19	-26.3
4	37364	0.86	4	275	TP 15	153	.381	927	960	3.4	383	475	19.4	24	19	-26.3
5	37363	0.86	4	275	TP 15	112	.381	927	1080	14.2	284	375	24.3	24	18	-33.3
6	32581	0.88	4	275	GC 415	38	.279	1600	1680	4.8	127	148	14.2	18	15	-20.0
7	22866	0.73	4	160	TP 15	88	.457	1400	1560	10.3	231	283	18.4	24	19	-26.3
8	24975	0.73	4	160	TP 15	62	.457	1400	1740	19.5	155	218	28.9	24	17	-41.2
9	22866	0.73	4	160	GC 015	93	.457	1400	1380	-1.5	233	275	15.3	24	20	-20.0
10	24975	0.73	4	160	GC 015	49	.457	1400	1680	16.7	122	165	26.1	24	18	-33.0
11	3876	0.71	3	233	GC 1025	35	.380	1800	1620	-11.1	41	38	-7.9	51	55	7.3
12	3878	0.71	3	233	GC 1025	25	.380	1800	1800	0	150	131	-14.0	10	11	9.1
13	22866	0.73	4	160	GC 415	63	.457	1400	1740	19.5	158	220	28.2	24	17	-41.0
14	3201	0.76	1	154	S 2	41	.080	1020	1200	15.0	246	232	-6.0	10	11	9.1
15	3928	0.70	4	286	S 1P	216	.100	975	1140	14.5	395	453	12.8	33	29	-13.8
16	3928	0.70	4	311	S 1P	216	.100	975	1080	9.7	395	435	9.2	33	30	-10.0
17	15909	0.78	2	180	GC 015	117	.180	1095	1560	29.8	102	144	42.2	69	49	-40.1
18	15910	0.78	2	180	GC 015	134	.210	1095	1320	17.0	103	127	18.9	78	63	-23.8
19	15909	0.78	2	180	GC 015	80	.230	1095	1440	24.0	67	90	25.6	72	53	-35.8
20	3189	0.77	4	229	GC 1025	19	.170	1100	1560	29.5	80	77	-3.9	14	11	27.3
21	3189	0.77	4	262	GC 1025	23	.1370	1100	1320	16.7	70	168	58.3	20	17	-17.6
								OVERALL MEAN VARIANCE = 11.63%			OVERALL MEAN VARIANCE = 17.19%			OVERALL MEAN VARIANCE = -21.32%		
								STANDARD DEVIATION = 10.9%			STANDARD DEVIATION = 16.5%			STANDARD DEVIATION = 15.5%		

NOTES:

(i) Predicted results from factor proving IMPS.

(ii) Start diameter = equivalent diameter, D.O.C. = 1 mm.

(iii) Twelve copy lathes used.

(iv) Variance calculated on the basis of:

$$\frac{(\text{Predicted value} - \text{Actual value}) \times 100\%}{(\text{Predicted value})}$$

SUMMARY OF IMPS CORE DATA RESULTS

Figure 58

			ANALYSIS (1)						ANALYSIS (2)					
						OUTPUTS						OUTPUTS		
TOOL GRADE SELECTED FROM PROGRAM 3	MACHINE TOOL FACTOR	DATUM SPEED MODIFIER	ACTUAL T.C.F. DISTRIBUTION ABOUT MEAN (1%)	AVERAGE T.C.F. (ACTUAL)	TOOL LIFE CUTTING TIME x ACTUAL T.C.F.	PERIPHERAL CUTTING SPEED REVS. PER SEC. (-ve)	CUTTING TIME (SECS.)	T.C.F.	NORMALISED MEAN T.C.F. .3mm FLANK WEAR	NORMALISED T.C.F. DISTRIBUTION ABOUT MEAN (1%)	THEORETICAL TOOL LIFE ACTUAL CUTTING TIME x NORMALISED MEAN T.C.F.	PERIPHERAL CUTTING SPEED REVS. PER SEC. (-ve)	CUTTING TIME (SECS.)	T.C.F.
1025	1.0	1.0	14.4	97	39	114 (22)	22	104	160	6.2	64	101 (19)	25.3	151
1025	0.73	1.0	14.4	97	39	83 (16)	31	75	160	6.2	64	74 (14)	35	110
1025	1.0	1.3	14.4	97	39	149 (29)	23	136	160	6.2	64	132 (25)	19	197
1025	0.73	1.3	14.4	97	39	109 (21)	23	99	160	6.2	64	96 (18)	27	143
1025	1.0	1.5	14.4	97	39	172 (33)	15	157	160	6.2	64	152 (29)	17	227
1025	0.73	1.5	14.4	97	39	125 (24)	24	114	160	6.2	64	111 (21)	23	166
1025	1.0	1.8	14.4	97	39	206 (40)	12	188	160	6.2	64	225 (43)	11	337
1025	0.73	1.8	14.4	97	39	151 (29)	17	137	160	6.2	64	133 (25)	19	199

(FACTOR PROVING IMPS - TEST REFERENCE NO. (1))

EXAMPLE OF FACTOR PROVING IMPS

Figure 59

(a) Firstly, and quite legitimately, tools were changed when workpiece size tolerances were exceeded.

(b) Secondly, the machine tool setters' custom and practice of changing tools at 'convenient' times during the shift, i.e. tea breaks, end of shift etc.

Improvements in setting practices enabled tool life extensions to be achieved in ten of these twelve cases by an average of some 30%.

Opportunities for increasing the parameters of depth of cut and feed rate were less easily achievable given the time constraints under which the research work was performed, combined with the very real problem of industrial research that all machine down-time for machine changeovers, etc., equated to production components lost. It was, however, possible to elevate the feed rates in two instances from the original values.

At this initial core data validation stage the understanding for the potential to achieve tool interchangeability between suppliers was less successful. As has been mentioned previously the Company could gain significant commercial advantage if the Purchasing function had the ability to procure 'generic' tool grades from a range of home-based, or indeed world-wide tool suppliers. Unfortunately before this situation can be arrived at it is essential that the concept of supplier-based tool interchangeability has to be proven at the machine tool level against Company defined manufacturing standards. An early attempt to understand this problem was made in tool trial numbers 2, 3, 4 and 5, reference to Figure 58, whereby like tools within the ISO grade profile chart, i.e. Sandvik GC 415 and Seco TP 15, were compared to each other under similar machining conditions. However, this limited exercise, while indicating small variance in performance, cannot be taken as conclusive evidence supporting the potential for interchangeability and the subject area requires a far greater level of research effort with consideration being given to comparisons of tool material structural compositions as a basis for interchangeability.

Initial observations are that a lowering in manufacturing standards may be necessary if wide-spread tool supplier interchangeability was to be adopted, and such a measure would not be acceptable from an Operations Management level of focus unless the cost/benefits were fully justified.

9.2 PLANT-WIDE APPLICATION OF IMPS

The practice for each turning related cutting tool trial was to select one operation for generating the theoretical IMPS machinability standards. Reference to Figures 60 and 61 will show that for component 22G 1096 (first speed gear) operation 20, station 2 (column d) was selected as the IMPS pilot and key reference data taken from the formal IMPS output related to:-

(i) Machine tool spindle speed

(ii) Tool contact time

(iii) Tool material grade

(iv) Tool change frequency

The details of the coding system referred to in Figure 60 for cutting condition and test end codes are given in Figure 62.

As IMPS was moved away from the early work at Longbridge and onto the core data copy lathes it was possible to refine the system, particularly in the areas of the achievement of component surface tolerances and chip breaker style selection. However, it was found that the core machinability data only required marginal adjustments in order to reflect potential turning machinability standards Plant-wide.

The net result of conducting this in-depth exercise was as follows:-

(a) Extended tool life was achieved upon 97 operations ranging from a nominal 5% to 650%. It should be stressed, however, that although

BL TOOL TRIAL REPORT	LOCATION COVENTRY ENGINE PLANT - NO.2 MACHINE	SHEET 1 OF 2 SHEET(S)	TOOL TRIAL REFERENCE NO. 72
INVESTIGATOR S.FELL	DATE 23.6.81	COST CENTRE 604	TURNING,BORING,FACING ETC. TURNING/FACING
COMPONENT NO. 220 1096		M/C NO. BMA 33878	
COMPONENT DESCRIPTION 1ST.SPEED GEAR		M/C DESCRIPTION CONOMATIC AUTO	
MATERIAL 805 H20	M/ABILITY GROUP 4	NO. OF STATIONS 6 SPINDLE	CONTROLLING STATION -
HARDNESS 165 HBN		CUTTING FLUID SOLUBLE OIL SUPEREDGE NO. 4	
ESTIMATED ANNUAL PRODUCTION 5625 X 45.8 = 257.625		M/C FACTOR 0.71	

FEATURE REF.		a		b		c		d		e		IMPS PILOT STN. * = d	
NOMINAL DIAMETER		OP.20 STN.1		OP.20 STN.1		OP.20 STN.2		OP.20 STN.2		OP.20 STN.3			
(FOR FACING GIVE START	u.o.m	existing	revised	existing	revised	existing	revised	existing	revised	existing	revised	revised	predicted
AND FINISH DIAS.)	in.	1.92		1.59		2.914		3.34		1.62			
LENGTH	in.	0.347		0.24		0.422		0.40		0.06			
REVS./MIN.		392	392	392	392	392	392	392	392	392	392	392	503
FEED	in./rev.	0.003	0.003	0.003	0.003	0.0025	0.0025	0.0025	0.0025	0.002	0.002		
TOOL CONTACT TIME	min.	0.295	0.295	0.204	0.204	0.43	0.43	0.408	0.408	0.08	0.08	0.408	0.317
D.O.C.	in.	0.06	0.06	0.102	0.102	0.06	0.06	0.06	0.06	0.06	0.06		
SURFACE SPEED	ft./min.	196	196	162	162	297	297	341	341	165	165		
CUTTING CONDITION CODE		1	1	1	1	1	1	1	1	1	1		
CHIPFORM CODE		4.3	4.2	2.2	2.2	2.2	2.2	4.3	4.2	6.1	6.1		
TEST END CODE		B(6)	B(1)	A(1)	A(1)	B(6)	B(1)	A(1)	A(1)	A(1)	A(1)		
INSERT REF.		TPUN 22 04 16	SNMG 12 04 08	TPGN 16 03 08	TPUN 16 03 08	TPUN 16 03 08	TNMG 16 04 08	SNMG 12 04 08	SNMG 12 04 08	TPGN 16 03 08	TPGN 16 03 08		
INSERT GRADE		135	135	SIP	135	1025	015	135	135	GW 520	135	135	135
CHIPBREAKER		-	15	-	-	-	61	-	15	-	-		
NUMBER OF EDGES		3	8	3	3	3	6	8	8	3	3		
T.C.F.		1:250	1:250	1:250	1:250	1:250	1:200	1:250	1:250	1:300	1:300	1:250	1:320
PIECES/INSERT		750	2000	750	750	750	1200		2000	900	900		
% INCREASE IN PIECES	%		166		0		60		0		0		
INSERT COST	£	2.06	1.90	2.14	1.32	1.32	1.78	1.90	1.90	2.55	2.55		
EXISTING COST/COMPONENT	p	0.274		0.285		0.176		0.095		0.283			
REVISED COST/COMPONENT	p		0.095		0.176		0.148		0.095		0.283		
% DECREASE IN COST	%		65		38		15		-		-		
ANNUAL COST SAVING	£		461.14		280.81		72.13		-		-		
TOTAL ANNUAL COST SAVING	£											£ 937.68	

IMPS ASSISTED TOOL TRIAL REPORT

Figure 60

ITERATIVE MACHINING PARAMETER SELECTION

COMPT NO. 228 1096 COMPT DESCRIPTION 1ST SPEED GEAR

INITIAL RESULTS

SPEED FROM FEED	(M/MIN):-	231
SPEED FROM TOOL LIFE	(M/MIN):-	144
SPEED FROM MACHINE FACTOR	(M/MIN):-	102
SPEED FROM COMPONENT HARDNESS	(M/MIN):-	139

!!

SURFACE CUTTING SPEED	(M/MIN):-	139
ROTATIONAL SPEED	(R.P.M):-	503
FEED RATE	(MM/REV):-	.0635
DEPTH OF CUT	(MM):-	1.524
SPECIFIC CUTTING FORCE 'KS'	(KG/MM):-	-39
POWER REQUIREMENT	(KW):-	-.08
TOOL LIFE	(MINUTES):-	102
STANDARD TIME	(MINUTES):-	.317
TOOL CHANGE FREQUENCY	(COMPTS):-	320
RECOMMENDED TOOL GRADE	:-	GC135

COMPT.NO. 228 1096 COMPT.DESCRIPTION- 1ST SPEED GEAR

MATERIAL GROUP:- 4

OPERATION SUMMARY SHEET

OP.NO.	LENGTH (MM)	START OD (MM)	D.O.C. (MM)	SPEED (M/MIN)	R.P.M.	FEED (MM)	STD.TIME (MINS)	T.C.F. (CPTS)
10	10.16	87.884	1.524	139	503	.0635	.317	320

TOOLING

OP.NO.	TOOL SPECIFICATION	GRADE	CLASSIFICATION
10	SNMG 120408	GC135	A1471-DSNA-03

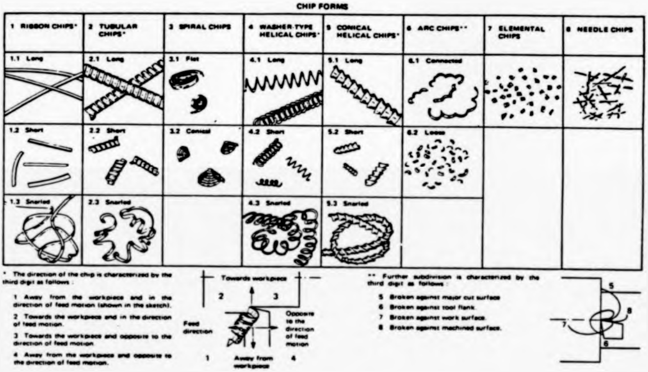
IMPS PILOT OPERATION

Figure 61

CUTTING CONDITION CODES

1. Clean surface, no runout or interruptions
2. Clean surface, moderate runout, no interruptions
3. Clean surface, high runout (over 25% of insert)
4. Clean surface, severe runout or interrupted cutting
5. Scale, minimal runout
6. Scale, moderate runout
7. Scale, high runout
8. Scale, interrupted cutting
9. Severe scale, severe interruptions
10. Sand, moderate runout

CHIP FORMS



TEST END CODES

(A) Workpiece Criteria

1. Workpiece size exceeds tolerance stipulated on operation
2. Workpiece surface finish exceeds tolerance stipulated on operation

(B) Tool Criteria

1. Flank Wear
2. Cratering
3. Thermal cracking
4. Chipping and breakage
5. Built up edge
6. Edge deformation
7. Spalling
8. Scaling off of coating

(C) Other

1. Chatter
2. Unacceptable chips
3. Limit of machine power

Source: BS 5623 (85) 1979
Tool life testing with single-point turning tools (p. 41)

CUTTING CONDITION AND TEST END CODES

Figure 62

these extensions in tool life were obtained, in the main, as a result of a change in tool material grade, the findings of the investigations conducted upon the benchmark copy lathes clearly showed that tools were often being changed needlessly on the basis of operator/setter custom and practice, thus simply by reappraising the criteria used by shop floor operatives in the determination of the end of tool life, tool life extensions were possible. So great was the concern over needless premature tool changing that a survey was carried out to measure the typical amounts of flank wear being achieved upon inserts discarded by machine operators and returned to the tool stores for salvage. This analysis revealed that the average flank wear on discarded tools (450 cutting edges checked) was 0.21 mm.

(b) Increased machining parameters were implemented upon 10 operations.

(c) Five operations were completely eliminated by increasing the severity of preceding or subsequent operations.

(d) Only nine additions to the initial standard tooling catalogue were necessitated.

The above results are those which were implemented upon the 422 operations investigated with the majority of the increase in tool life mentioned in (a), and all of the benefits described in (b) and (c) being applicable to turning operations. In hindsight it is clear that still further potential for improvements, particularly in non-turning operations, existed but this remained unexploited because of the time necessary to develop IMPS type standards and the subsequent exhaustive tool trials necessary. These results, however, were sufficiently encouraging to give the confidence to manufacturing related personnel at Coventry Engine Plant to introduce the standard range of inserts to the remainder of the factory without extensive tool trials being conducted upon each machine, problems of inadequate tool performance being dealt with on an exception basis.

A summary of the audited results achieved following this second phase of activity was as follows:-

(a) Standard range of indexable inserts reduced from 785 to 120 varieties.

(b) 118 standard hours were saved in machine tool setting labour content per week.

(c) Savings in direct tool costs for turning operations totalling £20.5K per annum, reference to Figure 63 for the components in question.

9.3 TOOL MATERIAL SUPPLY AND CONTROL

The tool material supply and control element of ATOMS can be viewed in terms of three phases of distinct activity, and these were:-

(a) The implementation of basic stock control mechanisms for indexable inserts only.

(b) The enhancement of (a) to move from stock to flow control disciplines.

(c) The initial expansion of the ATOMS principles to cover other, non-indexable insert-related tooling families.

Discussion with respect to the benefits gained from the implementation of each element is contained in the following sub-sections.

9.3.1 Stock Control

The situation as at January 1981 was an inventory value of £93.5K for a range of 780 varieties of indexable inserts. There were no formal links

ITEM NO.	COMPONENT		MACHINE TOOL TYPE	ANNUAL TOOL COST SAVING £	COMMENTS
	NO.	DESCRIPTION			
1	DAM 3092	Pinion Shaft	Fisher Lathe	£6375.60	. Elimination of Tooling . Special Tools Replaced by standard . Cutting Edges increased from 4 to 8 per insert . Tool Grade changed
2	RKC 0199	Differential Case	Hey Special Lathe	£2210.00	. Elimination of Tooling . Special Tools replaced by standard . Tool Grade Changed
3	UKC 4217	External Flange	Acme Gridley	£1886.40	. Elimination of Tooling . Precision tolerance inserts replaced by utility grades . Tool Grade changed
4	DAM 2921	Crankshaft Primary Gear	Frontor Double Spindle	£1602.42	. Tool Grade changed
5	DAM 4932	2nd Speed Gear	Frontor Double Spindle	£1514.80	. Tool Grade changed . Improved chip breaker style
6	FAM 4418	Swivel Hub	Ryder Multi Spindle	£1452.00	. Tool Grade changed . Reduction in insert size
7	22G 1091	3/4th Coupling Sleeve	Conomatic 6 Spindle Auto Lathe	£1208.24	. Insert Style changed . Tool Grade changed
8	DAM 2925	Primary Driven Gear	Gridley 6 Spindle Automatic	£1057.31	. Insert Style changed . Tool Grade changed . Improved chip breaking
9	TKC 1741	Extension Shaft	Maxi Turn Lathe	£979.20	. Reduction in Insert size . Tool Grade changed . Improved Chip breaker style
10	22G 1096	1st Speed Gear	Conomatic 6 Spindle Auto Lathe	£937.68	. Reduction in Insert size . Tool Grade changed . Improved Chip breaking
11	RKC 4990	Axle Shaft	Hey Special Lathe	£717.12	. Insert Style changed . Tool Grade changed . Improved chip breaking
12	DAM 7002	U. J. Flange	Herbert 2A Capstan	£533.20	. Tooling Elimination . Tool Grade changed . Improved chip breaking
TOTAL ANNUAL TOOL COST SAVINGS (IMPS Assisted Turning Operations)				£20473.97	

ANNUAL TOOL COST SAVINGS (TURNING OPERATIONS)

Figure 63

between the forward component manufacturing requirements and the inventory levels, and tool re-order quantities were decided by tool stores clerical and hourly paid staff. Although there was every confidence that the IMPS assisted tool trials would eventually provide a firm foundation from which tool material supply procedures could be developed, the full benefits from this initiative would not be seen for several months. Against this background a package of simple measures was implemented in order to establish an improved level of control over the existing situation which, in hindsight, was preparing the way for the full ATOMS routing implementation.

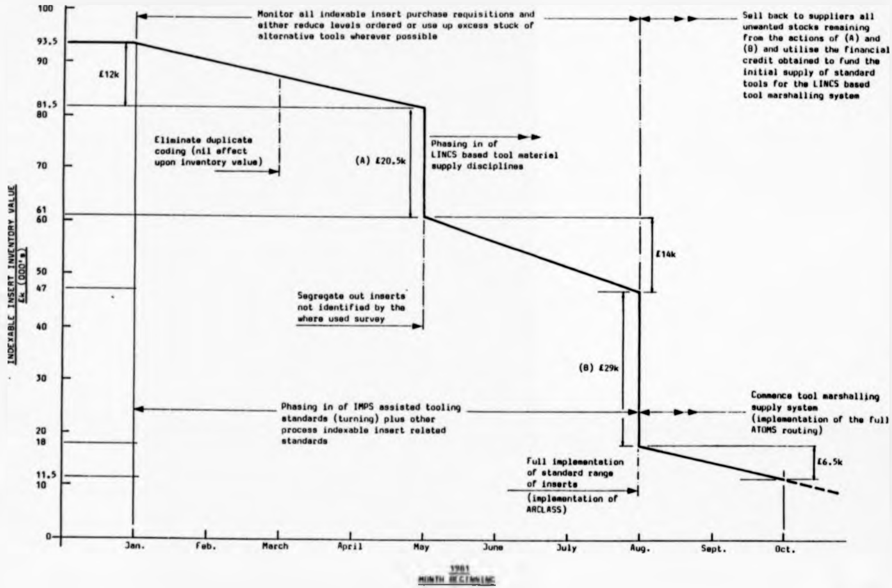
Details of the measures taken were as follows:-

(a) A simple discipline was implemented whereby all tooling purchase requisitions, relating to indexable inserts and spares, raised by the tool stores staff were independently monitored by the writer, concurrent with the initiation of the 'where used' data collection exercise. Surprisingly, this identified such fundamental errors as:-

(i) Inserts being re-ordered where there was no further requirement for them, i.e. the component in question was being phased out of production, but no-one had informed the tool stores.

(ii) It became apparent that the stores personnel were building over-cautious safety levels into their re-ordering levels, and this was typified by the ordering on one purchase requisition of up to six months' stock for a standard 'off the shelf' tool. The main reason given for this defensive approach was a general lack of confidence in the time taken for purchase requisitions to be passed through the internal system before the order was actually placed with the supplier.

Reference to Figure 64 will show that this simple 'portcullis' action enabled a £12K reduction in inventory by May.



REDUCTION OF INDEXABLE INSERT TOOLING AT COVENTRY ENGINE PLANT DURING 1981

Figure 64

(b) Midway through this period a clinical review of the Plant's tool coding and classification system was undertaken which highlighted 49 instances of duplicate coding caused by non-familiarity of stores personnel with the technological content of tool descriptions, thus duplications were typified by examples such as the following:-

Code Number	Tool Description
SV 22833	TNMG 16 04 08 GC 1025
SV 25221	TNMG 16 04 08 1025 GC

Although the identification of such mistakes did not have any effect upon inventory values held since all common items were simply physically moved to be held in one stores bin location, the elimination of duplicate codes reduced the coded indexable insert range by some 49 items from 780 to 731.

(c) By May, the tool/component 'where used' data collection exercise as described in Section 6.6.3 had been completed and it was possible to identify all those tooling varieties which were recognised as coded items for which no claim for requirement had been made by the production areas. A staggering 295 indexable insert varieties were found to be redundant, i.e. no end use, with a total inventory value of £20.5K. This exercise had highlighted a fundamental problem, and it was agreed with the local management to remove the inserts from the existing inventory and place them in a 'bonded stores', the final use for these tools will be discussed later.

This exercise had therefore reduced, with no effect upon Plant performance, the inventory value by £20.5K and reduced the range of indexable inserts available for issue by 295 varieties instantaneously. At this point in time the insert inventory figure was £61K and comprised some 436 varieties.

(d) In the intervening period between May and August the operation in the tool stores of the microcomputer based LINCS module was phased in which controlled all indexable insert stock recording and issue disciplines and this coupled with the continuation of the purchase requisition monitoring system described in (a) had the net effect of a further £14K reduction in inventory.

(e) Running concurrently with the actions described in (a) to (d) the IMPS assisted tool standardisation exercise was being conducted which resulted in the implementation in August of the standard range of 120 indexable insert turning and milling tools to support the Plant's manufacturing activity. In the space of one weekend the new ARCLASS based standard tooling catalogue was introduced, which had the net effect of reducing the range of tools available from 436 to 120 and a further £29K of tools was taken from the inventory and placed in the bonded stores. By this time the indexable insert inventory had been reduced by value to £18K. An even greater reduction had been anticipated, but it was apparent that high levels of tool stocks for the new standard range of tools had been inherited from past inadequate stock control procedures.

(f) Between August and October the operation of the LINCS computer-based stock recording and issue monitoring disciplines, utilising the tool/component 'where-used' file to monitor whether tool purchase requisitions were bona fide, was practised and indeed manned by existing tool stores personnel.

In addition, the elimination of the existing ordering system was achieved in favour of a locally controlled 'open ordering' procedure, realistic estimates of order quantities being obtained on a gross bill of tooling material basis by linking the forward manufacturing programme into the 'where-used' files which by this time had been extended to incorporate tool consumption data collected in the course of the rationalisation exercise. In this way, ordering lead times were reduced from eight weeks to one, and the confident stipulation of the range of tools required enabled the two major suppliers, i.e. Sandvik and Seco, to hold realistic back-up stocks at their own central warehouses.

Throughout this period extremely low level max/min quantities were established for each of the 120 variety of inserts which acted as a buffer stock.

9.3.2 Flow Control

Clearly, by August the full benefits of control were beginning to emerge and the experience of significant reductions in inventory which had been achieved, without jeopardising component production, led to the serious questioning as to whether indexable inserts was a tooling family for which a 'nil inventory' policy could be applied, viz. the operation of the Plant without having resources to the holding of back-up 'buffer' stocks within the tool stores. Having gained an appreciation of the way in which Japanese industries had applied such 'nil inventory' methodology, to produce parts via their 'KANBAN' system approach, a tool 'Marshalling' system for indexable inserts was installed upon one particular cost centre (i.e. 738) manufacturing two components (FAM 9432, FAM 9433 - Mini Metro radius arms), controlled by one Production Supervisor. The principles of the system are outlined in Chapter Eight and referring to the terminology adopted, this cost centre was operated at a level 1 control, i.e. the most sophisticated level possible specific to each component in question. As depicted in Figure 56, page 246, a computer generated report was produced on a weekly basis for each component upon the cost centre, the package of tooling being made physically available for collection by the Supervisor the following week. To support this supply philosophy, deliveries were made by the Plant's two main suppliers on a weekly basis in packaging commensurate with the level of control in operation. Tools from the remaining suppliers (i.e. Kennametal and Valenite Modco) were extracted from the main store's stock by stores personnel to complete the tool requirement package for the cost centre.

Adoption of this philosophy, which guaranteed supply of tools for the supervisor on a weekly basis eliminated the custom and practice of holding personal 'contingency' stocks upon the section by virtue of the increased confidence level in not encountering a stores 'stock-out' situation.

Reference to Figure 64 will show that the joint actions from August onwards reduced the inventory still further to a figure of £11.5K by October at which stage the ATOMS project was handed over to the Plant for ongoing maintenance. It is considered that with the further expansion of the 'Tool Marshalling' system to cover all of the major cost centres at the Plant would reduce the inventory to an optimum level of between £4K to £6K.

Finally, two important aspects should be commented upon:-

(a) While the period January to October 1981 witnessed a reduction in indexable insert inventory from £93.5K to £11.5K (an 80% reduction) there was only a corresponding marginal reduction in the manufacturing activity at Coventry Engine Plant and this is best shown by comparing the reduction in standard hours generated by the machining cost centres for the same period, i.e. 29,500 to 27,650 (a 6% reduction in manufacturing activity).

(b) In total £49K of indexable inserts which had no identifiable end use were placed in a bonded stores, and this provided a useful resource in three main areas, which were:-

(i) The position of the bonded inserts was discussed with the local Management and the decision was taken to use up the stock as alternative tools to the recommended standard tool over a period of time. Therefore, from May onwards every indexable insert purchase requisition was not only checked to see if the tools were required, and if they were, the details of the requisition were then matched against the list of bonded inserts to establish whether or not a short-term alternative could be found.

This action was found to be particularly successful for roughing and semi-roughing operations, and due mainly to the flexibility of the line supervision and machine tool setters it was possible to utilise £14.5K by value of the bonded stock.

(ii) Of the remaining bonded stock, i.e. £35K by value at standard cost, it was discovered that a large percentage of this total was, in fact, tools sold previously to Coventry Engine Plant by one supplier, i.e. Sandvik. Therefore, a commercial agreement was made whereby Sandvik took back stock valued at £27.5K and in return offered Coventry Engine Plant £12K of credit to fund the bulk of the new range of inserts.

(iii) Of the remaining £7.5K's worth of insert bonded stock, the majority of which were special application tools, efforts were made to modify them in the toolroom for alternative use, and as a last resort the remaining tools were circulated to other Austin Morris Plants for possible use.

9.3.3 Initial System Expansion

As the ATOMS routing began to generate significant economic benefits there was a corresponding request by local management to cover other tooling families, and as a result two courses of action were initiated, these being:-

(a) Organise a thorough and exhaustive stocktake of all cutting tools held in the tool stores, logging 'last movement' dates from the record cards. This data was then loaded to the Plant minicomputer from which it was possible to produce a non-moving stock record by tool value from which Management decision could be made. This disciplined tool stockholding review system, although tedious, yielded some significant results for the Plant in terms of inventory reductions.

(b) An action plan was devised, modelled upon the ATOMS experience, whereby tool suppliers were involved to establish machinability data, standard ranges of tools, and methods of supply for abrasives, drills, tapps and reamers (including all spares, i.e. toolholders, dressing diamonds etc.).

Unfortunately after commencing the initial work upon the ATOMS expansion the Plant closure announcement was made and further work at Coventry ceased. However, at the conclusion of implementation of the broad spectrum of activities outlined throughout this Chapter the level of tooling and related inventories at Coventry Engine Plant stood at £680K in October 1981, a reduction of £240K from the January figure of £920K. It is considered that the continuation of the disciplined Tool Stockholding Review procedure combined with the controlled expansion of the ATOMS concepts would have provided the means to reduce still further this inventory figure by a significant amount. Further consideration is given to this argument within the following Chapter.

CHAPTER TEN

10.0 SYSTEM EXPANSION AND MAINTENANCE

Throughout the development and implementation of ATOMS the medium-term system expansion and maintenance requirements were always strategic elements within the implementation strategy. From a management control perspective this can be viewed in terms of:-

(a) The individual plant

(b) Across a number of manufacturing locations, i.e. Operations activity

Discussion on the potential for system expansion, and therefore by implication the identification of areas of future research work, viewed from these two levels of focus, is contained in the following sub-sections.

10.1 EXPANSION AT PLANT LEVEL

Activity at this level can be viewed in terms of a straight forward expansion of ATOMS to embrace other machining processes, i.e. grinding, drilling, reaming, tapping, etc., or in terms of developing an even broader base to ATOMS by incorporating such features as tool design, maintenance and disposal.

With respect to the first option, irrespective of the process under review the prioritised mechanistic procedure adopted throughout ATOMS of initially establishing control at the cutting edge followed by the implementation of the necessary supportive tool material supply disciplines, should be pursued.

Specific aspects for consideration when implementing a work programme for the general expansion of ATOMS include:-

10.1.1 IMPS

(a) A major element of the process planning work was found to be related to component modifications utilising existing, somewhat dated, manufacturing facilities. This level of work activity demanded a requirement for the general expansion of the IMPS turning module to accommodate elements of other process operations generally associated with single point turning, i.e. boring, forming, facing, grooving, part off, threading, etc.

(b) It is recognised that the core of the IMPS machinability data is coated tungsten carbide orientated and, reflects to a large degree, the process capability of the existing machine tools. While in a limited number of areas within the plant advanced tooling technology typified by Polycrystalline Diamond, Cubic Boran Nitride and Si-Al-O-N's were being utilised the related machinability data had not assumed a high system user requirement profile within IMPS due to the existing machine tool/age condition profile.

While Tungsten Carbide based tooling will still have a significant role to play in the future, its span of activity will be reduced with the introduction of new high performance machine tools which should have the capability to exploit the potential of the advanced tooling technologies. Therefore, recognising this changing profile the IMPS data base should be extended to cover in more detail the predicted/ actual performance of selected new tooling technologies.

The addition of this data will provide an even stronger platform from which critical forward planning decisions with respect to machine tool procurement could be made.

10.1.2 LINCS

One of the major difficulties encountered at Coventry Engine Plant was that as the improved levels of control over tooling became generally associated with the ATOMS routing, resulting pressures increased from local management to expand the system concepts to cover other tooling families as quickly as possible. Clearly, the expansion of all of the ATOMS modules would take time, particularly development of the IMPS algorithms, and therefore, it was agreed that an expansion of ARCLASS and LINCS would be possible to install an improved level of control, and this was based on the coverage of existing ranges of grinding wheels, drills, etc. This short-term system expansion concentrating on ARCLASS and LINCS was of concern as it resulted in a departure from the ATOMS philosophy of building the control mechanisms from an IMPS related data base. However, practically, it did mean that general controls could be established very quickly and at the initiative of the Plant Management system expansion was initiated.

This rapid expansion created further pressures in terms of the APPLE microcomputer and while, in hindsight, it is now recognised that many of the operational problems encountered could have been minimised with an increased main memory capability, supported by the benefits of Winchester hard disk mass data storage technology and a more interactive DOS such as CP/M. In an attempt to relieve many of the system operational/reliability limitations the decision was taken to transfer the LINCS module to a recently installed CMC Sovereign microcomputer which had 50 megabyte hard disk storage capacity and indexed sequential text file formatting capabilities. This mini computer with its supportive software and peripheral hardware, had been obtained by the local management to implement systems based, Financial and Production and Material Control (Direct Materials) procedures. One of the major benefits, with respect to tool control, from this decision was that potentially one piece of hardware would house the total non-productive material recording systems for the Plant, and generated management accounting reports of cost centre tool usage, thus the on-line real time (OLRT) updating and 'where used' file extensions served to enhance the LINCS control features. Additionally, the fact that the product build programme forecasts were also to be held upon this hardware eliminated the need to manually re-input such data to generate the forward tooling bill of material; a link into this file was all that was required.

The technical benefits gained from operating the system upon the mini-computer supported by its increased reliability, and most importantly the opportunity that it presented to organise data in an indexed sequential manner as opposed to the sequential format made mandatory by the limited APPLE DOS capabilities. The fundamental benefit derived from index sequential file operation lies in the fact that the essential data relating to tool change frequency, number of tools utilised upon the individual operation, and number of edges per tool, could be accessed equally as quickly by nominating a component number, as by nominating a tool code number. It will be noted by reference to Figure 54, page 243, which shows the revised file structures for LINCS suitably structured for indexed sequential operation, that the record key comprises of a chain of first level system enquiry information relating to cost centre, component number, machine number and tool (ARCLASS) number. Likewise, the subsequent filed data identifies:-

(a) Quantity of tools upon the operations

(b) Number of cutting edges available

(c) Tool change frequency

The highly interactive nature of the CMC disk operating system facilitated a very flexible approach to system enquiry by the user. Typical examples of this flexibility are as follows:-

Record Key				Data		
Cost Centre	Comp't No	Machine No	Tool No	Qty on Job	TCF	No of Edges

Inputs of the known items within the record key and the 'packing' of unknowns with question mark symbols enables the generation of all conforming records and data, thus the user input of

??? DAM 477 ??? -----------?

will enable the location and display of the record keys given below:-

Cost Centre	Comp't No	Machine No	Tool No	Qty on Job	TCF	No of Edges
105	DAM 477	BME 1866	X61471-BTNB-01	2	500	6
105	DAM 477	BME 8055	X61471-BTNA-01	1	500	6
220	DAM 477	BME 1222	X61471-BSNA-01	2	100	8

Likewise, a known tool input would generate all 'where used' details and so on. This relatively simple facility fulfilled the requirements of process planning engineers to have rapid access to component related tooling data, and also enabled changes to planned tooling (in line with component modifications, etc.) to be quickly recognised by stores personnel with respect to the holding in stock, and re-ordering of, tool material for an obsolete component.

Finally, further logical expansions of the LINCS concept would include:-

(a) Enhancements in the levels of systems based communications protocols operating within the Company and with the various tool suppliers leading to the possible elimination of manually generated paperwork. This would result in even further requirements of tool procurement times and internal inventory levels.

(b) A further area of system expansion would be to pursue a somewhat more radical approach of nominating vendors to become completely responsible for supply of a predetermined number of tool lives/ cutting edges on a regular basis to selected high component volume cost centres. In principle this would require the vendor to supply all the tool families required by the end user to meet his manufacturing programme and would include standard/purpose-designed, disposable/reground tools alike.

10.1.3 General Expansion of ATOMS

Despite the improved level of control established through the implementation of the ATOMS routing it should still be recognised that its disciplines were aimed specifically at standard tooling, and while many of the control principles are relevant to special (purpose-designed) tools the system concept does require further enhancement if the overall problem of tool control is to be addressed. The remaining areas to be considered are:-

(a) Design
(b) Maintenance
(c) Disposal

Brief comment upon each item is contained in the following sub-sections:-

10.1.3.1 Tool Design

The opportunity to link the IMPS and ARCLASS control mechanisms into a computer aided design (CAD) facility offers interesting potential in areas such as:-

(a) It is recognised that although IMPS is a highly interactive system, it still requires much input of component dimensional details. The advent of CADS presents an opportunity to incorporate the IMPS logic and data into a system with enhanced graphics and digitising capabilities to reduce still further the need for manual input.

(b) Again the combination of ARCLASS as an information retrieval mechanism with a CADS based standard tooling catalogue for standard and purpose-designed tools alike would offer a service to several system end users.

Reference to Figure 65 illustrates how standard data files containing the appropriate graphics and text, which would be accessible through the ARCLASS designation, could be utilised to generate a standard tooling information output for use in the key areas of:-

(i) Manufacturing control

(ii) Technology planning

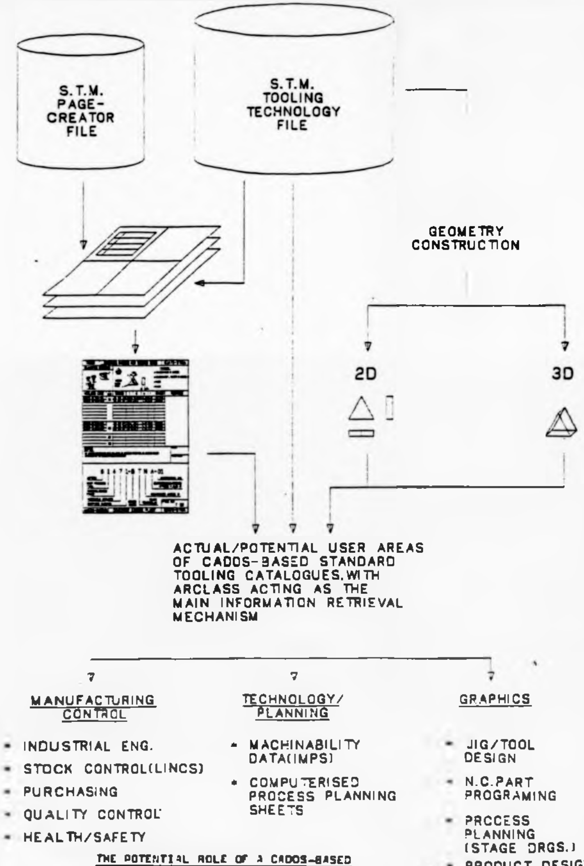
(iii) Graphics based activities

10.1.3.2 Tool Maintenance

The fundamental difference between the tools used to develop the ATOMS routing and the majority of other cutting tool families is that while indexable inserts are generally classed as disposable tools, the remainder require the support of a regrind/redress facility.

It is recognised that this subject area has not been addressed within the main body of the thesis and represents a further area for consideration in terms of overall tool management.

Control disciplines required for this subject area to become accommodated with ATOMS include:-



THE POTENTIAL ROLE OF A CADOS-BASED STANDARD TOOLING CATALOGUE

Figure 65

(a) A major limitation encountered at Coventry Engine Plant was the freedom given to machine tool setters in terms of the free hand grinding of certain form tools on pedestal grinding machines. This practice would have to be eliminated, and a discipline implemented whereby all tool regrinding should take place within a central tool maintenance facility.

(b) With the necessary enhancements required of IMPS it is envisaged that the system would control:-

(i) Regrind tool geometry

(ii) The number of regrinds allowable per tool

(c) The remaining base requirements are the implementation of:-

(i) A factory-wide tool tracking facility to monitor and control the number of tools actually in the system at any one moment in time. It is considered that this would present an interesting Operational Research exercise as the system would need to identify priority tooling, and also implement a discipline which ensured that all reground tools had been used before any new tools were issued from the tool stores.

(ii) A work scheduling system for the cutter grinding section.

10.1.3.3 Tool Disposal

Possible alternative uses for used tools always presents an interesting challenge, particularly in re-using finishing tools on roughing operations, and it is recommended that this 'back stop' facility is incorporated into the overall system.

10.1.4 Plant Level System Maintenance

In handing the project over to the Plant Management for ongoing systems maintenance and expansion the following responsibilities were identified:

(a) The Process Engineer who had been associated with the project throughout became the custodian for IMPS and ARCLASS, and the 'where used' files within LINCS.

(b) One Production and Material Control Analyst to become responsible for:-

(i) Maintenance of the reduced stock levels

(ii) The generation of the weekly tooling bills of material

(iii) The operation of the tool 'marshalling' system.

(c) A senior manufacturing manager was given the overall responsibility for system expansion and towards the end of the period of research work had commenced upon the following tooling families:

(i) All abrasives

(ii) Drills

(iii) Tapps

(iv) Reamers

(v) Dressing diamonds

10.2 POTENTIAL BENEFITS

Although the ATOMS routing was based upon the control of indexable inserts it is possible to estimate the potential savings across all tooling families utilised at Coventry Engine Plant.

The previous chapter has shown that the results obtained in terms of inventory reduction and estimated annual expenditure resulting from the implementation of the ATOMS routing were:-

(i) An 88% reduction in inventory

(ii) An estimated 18% reduction in expenditure

It would be misleading to suggest that such significant savings could be achieved for all tooling families, but it is considered that for standard 'off the shelf' tooling, as identified in the main by categories (1) to (7) in Figure 66, that savings/reductions approaching the ATOMS

ITEM NO.	TOOL FAMILY	1980 FULL YEAR EXPENDITURE	INVENTORY VALUE AT STOCK TAKE DECEMBER 1980
1.	Abrasives	129.6	139.3
2.	Index Inserts	112.0	93.5*
3.	Twist Drills	79.8	85.79
4.	Tool holders	68.3	100.24
5.	Tapps and Dies	62.0	66.65
6.	Reamers	60.8	65.36
7.	Diamond Tools	51.7	55.58
	SUB-TOTAL	564.2	606.42
8.	Other Tools:- Including, (i) Brazed (ii) Specials (iii) Forging Dies (iv) Welding Tips (v) Hand (vi) Other	291.7	313.58
	TOTALS	£855.9	£920*

N.B.: (a) All figures in £000's.

(b) Inventory items marked thus * were audited figures with the remainder being estimated values based on a ratio of annual expenditure.

AN ANALYSIS OF TOOLING EXPENDITURE/INVENTORY VALUES FOR 1980 (COVENTRY ENGINE PLANT)

Figure 66

routing proven levels could be achieved, and the impact of this would be as follows:-

(i) Inventory reduction: £606.42 x 70% = £424.5K

(ii) Expenditure: £564.2 x 15% = £84.6K

For the remaining tools as identified by item (8) in Figure 66 the potential savings are considered to be somewhat less, and the following figures would be more realistic:-

(i) Inventory reduction: £313.58K x 50% = £156.79K

(ii) Expenditure: £291.7K x 15% = £43.76K

Therefore, a summary of the potential overall benefits for Coventry Engine Plant would be:-

(i) Inventory reduction: 63% i.e. from £920K to £339.71K

(ii) Expenditure: 15% i.e. from £855.9K to £727.5K

If the savings resulting from the implementation of the ATOMS routing as described in this thesis are deducted from these totals, i.e.

(a) Inventory reduction potential - indexable insert reduction achieved =

£580.29K - £84.5K = £495.79K

a once off saving of

£495.79K x 15% = <u>£74.37K</u>

(b) Expenditure reduction potential - estimated indexable insert reduction achieved =

£128.36K - £20.47K = <u>£107.89K per annum</u>

10.3 SYSTEM EXPANSION AT OPERATIONS LEVEL

System expansion to cover Birmingham Operations presents organisational rather than engineering problems in terms of:-

(a) The number of Plant and Divisionally based Process Planning and Production and Material Control Departments.

(b) The excessive number of tool stores throughout Birmingham Operations, which at the time of writing, totalled sixteen.

The possible resolution to these problems is discussed in the following sub-sections:-

10.3.1 Stores Rationalisations

Within the four factories comprising Birmingham Operations cutting tools and related items are held in no less than sixteen consumable material stores, a situation which, historically, is based upon the operation of labour intensive stock control systems. Standardisation of computer based inventory control systems and the gradual phasing in of the ATOMS disciplines offers significant stores rationalisation potential. Appropriate action should be taken to reduce the number of stores allowed to hold more than say one week's requirement of tooling related inventories from sixteen to five, the locations of which should be:-

Longbridge Power Train	2 stores
Longbridge Body & Assembly	1 store
Drews Lane/Radford	1 store
Coventry Engine Plant	1 store

Any local stores in addition to these should only be used as distribution points for the LINCS tool marshalling system.

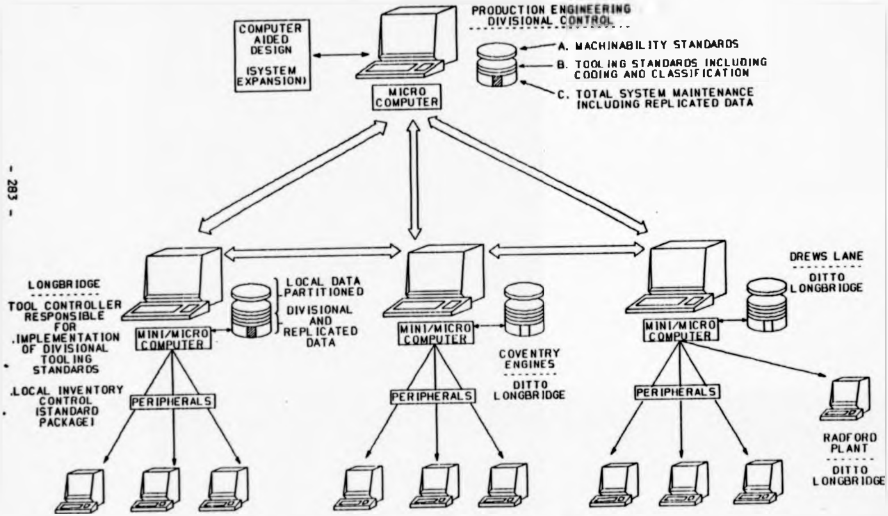
10.4 BIRMINGHAM OPERATIONS - SYSTEM MAINTENANCE

Finally consideration should be given to the practicalities of maintaining ATOMS across several manufacturing locations, and reference to Figure 67 portrays a possible system configuration which has implications in terms of organisational structures as well as hardware requirements. Brief comment upon the implementation of such an operational system is as follows:-

(a) There is a danger that when faced with the cutting tool profile for Birmingham Operations, in terms of inventory and expenditure values, the task of attempting to implement an improved tool management system would appear to be daunting. However, the key lesson learnt from the ATOMS routing is that the foundation for control is the development of process specific IMPS data bases, and this would be true irrespective of the number of factories involved. Indeed, there is no reason why, with a limited amount of data enhancement to embrace advanced tooling materials, the single point (turning) data base developed at Coventry Engine Plant should not be used as the initial standard for all of Birmingham Operations.

In the absence of a computer aided design facility, the potential for which was discussed in sub-section 10.1.3.1, it is considered that all of the IMPS/ARCLASS maintenance and development is well suited to a microcomputer based medium, and should be under the direct control of a small select team of highly trained process engineers who would be divisionally based.

(b) At the Plant level it is recommended that each geographic location appoints an acknowledged tool controller whose main functions would be:-



OVERVIEW OF THE PROPOSED BIRMINGHAM OPERATIONS TOOL CONTROL SYSTEM COMMUNICATIONS NETWORK

Figure 67

(i) The local custodian to ensure the correct implementation of the divisionally based IMPS/ARCLASS standards. It is envisaged that while the Plant personnel would have a read only access to the standards, this should not discourage the individuals involved from submitting any ideas for improving machining conditions back to the divisionally based authorised control for evaluation.

(ii) The day-to-day operation of a LINCS based module, in terms of generating tooling bills of material, etc., would be a local responsibility and due to the nature of the potentially high data transaction rate at the Longbridge Plant (presently estimated at 40,000 per month for cutting tools) the activity would be better suited to a minicomputer.

CONCLUSIONS

While many aspects relating to tool control have been previously studied it is argued that the realisation of the full potential of a control system can only be achieved by defining and prioritising the interdependent nature of related sub-systems followed by their subsequent linking to form a 'whole' system.

This thesis has examined a concept whereby the prime sub-system has been identified as establishing the correct technological manufacturing standard at the point of metal removal which is then linked to the necessary supportive sub-systems to ensure:-

- The ongoing maintenance of that standard.
- The support of component production volume related tool material supply requirements.

The key system characteristics were found to be:-

- The machinability data utilised must reflect the actual manufacturing environment under consideration as the system output acts as a decision-making aid in the setting of process standards and the evaluation of alternative methods.
- The tool classification and coding system should have flexibility in terms of character strings with a high level of significance to facilitate system linking.
- The importance of a very simple tool/component 'where used' data file in terms of tool material supply and maintaining necessary disciplines was significant.

The range of benefits gained from this linked systems approach were:-

- Improvements in cutting tool performance and machine tool utilisation.
- Reductions in tooling related inventory and expenditure.
- Reductions in direct and indirect labour content.

In order to established a system of this type the following requirements are necessary:-

- While recognising the sensitivity of many individuals to changes in custom and practice, the ability to create the opportunity for the implementation of new ideas was under-pinned by a significant time investment in selling those ideas, and supportive education, at all levels within the Company which resulted in the commitment necessary for progress to be made.
- The introduction of greater control disciplines both internally, i.e. tool planning, application, supply, and externally over the tool suppliers, by limiting their spheres of influence within the Company.
- Despite the improved level of control disciplines the tool material suppliers should still be recognised as an integral element of the overall tool management system.
- The ability to adjust levels of focus within an overall system boundary is necessary in terms of problem analysis and for system linking. Over-emphasis upon any one of the three sub-systems within the ATOMS system would have been to the detriment of understanding the problem of tool control as a whole.
- Having established a linked systems based solution which functions on sub-system expansion and medium-term maintenance with respect to data, hardware, software and personnel training/organisational requirements should not be undervalued.

* * * * * * * * * * *

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APPENDIX (A)

MACHINE TOOL PROFILE - COVENTRY ENGINE PLANT

The following age profile for the machine tools at Coventry Engine Plant was established as the result of a Plant-wide census (12th June, 1980).

Age (years)	No of Machines
0 - 5	207
6 - 10	647
11 - 15	785
16 - 20	653
21 - 25	317
26 - 30	561
30+	960
	TOTAL 4,130

∴ Average = 20 years

Machinability Group No. 1

	FEED RATE (mm/rev)	CUTTING SPEEDS (m/min)					
		'HARD' TOOL		'STANDARD' TOOL		'TOUGH' TOOL	
		GC 015		GC 1025		GC 135	
		Absolute	Relative	Absolute	Relative	Absolute	Relative
(6)	0.15	460	1.91	450	1.95	320	1.93
(5)	0.25	385	1.60	370	1.60	265	1.60
(4)	0.4	335	1.39	320	1.39	230	1.39
(3)	0.5	300	1.25	285	1.23	205	1.24
(2)	0.6	280	1.16	265	1.15	190	1.15
(1)	0.8*	240	1	230	1	165	1
	y		x		x		x

* Datum Feed Rate

	'HARD' TOOL	'STANDARD' TOOL	'TOUGH' TOOL
Logarithmic Relationships of y versus x	y = -2.616x -0.138	y = -2.526x -0.166	y = -2.557x -0.159
Correlation Coefficient	0.994	0.997	0.996

Mean Material Hardness = 110HB

Tool Life = 15 mins. (0.3 mm Flank wear or equivalent)

Machinability Group No. 2

	FEED RATE (mm/rev)	CUTTING SPEEDS (m/min)					
		'HARD' TOOL		'STANDARD' TOOL		'TOUGH' TOOL	
		GC 015		GC 1025		GC 135	
		Absolute	Relative	Absolute	Relative	Absolute	Relative
(6)	0.15	390	1.85	375	1.87	280	1.93
(5)	0.25	335	1.59	320	1.60	235	1.62
(4)	0.4	290	1.38	275	1.37	195	1.34
(3)	0.5	255	1.21	245	1.22	180	1.24
(2)	0.6	240	1.14	230	1.15	165	1.13
(1)	0.8*	210	1	200	1	145	1
	y		x		x		x

* Datum Feed Rate

	'HARD' TOOL	'STANDARD' TOOL	'TOUGH' TOOL
Logarithmic Relationships of y versus x	y = -2.677x -0.163	y = -2.662x -0.157	y = -2.548x -0.181
Correlation Coefficient	0.9939	0.9953	0.9984

Mean Material Hardness = 150HB

Tool Life = 15 mins. (0.3 mm Flank wear or equivalent)

APPENDIX (B)

SANDVIK LTD., MACHINABILITY DATA

Sheet 1 of 3

Machinability Group No. 3

	FEED RATE (mm/rev)	CUTTING SPEEDS (m/min)					
		'HARD' TOOL		'STANDARD' TOOL		'TOUGH' TOOL	
		GC 015		GC 1025		GC 135	
		Absolute	Relative	Absolute	Relative	Absolute	Relative
(6)	0.15	510	1.78	412	1.83	285	2.00
(5)	0.25	435	1.52	345	1.53	232	1.63
(4)	0.4	375	1.31	300	1.33	195	1.36
(3)	0.5	345	1.21	277	1.23	180	1.26
(2)	0.6	315	1.10	255	1.13	165	1.15
(1)	0.8*	285	1	225	1	142	1
	y		x		x		x

* Datum Feed Rate

Logarithmic Relationships of y versus x	y = -2.860x -0.189	y = -2.814x -0.162	y = -2.464x -0.167
Correlation Coefficient	0.997	0.997	0.998

Mean Material Hardness = 180HB

Tool Life = 15 mins. (0.3 mm Flank wear or equivalent)

Machinability Group No. 4

	FEED RATE (mm/rev)	CUTTING SPEEDS (m/min)					
		'HARD' TOOL		'STANDARD' TOOL		'TOUGH' TOOL	
		GC 015		GC 1025		GC 135	
		Absolute	Relative	Absolute	Relative	Absolute	Relative
(6)	0.15	292	1.85	233	1.82	158	1.90
(5)	0.25	247	1.57	195	1.52	135	1.63
(4)	0.4	217	1.38	173	1.35	113	1.36
(3)	0.5	195	1.23	158	1.23	98	1.18
(2)	0.6	180	1.14	143	1.11	90	1.09
(1)	0.8*	157	1	128	1	83	1
	y		x		x		x

* Datum Feed Rate

Logarithmic Relationships of y versus x	y = -2.722x -0.148	y = -2.803x -0.166	y = -2.451x -0.242
Correlation Coefficient	0.994	0.994	0.994

Mean Material Hardness = 345HB

Tool Life = 15 mins. (0.3 mm Flank wear or equivalent)

Sheet 2 of 3

Machinability Group No. 5

	FEED RATE (mm/rev)	CUTTING SPEEDS (m/min)					
		'HARD' TOOL		'STANDARD' TOOL		'TOUGH' TOOL	
		GC 015		GC 315		N	
		Absolute	Relative	Absolute	Relative	Absolute	Relative
(6)	0.15	290	2.23	210	2.21	130	2.16
(5)	0.25	240	1.84	175	1.84	110	1.83
(4)	0.4	195	1.50	145	1.52	95	1.58
(3)	0.5	175	1.34	130	1.36	85	1.41
(2)	0.6	160	1.23	120	1.26	75	1.25
(1)	0.8*	130	1	95	1	60	1
	y		x		x		x

* Datum Feed Rate

Logarithmic Relationships of y versus x	$y = -2.113x - 0.119$	$y = -2.153x - 0.086$	$y = -2.171x - 0.066$
Correlation Coefficient	0.993	0.987	0.976

Mean Material Hardness = 200HB

Tool Life = 15 mins. (0.3 mm Flank wear or equivalent)

Machinability Group No. 6

	FEED RATE (mm/rev)	CUTTING SPEEDS (m/min)					
		'HARD' TOOL		'STANDARD' TOOL		'TOUGH' TOOL	
		GC 015		GC 315		N	
		Absolute	Relative	Absolute	Relative	Absolute	Relative
(6)	0.15	330	1.57	285	1.46	120	1.71
(5)	0.25	295	1.40	245	1.25	110	1.57
(4)	0.4	265	1.26	225	1.15	90	1.28
(3)	0.5	255	1.21	215	1.10	85	1.21
(2)	0.6	245	1.16	205	1.05	80	1.14
(1)	0.8*	210	1	195	1	70	1
	y		x		x		x

* Datum Feed Rate

Logarithmic Relationships of y versus x	$y = -3.857x - 0.055$	$y = -4.441x - 0.273$	$y = -3.010x - 0.150$
Correlation Coefficient	0.981	0.995	0.989

Mean Material Hardness = 200HB

Tool Life = 15 mins. (0.3 mm Flank wear or equivalent)

APPENDIX (C)

PROGRAM FOR PLOTTING COMPONENT SURFACE SPEED/FEED RELATIONSHIP

```
]LIST

10  DIM X(100)
20  DIM Y(100)
25  REM  THE ABOVE ARE X,Y CO-ORDINATES INPUT
60  REM  A & B ARE USED FOR CALCULATION OF BEST FIT LINES E
     TC AS ARE C & D BELOW
61  DIM O(100),OO(100)
65  DIM C(100)
70  DIM D(100)
79  CLEAR : TEXT
80  HOME : VTAB 8: PRINT "LOGARITHMIC GRAPH PLOTTING MODULE
     ": PRINT "==";
81  PRINT "================================": PRINT : PRINT
     "MAX NO.OF POINTS IS 100": PRINT : PRINT "STATISTICAL
     ANALYSIS OF BEST FIT LINE": PRINT "(USING 'LEAST SQUAR
     ES' METHOD) IS ALSO": PRINT "CONDUCTED."
82  PRINT "": PRINT "TYPE 'END' AS X CO-ORD INPUT TO CEASE"
     : PRINT ""
85  INPUT "HIT REURN TO CONTINUE:-";AA$
111  HOME
112  PRINT "        GRAPH PLOTTING MODULE"
120  PRINT "        ***********************"

140  PRINT ""
150  PRINT ""
155  PRINT "----------------------------------------"
160  PRINT "POINT NO.      X VALUE     Y VALUE"
170  PRINT "----------------------------------------"
180  POKE 34,9
200  REM  ::::::::::::::::::::::::::::::::::::::::
210  REM  START INPUTTING POINTS NOW
220 A = 10
250 I = I + 1
255 A = A + 1
256  IF A > 23 THEN A = 24
260  VTAB A: HTAB 3: PRINT I
270  HTAB 19: VTAB A: INPUT X$
280  IF X$ = "END" THEN 400
281  REM  ***** GOTO SORT PROGRAM THEN***********
290 X(I) =  VAL (X$)
300  HTAB 30: VTAB A: INPUT Y(I)
310  GOTO 250
400  REM -------------------------
401  REM  STATISTICAL ANALYSIS SECTION
402  REM  --------------------------
403  FOR N = 1 TO (I - 1):X(N) =  LOG (X(N)):Y(N) =  LOG (Y
     (N)): NEXT N
405  FOR N = 1 TO (I - 1):SX = SX + X(N):SY = SY + Y(N):S2X
      = S2X + (X(N) ^ 2): NEXT N
410  FOR N = 1 TO (I - 1):SUMPROD = SUMPROD + (X(N) * Y(N))
     : NEXT N
415 B = (((I - 1) * SUMPROD) - (SX * SY)) / (((I - 1) * S2X
```

```
    I - (SX ^ 2))
420 A = (SY - (B * SX)) / (I - 1)
425  REM  ================ NOW CALCULATE REGRESSION LINE POIN
    TS=================
440  FOR N = 1 TO (I - 1):C(N) = A + (B * X(N)): NEXT N
500  REM  ********CALCULATE REGRESSION COEFFICIENT ********
    **********
510  FOR N = 1 TO (I - 1):CY = CY + (C(N) * Y(N)):SC = SC +
    (C(N)):YS2 = YS2 + (Y(N) ^ 2):Y2 = Y2 + (C(N) ^ 2): NEXT
    N
511 R1 = ((I - 1) * CY) - (SY * SC)
515 R2 = ((YS2) * (I - 1)) - (SY ^ 2)
520 R3 = ((I - 1) * Y2) - (SC ^ 2)
530 R4 =  SQR (R2 * R3)
540 R = R1 / R4
550  REM  R IS THE REGRESSION COEF*
560 R$ =  STR$ (R)
570 R$ =  LEFT$ (R$,5)
999  REM  ***********************************************
1000  REM  SECTION TO SORT DATA POINTS INTO ASCENDING X ORD
    ER AND FIND HIGHEST Y VALUE
1001  REM  **********************************************
1009 MY = 10 ^ 30: REM  MY IS THE MINIMUM VALUE OF ALL THE
    Y'S INPUT-USE IT FOR SCALING
1010  FOR T = 1 TO (I - 1)
1020  IF Y(T) > YM THEN YM = Y(T)
1021  REM  YM IS NOW THE MAXIMUM VALUE OF ALL THE Y CO-ORDI
    NATES
1022  IF Y(T) < MY THEN MY = Y(T)
1023  NEXT T
1030 YSCALER = 150 / (YM - MY)
1031  REM  MULTIPLY ALL Y(I)'S BY YSCALER EVENTUALLY TO GIV
    E GOOD GRAPH LAYOUT
1050  REM  SORTING PROCEDURE FOLLOWS:-
1060  FOR L = 1 TO (I - 2)
1070  FOR M = (L + 1) TO (I - 1)
1080  IF X(L) < X(M) THEN 1300
1090 XT = X(L):YT = Y(L)
1100 X(L) = X(M):Y(L) = Y(M)
1110 X(M) = XT:Y(M) = YT
1300  NEXT M
1310  NEXT L
1350  REM  SHOULD NOW HAVE ALL POINTS ARRANGED IN ASCENDING
     X VALUES
1360  FOR T = 1 TO (I - 1):X(T) = X(T) - X(1): NEXT T
1370  FOR T = 1 TO (I - 1):Y(T) = Y(T) - MY: NEXT T
1400 XSCALER = 275 / X(I - 1)
1410  REM  MULTIPLY ALL X VALUES BY THIS SCALING FACTOR TO
    GIVE GOOD PRESENTATION
1500  REM  START PLOTTING !!!
1510  IF A$ = "A" THEN 1700
1520  IF A$ = "B" THEN 1900
1530  REM  -MUST THEREFORE WANT CARTESIAN *AND* LOG-LOG PLO
    TTING !
1540  FOR N = 1 TO (I - 1):X(N) =  INT (X(N) * XSCALER):Y(N
    ) =  INT (Y(N) * YSCALER): NEXT N
1700  POKE 34,0
1705  HOME
1710  HGR
1715  HCOLOR= 3
1720  HPLOT 0,0 TO 0,150
1730  HPLOT  TO 270,150
1800  REM  PLOT CARTESIAN CO-ORDINATES NOW
1809  HCOLOR= 6
1810  FOR N = 1 TO (I - 2)
1820  HPLOT X(N),Y(N) TO (X(N + 1),Y(N + 1)
1830  NEXT N
1850  VTAB 21
1860  PRINT "REGRESSION-INTCP'T=";A
1870  PRINT "**********-GRAD=";B
1890  PRINT "CORRELATION COEFFICIENT=";R
1900  PRINT "HIT 'R' TO RE-RUN:-:,'E' TO END";
1901  GET AA$
1910  IF AA$ = "R" THEN 79
1920  IF AA$ = "E" THEN  TEXT : HOME : END
1930  GOTO 1900
```

APPENDIX (D)

IMPS - PROGRAM

```
90  PR# 0
100  TEXT
105  HOME
110  PRINT " B.L.LTD (AUSTIN ROVER GROUP)
120  PRINT " "
130  PRINT "        *******************"
140  PRINT "        *                 *"
150  PRINT "        * I . M . P . S . *"
160  PRINT "        *                 *"
170  PRINT "        *******************"
180  PRINT " "
190  PRINT "        ITERATIVE MACHINING"
200  PRINT "        PARAMETER SELECTION"
210  PRINT "        (SINGLE POINT"
220  PRINT "            TURNING MODULE)"
230  PRINT "": PRINT ""
240  PRINT "IMPORTANT: THIS SOFTWARE IS THE"
250  PRINT "PROPERTY OF B.L.LTD. AND SHOULD"
260  PRINT "NOT BE REPRODUCED WITHOUT PRIOR"
270  PRINT "CONSENT FROM P.H.SUMMERFIELD."
280  PRINT
290  PRINT
300  PRINT " "
400  PRINT "HIT 'RETURN' TO CONTINUE": GET AA$
650  PR# 0
660  TEXT
700  HOME
710  VTAB (6): INPUT "GIVE COMPONENT NO. - ";CN$
720  VTAB (14): PRINT "GIVE COMPONENT DESCRIPTION -"
730  PRINT : INPUT CD$
735  IF  LEN (CD$) > 15 THEN  PRINT : PRINT "PLEASE LIMIT T
     O 15 CHARACTERS": GOTO 730
740  HOME
760  GOSUB 16500: REM  INPUT DATA FROM FILES
770  GOSUB 16694: REM  INPUT MATERIAL TYPE
780  GOSUB 25000: REM  LOAD & DISPLAY CONSTITUENT LEVELS
790  GOSUB 17100: REM  DISPLAY RECOMMENDATIONS FOR CARBIDE
     GRADE
810  PRINT : INPUT "IS BATCH HARDNESS KNOWN (Y OR N):-";AA$

820  IF AA$ = "Y" THEN  PRINT " ": INPUT "GIVE FIGURE (HB):
     -";MH
825  IF AA$ = "Y" THEN  GOTO 840
830 MH = H
840  PRINT : PRINT "HIT 'RETURN' TO CONTINUE:-";
850  GET AA$
860  HOME : VTAB 5: PRINT "FOR 'STEPPED' COMPONENTS PRODUCE
     D ON": PRINT "": PRINT "A SINGLE MACHINE SPEED BASIS P
     LEASE HIT": PRINT " ": PRINT "THE KEY 'S' TO BRANCH TO
      SUBROUTINE TO": PRINT " ": PRINT "CALCULATE MEAN DIA.
      AND LENGTH
```

```
870  GET AA$
880  IF AA$ = "S" THEN  GOSUB 13000
890  REM  ==============================================
900  REM  FINISHING ROUTINE SECTION
910  REM  ==================================
920 CNTR = 1: REM  THIS IS THE COUNTER TO TELL YOU HOW MANY
     TIMES YOU'VE BEEN THROUGH THE VARIOUS PARTS OF THE PR
    OGRAM
930  HOME
940  INPUT "GIVE FINAL SURFACE FINISH REQ'D(UM):-";FSF
950  INPUT "GIVE FINAL SIZE TOLERANCE TO BE ACHIEVED (+/-)M
    M:-";TSF
960  PRINT " ": PRINT " "
970  INPUT "GIVE START OD FROM ROUGH(MM):-";SOD
980  PRINT " "
990  INPUT "GIVE FINAL FINISHED O/D(MM):-";FFOD
1000  IF FFOD >  = SOD THEN  PRINT : PRINT "ERROR HAS BEEN
    MADE (FINAL O/D >START O/D)": GOTO 970
1010  REM  ==============================================
    ==
1020  REM  SECTION TO DECIDE UPON FINISHING OP STOCK REMOVA
    L
1030  IF FSF <  = FT(1) THEN C1 = 1: GOTO 1080
1040  IF FSF <  = FT(2) THEN C1 = 2: GOTO 1080
1050  IF FSF <  = FT(3) THEN C1 = 3: GOTO 1080
1060  IF FSF <  = FT(4) THEN C1 = 4: GOTO 1080
1070 C1 = 5: REM  DUMMY VALUE
1080  REM  C1 IS THE 'CRITICAL INTERVAL' AS DICTATAED BY SU
    RFACE FINISH CRITERIA
1090  IF TSF <  = ST(1) THEN C2 = 1: GOTO 1140
1100  IF TSF <  = ST(2) THEN C2 = 2: GOTO 1140
1110  IF TSF <  = ST(3) THEN C2 = 3: GOTO 1140
1120  IF TSF <  = ST(4) THEN C2 = 4: GOTO 1140
1130 C2 = 5: REM  DUMMY VALUE
1140  REM  C2 IS THE 'CRITICAL INTERVAL' AS DICTATED BY SIZ
    E TOLERANCE CRITERIA
1150  IF C1 <  = C2 THEN C = C1: GOTO 1170
1160 C = C2
1170  REM  C IS THE MORE CRITICAL INTERVAL OF C1 AND C2
1180  HOME : HTAB 12: PRINT "FINISHING ROUTINE"
1190  HTAB 12: PRINT "================="
1200  PRINT " "
1205 DE = (SOD - FFOD) / 2
1210  IF C = 5 THEN  PRINT "DO NOT HAVE A CRITICAL FINAL D.
    O.C.": PRINT "TOTAL STOCK TO REMOVE=";DE;" MM": INPUT
    "SELECT A FINISHING D.O.C (MM):-";D(1): GOTO 1285
1212  IF DC(C) > DE THEN DC(C) = DE
1220  PRINT "CRITICAL FINAL D.O.C": PRINT : PRINT "": PRINT
    "RECOMMEND A D.O.C. OF :-";DC(C);" MM"
1230  PRINT " ": PRINT " "
1240  INPUT "SELECT FINAL OP. D.O.C.(MM):-";D(1)
1250  IF C = 5 THEN 1285
1260  IF D(1) > DC(C) THEN  PRINT " ": PRINT "THIS VALUE IS
     GREATER THAN RECOMMENDED  -DO YOU WISH TO CHANGE IT?(
    Y OR N):-";: INPUT AA$: PRINT " "
1270  IF D(1) <  = DC(C) THEN 1285
1280  IF AA$ <  > "N" THEN 1240
1285  IF D(1) > DE THEN  PRINT "D.O.C. SELECTED IS GREATER
    THAN REQUIRED : RE-INPUT": GOTO 1240
1290  INPUT "HIT 'RETURN' TO CONTINUE:-";AA$:OD(1) = FFOD +
    (2 * (D(1))): GOTO 1380: REM  FACTORING ROUTINE
1300  REM  **** SECTION TO DEAL WITH NON-FINISHING D.O.C. D
    ETAILS ****
1310 CNTR = CNTR + 1
1315  IF ( INT ((SOD - (FFOD + (2 * (D(1))))) * 500 + 0.5) /
    1000) = 0 THEN  GOTO 22000
1316  IF ( INT ((FFOD + (2 * D(1)) * 1000 + 0.5) / 1000)) =
    0 THEN  GOTO 22000
1320  IF CNTR = 2 THEN  PRINT "STOCK REMAINING TO BE REMOVE
    D="; INT (1000 * (((SOD - (FFOD + (2 * (D(1))))) / 2))
    ) / 1000:OD(CNTR) = SOD: GOTO 1360
1330  IF CNTR >  = 3 THEN OD(CNTR) = (OD(CNTR - 1)) - (2 *
    (D(CNTR - 1)))
1332 SR = ((OD(CNTR) - OD(1)) / 2)
1334  IF SR < 0.001 THEN SR = 0: PRINT "ALL STOCK HAS BEEN
    REMOVED": GOTO 22000
1336  PRINT "STOCK REMAINING=";SR;" MM": GOTO 1360
1340  IF (FFOD + (2 * D(1)) = SOD) THEN  PRINT "ALL STOCK H
    AS BEEN REMOVED IN ONE PASS": GOTO 22000
1350  IF OD(CNTR) = (FFOD + (2 * (D(1)))) THEN  PRINT "ALL
    STOCK HAS BEEN REMOVED": GOTO 22000
1360  INPUT "SELECT D.O.C.:-";D(CNTR)
1370  REM  WE NEED TO PUT IN A CHECKING ROUTINE HERE TO ENS
    URE THAT WE DO NOT REQUEST TO REMOVE MORE STOCK THAN A
    CTUALLY REMAINS
1375  PRINT : PRINT
1380  INPUT "IS MACHINE FACTOR KNOWN ?(Y/N) :-";Q$
1400  IF Q$ <  > "N" THEN 1430
1410  GOSUB 11000
1420  GOTO 1440
1430  INPUT "ENTER FACTOR HERE :-";FA$
1440 HARD$ = H1S$:STD$ = N1S$:TGH$ = T1S$:HSS$ = "HSS":BEST
    $ = "GC415"
1450  IF  VAL (FA$) <  = 0.72 THEN REC$ = T1S$:ALT$ = HSS$:
    GOTO 1480
1460  IF  VAL (FA$) >  = 0.80 THEN REC$ = H1S$:ALT$ = N1S$:
    GOTO 1480
1470 REC$ = N1S$:ALT$ = T1S$: REM   THIS IS THE RECOMMENDAT
    ION FOR THE RANGE OF FACTOR 0.72<F<0.8
1480  IF  VAL (FA$) < .65 THEN 1500
1485  IF  VAL (FA$) > 0.85 THEN 1492
1490  GOTO 1515
1492  PRINT "THIS MACHINE IS LIKELY TO BE ABLE TO   ": PRINT
    "SUCCESSFULLY UTILISE SYALON-BASED ": PRINT "CERAMIC T
    OOLING-REFER TO HANDBOOK": PRINT "FOR PARAMETERS"
1493  PRINT " "
1494  INPUT "DO YOU WISH TO USE HIGHEST GRADE CARBIDE (ANSW
    ER Y OR N):-";AA$
1496  IF AA$ = "Y" THEN REC$ = BEST$:ALT$ = HARD$
1498  GOTO 1515
1500  INPUT "FACTOR IS VERY LOW, DO YOU WISH TO CHANGE MACH
    INE OR TOOLING SET-UP? (Y/N)";QQ$
1510  IF QQ$ = "Y" THEN 1410
1515 REC$(CNTR) = REC$
1520  HOME : VTAB 12: PRINT "FACTORING NOW COMPLETE": FOR Z
```

```
    Z = 1 TO 100: NEXT ZZ: PRINT "RECOMMENDED TOOL GRADE I
    S:-";REC$: PRINT "ALTERNATIVE GRADE IS:-";ALT$: INPUT
    "HIT RETURN TO CONTINUE:-";AA$
1530  IF D(CNTR) > (MDOC * ( VAL (FA$))) THEN  FOR XX = 1 TO
    3: FOR YY = 1 TO 60:Z1 =  PEEK ( - 16336): NEXT YY: NEXT
    XX: PRINT "MAX D.O.C. ACHIEVABLE IS ";(MDOC * ( VAL (F
    A$)));" MM": GOTO 1550
1540  GOTO 1610
1550  PRINT "M/C IS UNLIKELY TO BE ABLE TO ACHIEVE   D.O.C.
    STIPULATED.": PRINT : PRINT "DO YOU WISH TO CHANGE:-"
    : PRINT : PRINT "(A.)-D.O.C.": PRINT : PRINT "OR": PRINT
    : PRINT "(B.)-MACHINE SELECTED ?": PRINT : INPUT "INPU
    T A OR B AS APPROPRIATE:-";AA$
1560  IF AA$ = "B" THEN 1380: REM  GO BACK TO THE FACTORING
    SECTION & 'RATE' THE NEW MACHINE
1570  REM  SINCE YOU HAVE ARRIVED HERE THEN YOU MUST WANT T
    O RESELECT D.O.C.
1580  INPUT "GIVE NEW D.O.C.(MM):-";D(CNTR)
1590  IF D(CNTR) <  = (MDOC * ( VAL (FA$))) THEN 1610
1600  PRINT "D.O.C. IS STILL TO HIGH FOR THIS M/C.": GOTO 1
    550
1610  IF CNTR <  > 1 THEN  GOSUB 10110
1615  IF CNTR = 1 THEN  GOSUB 9900
1840  HOME
1850  PRINT "I.M.P.S. MACHINING PARAMETER SELECTION"
1860  PRINT "======================================"
1870  PRINT
1880  PRINT ""
1890  INPUT "GIVE LENGTH OF CUT (MM):-";L(CNTR)
1900  PRINT ""
1910  INPUT "SELECT FEED RATE (MM/REV):-";F(CNTR):F = F(CNT
    R)
1920  IF CNTR = 1 THEN RAD = (((F(CNTR)) ^ 2) * 1000) / (18
    * FSF * ( SQR (3))): PRINT " ": PRINT " APPROPRIATE T
    OOL NOSE RADIUS IS:-"; INT (RAD * 10): PRINT " TENTHS
    OF A MILLIMETRE OR GREATER": PRINT " "
1930  IF F > (MFEED *  VAL (FA$)) THEN  FOR XX = 1 TO 3: FOR
    YY = 1 TO 60:Z1 =  PEEK ( - 16336): NEXT YY: NEXT XX: PRINT
    "MAX FEED ACHIEVABLE IS:-";(MFEED *  VAL (FA$)): GOTO
    1910
1940  PRINT
1950  INPUT "SELECT TOOL LIFE (MINS):-";T(CNTR):T = T(CNTR)

1956  HOME
1960  GOSUB 7610
1965 UU = UU + 10
1970  GOSUB 13900: REM  CALCULATING SECTION
2930  PR# 0
2940  REM  SECTION TO QUESTION SPINDLE SPEED
2950  INPUT "IS SPINDLE SPEED ACHIEVABLE(Y OR N):-";AA$
2960  IF AA$ = "Y" THEN  GOTO 2975
2970  IF AA$ = "N" THEN  GOSUB 16005
2972  GOTO 2990
2975  GOTO 17500
2980  REM  HAVE NOW RETURNED FROM SPINDLE SPEED ALTERATION
    SUBROUTINE
2990  HOME
```

```
3000  PRINT "I.M.P.S RESULTS (SPINDLE SPEED REDUCED)"
3010  PRINT "***************************************"
3020  PRINT "PLEASE NOTE CHANGES TO STANDARD TIME,   TOOL L
    IFE ,TCF ,AND POWER ": PRINT ""
3030  GOSUB 4120: REM  PRINT OUT DETAILS
3040  REM  HAVE NOW RETURNED FROM PRINTING DETAILS ON SCREE
    N
3050  IF QZ = 0 THEN  GOTO 17500
3060  IF QZ = 1 THEN  GOSUB 18490: REM  TOOL SELECTION
3070  GOTO 1300
3080  REM ================================================
    ==============END OF MAIN PROGRAM=====================
    ======================================================

4120  REM  PRINTING ON SCREEN ROUTINE
4125 BA = 10
4130  PRINT
4140 DD$ =  STR$ (D(CNTR)): FOR ZZ = 1 TO  LEN (DD$): IF  MID$
    (DD$,ZZ,1) = "." THEN DD$ =  LEFT$ (DD$,(ZZ + 2)): NEXT
    ZZ
4150  PRINT "DEPTH OF CUT(M.M.):-";DD$
4160 F$ =  STR$ (F(CNTR))
4170  FOR ZZ = 1 TO  LEN (F$)
4180  IF  MID$ (F$,ZZ,1) = "." THEN 4200
4190  NEXT ZZ
4200 F$ =  LEFT$ (F$,(ZZ + 2))
4210  PRINT "FEED RATE(MM/REV):-";F$
4220  PRINT "SURFACE CUTTING SPEED (M/MIN):-"; INT (V2(CNTR
    ))
4230  PRINT "ROTATIONAL SPEED (R.P.M.):-"; INT (N(CNTR) * 6
    0)
4240  PRINT "TURNED LENGTH(MM):-";L(CNTR)
4250 T$ =  STR$ (T(CNTR))
4260  FOR ZZ = 1 TO  LEN (T$)
4270  IF  MID$ (T$,ZZ,1) = "." THEN 4290
4280  NEXT ZZ
4290 T$ =  LEFT$ (T$,(ZZ - 1))
4300  PRINT "TOOL LIFE SELECTED (MINS):-";T$
4310  PRINT "TOOLCHANGE FREQUENCY (COMPTS):-"; INT (TCF(CNT
    R))
4320 PO$ =  STR$ (POWER(CNTR))
4330  FOR ZZ = 1 TO  LEN (PO$)
4340  IF  MID$ (PO$,ZZ,1) = "." THEN 4360
4350  NEXT ZZ
4360 PO$ =  LEFT$ (PO$,(ZZ + 2))
4370  PRINT "POWER REQ'D (KW):-";PO$
4380  PRINT "'KS'SPECIFIC FORCE VALUE(KG/MM):-"; INT (K1S(C
    NTR))
4390 ST$ =  STR$ (STDTIME(CNTR))
4400  FOR ZZ = 1 TO  LEN (ST$)
4410  IF  MID$ (ST$,ZZ,1) = "." THEN 4430
4420  NEXT ZZ
4430 ST$ =  LEFT$ (ST$,(ZZ + 3))
4440  PRINT "STANDARD TIME (MINS):-";ST$
4450  PRINT
4460  PRINT "========================================"
4480  INPUT "IS HARD COPY REQ'D (Y OR N):-";AA$
4490  IF AA$ = "Y" THEN  HOME : PR# 1: GOSUB 20191
```

```
4500  RETURN
4510  REM  ##################################################
     ####################
7500 HARD$ = HIS$:STD$ = NIS$:TGH$ = TIS$:HSS$ = "HSS"
7510  IF  VAL (FA$) < 0.5 THEN REC$ = TGH$:ALT$ = HSS$
7520  IF  VAL (FA$) > 0.75 THEN REC$ = HARD$:ALT$ = STD$
7530 REC$ = STD$:ALT$ = TGH$: REM  THIS IS THE RECOMMENDATI
     ON FOR THE RANGE OF FACTOR 0.5-0.75
7540  RETURN
7610  REM ========CHIPBREAKER==============================
     ====================================
9000  VTAB (8): INVERSE
9001  PRINT "COMPUTING CHIPBREAKER RECOMMENDATION": NORMAL
     : PRINT : PRINT : PRINT
9002  IF CNTR <  > 1 THEN 9005
9003  DIM CH(16,16)
9005 X1 =  INT (D(CNTR) + .5)
9010 Y1 =  INT (F(CNTR) * 10 + .5)
9015  FOR PP = 1 TO 16
9020  FOR QQ = 1 TO 16
9025  READ CH(PP,QQ)
9030  NEXT QQ
9035  NEXT PP: RESTORE
9040  IF CH(X1,Y1) = 1.0 THEN 9080
9045  IF CH(X1,Y1) = 1.1 THEN 9085
9050  IF CH(X1,Y1) = 1.2 THEN 9090
9055  IF CH(X1,Y1) = 1.3 THEN 9095
9060  IF CH(X1,Y1) = 1.4 THEN 9100
9065  IF CH(X1,Y1) = 1.5 THEN 9105
9070  IF CH(X1,Y1) = 1.6 THEN 9110
9075  IF CH(X1,Y1) = 1.7 THEN 9115
9080  PRINT "RECOMMENDED CHIPBREAKER STYLE IS B.L.STANDARD
     TYPE D":C1H$ = "D":C2H$ = "A": GOTO 9175
9085  PRINT "RECOMMENDED CHIPBREAKER STYLE IS B.L.STANDARD
     TYPE C":C1H$ = "C":C2H$ = "A": GOTO 9175
9090  PRINT "RECOMMENDED CHIPBREAKER STYLES IN ORDER OF PRE
     FERENCE ARE B.L.STANDARD TYPES C AND B":C1H$ = "C":C2H
     $ = "B": GOTO 9175
9095  PRINT "RECOMMENDED CHIPBREAKER STYLES IN ORDER OF PRE
     FERENCE ARE B.L.STANDARD TYPES B AND C":C1H$ = "B":C2H
     $ = "C": GOTO 9175
9100  PRINT "RECOMMENDED CHIPBREAKER STYLE IS B.L.STANDARD
     TYPE B":C1H$ = "B":C2H$ = "B": GOTO 9175
9105  PRINT "RECOMMENDED CHIPBREAKER STYLES IN ORDER OF PRE
     FERENCE ARE B.L.STANDARD TYPES B AND E":C1H$ = "B":C2H
     $ = "E": GOTO 9175
9110  PRINT "RECOMMENDED CHIPBREAKER STYLE IS B.L.STANDARD
     TYPE B OR E:"C1H$ = "B":C2H$ = "E": GOTO 9175
9115  PRINT "RECOMMENDED CHIPBREAKER STYLES IN ORDER OF PRE
     FERENCE ARE B.L.STANDARD TYPES E AND B":C1H$ = "E":C2H
     $ = "B": GOTO 9175
9120  PRINT "RECOMMENDED CHIPBREAKER STYLE IS B.L.STANDARD
     TYPE E":C1H$ = "E":C2H$ = "E": GOTO 9175
9121  FOR I = 1 TO 50
9122 II = I *  SQR (I)
9123  NEXT I
9125  DATA   1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.
     0,1.0,1.0,1.0,1.0,1.1,1.1,1.1,1.1,1.0,1.0,1.0,1.0,1.0,
     1.0,1.0,1.0,1.0,1.0,1.0,1.0
9130  DATA  1.0,1.1,1.2,1.3,1.5,1.6,1.7,1.8,1.8,1.0,1.0,1.0
     ,1.0,1.0,1.0,1.0,1.0,1.1,1.2,1.4,1.5,1.6,1.7,1.8,1.8,1
     .0,1.0,1.0,1.0,1.0,1.0,1.0
9135  DATA  1.0,1.0,1.4,1.4,1.5,1.6,1.7,1.8,1.8,1.0,1.0,1.0
     ,1.0,1.0,1.0,1.0,1.0,1.0,1.4,1.4,1.5,1.6,1.7,1.8,1.8,1
     .0,1.0,1.0,1.0,1.0,1.0,1.0
9140  DATA  1.0,1.0,1.4,1.4,1.5,1.6,1.7,1.8,1.8,1.0,1.0,1.0
     ,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1
     .0,1.0,1.0,1.0,1.0,1,0,1.0
9145  DATA  1.0,1.0,1.0,110,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0
     ,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1
     .0,1.0,1.0,1.0,1.0,1.0,1.0
9150  DATA  1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0
     ,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1
     .0,1.0,1.0,1.0,1.0,1.0,1.0
9155  DATA  1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0
     ,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1
     .0,1.0,1.0,1.0,1.0,1.0,1.0
9160  DATA  1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0
     ,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1
     .0,1.0,1.0,1.0,1.0,1.0,1.0
9165  PRINT
9170  PRINT
9175  INPUT "HIT 'RETURN TO CONTINUE:-";AA$
9180  RETURN
9900  REM  SURFACE FINISH CHART
10000  HOME
10005  PRINT "APPROPRIATE FEED/NOSE RAD COMBINATIONS"
10010  PRINT "========================================="
10015  PRINT "(SURFACE FINISH=";FSF;" UM C.L.A.)"
10020  PRINT "-----------------------------------------"
10025  PRINT "! NOSE RAD(MM) ";"!";"  FEED RATE (MM/REV)  !
     "
10030  PRINT "---------------!-----------------------"
10035  FOR ZZ = 1 TO 7
10040  PRINT "!               !                       !"
10045  PRINT "-----------------------------------------"
10050  NEXT ZZ
10055  FOR ZZ = 0.4 TO 3.2 STEP 0.4
10060  HTAB 6
10065  VTAB ((ZZ * 5) + 6)
10070  PRINT ZZ
10075 F =  SQR ((FSF / 1000) * (18 * ( SQR (3)) * ZZ))
10080  HTAB 26
10085  VTAB ((ZZ * 5) + 6)
10090 F$ =  LEFT$ ( STR$ (F),3): PRINT F$
10095  NEXT ZZ
10100  PRINT
10105  INPUT "HIT 'RETURN' TO CONTINUE:-";AA$
10106  RETURN
10110  HOME
10500  REM  FEED NOSE RADIUS CHART
10505  REM  SUBROUTINE TO PREDICT SURFACE FINISH ACHIEVABLE
     FROM THE INITIAL FEED RATE ARRIVED AT FOLLOWING ALL M
     ODIFICATIONS
10510  HOME
```

```
10515  PRINT "SURFACE FINISH ESTIMATES"
10520  PRINT "========================================"
10525  PRINT "(FEED RATE =";F;" MM/REV)"
10530  PRINT "*--------------*----------------------*"
10535  PRINT "! NOSE RAD(MM) ";"!";" SURF FINISH(MICRO-M) !
   "
10540  PRINT "*--------------*----------------------*"
10545  FOR ZZ = 1 TO 7
10550  PRINT "!              !                      !"
10555  PRINT "*--------------*----------------------*"
10560  NEXT ZZ
10565  FOR ZZ = 0.4 TO 3.2 STEP 0.4
10570  HTAB 6
10575  VTAB ((ZZ * 5) + 6)
10580  PRINT ZZ
10585 RA = (F * F) / (18 * ( SQR (3)) * ZZ)
10590 RA = RA * 1000
10595  HTAB 26
10600  VTAB ((ZZ * 5) + 6)
10605 RA$ =  LEFT$ ( STR$ (RA),3): PRINT RA$
10610  NEXT ZZ
10615  PRINT
10620  INPUT ZX$
10625  RETURN
10900  REM  M/C FACTORING
11000  HOME
11010  PRINT
11020  PRINT  TAB( 7);"MACHINE FACTORING ROUTINE"
11030  PRINT  TAB( 7);"========================="
11040  PRINT : PRINT
11050  PRINT "THIS SECTION IS DIVIDED INTO 4"
11060  PRINT
11070  PRINT "MAIN PARTS. IN EACH PART YOU "
11080  PRINT
11090  PRINT "ARE ASKED TO PICK THE DESCRIPTION"
11100  PRINT
11110  PRINT "WHICH MOST ACCURATELY DESCRIBES"
11120  PRINT
11130  PRINT "THE MACHINE CONCERNED. TO DO THI"
11140  PRINT
11150  PRINT "SIMPLY PRESS THE NUMBERED KEY"
11160  PRINT
11170  PRINT "FOR THE CORRESPONDING DESCRIPTION"
11180  PRINT
11190  PRINT "FOLLOWED BY 'RETURN'."
11200  PRINT
11210  PRINT : PRINT
11220  INPUT "TO PROCEED PRESS 'RETURN'.";AAA$
11230  HOME
11240  VTAB (2)
11250  PRINT  TAB( 2);"1. MACHINE STRUCTURE"
11260  PRINT  TAB( 2);"--------------------"
11270  PRINT
11280  PRINT  TAB( 2);"IS MACHINE BODY MADE FROM:-"
11290  PRINT
11300  PRINT  TAB( 10);"1. CAST IRON"
11310  PRINT  TAB( 10);"2. STEEL"
11320  PRINT  TAB( 10);"3. BOTH/OTHER    ...?"
11330  PRINT : HTAB (15)
11340  INPUT M
11350  IF M = 1 THEN MM = 1.0: GOTO 11390
11360  IF M = 2 THEN MM = 0.975: GOTO 11390
11370  IF M = 3 THEN MM = 0.94: GOTO 11390
11380  GOTO 11340
11390  PRINT
11400  PRINT  TAB( 2);"MACHINE CONSTRUCTION. IS IT:-"
11410  PRINT
11420  PRINT  TAB( 10);"1. 1-PIECE CAST BODY"
11430  PRINT  TAB( 10);"2\ SEPARATE BED ONLY"
11440  PRINT  TAB( 10);"3. ALL MAJOR PARTS SEPARATE"
11450  PRINT : HTAB (15)
11460  INPUT C
11470  IF C = 1 THEN CC = 0.97: GOTO 11510
11480  IF C = 2 THEN CC = 0.985: GOTO 11510
11490  IF C = 3 THEN CC = 1.0: GOTO 11510
11500  GOTO 11460
11510  PRINT
11520  PRINT  TAB( 2);"IS MACHINE MOUNTING :-"
11530  PRINT
11540  PRINT  TAB( 10);"1. BOLTED & GROUTED"
11550  PRINT  TAB( 10);"2. BOLTED ONLY"
11560  PRINT  TAB( 10);"3. GROUTED ONLY"
11570  PRINT  TAB( 10);"4. FREE STANDING   ...?"
11580  PRINT : HTAB (15)
11590  INPUT MOU
11600  IF MOU = 1 THEN WW = 1.0: GOTO 11650
11610  IF MOU = 2 THEN WW = 0.987: GOTO 11650
11620  IF MOU = 3 THEN WW = 0.975: GOTO 11650
11630  IF MOU = 4 THEN WW = 0.96: GOTO 11650
11640  GOTO 11590
11650 MST = MM * CC *.WW
11660  HOME
11670  VTAB (2)
11680  PRINT  TAB( 2);"2. COMPONENT RIGIDITY"
11690  PRINT  TAB( 2);"---------------------"
11700  PRINT : PRINT
11710  PRINT  TAB( 2);"DESCRIBE UNSUPPORTED LENGTHS"
11720  PRINT  TAB( 2);"OR DIAMETERS OF COMPONENT:-"
11730  PRINT
11740  PRINT  TAB( 10);"1. SMALL & SOLID"
11750  PRINT  TAB( 10);"2. LARGE & FLEXIBLE"
11760  PRINT  TAB( 10);"3. BETWEEN THESE"
11770  PRINT
11780  HTAB (15)
11790  INPUT CR$
11800  IF CR$ = "1" THEN RR = 1.0: GOTO 11840
11810  IF CR$ = "2" THEN RR = 0.825: GOTO 11840
11820  IF CR$ = "3" THEN RR = 0.92: GOTO 11840
11830  GOTO 11790
11840  HOME
11850  VTAB (2)
11860  PRINT  TAB( 2);"3. TOOL RIGIDITY"
11870  PRINT  TAB( 2);"----------------"
11880  PRINT : PRINT
11890  PRINT  TAB( 2);"DESCRIBE TOOLHOLDER :-"
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```
11900  PRINT
11910  PRINT  TAB( 10);"1. LONG O'HANG/DIAMETER"
11920  PRINT  TAB( 10);"2. SHORT O'HANG/DIAMETER"
11930  PRINT  TAB( 10);"3. BETWEEN THESE"
11940  PRINT : HTAB (15)
11950  INPUT TR$
11960  IF TR$ = "1" THEN TT = 0.825: GOTO 12000
11970  IF TR$ = "2" THEN TT = 1.0: GOTO 12000
11980  IF TR$ = "3" THEN TT = 0.92: GOTO 12000
11990  GOTO 11940
12000  HOME
12010  VTAB (2)
12020  PRINT  TAB( 2);"4. MACHINE CONDITION"
12030  PRINT  TAB( 2);"--------------------"
12040  PRINT : PRINT
12050  PRINT  TAB( 2);"HOW OLD IS MACHINE? :-"
12060  PRINT
12070  PRINT  TAB( 10);"1. 5 YEARS OR LESS"
12080  PRINT  TAB( 10);"2. 6-10 YEARS"
12090  PRINT  TAB( 10);"3. 11-25 YEARS"
12100  PRINT  TAB( 10);"4. MORE THAN 25 YEARS"
12110  PRINT : HTAB (15)
12120  INPUT AG$
12130  IF AG$ = "1" THEN AA = 2.24: GOTO 12180
12140  IF AG$ = "2" THEN AA = 2.17: GOTO 12180
12150  IF AG$ = "3" THEN AA = 2.09: GOTO 12180
12160  IF AG$ = "4" THEN AA = 2.0: GOTO 12180
12170  GOTO 12110
12180  PRINT
12190  PRINT  TAB( 2);"PAST USAGE OF MACHINE :-"
12200  PRINT
12210  PRINT  TAB( 10);"1. LIGHT"
12220  PRINT  TAB( 10);"2. MODERATE"
12230  PRINT  TAB( 10);"3. HEAVY"
12240  PRINT : HTAB (15)
12250  INPUT PU$
12260  IF PU$ = "1" THEN PP = 2.24: GOTO 12300
12270  IF PU$ = "2" THEN PP = 2.15: GOTO 12300
12280  IF PU$ = "3" THEN PP = 2.0: GOTO 12300
12290  GOTO 12240
12300  PRINT
12310  PRINT  TAB( 2);"DESCRIBE RUNNING CONDITION :-"
12320  PRINT
12330  PRINT  TAB( 10);"1. NORMAL"
12340  PRINT  TAB( 10);"2. REASONABLE"
12350  PRINT  TAB( 10);"3. POOR"
12360  PRINT : HTAB (15)
12370  INPUT RC$
12380  IF RC$ = "1" THEN DD = 0.5: GOTO 12420
12390  IF RC$ = "2" THEN DD = 0.43: GOTO 12420
12400  IF RC$ = "3" THEN DD = 0.35: GOTO 12420
12410  GOTO 12360
12420 AP = (AA * PP) / 10
12430 AP = ( INT (100 * AP)) / 100
12440 AD = AP + DD
12450 MC = 1 - AD
12460 MC = MC * 0.65
12470 YY = MST * RR * TT - MC
12480  HOME
12490  VTAB (8)
12500  HTAB (7)
12510  INVERSE
12520  PRINT "MACHINE FACTOR = "; INT (100 * YY) / 100
12530  NORMAL
12540  PRINT  TAB( 7);"===================="
12550  VTAB (15)
12560 FA =  INT (100 * YY) / 100
12570 FA$ =  STR$ (FA)
12580  PRINT  TAB( 1);"PLEASE NOTE THIS FOR FUTURE REFERENC
     E"
12590  FOR I = 1 TO 200
12600 X = I * I * I
12610  NEXT I
12620  PRINT : PRINT
12630  PRINT : PRINT : PRINT : PRINT : PRINT
12640  INPUT "HIT 'RETURN TO CONTINUE";XP$
12645  RETURN
12650  HOME
12900  REM  EQUIVALENT DIAMETERS
13000  HOME
13010  INPUT "HOW MANY DIAMETERS ?:-";N
13020  DIM D(N),L(N),R(N)
13030  FOR I = 1 TO N
13040  PRINT " "
13050  PRINT " GIVE DIAMETER ";I;" :-";
13060  INPUT D(I)
13070  PRINT "GIVE ASSOCIATED LENGTH ";I;" :-";
13080  INPUT L(I)
13090  NEXT I
13100  FOR I = 1 TO N:R(I) = D(I) / 2: NEXT I: REM  CONVERT
     ALL DIAMETERS TO RADII
13110  REM -------------------------------------------------
     ------------------
13120  FOR I = 1 TO N:D1 = D1 + L(I): NEXT I
13130  FOR I = 1 TO (N - 1):D2 = D2 + ( ABS (R(I) - R(I + 1
     ))): NEXT I
13140 DE = D1 + D2: REM   DE IS THE FINAL EXPRESSION DENOMI
     NATOR
13150  REM ------------------------------------
13160  FOR I = 1 TO N:N1 = N1 + (L(I) * D(I)): NEXT I
13170  FOR I = 1 TO (N - 1)
13180  IF R(I) > R(I + 1) THEN R = R(I):R(I) = R(I + 1):R(I
     + 1) = R:ZZ = 10000
13190 N2 = N2 + ( SQR ((((R(I) ^ 2) + ((R(I + 1) ^ 2)) * 2)
     ) * (R(I + 1) - R(I))))
13200  IF ZZ = 10000 THEN R = R(I):R(I) = R(I + 1):R(I + 1)
     = R:ZZ = 0
13210  NEXT I
13220 NU = N1 +  ABS (N2): REM  THIS IS THE NUMERATOR OF TH
     E TOTAL EXPRESSION
13230  REM ------------------------------------------
13240 A1 = NU / DE: REM  THIS IS THE AVERAGE DIAMETER
13245 A1 = ( INT ((A1 * 1000) + 0.5)) / 1000)
13250 A2 = DE: REM  THIS IS TOTAL LENGTH
13260  PRINT " ": PRINT " ";
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13270  PRINT "AVERAGE DIAMETER=";A1;" UNITS"
13280  PRINT " "
13290  PRINT "TOTAL EQUIVALENT LENGTH=";A2;" UNITS"
13300  PRINT : PRINT : INPUT "HIT 'RETURN TO CONTINUE:-";AA
    $
13310  RETURN
13900  REM   CALCULATING SECTION
14000  REM  CALCULATING SECTION
14010  IF REC$ = HARD$ THEN S = B11S * ( EXP (( LOG (F) - I
    1) / S1))
14020  REM  SPEED IS NOW GENERATED FROM FEED
14030  IF REC$ = STD$ THEN S = B21S * ( EXP (( LOG (F) - I2
    ) / S2))
14040  IF REC$ = TGH$ THEN S = B31S * ( EXP (( LOG (F) - I3
    ) / S3))
14045  IF REC$ = "GC415" THEN S = (B11S * ( EXP (( LOG (F) -
    I1) / S1))) * 1.1
14050  REM  ********* HAVENT GOT THE HSS CALCULATION IN YET
    *************
14060  HOME
14070  PRINT "I.M.P.S. INITIAL RESULTS"
14080  PRINT "========================"
14090  PRINT
14100  PRINT "SPEED FROM FEED="; INT (S);" M/MIN"
14110  REM  **********************
14120  REM  NOW MODIFY FOR TOOL LIFE SELECTED
14130 V1 = S *  EXP (IL + (SL * ( LOG (T))))
14150 V1(1) = V1
14160  PRINT "SPEED MODIFIED FOR TOOL LIFE:-"; INT (V1)
14170  REM  SECTION TO FACTOR DOWN SPEED AS PREDICTED FROM
    LOGARITHMIC EQUATIONS
14180 V2 = V1 * ( VAL (FA$))
14190  PRINT "FINALLY FACTORED SPEED (M/MIN):-"; INT (V2)
14200 V2(CNTR) =  INT (V2 * (1 + (((H - MH) / 10) * HM))): REM
    HARDNESS MODIFICATION
14210  PRINT "SPEED MODIFIED FOR COMPT HARD NESS:-";V2(CNTR
    )
14260  REM  NOW IN A POSITION TO CALCULATE ROGH ESTIMATES
14270 N(CNTR) = (1000 * V2(CNTR)) / (60 * 3.142 * OD(CNTR))

14280 STDTIME(CNTR) = L(CNTR) / (F(CNTR) * N(CNTR) * 60): REM
    STANDARD TIME IN MINUTES
14285 ST$(CNTR) =  STR$ (STDTIME(CNTR))
14290 K1S(CNTR) = KS * ( EXP (( LOG (F(CNTR)) - I4) / S4))
14300 K1S(CNTR) =  INT (K1S(CNTR) * (1 + (((MH - H) / 10) *
    HK))): REM  MODIFY FOR HARDNESS
14310 POWER(CNTR) = (D(CNTR) * F(CNTR) * V2(CNTR) * K1S(CNT
    R)) / 6120: REM    POWER IN KW
14320  PRINT "-------------------------------------"
14330  PRINT
14340  PRINT "DEPTH OF CUT(MM):-";D(CNTR)
14350  PRINT "FEED RATE(MM/REV):-";F(CNTR)
14360  PRINT "SURFACE CUTTING SPEED (M/MIN):-"; INT (V2(CNT
    R))
14370  PRINT "ROTATIONAL SPEED (R.P.M.):-"; INT (N(CNTR) *
    60)
14380  PRINT "TURNED LENGTH(MM):-";L(CNTR)
14390  PRINT "TOOL LIFE SELECTED (MINUTES):-";T(CNTR)
14400 TCF(CNTR) =  INT (T(CNTR) /  VAL (ST$(CNTR)))
14410  PRINT "TOOLCHANGE FREQUENCY(COMPTS):-";TCF(CNTR)
14430  FOR ZZ = 1 TO  LEN (ST$(CNTR))
14440  IF  MID$ (ST$(CNTR),ZZ,1) = "." THEN 14460
14450  NEXT ZZ
14460 ST$(CNTR) =  LEFT$ (ST$(CNTR),(ZZ + 3))
14470 PO$(CNTR) =  STR$ (POWER(CNTR))
14480  FOR ZZ = 1 TO  LEN (PO$(CNTR))
14490  IF  MID$ (PO$(CNTR),ZZ,1) = "." THEN 14510
14500  NEXT ZZ
14510 PO$(CNTR) =  LEFT$ (PO$(CNTR),(ZZ + 2))
14520  PRINT "STANDARD TIME (MINUTES):-";ST$(CNTR)
14530  PRINT "'KS' SPECIFIC FORCE VALUE(KG/MM):-"; INT (K1S
    (CNTR))
14540  PRINT "POWER (KW):-";PO$(CNTR)
14550  PRINT
14560  PRINT "---------------------------------------"
14580  INPUT "IS HARD COPY REQ'D?(Y OR N):-";AA$
14590  IF AA$ = "Y" THEN  PR# 1:BA = 1: GOTO 20000
14595  RETURN
16000  REM  INSUFFICIENT SPINDLE SPEED
16005  REM  SUBROUTINE FOR RECALCULATION GIVEN INSUFFICIENT
    SPINDLE SPEED
16010  INPUT "GIVE MAX SPINDLE SPEED(R.P.M.) :- ";NN
16012 NN = (NN / 60)
16013 N(CNTR) = NN
16015 SS = (60 * NN * 3.142 * OD(CNTR)) / 1000: REM   THIS
    IS NOW THE  MAX  ACHIEVABLE CUTTING SPEED IN M/MIN
16018 STDTIME(CNTR) = L(CNTR) / (F(CNTR) * NN * 60)
16020 V2(CNTR) =  INT (SS / (1 + (((H - MH) / 10) * HM)))
16025  REM  WE MUST NO 'UN-FACTOR' THIS TO ARRIVE AT 'THEOR
    ETICAL' CUTTING SPEED TO DETERMINE TOOL LIFE
16030 V1 = V2(CNTR) / ( VAL (FA$))
16035 Y = ( LOG (V1 / V1(1)) /  LOG (0.86))
16040 T(CNTR) =  INT (T(CNTR) * (2 ^ Y))
16045 TCF(CNTR) =  INT (T(CNTR) / STDTIME(CNTR))
16050 ST$(CNTR) =  STR$ (STDTIME(CNTR))
16055  FOR ZZ = 1 TO  LEN (ST$)
16060  IF  MID$ (ST$(CNTR),ZZ,1) = "." THEN 16070
16065  NEXT ZZ
16070 ST$(CNTR) =  LEFT$ (ST$(CNTR),ZZ + 3)
16075  RETURN
16500  REM  MATERIAL GROUP &GRADE REC
16510 D$ = ""
16520  HOME
16530  PRINT "I.M.P.S. MACHINING PARAMETER SELECTION"
16540  PRINT "======================================"
16550  VTAB 12: PRINT "CONTENTS OF STANDARD TOOLING MANUAL
    ARE": PRINT "     NOW BEING LOADED"
16560 D$ = ""
16570  PRINT D$;"OPEN CODING SYSTEM SUMMARY"
16580  PRINT D$;"READ CODING SYSTEM SUMMARY"
16590  INPUT J1: REM  NO. OF CODES
16600  DIM CODNG$(J1),NUMBEROFCODES$(J1)
16610  DIM TLCODE$(30): REM  THIS ALLOWS US TO HAVE 30 TOOL
    CODES UPON EACH 'PAGE' OF THE 'STANDARD TOOLING MANUA
   L'
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16620  FOR I = 1 TO JJ
16640  INPUT CODNO$(I)
16650  INPUT NUMBEROFCODES$(I)
16660  NEXT I
16670  PRINT D$;"CLOSE CODING SYSTEM SUMMARY"
16680  PRINT : PRINT "DETAILS NOW LOADED"
16690  REM  ****** TOOL CODES NOW LOADED FROM AN 'EXTRA DIR
     ECTORY' TYPE FILF HOLDING DETAILS OF ALL CODES STORED
     **********
16691  GOTO 24561
16694  INPUT "PLEASE INPUT WORKPIECE MATERIAL DESCRIPTION:-
     ";XX$
16698  FOR COUNT = 1 TO KK
16700  REM  SECTION TO LOAD 'MATERIALS INDEX' FILE DETAILS
     INTO RAM
16702  IF MN$(COUNT) = XX$ THEN MM = MM(COUNT):HT = HT(COUN
     T):P = P(COUNT): GOTO 16720: REM  HAVE FOUND THE APPRO
     PRIATE MATERIAL IN THE FILE
16706  NEXT COUNT
16710  PRINT "MATERIAL NOT HELD ON FILE": GOTO 16694
16720 O$ = "OPEN MACHINABILITY GROUP " +  STR$ (MG(COUNT))
16730 R$ = "READ MACHINABILITY GROUP " +  STR$ (MG(COUNT))
16740 C$ = "CLOSE MACHINABILITY GROUP " +  STR$ (MG(COUNT))

16750  PRINT D$;O$
16760  PRINT D$;R$
16770  PRINT D$;O$
16780  PRINT D$;R$
16790  INPUT MDOC
16800  INPUT MFEED
16810  INPUT W1CC$
16820  INPUT W2CC$
16830  INPUT H1S$
16840  INPUT B11S
16850  INPUT S1
16860  INPUT I1
16870  INPUT H1S$
16880  INPUT B21S
16890  INPUT S2
16900  INPUT I2
16910  INPUT T1S$
16920  INPUT B31S
16930  INPUT S3
16940  INPUT I3
16950  INPUT SL
16960  INPUT IL
16965  INPUT H
16970  INPUT HM
16975  INPUT KS
16980  INPUT HK
16985  INPUT S4
16990  INPUT I4
16995  INPUT KB
17000  FOR ZZ = 1 TO 4
17005  INPUT ST(ZZ)
17010  INPUT FT(ZZ)
17015  INPUT DC(ZZ)
17020  NEXT ZZ
17025  PRINT D$;C$
17030  RETURN
17100  HOME
17110  PRINT "MATERIAL TYPE:-";XX$
17120  PRINT "======================================="
17130  PRINT : PRINT : PRINT "M/CABILITY GROUP NO:-";MG(COU
     NT)
17140  PRINT : PRINT "RECCOMENDED CARBIDE CLEARANCE ('S:-";
     W1CC$
17150  HTAB 34
17160  PRINT W2CC$
17170  PRINT
17180  PRINT "APPLICABLE 'HARD' GRADE:-";H1S$
17190  PRINT : PRINT "APPLICABLE 'STANDARD' GRADE:-";H1S$
17200  PRINT : PRINT "APPLICABLE 'TOUGH' GRADE:-";T1S$
17210  RETURN
17500  REM   ********************************POWER ETC RECALC
     ************************************************
17505 QZ = 1
17510  REM  SECTION TO DETERMINE WETHER POWER IS AVAILABLE
17520  INPUT "IS POWER AVAILABLE ?:-";AA$
17530  IF AA$ = "Y" THEN 17740
17540  IF AA$ = "N" THEN 17560
17550  GOTO 17520
17560  REM  WE NOW KNOW THAT INSUFFICIENT POWER IS AVAILABL
     E,MUST ASK FOR MAX SPEED & MAX FEED
17570  INPUT "GIVE MAX SPEED(REVS/SEC):-";MS
17580  INPUT "GIVE MAX FEED(MM/REV):-";MF
17590  INPUT "GIVE MAX POWER(KW):-";MP
17600  REM  THERE ARE 2 WAYS TO CALCULATE POWER REDUCTION-(
     A)REDUCE DOC ONLY,(B) OPTIMISE A/C TO CERTAIN GROUND R
     ULES OF PRECEDENCE
17610  GOSUB 18010: REM  SUBROUTINE TO CALCULATE NEW DOC
17620  REM  HAVE NOW CALCULATED NEW DOC AND PRINTED ON SCRE
     EN
17630  GOSUB 18180: REM  SUBROUTINE FOR PSEUDO-OPTIMISATION

17640  REM  HAVE NOW RETURNED
17650  HOME
17660  HTAB 10
17670  PRINT "I.M.P.S. RESULTS"
17680  PRINT "***************************************"
17690  PRINT "NOTE ALL-ROUND CHANGES": PRINT
17700  GOSUB 4120: REM  PRINT OUT DETAILS
17710  REM  HAVE NOW RETURNED FROM PRINTING
17720  PR# 0
17730  REM  NOW SELECT TOOL AT 16500-
17740  INPUT "ARE PARAMETERS ACCEPTABLE? (Y OR N):-";AA$
17750  IF AA$ = "Y" THEN 3050
17760  IF AA$ = "N" THEN 17780
17770  GOTO 17730
17780  INPUT "TRY ANOTHER M/C (Y OR N):-";AA$
17790  IF AA$ = "Y" THEN 1380
17800  IF AA$ = "N" THEN 1550
17810  GOTO 17780
17820  RETURN
18000  REM ---------------------------------D/L TEMP & POWE
```

```
R===========================================================
=======================
18010  REM  ********************************************
18020  REM  TEMPORARY                   SUBROUTINE FOR DREWS L
     ANE DEMO
18030 DTEMP = (MP * 11280) / (F(CNTR) * V2(CNTR) * K1S(CNTR
     ))
18040  HOME
18050  HTAB 10: PRINT "I.M.P.S. RESULTS"
18060  PRINT "******************************************"
18070 DT$ =  STR$ (DT)
18080  FOR ZZ = 1 TO  LEN (DT$)
18090  IF  MID$ (DT$,ZZ,1) = "." THEN 18110
18100  NEXT ZZ
18110 DT$ =  LEFT$ (DT$,(ZZ + 2))
18120  PRINT : PRINT "EITHER REDUCE D.O.C. TO:-";DT$;"MM"
18130  PRINT
18140  INPUT "OR:-";AA$
18150  HOME
18160  RETURN
18170  REM  ************************************************
     ****
18180  REM  SUBROUTINE TO CALCULATE POWER ,ITERATIVELY REDU
     CING FEED AND HOLDING SPEED 'CONSTANT' THEN ALTER TOOL
      LIFE IF NEED BE
18190  REM  THIS S/R IS TEMP METHOD FOR D/L PRESN. SINCE WE
      SHOULD NEED TO STORE ALL ORIGINAL VALUES CALCULATED T
     O DO THE THE NEXT S/R WHICH HOLDS FEED 'CONSTANT' ANDR
     EDUCES SPEED ITERATIVELT BY 10 M/MIN
18200 F1 = F(CNTR): REM  STORE  1ST EVER FEED SELECTED AFTE
     R ANY SPEED RESTRICTIONS HAVE BEEN CATERED FOR
18210 F(CNTR) = F(CNTR) - 0.01
18220  IF REC$ = HARD$ THEN S = B11S * ( EXP (( LOG (F) - I
     1) / S1)))
18230  IF REC$ = STD$ THEN S = B21S * ( EXP (( LOG (F) - I2
     ) / S2))
18240  IF REC$ = TGH$ THEN S = B31S * ( EXP (( LOG (F) - I3
     ) / S3))
18250 LF = ( LOG (T / 15) /  LOG (2))
18260 V1 = S * (0.86 ^ LF)
18270 V2(CNTR) = V1 * ( VAL (FA$))
18280 N(CNTR) = ((1000 * (V2(CNTR))) / (60 * 3.142 * OD(CNT
     R)))
18290 STDTIME(CNTR) = (L(CNTR)) / (F(CNTR) * N(CNTR) * 60)
18300 ST$(CNTR) =  STR$ (STDTIME(CNTR))
18310  FOR ZZ = 1 TO  LEN (ST$(CNTR))
18320  IF  MID$ (ST$(CNTR),ZZ,1) = "." THEN 18340
18330  NEXT ZZ
18340 ST$(CNTR) =  LEFT$ (ST$(CNTR),(ZZ + 3))
18350 K1S(CNTR) = KS * ( EXP (( LOG (F(CNTR)) - I4) / S4))
18360 K1S(CNTR) =  INT (K1S(CNTR) * (1 + (((MH - H) / 10) *
     HK)))
18370 POWER(CNTR) = (D(CNTR) * F(CNTR) * V2(CNTR) * K1S(CNT
     R)) / 6120
18380 TCF(CNTR) =  INT (T(CNTR) / STDTIME(CNTR))
18390  IF N(CNTR) > MS THEN T(CNTR) = T(CNTR) + 1:F(CNTR) =
     F1: GOTO 18210
18400  IF POWER(CNTR) > MP THEN 18210
18410  REM  SHOULD NOW HAVE SOLVED THE PROBLEM. GO AND PRIN
     T OUT THE ANSWER
18420  RETURN
18490  REM ================================CHOOSE INSERT--
     ---------------------------------------------==========
     =============
18500  PRINT "DO YOU WANT BRAZED TOOLING(B)": INPUT " OR IN
     DEXABLE INSERT TOOLING(I):-";AA$
18510  IF CNTR <  > 1 THEN  GOSUB 10505
18520  IF AA$ = "B" THEN  END : REM  HAVEN'T GOT A STANDARD
     S MANUAL FOR BRAZED TOOLS YET
18530  IF AA$ = "I" THEN 18550
18540  GOTO 2950
18550 I = 1: REM   TOTAL NO OF 'PAGE HEADINGS' FROM THE 'ST
     ANDARD TOOLING MANUAL'
18560  IF  LEFT$ (CODNG$(I),4) = "X614" THEN 18590: REM   C
     HECKING WHETHER WE'RE DEALING WITH INSERTS
18570 I = I + 1: IF I <  = J1 THEN 18560: REM   HAVE HAD TO
      PUT THIS IN INSTEAD OF 'NEXT I' BECAUSE I KEEP GETTIN
     G 'NEXT W/O FOR ERROR' OCCURING
18580  GOTO 19040
18590  REM   NOW WE KNOW THAT WE HAVE AN INSERT TURNING TOO
     L
18610  IF REC$ = "GC015" THEN X$ = "B":Y$ = "1":Z$ = "7": REM
        THIS GIVES US THE ABILITY TO SORT THROUGH THE CODI
     NG SYSTEM SUMMARY FILE OF SANDVIK TOOLS FOR THE REQUIR
     ED GRADE
18620  IF REC$ = "GC1025" THEN X$ = "C":Y$ = "1":Z$ = "7"
18630  IF REC$ = "GC135" THEN X$ = "D":Y$ = "1":Z$ = "7"
18640  IF REC$ = "GC315" THEN X$ = "J":Y$ = "1":Z$ = "7"
18642  IF REC$ = "GC415" THEN X$ = "A":Y$ = "1":Z$ = "7"
18645  IF REC$ = "N" THEN X$ = "K":Y$ = "1":Z$ = "7"
18650  REM  NOW TOT UP THE NO.OF APPLICABLE TOOL CODES ETC.

18660  IF  LEFT$ (CODNG$(I),8) = "X614" + Z$ + Y$ + "-" + X
     $ THEN 18690
18670 I = I + 1: IF I <  = J1 THEN 18560: REM   HAVE HAD TO
      PUT THIS IN INSTEAD OF 'NEXT I' BECAUSE I KEEP GETTIN
     G 'NEXT W/O FOR ERROR' OCCURING
18680  GOTO 19040
18685  REM   NOW GOING TO CHECK WHETHER WE HAVE CORRECT CLE
     ARANCE ANGLES AND CHIPBREAKER STYLES
18690  IF  RIGHT$ (CODNG$(I),2) = (W1CC$ + C1H$) THEN 18730

18695  IF  RIGHT$ (CODNG$(I),2) = (W2CC$ + C1H$) THEN 18730

18700  IF  RIGHT$ (CODNG$(I),2) = (W1CC$ + C2H$) THEN 18730

18705  IF  RIGHT$ (CODNG$(I),2) = (W2CC$ + C2H$) THEN 18730

18710 I = I + 1: IF I <  = J1 THEN 18560: REM   HAVE HAD TO
      PUT THIS IN INSTEAD OF 'NEXT I' BECAUSE I KEEP GETTIN
     G 'NEXT W/O FOR ERROR' OCCURING
18720  GOTO 19040
18730  GOTO 18760: REM    WE NOW HAVE APPLICABLE TOOL GROUP
     S
18740 I = I + 1: IF I <  = J1 THEN 18560: REM   HAVE HAD TO
```

```
    PUT THIS IN INSTEAD OF 'NEXT I' BECAUSE I KEEP GETTIN
   G 'NEXT W/O FOR ERROR' OCCURING
18750  GOTO 19040
18760  REM SECTION TO DISPLAY APPROPRIATE TOOL TYPES ON THE
    SCREEN
18770 TTL = TTL + 1: REM  THIS IS THE TOTAL NO. OF APPLICAB
    LE 'PAGE HEADINGS' FROM THE 'STANDARD TOOLING MANUAL'
18780 O$ = "OPEN " + CODNG$(I)
18790 R$ = "READ " + CODNG$(I)
18800 C$ = "CLOSE " + CODNG$(I)
18810  PRINT D$;O$
18820  PRINT D$;R$
18830  INPUT NUMBEROFCODES$
18840  FOR J2 = 1 TO  VAL (NUMBEROFCODES$)
18850  INPUT TLCODE$(J2)
18860  NEXT J2
18870  PRINT D$;C$
18880  REM  NOW PRINT ON SCREEN
18890  HOME
18900  PRINT "TOOL FAMILY:-";CODNG$(I)
18910  PRINT "**************************"
18920  IF  MID$ (CODNG$(I),6,1) = "1" THEN  PRINT "SUPPLIER
   =SANDVIK": GOTO 18960
18960  PRINT " RECOMMENDED GRADE IS :-";REC$
18970  GOTO 18990
18980  PRINT "   GRADE=H.S.S."
18990  PRINT ""
19000  FOR ZZ = 1 TO  VAL (NUMBEROFCODES$): PRINT "-";ZZ;"
   ";TLCODE$(ZZ): NEXT ZZ
19010  PRINT "": PRINT ""
19020  INPUT "DO YOU WISH TO SELECT ? (Y OR N):-";AA$
19030  IF AA$ = "Y" THEN 19110
19040 I = I + 1: IF I.<  = J1 THEN 18560: REM  HAVE HAD TO
   PUT THIS IN INSTEAD OF 'NEXT I' BECAUSE I KEEP GETTING
    'NEXT W/O FOR ERROR' OCCURING
19050  IF TTL = 0 THEN  PRINT "NO APPLICABLE TOOL GROUPS": END

19060  VTAB 22: PRINT "YOU HAVE NOW SEEN ALL AVAILABLE TOOL
   S."
19070  INPUT "DO YOU WISH TO RE-VIEW(Y OR N):-";AB$
19080  IF AB$ = "Y" THEN 18550
19090  GOTO 19060
19100  REM  ******************************************
19110  REM  SECTION TO SELECT TOOL
19120  INPUT "WHICH TOOL ITEM NO.?:-";NN
19130 NN$ = "0" +  STR$ (NN):NN$ =  RIGHT$ (NN$,2)
19140  PRINT
19150  PRINT "TOOL SELECTED IS :-";: PRINT CODNG$(I);: PRINT
   "-";: PRINT NN$
19160  PRINT "TECHNICAL DESCRIPTION:-";TLCODE$(NN)
19170  REM  NOW PREDICT SURFACE FINISH
19180  PRINT "EST SURFACE FINISH (MICRO-M):-";
19190 R$ =  RIGHT$ (TLCODE$(NN),2):R =  VAL (R$) / 10
19200 RA = (1000 * F * F) / (18 * ( SQR (3)) * R)
19210 RA$ =  LEFT$ ( STR$ (RA),3)
19220  PRINT RA$: PRINT
19224 LD =  LEN (CODNG$(I))
19225 DODNG$(CNTR) =  RIGHT$ (CODNG$(I),LD - 1) + "-" + NN$
   :TCODE$(CNTR) = TLCODE$(NN)
19230  RETURN
20000  REM  INITIAL RESULTS PRINT OUT***********************
   ********************************************************
   ****************************
20010  PR# 1
20015  IF CNTR = 1 THEN  PRINT  CHR$ (27); CHR$ (67); CHR$
   (0); CHR$ (11);
20020  IF CNTR <  > 1 THEN  PRINT  CHR$ (12)" "
20030  PRINT  CHR$ (27); CHR$ (65) CHR$ (8)
20050  PRINT  CHR$ (14)"ITERATIVE MACHINING PARAMETER SELEC
   TION"
20060  PRINT  CHR$ (20)" "
20070  PRINT  TAB( 2);"COMPT NO. ";CN$; TAB( 32);"COMPT DES
   CRIPTION  ";CD$
20090  PRINT
20100  PRINT  TAB( 2);"INITIAL RESULTS"
20120  PRINT
20130  PRINT  TAB( 3)"SPEED FROM FEED                   (M/M
   IN):- "; INT (S)
20140  PRINT  TAB( 3)"SPEED FROM TOOL LIFE              (M/M
   IN):- "; INT (V1)
20150  PRINT  TAB( 3)"SPEED FROM MACHINE FACTOR         (M/M
   IN):- "; INT (V2)
20160  PRINT  TAB( 3)"SPEED FROM COMPONENT HARDNESS     (M/M
   IN):- ";V2(CNTR)
20170  PRINT
20180  PRINT  TAB( 3)"::::::::::::::::::::::::::::::::::::::
   ::::::::"
20190  PRINT " "
20191  IF BA = 10 THEN  PRINT  TAB( 3)"AFTER SPINDLE SPEED
   ITERATION": PRINT
20200  PRINT  TAB( 3)"SURFACE CUTTING SPEED             (M/M
   IN):- "; INT (V2(CNTR))
20210  PRINT  TAB( 3)"ROTATIONAL SPEED                  (R.P
   .M):- "; INT (60 * N(CNTR))
20220  PRINT  TAB( 3)"FEED RATE                         (MM/R
   EV):- ";F(CNTR)
20230  PRINT  TAB( 3)"DEPTH OF CUT                          (
   MM):- ";D(CNTR)
20240  PRINT  TAB( 3)"SPECIFIC CUTTING FORCE 'KS'       (KG/
   MM):- "; INT (K1S(CNTR))
20250  PRINT  TAB( 3)"POWER REQUIREMENT                     (
   KW):- ";PO$(CNTR)
20260  PRINT  TAB( 3)"TOOL LIFE                         (MINUT
   ES):- ";T(CNTR)
20270  PRINT  TAB( 3)"STANDARD TIME                     (MINUT
   ES):- ";ST$(CNTR)
20280  PRINT  TAB( 3)"TOOL CHANGE FREQUENCY             (COMP
   TS):- ";TCF(CNTR)
20290  PRINT  TAB( 3)"RECOMMENDED TOOL GRADE
      :- ";REC$
20300  PRINT
20310  PRINT  TAB( 3)"---------------------------------------
   --------"
20320  PR# 0
20330  RETURN
```

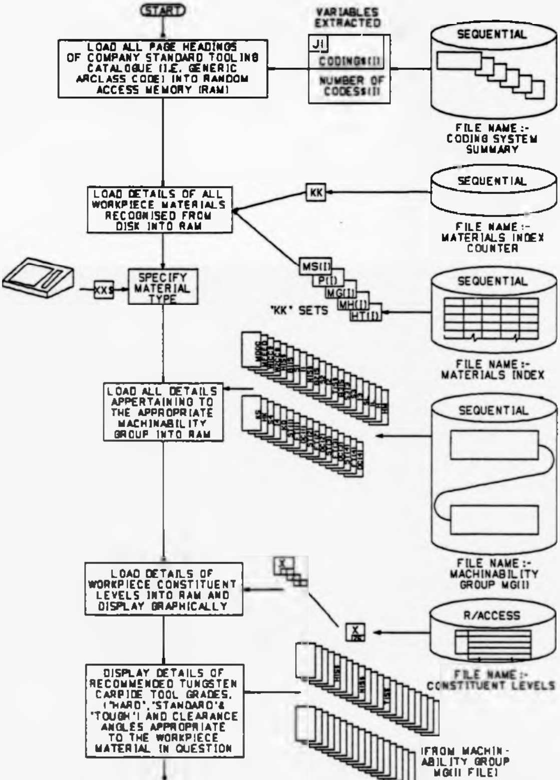
```
22000  PR# 1
22010  HOME
22020  PRINT  CHR$ (12)" "
22021  PRINT  CHR$ (15)
22022  PRINT  CHR$ (27); CHR$ (65); CHR$ (8)
22023  PRINT  TAB( 100)"AUSTIN ROVER GROUP,P&PE,LONGBRIDGE"

22024  PRINT  CHR$ (18)
22040  PRINT  TAB( 4)"COMPT.NO. ";CN$; SPC( 20);"COMPT.DESC
    RIPTION- ";CD$
22050  PRINT  TAB( 4)"---+--------------"; SPC( 13);"-------
    ------------------------------"
22060  PRINT " "
22070  PRINT  TAB( 4)"MATERIAL GROUP:- ";MG(COUNT)
22080  PRINT  TAB( 4)"------------------------"
22090  REM   VAR'B'L NAME?
22100  PRINT  CHR$ (14)" "
22110  PRINT  CHR$ (14); TAB( 5)"*-----------------------
    *"
22120  PRINT  CHR$ (14); TAB( 5);"!"; SPC( 25);"!"
22130  PRINT  CHR$ (14); TAB( 5);"! OPERATION SUMMARY SHEET
     !"
22140  PRINT  CHR$ (14); TAB( 5);"!"; SPC( 25);"!"
22150  PRINT  CHR$ (14); TAB( 5);"*-----------------------
    -*"
22160  PRINT  CHR$ (20)" "
22170  PRINT "*-------------------------------------------
    ------------------------------*"
22180  PRINT "!"; TAB( 76)"!"
22190  PRINT "!  OP.NO.  LENGTH  START OD  D.O.C.  SPEED  R
    .P.M.  FEED  STD.TIME  T.C.F. !"
22200  PRINT "!"; TAB( 76)"!"
22210  PRINT "!          (MM)       (MM)     (MM)  (M/MIN)
           (MM)    (MINS)    (CPTS) !"
22220  PRINT "*-------------------------------------------
    ------------------------------*"
22230 ZZ = 0
22240  IF CNTR = 2 THEN 22520
22250  FOR NZ = 2 TO (CNTR - 1)
22260 ZZ = ZZ + 10
22270 S(NZ) = S2(NZ)
22280 N(NZ) =  INT (60 * N(NZ))
22290 LZ =  LEN ( STR$ (ZZ))
22300 LL =  LEN ( STR$ (L(NZ)))
22310 LOD =  LEN ( STR$ (OD(NZ)))
22320 LD =  LEN ( STR$ (D(NZ)))
22330 LS =  LEN ( STR$ (V2(NZ)))
22340 LN =  LEN ( STR$ (N(NZ)))
22350 LF =  LEN ( STR$ (F(NZ)))
22360 LAST =  LEN (ST$(NZ))
22370 LTC =  LEN ( STR$ (TC(NZ)))
22380  PRINT "!"; TAB( 76);"!"
22390  PRINT "!"; TAB( 4);ZZ;
22400  PRINT  SPC( 8 - LZ);L(NZ);
22410  PRINT  SPC( 9 - LL);OD(NZ);
22420  PRINT  SPC( 9 - LOD);D(NZ);
22430  PRINT  SPC( 8 - LD);V2(NZ);
22440  PRINT  SPC( 8 - LS);N(NZ);
22450  PRINT  SPC( 8 - LN);F(NZ);
22460  PRINT  SPC( 8 - LF);ST$(NZ);
22470  PRINT  SPC( 8 - LAST);TC(NZ);
22480  PRINT  SPC( 6 - LTC);"!"
22490  PRINT "!"; TAB( 76)"!"
22500  PRINT "*-------------------------------------------
    ------------------------------*"
22510  NEXT NZ
22520 N(1) =  INT (60 * N(1))
22530 ZZ = ZZ + 10
22540 S(1) = S2(1)
22550 LZ =  LEN ( STR$ (ZZ))
22560 LL =  LEN ( STR$ (L(1)))
22570 LOD =  LEN ( STR$ (OD(1)))
22580 LD =  LEN ( STR$ (D(1)))
22590 LS =  LEN ( STR$ (V2(1)))
22600 LN =  LEN ( STR$ (N(1)))
22610 LF =  LEN ( STR$ (F(1)))
22620 LAST =  LEN (ST$(1))
22630 LTC =  LEN ( STR$ (TC(1)))
22640  PRINT "!"; TAB( 76);"!"
22650  PRINT "!"; TAB( 4);ZZ;
22660  PRINT  SPC( 8 - LZ);L(1);
22670  PRINT  SPC( 9 - LL);OD(1);
22680  PRINT  SPC( 9 - LOD);D(1);
22690  PRINT  SPC( 8 - LD);V2(1);
22700  PRINT  SPC( 8 - LS);N(1);
22710  PRINT  SPC( 8 - LN);F(1);
22720  PRINT  SPC( 8 - LF);ST$(1);
22730  PRINT  SPC( 8 - LAST);TC(1);
22740  PRINT  SPC( 6 - LTC);"!"
22750  PRINT "!"; TAB( 76)"!"
22760  PRINT "*-------------------------------------------
    ------------------------------*"
22770  PRINT
22780  PRINT  CHR$ (14)" "
22790  PRINT  CHR$ (14); TAB( 14)"*---------*"
22800  PRINT  CHR$ (14); TAB( 14)"! TOOLING !"
22810  PRINT  CHR$ (14); TAB( 14)"*---------*"
22820  PRINT  CHR$ (20)" "
22830  PRINT "*-------------------------------------------
    ------------------------------*"
22840  PRINT "!
                                                    !"
22850  PRINT "!   OP.NO.     TOOL SPECIFICATION     GRADE
      CLASSIFICATION             !"
22860  PRINT "!
                                                    !"
22870  PRINT "*-------------------------------------------
    ------------------------------*"
22880 ZZ = 0
22885  IF CNTR = 2 THEN 23010
22890  FOR MQ = 2 TO (CNTR - 1)
22900 ZZ = ZZ + 10
22910 LI =  LEN (TCODE$(MQ))
22920 LR =  LEN (REC$(MQ))
22925 LD =  LEN (DODNG$(MQ))
```

```
22930  PRINT "!
                                         !"
22940  PRINT "!"; TAB( 7);ZZ;
22950  PRINT  SPC( 10);TCODE$(MQ);
22960  PRINT  SPC( 20 - LI);REC$(MQ);
22970  PRINT  SPC( 13 - LR);DODNG$(MQ);
22975  PRINT  SPC( 24 - LD);"!"
22980  PRINT "!
                                         !"
22990  PRINT "$--------------------------------------------
     ------------------------------$"
23000  NEXT MQ
23010 MQ = 1
23012 LI =  LEN (TCODE$(1))
23014 LR =  LEN (REC$(1))
23016 LD =  LEN (DODNG$(1))
23020  PRINT "!
                                         !"
23030 ZZ = ZZ + 10
23040  PRINT "!"; TAB( 7);ZZ;
23050  PRINT  SPC( 10);TCODE$(MQ);
23060  PRINT  SPC( 20 - LI);REC$(MQ);
23070  PRINT  SPC( 13 - LR);DODNG$(MQ);
23075  PRINT  SPC( 24 - LD);"!"
23080  PRINT "!
                                         !"
23090  PRINT "$--------------------------------------------
     ------------------------------$"
23100 D$ = "": PRINT D$;"RUN IMPS GRAPHICS"
24561  REM  SECTION TO LOAD 'MATERIALS INDEX' FILE INTO RAM
24570 D$ = "": REM  CTRL-D
24580  PRINT D$;"OPEN MATERIALS INDEX COUNTER"
24585  PRINT D$;"READ MATERIALS INDEX COUNTER"
24590  INPUT KK: REM  NO. OF MATERIALS IN MATERIALS INDEX F
     ILE
24600  PRINT D$;"CLOSE MATERIALS INDEX COUNTER"
24610  PRINT D$;"OPEN MATERIALS INDEX"
24620  PRINT D$;"READ MATERIALS INDEX"
24630  FOR I = 1 TO KK
24640  INPUT MN$(I)
24645  INPUT P(I)
24650  INPUT MG(I)
24655  INPUT MH(I)
24660  INPUT HT(I)
24670  NEXT I
24680  PRINT D$;"CLOSE MATERIALS INDEX"
24690  RETURN
25000  REM    SECTION TO REA IN AND DISPLAY CONSTITUENT LEV
     ELS
25005 D$ = "": REM  CTRL-D
25006  DIM X(26)
25010  PRINT D$;"OPEN CONSTITUENT LEVELS,L150"
25020  PRINT D$;"READ CONSTITUENT LEVELS,R";P
25030  FOR I = 1 TO 26: INPUT X(I): NEXT I
25040  PRINT D$;"CLOSE CONSTITUENT LEVELS"
25050  PRINT " "; INPUT "HIT 'RETURN' FOR DISPLAY OF CONSTI
     TUENTS";AA$
25060  HOME
25070 MXM = 0
25080  FOR I = 2 TO 26 STEP 2
25090  IF X(I) = 100 THEN 25110
25100  IF MXM < X(I) THEN MXM = X(I)
25110  NEXT I
25120  REM  SHOULD NOW HAVE MXM=HIGHEST NONE-100 NUMBER
25130  REM  NOW SCALE EVERYTHING TO 37(INCLUDING 100)
25140  FOR I = 1 TO 26
25150 X(I) =  INT (X(I) * (35 / MXM))
25160  NEXT I
25170  REM  NOW START PLOTTING !
25180  GR
25190  COLOR= 15
25200  VLIN 0,39 AT 1
25210  HLIN 1,39 AT 39
25220  FOR I = 0 TO 36 STEP 4
25230  HLIN 0,1 AT I
25240  NEXT I
25250 J = 0
25260  FOR I = 2 TO 26 STEP 2
25270  IF X(I) > 35 THEN 25370
25280  COLOR= 8
25290  VLIN 39,(39 - (X(I - 1))) AT (I + J)
25300  COLOR= 3
25310  VLIN (39 - (X(I - 1))),(39 - X(I)) AT (I + J)
25320  COLOR= 8
25330  VLIN 39,(39 - (X(I - 1))) AT (I + J + 1)
25340  COLOR= 3
25350  VLIN (39 - (X(I - 1))),(39 - X(I)) AT (I + J + 1)
25360  GOTO 25420
25370  REM  SECTION TO PLOT OUT ORANGE 'MINIMUM' VALUES
25380  COLOR= 7
25390  VLIN 0,5 AT (I + J)
25400  VLIN 0,5 AT (I + J + 1)
25410  REM ********************
25420 J = J + 1
25430  NEXT I
25440  COLOR= 15
25450  HLIN 1,39 AT 39
25460  HOME
25470  PRINT " C  S  M  S  P  C  M  N  P  C  A  Z  F"
25480  PRINT "    I  N        R  O  I  B  U  L  N  E"
25490  PRINT "VERTICAL SCALE=";MXM / 10;" %POINTS";
25500  PRINT "  HIT 'RETURN'";
25510  GET AA$
25520  HOME : TEXT
25530  RETURN
```

APPENDIX (E)

IMPS - FLOW CHART



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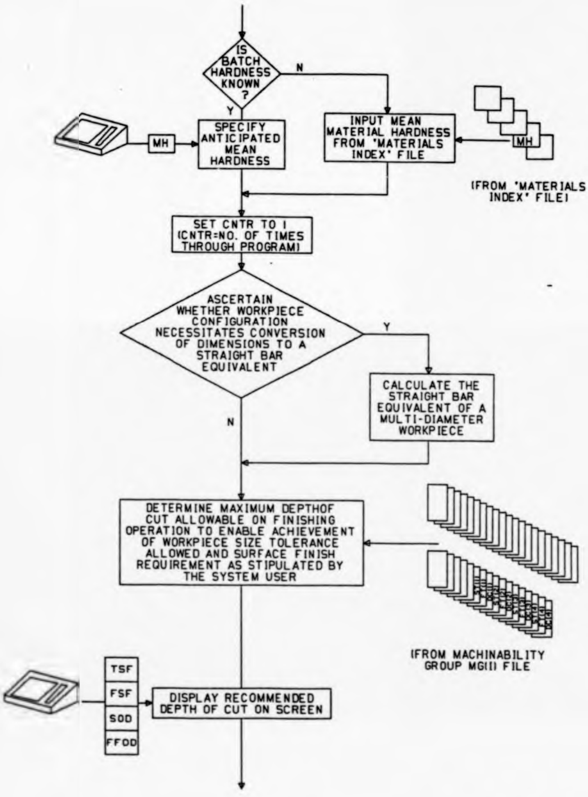
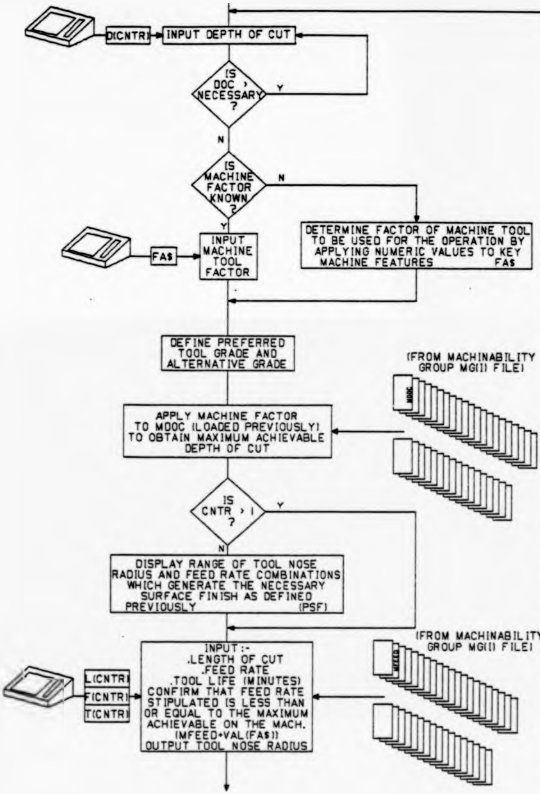
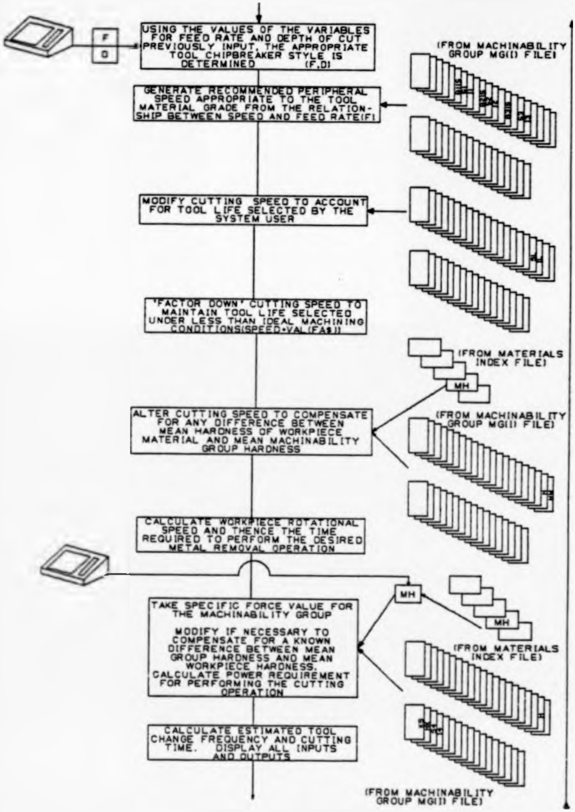
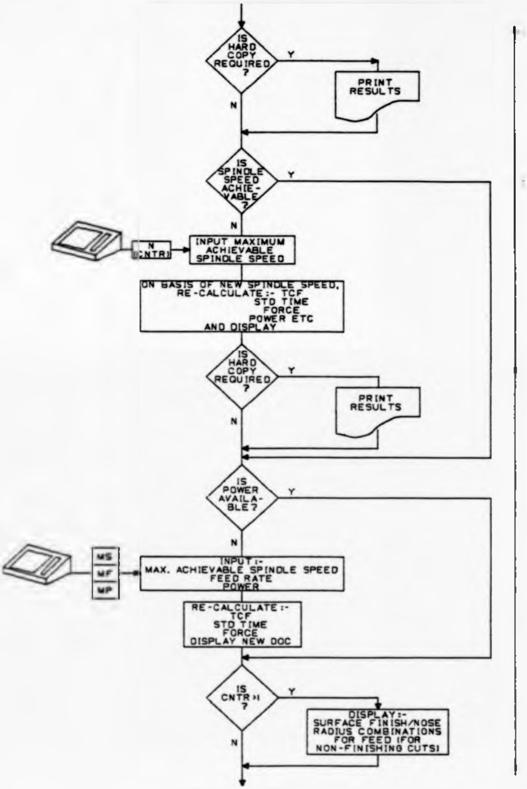

IS BATCH HARDNESS KNOWN ?
N
Y
MH
SPECIFY ANTICIPATED MEAN HARDNESS
INPUT MEAN MATERIAL HARDNESS FROM 'MATERIALS INDEX' FILE
MH
(FROM 'MATERIALS INDEX' FILE)
SET CNTR TO 1 (CNTR=NO. OF TIMES THROUGH PROGRAM)
ASCERTAIN WHETHER WORKPIECE CONFIGURATION NECESSITATES CONVERSION OF DIMENSIONS TO A STRAIGHT BAR EQUIVALENT
Y
N
CALCULATE THE STRAIGHT BAR EQUIVALENT OF A MULTI-DIAMETER WORKPIECE
DETERMINE MAXIMUM DEPTHOF CUT ALLOWABLE ON FINISHING OPERATION TO ENABLE ACHIEVEMENT OF WORKPIECE SIZE TOLERANCE ALLOWED AND SURFACE FINISH REQUIREMENT AS STIPULATED BY THE SYSTEM USER
(FROM MACHINABILITY GROUP MG(I) FILE
TSF
FSF
SOD
FFOD
DISPLAY RECOMMENDED DEPTH OF CUT ON SCREEN



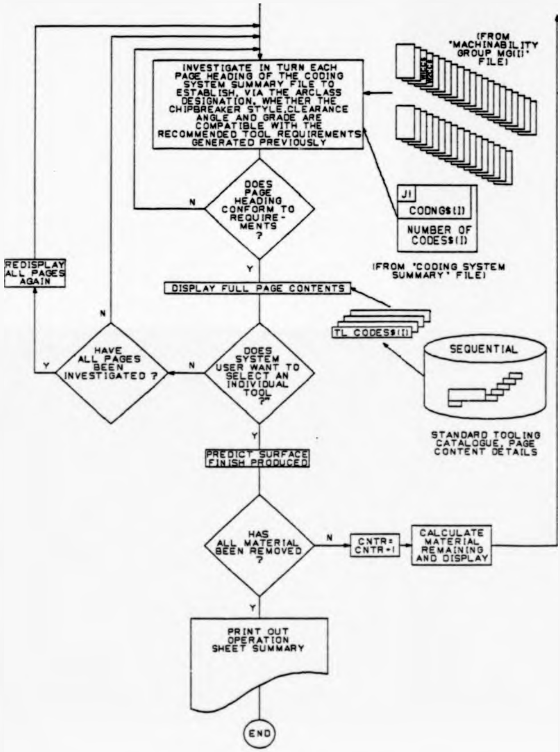
D(CNTR)
INPUT DEPTH OF CUT
IS DOC > NECESSARY ?
Y
N
IS MACHINE FACTOR KNOWN ?
N
Y
FA$
INPUT MACHINE TOOL FACTOR
DETERMINE FACTOR OF MACHINE TOOL TO BE USED FOR THE OPERATION BY APPLYING NUMERIC VALUES TO KEY MACHINE FEATURES FA$
DEFINE PREFERRED TOOL GRADE AND ALTERNATIVE GRADE
(FROM MACHINABILITY GROUP MG(I) FILE)
MDOC
APPLY MACHINE FACTOR TO MDOC (LOADED PREVIOUSLY) TO OBTAIN MAXIMUM ACHIEVABLE DEPTH OF CUT
IS CNTR > 1 ?
Y
N
DISPLAY RANGE OF TOOL NOSE RADIUS AND FEED RATE COMBINATIONS WHICH GENERATE THE NECESSARY SURFACE FINISH AS DEFINED PREVIOUSLY (PSF)
(FROM MACHINABILITY GROUP MG(I) FILE)
MFEED
L(CNTR)
F(CNTR)
T(CNTR)
INPUT :-
.LENGTH OF CUT
.FEED RATE
.TOOL LIFE (MINUTES)
CONFIRM THAT FEED RATE STIPULATED IS LESS THAN OR EQUAL TO THE MAXIMUM ACHIEVABLE ON THE MACH. (MFEED+VAL(FA$))
OUTPUT TOOL NOSE RADIUS


F
D
USING THE VALUES OF THE VARIABLES FOR FEED RATE AND DEPTH OF CUT PREVIOUSLY INPUT, THE APPROPRIATE TOOL CHIPBREAKER STYLE IS DETERMINED (F,D)
(FROM MACHINABILITY GROUP MG(I) FILE)
GENERATE RECOMMENDED PERIPHERAL SPEED APPROPRIATE TO THE TOOL MATERIAL GRADE FROM THE RELATIONSHIP BETWEEN SPEED AND FEED RATE(F)
MODIFY CUTTING SPEED TO ACCOUNT FOR TOOL LIFE SELECTED BY THE SYSTEM USER
'FACTOR DOWN' CUTTING SPEED TO MAINTAIN TOOL LIFE SELECTED UNDER LESS THAN IDEAL MACHINING CONDITIONS(SPEED•VAL(FA$))
(FROM MATERIALS INDEX FILE)
MH
ALTER CUTTING SPEED TO COMPENSATE FOR ANY DIFFERENCE BETWEEN MEAN HARDNESS OF WORKPIECE MATERIAL AND MEAN MACHINABILITY GROUP HARDNESS
(FROM MACHINABILITY GROUP MG(I) FILE)
CALCULATE WORKPIECE ROTATIONAL SPEED AND THENCE THE TIME REQUIRED TO PERFORM THE DESIRED METAL REMOVAL OPERATION
MH
MH
TAKE SPECIFIC FORCE VALUE FOR THE MACHINABILITY GROUP
MODIFY IF NECESSARY TO COMPENSATE FOR A KNOWN DIFFERENCE BETWEEN MEAN GROUP HARDNESS AND MEAN WORKPIECE HARDNESS. CALCULATE POWER REQUIREMENT FOR PERFORMING THE CUTTING OPERATION
(FROM MATERIALS INDEX FILE)
CALCULATE ESTIMATED TOOL CHANGE FREQUENCY AND CUTTING TIME. DISPLAY ALL INPUTS AND OUTPUTS
(FROM MACHINABILITY GROUP MG(I) FILE)



IS HARD COPY REQUIRED ?
Y
N
PRINT RESULTS
IS SPINDLE SPEED ACHIE-VABLE ?
Y
N
N CNTR1
INPUT MAXIMUM ACHIEVABLE SPINDLE SPEED
ON BASIS OF NEW SPINDLE SPEED, RE-CALCULATE :- TCF STD TIME FORCE POWER ETC AND DISPLAY
IS HARD COPY REQUIRED ?
Y
N
PRINT RESULTS
IS POWER AVAILA-BLE?
Y
N
MS
MF
MP
INPUT :- MAX. ACHIEVABLE SPINDLE SPEED FEED RATE POWER
RE-CALCULATE :- TCF STD TIME FORCE DISPLAY NEW DOC
IS CNTR>1 ?
Y
N
DISPLAY :- SURFACE FINISH/NOSE RADIUS COMBINATIONS FOR FEED (FOR NON-FINISHING CUTS)

Sheet 5 of 6


INVESTIGATE IN TURN EACH PAGE HEADING OF THE CODING SYSTEM SUMMARY FILE TO ESTABLISH, VIA THE ARCLASS DESIGNATION, WHETHER THE CHIPBREAKER STYLE,CLEARANCE ANGLE AND GRADE ARE COMPATIBLE WITH THE RECOMMENDED TOOL REQUIREMENTS GENERATED PREVIOUSLY
(FROM "MACHINABILITY GROUP MG(I)" FILE)
DOES PAGE HEADING CONFORM TO REQUIRE-MENTS ?
N
Y
J1
CODNG$(I)
NUMBER OF CODES$(I)
(FROM "CODING SYSTEM SUMMARY" FILE)
DISPLAY FULL PAGE CONTENTS
TL CODES$(I)
SEQUENTIAL
STANDARD TOOLING CATALOGUE, PAGE CONTENT DETAILS
REDISPLAY ALL PAGES AGAIN
HAVE ALL PAGES BEEN INVESTIGATED ?
DOES SYSTEM USER WANT TO SELECT AN INDIVIDUAL TOOL ?"
PREDICT SURFACE FINISH PRODUCED
HAS ALL MATERIAL BEEN REMOVED ?
CNTR= CNTR+1
CALCULATE MATERIAL REMAINING AND DISPLAY
PRINT OUT OPERATION SHEET SUMMARY
END

APPENDIX (F)

MATERIAL INDEX CREATOR PROGRAM

```
]LIST

5  REM  MATLS INDEX CREATOR
10  DIM MN$(100): REM  MATL NAME
20  DIM X(100,26): REM  MATL CONSTITUENT LIMITS
25  DIM P(100): REM  DETAIL OF POSITION OF MATERIAL CONSTIT
    UENT LEVEL IN FILE 'CONSTITUENT LEVELS'
30  DIM MG(100): REM MATL M/CABILITY NOS
40  DIM MH(100): REM  MEAN HARDNESS
50  DIM HT(100): REM  HARDNESS TOLERANCE ABOUT MEAN
60  HOME
70  PRINT "PROGRAM TO CREATE 'MATERIALS INDEX' FILE"
80  PRINT "              FROM SCRATCH"
90  PRINT "========================================"
100  PRINT
110  PRINT
120  PRINT "NOTES:-"
130  PRINT "*****"
140  PRINT
150  PRINT "MAX NO. OF MATERIAL NAMES IS 100"
160  PRINT
170  PRINT "USE THE PROGRAM 'FILE AMENDER' TO "
180  PRINT "UPDATE ANY PART OF THE FILE ONCE CREATED"
190  VTAB 20
200  INPUT "HIT 'RETURN' TO CONTINUE:-";AA$
210  REM  SECTION TO INPUT DATA
220  HOME
230  PRINT "INPUT DATA AS PROMPTED."
240  PRINT
250  PRINT
260  PRINT "********************************"
270  PRINT
280  PRINT "TO TERMINATE DATA INPUT (AND THEREBY": PRINT "O
     F COURSE COMMIT DATA TO DISK),GIVE": PRINT "THE MATERI
     AL SPEC. AS 'END'"
290  PRINT
300  PRINT "********************************"
310  VTAB 20
320  INPUT "HIT 'RETURN' TO COMMENCE DATA INPUT:-";AA$
330  HOME
340  FOR N = 1 TO 100
350  HOME
360  PRINT "DATA ITEM NO:-";N
370  PRINT "--------------------------------"
380  INPUT "GIVE MATERIAL SPEC.:-";MN$(N)
390  IF MN$(N) = "END" THEN N = N - 1: GOTO 940
395 P(N) = N: REM  POSITION OF CONSTITUENT LEVEL DETAILS IN
     RA-FILE 'CONSTITUENT LEVELS'
400  INPUT "GIVE M/CABILITY GROUP NO.:-";MG(N)
410  INPUT "GIVE MEAN HARDNESS (HB):-";MH(N)
420  INPUT "GIVE HARDNESS TOLERANCE ABOUT MEAN(+/-)  :-";HT
     (N)
430  PRINT " "
```

```
440 A = 10
450  VTAB A
460  INPUT "CARBON LOWER LIMIT:-";X(N,1)
470  VTAB A
480  HTAB 28
490  INPUT "UPPER:-";X(N,2)
500  INPUT "SILICON LOWER LIMIT:-";X(N,3)
510  VTAJ A + 1
520  HTAB 28
530  INPUT "UPPER:-";X(N,4)
540  INPUT "MANGANESE LOWER LIMIT:-";X(N,5)
550  VTAB A + 2
560  HTAB 28
570  INPUT "UPPER:-";X(N,6)
580  INPUT "SULPHUR LOWER LIMIT:-";X(N,7)
590  VTAB A + 3: HTAB 28
600  INPUT "UPPER:-";X(N,8)
610  INPUT "PHOSPHRS LOWER LIMIT:-";X(N,9)
620  VTAB A + 4: HTAB 28
630  INPUT "UPPER:-";X(N,10)
640  INPUT "CHROMIUM LOWER LIMIT:-";X(N,11)
650  VTAB A + 5: HTAB 28
660  INPUT "UPPER:-";X(N,12)
670  INPUT "MOLY LOWER LIMIT:-";X(N,13)
680  VTAB A + 6: HTAB 28
690  INPUT "UPPER:-";X(N,14)
700  INPUT "NICKEL LOWER LIMIT:-";X(N,15)
710  VTAB A + 7: HTAB 28
720  INPUT "UPPER:-";X(N,16)
730  INPUT "COPPER LOWER LIMIT:-";X(N,19)
740  VTAB A + 8: HTAB 28
750  INPUT "UPPER:-";X(N,20)
760  INPUT "ALUMINIUM LOWER LIMIT:-";X(N,21)
770  VTAB A + 9: HTAB 28
780  INPUT "UPPER:-";X(N,22)
790  INPUT "ZINC LOWER LIMIT:-";X(N,23)
800  VTAB A + 10: HTAB 28
810  INPUT "UPPER:-";X(N,24)
820  INPUT "LEAD LOWER LIMIT:-";X(N,17)
830  VTAB A + 11: HTAB 28
840  INPUT "UPPER:-";X(N,18)
850  INPUT "IRON LOWER LIMIT:-";X(N,25)
860  VTAB A + 12: HTAB 28
870  INPUT "UPPER:-";X(N,26)
910  INPUT "HIT 'R' AND RETURN TO REDO THIS PAGE:-";AA$
920  IF AA$ = "R" THEN 350
930  NEXT N
940  REM ************************
950  REM   SECTION TO CREATE THE FILE CALLED 'MATERIALS IND
     EX'
960  REM ****************************
970 D$ =  CHR$ (4)
980  PRINT D$;"OPEN MATERIALS INDEX"
990  PRINT D$;"WRITE MATERIALS INDEX"
1000  FOR Z = 1 TO N
1010  PRINT MN$(Z): REM  MATL NAME
1045  PRINT F(N): REM  CONSTITUENT LEVEL POSITION IN RA-FIL
      E
1050  PRINT MG(Z): REM  MATL GROUPING
1060  PRINT MH(Z): REM  MEAN HARDNESS
1070  PRINT HT(Z): REM  HARDNESS TOL ABOUT MEAN
1075  NEXT Z
1080  PRINT D$;"CLOSE MATERIALS INDEX"
1090  HOME
1100  PRINT "'MATERIALS INDEX' FILE NOW CREATED"
1110  PRINT
1120  PRINT D$;"OPEN MATERIALS INDEX COUNTER"
1130  PRINT D$;"WRITE MATERIALS INDEX COUNTER"
1140  PRINT N: REM   N IS KK IN ALL OTHER PROGS
1150  PRINT D$;"CLOSE MATERIALS INDEX COUNTER"
1160  PRINT D$;"OPEN CONSTITUENT LEVELS,L150"
1170  FOR Z = 1 TO N
1180  PRINT D$;"WRITE CONSTITUENT LEVELS,R";Z
1190  FOR ZZ = 1 TO 26
1200  PRINT X(Z,ZZ): REM  CONSTITUENT LEVELS
1210  NEXT ZZ
1220  NEXT Z
1230  PRINT D$;"CLOSE CONSTITUENT LEVELS"
1250  END
```

APPENDIX (G)

MACHINABILITY GROUP CREATOR PROGRAM

```
]LIST

10 D$ = "": REM  CNTRL-D
20  HOME
30  REM  PROGRAM TO CREATE MATERIAL MACHINABILITY GROUP FIL
     E
40  PRINT "THIS PROGRAM CREATES MACHINABILITY": PRINT "FILE
     S FOR TURNING OPERATIONS"
50  PRINT "LOAD A DISK INTO SLOT 6 OF THE APPLE": PRINT "AN
     D ANSWER QUESTIONS AS PROMPTED"
60  INPUT "PRESS 'RETURN' TO CONTINUE:-";AA$
70  HOME
80  INPUT "WHAT IS M/CABILITY GROUP NO?:-";FI$
90  INPUT "MAX D.O.C.(MM):-";MDOC
100  PRINT ""
110  INPUT "MAX FEED RATE(MM/REV):-";MFEED
120  PRINT ""
130  INPUT "1ST WC CLEARANCE ANGLE:-";W1CC$
140  PRINT
150  INPUT "2ND WC CLEARANCE ANGLE:-";W2CC$
160  PRINT
170  INPUT "1ST SUPPLIER'S HARD GRADE:-";H1S$
180  PRINT ""
190  INPUT "BASE SPEED(AT 0.8 MM/REV):-";B11S
200  PRINT
210  INPUT "SLOPE FOR FEED RATE SPEED COMPENSATION:-";S1
220  PRINT
230  INPUT "INTERCEPT FOR THE ABOVE:-";I1
240  PRINT
250  INPUT "1ST SUPPLIER'S STANDARD GRADE:-";N1S$
260  PRINT
270  INPUT "BASE SPEED(M/MIN):-";B21S
280  PRINT
290  INPUT "SLOPE FOR FEED RATE COMPENSATION:-";S2
300  PRINT
310  INPUT "INTERCEPT FOR THE ABOVE:-";I2
320  PRINT
330  INPUT "1ST SUPPLIER'S TOUGH GRADE:-";T1S$
340  PRINT
350  INPUT "BASE SPEED:-";B31S
360  PRINT
370  INPUT "SLOPE FOR FEED RATE COMPENSATION:-";S3
380  PRINT
390  INPUT "INTERCEPT FOR THE ABOVE:-";I3
400  PRINT
410  INPUT "SLOPE FOR TOOL LIFE COMPENSATION:-";SL
420  PRINT
430  INPUT "INTERCEPT FOR THE ABOVE:-";IL
440  PRINT
442  INPUT "GIVE MEAN HARDNESS(HB) OF GROUP:-";H
443  PRINT "GIVE HARDNESS MODIFIER(SPEED MULTIPLIER PER 10
     HB POINTS FROM MEAN VALUE JUST ENTERED:-";
444  INPUT HM
```

```
446  PRINT " "
450  INPUT "BASE KS VALUE (AT 90',0.8MM/REV):-";KS
460  INPUT "GIVE KS HARDNESS MODIFIER:-";HK
465  INPUT "SPEED MULTIPLIER FOR KS VARIATION IN      HARDNE
     SS PER 10 HB POINTS FROM MEAN       :-";HK
466  PRINT ""
470  INPUT "FEED RATE MULTIPLIER SLOPE:-";S4
480  INPUT "FEED RATE MULTIPLIER INTERCEPT:-";I4
490  PRINT
500  INPUT "GIVE INCREMENTAL KS QTY FOR              75' APP
     ROACH ANGLE:-";KD
510  PRINT
520  FOR ZZ = 1 TO 4
530  PRINT "GIVE SIZE TOLERANCE ";ZZ;" ON FINISHED": PRINT
     "PART (+/- MM):-";
540  INPUT ST(ZZ)
550  PRINT "GIVE ASSOCIATED SURFACE FINISH ON THIS": PRINT
     "PART (MICRO-M):-";
560  INPUT FT(ZZ)
570  PRINT "GIVE MAX FINISH OF STOCK REMOVAL TO": PRINT "AC
     HIEVE THESE LIMITS (MM):-";
580  INPUT DC(ZZ)
590  PRINT
600  NEXT ZZ
640  HOME : VTAB 12: PRINT "DETAILS NOW BEING COMMITED TO D
     ISK"
650  REM  *****************************************
660  REM  HAVE NOW LOADED ALL DATA INTO RAM
670  REM ******************************************
680  REM  NOW SAVE DETAILS ON DISK
690 O$ = "OPEN MACHINABILITY GROUP " + FI$ + ",S6"
700 W$ = "WRITE MACHINABILITY GROUP " + FI$
710 C$ = "CLOSE MACHINABILITY GROUP " + FI$
720  PRINT D$;O$
730  PRINT D$;W$
740  PRINT MODC
750  PRINT MFEED
760  PRINT W1CC$
770  PRINT W2CC$
780  PRINT H1S$
790  PRINT B11S
800  PRINT S1
810  PRINT I1
820  PRINT N1S$
830  PRINT B21S
840  PRINT S2
850  PRINT I2
860  PRINT T1S$
870  PRINT B31S
880  PRINT S3
890  PRINT I3
900  PRINT SL
910  PRINT IL
920  PRINT H
930  PRINT HM
940  PRINT KS
950  PRINT HK
960  PRINT S4
970  PRINT I4
980  PRINT KD
990  FOR ZZ = 1 TO 4
1000  PRINT ST(ZZ)
1005  PRINT FT(ZZ)
1010  PRINT DC(ZZ)
1020  NEXT ZZ
1030  PRINT D$;C$
1040  HOME
1050  PRINT "DATA NOW LOADED ONTO DISK"
1060  END
```

APPENDIX (H)

FILE AMENDER PROGRAM

```
]LIST

10  REM  PROGRAM TO COUNT UP THE NO.OF DATA ITEMS STORED IN
      A TEXT FILE AND DISPLAY ITS TOTAL CONTENTS IN BLOCKS
     OF 10 DATA ITEMS
15  REM  ****************************************************
     ******************************************************
     ********************************************
20  HOME
25  HTAB 12
30  PRINT "FILEAMENDER PROGRAM"
35  PRINT "======================================="
37  PRINT
40  PRINT : PRINT "THIS PROGRAM ENABLES THE OPERATOR TO": PRINT
     : PRINT "VIEW THE CONTENTS OF A SEQUENTIAL TEXT": PRINT
     : PRINT "FILE IN GROUPS OF 10 DATA ITEMS AT A": PRINT
     : PRINT "TIME, AND AMEND 'N' OF THOSE ITEMS AS": PRINT
     : PRINT "NECESSARY"
44  PRINT : PRINT
45  PRINT "(THE FILE MAY ALSO HAVE ITEMS APPENDED": PRINT :
      PRINT "TO IT UP TO A LIMIT OF 2000 DATA ITEMS"
50  PRINT : PRINT : INPUT "HIT 'RETURN' KEY TO CONTINUE:-";
     AA$
100  HOME
110  DIM A$(2000)
115  HTAB 8
120  VTAB 8: PRINT "WHAT IS THE TEXT FILE NAME ?"
125  PRINT
130  PRINT ":-";: INPUT FI$
140  PRINT : INPUT "WHICH SLOT IS IT ON ?:-";S$
150 O$ = "OPEN " + FI$ + ",S" + S$
160 R$ = "READ " + FI$
165 W$ = "WRITE " + FI$
170 C$ = "CLOSE " + FI$
180 D$ = "": REM  CNTRL-D
190  PRINT D$;O$
200  PRINT D$;R$
210  FOR I = 1 TO 2000
220  ONERR  GOTO 1000
230  INPUT A$(I)
240  NEXT I
250  PRINT D$;C$
260  PRINT "THIS FILE CONTAINS MORE THAN 2000 DATA": PRINT
     : PRINT "ITEMS-AM CLOSING NOW AND TAKING NO ACTION"
270  END
999  REM  ****************************************************
     ********************
1000  REM  SECTION ARRIVED AT WHEN ONE HAS ENCOUNTERED AN E
     RROR STATUS
1001  REM  ----------------------------------------------
     -------------------
```

```
1010  PRINT D$;C$
1020 Y =  PEEK (222): REM  Y IS THE CODE FOR THE REASON FOR
     THE ERROR
1030  IF Y = 5 THEN 2000
1040  REM  IF YOU HAVE ARRIVED AT THIS LINE THEN YOU HAVE A
    N ERROR OTHER THAN 'END OF DATA'
1050  IF Y = 1 THEN  PRINT "LANGUAGE NOT AVAILABLE"
1060  IF Y = 2 THEN  PRINT "RANGE ERROR"
1070  IF Y = 3 THEN  PRINT "RANGE ERROR"
1080  IF Y = 4 THEN  PRINT "DISK IS WRITE PROTECTED"
1090  IF Y = 6 THEN  PRINT "FILE NOT FOUND"
1100  IF Y = 7 THEN  PRINT "VOLUME MISMATCH"
1110  IF Y = 8 THEN  PRINT "I/O ERROR"
1120  IF Y = 9 THEN  PRINT "DISK IS FULL"
1130  IF Y = 10 THEN  PRINT "FILE IS LOCKED"
1140  IF Y = 11 THEN  PRINT "SYNTAX ERROR ENCOUNTERED"
1150  IF Y = 12 THEN  PRINT "TOO MANY TEXT FILES OPEN"
1160  IF Y = 13 THEN  PRINT "FILE TYPE MISMATCH"
1170  IF Y = 14 THEN  PRINT "PROGRAM TOO LARGE"
1180  IF Y = 15 THEN  PRINT "NOT A DIRECT COMMAND"
1190  POKE 216,0: REM  RESETS ERROR FLAG
1194  PRINT
1195  PRINT "AM CLOSING THE FILE-HAVE ENCOUNTERED AN"
1196  PRINT : PRINT "AN ERROR OTHER THAN 'END OF DATA'"
1200  END
2000  REM  ##################################################
    ##################################
2001  REM  SINCE WE ARE AT THIS POINT WE KNOW THAT THE FILE
     HAS BEEN EMPTIED OF ALL ITS DATA
2002  REM  ==============================================
    ============================
2010  HOME
2020 J = (I - 1): REM  J IS THE NO OF DATA ITEMS STORED IN
     THIS FILE
2030  PRINT "THE FILE CONTAINS ";J;" DATA ITEMS": PRINT "==
    ===================================": PRINT : POKE
    34,4
2040  PRINT "PRESS 'RETURN' TO GET DISPLAY OF DATA ": PRINT
    "IN GROUPS OF 10 AT A TIME"
2050  INPUT ":-";AA$
2060  PRINT ""
2070 L = 0
2080  FOR K = 1 TO J
2090  PRINT "DATA ITEM ";K;"   ";A$(K)
2110 L = L + 1
2140  IF L = 10 THEN L = 0: PRINT : INPUT "PRESS 'RETURN' T
    O CONTINUE LISTING:-";AA$: PRINT
2150  NEXT K
2160  PRINT : PRINT "END OF LISTING"
2165  TEXT
2170  PRINT "HIT 'P' FOR A HARD COPY PRINTOUT:-";
2180  GET XX$
2190  IF XX$ = "P" THEN  GOTO 10000
3000  REM  SECTION TO AMEND ALL THE REOIRED ITEMS (AND EXTE
    ND THE FILE IF REQUIRED)
3005  HOME
3010  PRINT "INPUT THE DATA ITEM NO. FOLLOWED BY"
3030  PRINT "THE DATA TO BE ASSOCIATED WITH IT"
3040  PRINT "--------------------------------------"
3050  PRINT "TERMINATE WITH A DATA ITEM NO:-0"
3060  PRINT "======================================"
3070  PRINT "DATA ITEM              DATA    "
3080  PRINT " NUMBER"
3090  PRINT "--------------------------------------"
3100  POKE 34,9
3150 MXM = J
3200  INPUT X: IF X = 0 THEN 5000
3205  IF X > MXM THEN MXM = X
3210  HTAB 10
3220  INPUT Z$
3230 A$(X) = Z$
3240  GOTO 3200
5000  REM  ################################################
    ###
5010  REM  S/R TO RECONSTRUCT THE FILE TO INCLUDE ALL AMEND
    ED AND ADDITIONAL DATA
5020  REM  ==========================
5030  PRINT D$;O$
5040  PRINT D$;W$
5050  FOR I = 1 TO MXM
5060  PRINT A$(I)
5070  NEXT I
5080  PRINT D$;C$
5085  TEXT : HOME : VTAB 10
5090  PRINT "FILE NOW RECREATED ON DISK"
5095  PRINT "========================="
5100  END
9999  REM  ############################
10000  REM  SUBROUTINE TO GET HARD COPY
10001  REM  ############################
10003  PR# 2
10004  PRINT D$;"               ": REM  CNTRL-I 75 N
10005  PRINT "FILE NAME:-";FI$
10006  PRINT "============================"
10007  PRINT
10010  FOR K = 1 TO J
10020  PRINT "DATA ITEM ";K;" :- ";A$(K)
10025  PRINT " "
10030  NEXT K
10040  PRINT : PRINT : PRINT "END OF LISTING"
10050  PRINT "============================"
10060  PR# 0: HOME
10070  GOTO 3000
```

APPENDIX (I)

STANDARD TOOLING CATALOGUE
PRELIM PROGRAM

```
]LIST

10 D$ = "": REM  CTRL-D
20  PRINT D$;"OPEN CODING SYSTEM SUMMARY"
30  PRINT D$;"WRITE CODING SYSTEM SUMMARY"
40  PRINT "0": REM   PUTTING ZERO IN AS VALUE OF J1
50  PRINT D$;"CLOSE CODING SYSTEM SUMMARY"
```

APPENDIX (J)

CODING SYSTEM CREATOR PROGRAM

```
]LIST

10 D$ = "": REM  CTRL-D
11  DIM CODNG$(500),NUMBEROFCODES$(500)
15  HOME
16  PRINT " LOCATE DISK IN SLOT 6"
17  PRINT " ": PRINT " ": PRINT " "
20  INPUT "GIVE FULL CODE NO:-";CODNG$: REM  THIS IS THE PA
     GE HEADING
30 CODNG$ = "X" + CODNG$: REM  MUST PREFIX ALL FILE NAMES W
     ITH A LETTER TO CONFORM WITH APPLE DOS REQUIREMENTS
40  INPUT "HOW MANY ITEMS TO GO IN THIS SECTION ?:-";NUMBER
     OFCODES$:N =  VAL (NUMBEROFCODES$)
50  DIM TLCODE$(N)
60  PRINT " "
70  FOR I = 1 TO N
80  INPUT "GIVE TOOL DESCRIPTION:-";TLCODE$(I): REM THIS IS
     THE FULL TOOL CODE
90  NEXT I
100 O$ = "OPEN " + CODNG$ + ",S6"
110 W$ = "WRITE " + CODNG$
120 C$ = "CLOSE " + CODNG$
130  PRINT D$;O$: REM  NOW CREATING THE STANDARD TOOLING CA
     TALOGUE FILES
140  PRINT D$;W$
150  PRINT NUMBEROFCODES$
160  FOR I = 1 TO N
170  PRINT TLCODE$(I)
180  NEXT I
190  PRINT D$;C$
200  REM   NOW UPDATE 'CODING SYSTEM SUMMARY' FILE (EFFECTI
     VELY THE EQUIVALENT OF AN EXTRA DIRECTORY)
210  PRINT D$;"OPEN CODING SYSTEM SUMMARY"
220  PRINT D$;"READ CODING SYSTEM SUMMARY"
230  INPUT J
240  IF J = 0 THEN 260
250  FOR I = 1 TO J: INPUT CODNG$(I): REM  CODE FOR CODE SE
     CTOR:INPUT NUMBEROFCODES$(I):REM NO. OF ITEMS STORED W
     ITHIN THIS CATEGORY:NEXT I
260 J = J + 1
270 CODNG$(J) = CODNG$
280 NUMBEROFCODES$(J) = NUMBEROFCODES$
290  PRINT D$;"CLOSE CODING SYSTEM SUMMARY"
300  PRINT D$;"OPEN CODING SYSTEM SUMMARY"
310  PRINT D$;"WRITE CODING SYSTEM SUMMARY"
320  PRINT J
330  FOR I = 1 TO J: PRINT CODNG$(I): PRINT NUMBEROFCODES$(
     I): NEXT I
340  PRINT D$;"CLOSE CODING SYSTEM SUMMARY"
350  END
```

APPENDIX (K)

DISK EXPANSION PROGRAM

```
]LIST

0  REM  RWTS POKES
10  DATA 169,12,160,10,32,217,3,68,65,84,1,96,1,0,17,8,32,1
     2,0,32,0,0,1,177,110,96,1,32,73,84,32,65,0,1,239,216
15  FOR J = 3072 TO 3107: READ N: POKE J,N: NEXT
20  POKE 3094,1: REM  SET UP READ CODE
30  POKE 3086,17: POKE 3087,0: CALL 3072: POKE 8312,0: POKE
     8313,0: POKE 3094,2: CALL 3072: POKE 3094,1
40  POKE 3086,17: POKE 3087,1: CALL 3072: POKE 8193,16: POKE
     8194,12: POKE 3094,2: CALL 3072
50  POKE 3086,16: FOR J = 12 TO 1 STEP  - 1: POKE 3087,J: POKE
     8194,J - 1: CALL 3072: NEXT
60  POKE 3087,J: POKE 8193,0: POKE 8194,0: CALL 3072
```

APPENDIX (L)

LINCS - TOOL DATA FILE CREATION PROGRAM

```
]LIST

10  DIM CC$(10)
20  DIM TI(10)
30  DIM CP(10)
40  DIM CO$(10,20)
50  DIM NM(10,20)
60  DIM MN$(10,20,5)
70  DIM Q(10,20,5)
80  DIM TCF(10,20,5)
90  DIM DN(10)
100  DIM AI(10)
110  POKE 33,40: POKE 34,0
120  HOME : PRINT : PRINT : PRINT
130  PRINT
140  PRINT "THIS PROGRAM CALCULATES THE B.O.M. FOR GIVEN CO
     MPONENT BUILD VOLUMES"
150  PRINT
160  PRINT "EACH COMPONENT WILL BE DISPLAYED ,FOLLOWED BY A
      QUESTION MARK"
170  PRINT
180  PRINT "YOU MUST INPUT THE VOLUME TO BE MADE,FOLLOWED B
     Y(RETURN)"
190  INVERSE
200  VTAB (22): PRINT "PRESS(RETURN) TO CONTINUE"
210  NORMAL
220  INPUT A$
230  HOME
240 TC$ = "COMPONENT DIRECTORY"
250 D$ =  CHR$ (4)
260  PRINT D$;"OPEN";TC$;",S6,D2"
270  PRINT D$;"READ";TC$
280  INPUT A
290  FOR I = 1 TO A
300  INPUT TC$(I)
310  NEXT I
320  PRINT D$;"CLOSE";TC$
330  PRINT "COMPONENT NUMBER         VOLUME"
340  POKE 34,2
350  FOR I = 1 TO A
360  PRINT TC$(I);"                         ?"
370  INPUT "                            ";V(I)
380  NEXT I
390  INVERSE
400  VTAB (22): PRINT "PRESS (RETURN) TO CONTINUE"
410  NORMAL
420  INPUT A$
430 TD$ = "TOOL DIRECTORY"
440  PRINT D$;"OPEN";TD$;",S6,D2"
450  PRINT D$;"READ";TD$
460  INPUT B
470  FOR I = 1 TO B
480  INPUT TD$(I)
```

```
490  NEXT I
500  PRINT D$;"CLOSE ";TD$
510  FOR R = 1 TO B
515 F$ = TD$(R)
520 D$ = "OPEN" + F$ + ",S6,D2"
530  PRINT D$;D$
540  PRINT D$;"READ"F$
550  INPUT TS$
560  INPUT TD$
570  INPUT SHAPE$
580  INPUT ISD$
590  INPUT GC$
600  INPUT UP
610  INPUT CE
620  INPUT B
630  INPUT L$
640  INPUT MI
650  INPUT ROD
660  INPUT TI
670  INPUT TR
680  INPUT CC
690  FOR I = 1 TO CC
700  INPUT CC$(I)
710  IF CC$(I) = "999" THEN 850
720  INPUT TI(I)
730  INPUT CP(I)
740  FOR J = 1 TO CP(I)
750  INPUT CO$(I,J)
760  INPUT NM(I,J)
770  FOR K = 1 TO NM(I,J)
780  INPUT MN$(I,J,K)
790  INPUT Q(I,J,K)
800  INPUT TCF(I,J,K)
810  NEXT K
820  NEXT J
830  NEXT I
840  GOTO 920
850  INPUT TI(I)
860  INPUT NO
870  FOR J = 1 TO NO
880  INPUT DN(J)
890  INPUT AI(J)
900  NEXT J
910  GOTO 830
920  POKE 34,0
930  PRINT D$;"CLOSE"F$
940  FOR I = 1 TO CC - 1
950  FOR M = 1 TO CP(I)
955  FOR P = 1 TO A
960 GG = 0
970  IF CO$(I,M) <  > TC$(P) THEN 1030
980  FOR L = 1 TO NM(I,M)
990 GG = V(P) * Q(I,M,L) / (TCF(I,M,L) * CE)
1000 BG = GG + BG
1010  NEXT L
1020 SUM(R,P) = SUM(R,P) + BG
1030  NEXT P
1040  NEXT M
1050  NEXT I
1060  FOR P = 1 TO A
1070 TT(R) = TT(R) + SUM(R,P)
1080  NEXT P
1090  NEXT R
1095  HOME : PRINT : PRINT : PRINT
1105  PRINT  TAB( 1);"TOOL ";
1108  PRINT  TAB( 20);"VOL. REQD."
1109  FOR I = 1 TO B
1110  PRINT  TAB( 2);TD$(I);
1115 TA%(I) = TT(I)
1117  IF (TT(I) - TA%(I)) >  = .5 THEN TA%(I) = TA%(I) + 1
1120  PRINT  TAB( 22);TA%(I)
1130  NEXT I
```

APPENDIX (M)

LINCS - TOOL ISSUE/RECEIPT PROGRAM

```
]LIST

10  POKE 34,0: POKE 33,40
20  DIM CC$(10)
30  DIM TI(10)
40  DIM CP(10)
50  DIM CO$(10,20)
60  DIM NM(10,20)
70  DIM MN$(10,20,5)
80  DIM Q(10,20,5)
90  DIM TCF(10,20,5)
100  DIM DN(10)
110  DIM AI(10)
120  HOME
180 D$ =  CHR$ (4)
190  HOME : PRINT : PRINT
200  PRINT "PLEASE KEY IN THE TOOL NAME": PRINT " ": PRINT
     ":-";
210  INPUT F$
215 F$ = "X" + F$
220 O$ = "OPEN" + F$ + ",S6,D2"
230  PRINT D$;O$
240  PRINT D$;"READ"F$
250  INPUT TS$
260  INPUT TD$
270  INPUT SHAPE$
280  INPUT ISO$
290  INPUT GC$
300  INPUT UP
310  INPUT CE
320  INPUT S
330  INPUT L$
340  INPUT MI
350  INPUT ROQ
360  INPUT TI
370  INPUT TR
380  INPUT CC
390  FOR I = 1 TO CC
400  INPUT CC$(I)
410  IF CC$(I) = "999" THEN 550
420  INPUT TI(I)
430  INPUT CP(I)
440  FOR J = 1 TO CP(I)
450  INPUT CO$(I,J)
460  INPUT NM(I,J)
470  FOR K = 1 TO NM(I,J)
480  INPUT MN$(I,J,K)
490  INPUT Q(I,J,K)
500  INPUT TCF(I,J,K)
510  NEXT K
520  NEXT J
530  NEXT I
540  GOTO 620
```

```
550  INPUT TI(I)
560  INPUT ND
570  FOR J = 1 TO ND
580  INPUT DN(J)
590  INPUT AI(J)
600  NEXT J
610  GOTO 530
620  POKE 34,0
630  PRINT D$;"CLOSE"F$
640  POKE 33,40
650  HOME
660  VTAB (1): PRINT "B.L.TOOL NO."
670  VTAB (2): PRINT "  ="; F$
680  VTAB (3): PRINT "TOOL SUPPLIER"
690  VTAB (4): PRINT "  ="; TS$
700  VTAB (5): PRINT "SUPL'RS SHAPE REF"
710  VTAB (6): PRINT "  ="; SHAPE$
720  VTAB (7): PRINT "STORES LOC'N"
730  VTAB (8): PRINT "  ="; L$
740  VTAB (9): PRINT "CURRENT STOCK"
745  IF ILFLAG = 1 THEN  INVERSE
747  IF RFLAG = 1 THEN  INVERSE
750  VTAB (10): PRINT "  ="; S
755  NORMAL
760  VTAB (11): PRINT "MIN.STOCK"
770  VTAB (12): PRINT "  ="; MI
780  VTAB (13): PRINT "RE-ORDER Q'TITY"
790  VTAB (14): PRINT "  ="; ROD
800  VTAB (15): PRINT "TOTAL ISSUES"
805  IF ILFLAG = 1 THEN  INVERSE
810  VTAB (16): PRINT "  ="; TI
815  NORMAL
820  VTAB (17): PRINT "TOTAL RECEIPTS"
825  IF RFLAG = 1 THEN  INVERSE
830  VTAB (18): PRINT "  ="; TR
835  NORMAL
837 ILFLAG = 0:RFLAG = 0
840  FOR I = 1 TO 18
850  VTAB (I): HTAB (18): PRINT "!"
860  NEXT I
870  VTAB (1): HTAB (19): PRINT "COST CENTRE    ISSUES"
880  FOR I = 1 TO CC
890  VTAB (2 * I + 1): HTAB (22): PRINT CC$(I)
900  VTAB (2 * I + 1): HTAB (35): PRINT TI(I)
910  NEXT I
920  INVERSE
930  VTAB (22): PRINT "PRESS (RETURN) TO CONTINUE"
940  NORMAL
950  INPUT A$
960  POKE 34,19
970  PRINT "DO YOU WISH TO MODIFY THE STOCK LEVELS(INPUT(M)
     ),OR EXIT(ANY OTHER KEY)"
980  INPUT A$
990  IF A$ <  > "M" THEN 2000
1000  PRINT " IS THIS AN ISSUE OR A RECEIPT?"
1010  INPUT SA$
1020  IF  LEFT$ (SA$,1) = "I" THEN ILFLAG = 1: GOTO 1050
1030  IF  LEFT$ (SA$,1) = "R" THEN RFLAG = 1: GOTO 1500
1040  GOTO 1000
1050  PRINT "HOW MANY HAVE BEEN ISSUED?"
1060  INPUT IV
1070  IF IV > S THEN 1360
1080  PRINT "PLEASE INPUT THE COST CENTRE AGAINST WHICH THE
     SE HAVE BEEN DRAWN"
1090  INPUT CNC$
1100  FOR I = 1 TO CC
1110  IF CNC$ = CC$(I) THEN 1290
1120  NEXT I
1130  PRINT "THIS IS NOT A VALID COST CENTRE FOR THIS TOOL"

1140  PRINT "YOU MUST ISSUE AN(A.I.D) AND INPUT THE AID NO.
      -THESE ISSUES WILL THEN BE DRAWN AGAINST COST CENTRE
     999"
1150  FOR I = 1 TO 4000
1160  NEXT
1170  PRINT "PLEASE KEY IN AID NO."
1180  INPUT DN(ND + 1)
1190 ND = ND + 1
1200  FOR I = 1 TO CC
1210  IF CC$(I) = "999" THEN 1250
1220  NEXT I
1230  REM  NO CC CALLED 999
1240 CC = CC + 1
1250 TI(CC) = TI(CC) + IV
1260 S = S - IV
1270 TI = TI + IV
1280  GOTO 1350
1290 TI(I) = TI(I) + IV
1300 TI = TI + IV
1310 S = S - IV
1350  GOTO 640
1360  PRINT "THERE ARE ONLY ";S;"IN STOCK-PLEASE TYPE IN AG
     AIN"
1370  GOTO 1050
1500  PRINT "HOW MANY HAVE BEEN RECEIVED?"
1510  INPUT REC
1520 S = S + REC
1530 TR = TR + REC
1540  GOTO 640
2000  PRINT "AM NOW SAVING MODIFIED DATA"
2040 D$ =  CHR$ (4)
2050 OD$ = "OPEN " + F$ + ",S6,D2"
2060  PRINT D$;OD$
2070  PRINT D$;"WRITE"F$
2080  PRINT TS$
2090  PRINT TD$
2100  PRINT SHAPE$
2110  PRINT ISO$
2120  PRINT GC$
2130  PRINT UP
2140  PRINT CE
2150  PRINT S
2160  PRINT L$
2170  PRINT MI
2180  PRINT ROD
```

```
2190  PRINT TI
2200  PRINT TR
2210  PRINT CC
2220  FOR I = 1 TO CC
2230  PRINT CC$(I)
2240  IF CC$(I) = "999" THEN 2400
2250  PRINT TI(I)
2260  PRINT CP(I)
2270  FOR J = 1 TO CP(I)
2280  PRINT CO$(I,J)
2290  PRINT NM(I,J)
2300  FOR K = 1 TO NM(I,J)
2310  PRINT MN$(I,J,K)
2320  PRINT Q(I,J,K)
2330  PRINT TCF(I,J,K)
2340  NEXT K
2350  NEXT J
2360  NEXT I
2370  PRINT D$;"CLOSE"F$
2380  PRINT : PRINT "NEW DATA NOW SAVED"
2385  PRINT "DO YOU WANT TO RUN AGAIN?"
2388  INPUT A$
2392  IF  LEFT$ (A$,1) = "Y" THEN  RUN
2395  PRINT D$;"RUN LINCS GRAPHICS & MENU,S6,D2"
2400  PRINT TI(I)
2410  PRINT ND
2420  FOR J = 1 TO ND
2430  PRINT DN(J)
2440  PRINT AI(I)
2450  NEXT J
2460  GOTO 2360
```

APPENDIX (N)

LINCS - TOOL/COMPONENT 'WHERE USED' PROGRAM

```
]LIST

5  POKE 34,0: POKE 33,40
10  DIM CC$(10)
20  DIM TI(10)
30  DIM CP(10)
40  DIM CO$(10,20)
50  DIM NM(10,20)
60  DIM MN$(10,20,5)
70  DIM Q(10,20,5)
80  DIM TCF(10,20,5)
90  DIM DN(10)
100  DIM AI(10)
110  HOME
150  NORMAL
160 D$ =  CHR$ (4)
170  HOME : PRINT : PRINT
180  PRINT "PLEASE KEY IN THE TOOL NAME": PRINT " ": PRINT
     ":-";
190  INPUT F$
191 F$ = "X" + F$
195 O$ = "OPEN" + F$ + ",S6,D2"
200  PRINT D$;O$
210  PRINT D$;"READ"F$
220  INPUT TS$
230  INPUT TD$
240  INPUT SHAPE$
250  INPUT ISO$
260  INPUT GC$
270  INPUT UP
280  INPUT CE
290  INPUT S
300  INPUT L$
310  INPUT MI
320  INPUT ROQ
330  INPUT TI
340  INPUT TR
350  INPUT CC
360  FOR I = 1 TO CC
370  INPUT CC$(I)
380  IF CC$(I) = "999" THEN 520
390  INPUT TI(I)
400  INPUT CP(I)
410  FOR J = 1 TO CP(I)
420  INPUT CO$(I,J)
430  INPUT NM(I,J)
440  FOR K = 1 TO NM(I,J)
450  INPUT MN$(I,J,K)
460  INPUT Q(I,J,K)
470  INPUT TCF(I,J,K)
480  NEXT K
490  NEXT J
500  NEXT I
```

```
510  GOTO 600
520  INPUT TI(I)
530  INPUT ND
540  FOR J = 1 TO ND
550  INPUT DN(J)
560  INPUT AI(J)
570  NEXT J
580  GOTO 500
600  POKE 34,0
605  PRINT D$;"CLOSE"F$
610  POKE 33,40
620  HOME
630  VTAB (1): PRINT "ARCLASS CODE"
640  VTAB (2): PRINT "=";F$
650  VTAB (3): PRINT "TOOL SUPPLIER"
660  VTAB (4): PRINT "  =";TS$
670  VTAB (5): PRINT "SUPPLIER REF"
680  VTAB (6): PRINT "  =";SHAPE$
690  VTAB (7): PRINT "STORES LOC'N"
700  VTAB (8): PRINT "  =";L$
710  VTAB (9): PRINT "CURRENT STOCK"
720  VTAB (10): PRINT "  =";S
730  VTAB (11): PRINT "MIN.STOCK"
740  VTAB (12): PRINT "  =";MI
750  VTAB (13): PRINT "RE-ORDER Q'TITY"
760  VTAB (14): PRINT "  =";ROQ
770  VTAB (15): PRINT "TOTAL ISSUES"
780  VTAB (16): PRINT "  =";TI
790  VTAB (17): PRINT "TOTAL RECEIPTS"
800  VTAB (18): PRINT "  =";TR
810  FOR I = 1 TO 18
820  VTAB (I): HTAB (17): PRINT "*"
830  NEXT I
840  VTAB (1): HTAB (18): PRINT "COST CENTRE   ISSUES"
850  FOR I = 1 TO CC
860  VTAB (2 * I + 1): HTAB (22): PRINT CC$(I)
870  VTAB (2 * I + 1): HTAB (35): PRINT TI(I)
880  NEXT I
890  INVERSE
900  VTAB (23): PRINT "PRESS (RETURN) TO CONTINUE"
910  NORMAL
920  INPUT A$
930  REM  ***************** PAGE 2*********
940  POKE 34,0: POKE 33,40
950  FOR I = 1 TO CC
955  HOME
960  INVERSE
970  VTAB (2): PRINT "COST CENTRE";CC$(I)
980  NORMAL
990  IF CC$(I) = "999" THEN 1180
1000  VTAB (4): PRINT "COMPONENT NO. M/C NO.  QUANTITY T.C.
   F."
1010  POKE 34,4
1020  FOR J = 1 TO CP(I)
1030  PRINT : PRINT  TAB( 3);CD$(I,J)
1040  FOR K = 1 TO NM(I,J)
1050  PRINT  TAB( 15);MN$(I,J,K); TAB( 25);Q(I,J,K); TAB( 3
   5);CF(I,J,K)
1060  NEXT K
1070  PRINT "-----------------------------------------"
1100  NEXT J
1104  INVERSE : VTAB (23): PRINT "PRESS (RETURN) TO CONTINU
   E": NORMAL
1106  INPUT A$
1110  NEXT I
1120  INVERSE
1130  VTAB (23): PRINT "PRESS(RETURN) TO CONTINUE"
1140  NORMAL
1150  INPUT A$
1160  POKE 34,0
1170  GOTO 1240
1180  REM ********PAGE 3**********
1185  TEXT : HOME
1190  VTAB (4): PRINT "AUTHORISED ISSUE DOCUMENTS"
1200  VTAB (6): PRINT "DOCUMENT NO.     NO. OF ISSUES"
1210  FOR P = 1 TO ND
1220  VTAB (6 + 2 * P): HTAB (3): PRINT DN(P)
1225  VTAB (6 + 2 * P): HTAB (20): PRINT AI(P)
1228  NEXT P
1230  GOTO 1110
1240  HOME : PRINT : PRINT : PRINT
1250  PRINT "DO YOU WISH TO RUN AGAIN?"
1260  INPUT A$
1270  IF  LEFT$ (A$,1) = "Y" THEN  RUN
1280  PRINT "  "
1290  PRINT "HIT 'RETURN' TO RETURN TO THE LINCS ": PRINT "
   "
1300  INPUT "SYSTEM MENU:-";AA$
1310  PRINT D$;"RUN LINCS GRAPHICS & MENU,S6,D2"
```

APPENDIX (D)

LINCS - TOOL BILL OF MATERIAL GENERATOR PROGRAM

```
]LIST

10  DIM CC$(10)
20  DIM TI(10)
30  DIM CP(10)
40  DIM CO$(10,20)
50  DIM NM(10,20)
60  DIM MN$(10,20,5)
70  DIM Q(10,20,5)
80  DIM TCF(10,20,5)
90  DIM DN(10)
100  DIM AI(10)
110  POKE 33,40: POKE 34,0
113  HOME
115  INVERSE : HTAB 8: PRINT "BILL OF MATERIALS (B.O.M.)"
117  HTAB 8: PRINT "--------------------------"
118  NORMAL
120  PRINT : PRINT : PRINT
130  PRINT
140  PRINT "THIS PROGRAM CALCULATES THE B.O.M. FOR        GI
     VEN COMPONENT BUILD VOLUMES."
150  PRINT
160  PRINT "EACH COMPONENT WILL BE DISPLAYED,             FO
     LLOWED BY A QUESTION MARK."
170  PRINT
180  PRINT "YOU MUST INPUT THE VOLUME TO BE MADE,         FO
     LLOWED BY (RETURN)."
190  INVERSE
200  VTAB (22): HTAB 8: PRINT "PRESS(RETURN) TO CONTINUE"
210  NORMAL
220  INPUT A$
230  HOME
240 TC$ = "COMPONENT DIRECTORY"
250 D$ =  CHR$ (4)
260  PRINT D$;"OPEN";TC$;",S6,D2"
270  PRINT D$;"READ";TC$
280  INPUT A
290  FOR I = 1 TO A
300  INPUT TC$(I)
310  NEXT I
320  PRINT D$;"CLOSE";TC$
330  PRINT "COMPONENT NUMBER        VOLUME"
335  PRINT "----------------        ------"
340  POKE 34,2
350  FOR I = 1 TO A
360  HTAB 6: PRINT TC$(I)
370  VTAB (I + 2): HTAB 26: INPUT "?";V(I)
380  NEXT I
390  INVERSE
400  VTAB (22): HTAB 4: PRINT "PRESS (RETURN) TO CONTINUE"
410  NORMAL
420  INPUT A$
430 TD$ = "TOOL DIRECTORY"
```

```
440  PRINT D$;"OPEN";TD$;",S6,D2"
450  PRINT D$;"READ";TD$
460  INPUT B
470  FOR I = 1 TO B
480  INPUT TD$(I)
490  NEXT I
500  PRINT D$;"CLOSE ";TD$
510  FOR R = 1 TO B
515 F$ = TD$(R)
520 D$ = "OPEN" + F$ + ",S6,D2"
530  PRINT D$;D$
540  PRINT D$;"READ"F$
550  INPUT TS$
560  INPUT TD$
570  INPUT SHAPE$
580  INPUT ISO$
590  INPUT BC$
600  INPUT UP
610  INPUT CE
620  INPUT S
630  INPUT L$
640  INPUT MI
650  INPUT ROG
660  INPUT TI
670  INPUT TA
680  INPUT CC
690  FOR I = 1 TO CC
700  INPUT CC$(I)
710  IF CC$(I) = "999" THEN 850
720  INPUT TI(I)
730  INPUT CP(I)
740  FOR J = 1 TO CP(I)
750  INPUT CO$(I,J)
760  INPUT NM(I,J)
770  FOR K = 1 TO NM(I,J)
780  INPUT MN$(I,J,K)
790  INPUT Q(I,J,K)
800  INPUT TCF(I,J,K)
810  NEXT K
820  NEXT J
830  NEXT I
840  GOTO 920
850  INPUT TI(I)
860  INPUT ND
870  FOR J = 1 TO ND
880  INPUT DN(J)
890  INPUT AI(J)
900  NEXT J
910  GOTO 830
920  POKE 34,0
930  PRINT D$;"CLOSE"F$
940  FOR I = 1 TO CC - 1
950  FOR M = 1 TO CP(I)
955  FOR P = 1 TO A
960 GG = 0
970  IF CO$(I,M) <> TC$(P) THEN 1030
980  FOR L = 1 TO NM(I,M)
990 GD = V(P) * Q(I,M,L) / (TCF(I,M,L) * CE)
1000 GG = GD + GG
1010  NEXT L
1020 SUM(R,P) = SUM(R,P) + GG
1030  NEXT P
1040  NEXT M
1050  NEXT I
1060  FOR P = 1 TO A
1070 TT(R) = TT(R) + SUM(R,P)
1080  NEXT P
1090  NEXT R
1095  HOME : PRINT : PRINT : PRINT
1105  PRINT  TAB( 7);"TOOL ";
1107  PRINT  TAB( 20);"VOL. REQD."
1108  PRINT  TAB( 7);"----          ----------"
1109  FOR I = 1 TO B
1110  PRINT  TAB( 2);TD$(I);
1115 TAX(I) = TT(I)
1117  IF (TT(I) - TAX(I)) >= .5 THEN TAX(I) = TAX(I) + 1
1120  PRINT  TAB( 22);TAX(I)
1125  PRINT
1130  NEXT I
1200 D$ = ""
1212  PRINT D$;"RUN LINCS GRAPHICS & MENU"
```

APPENDIX (P)

IMPS - INVERSION PROGRAM

```
]LIST

578 D$ = ""
579  HOME
580  PRINT "I.M.P.S. MACHINING PARAMETER SELECTION"
585  PRINT "======================================"
590  PRINT "": PRINT "": PRINT "": PRINT ""
605  VTAB 12
610  INPUT "GIVE COMPONENT MATERIAL GROUPING:-";MG(COUNT)
615  PRINT : PRINT
620  PRINT "DETAILS OF MATL GROUP ";MG(COUNT);" NOW BEING L
     OADED"
621 O$ = "OPEN MACHINABILITY GROUP " +  STR$ (MG(COUNT))
622 R$ = "READ MACHINABILITY GROUP " +  STR$ (MG(COUNT))
623 C$ = "CLOSE MACHINABILITY GROUP " +  STR$ (MG(COUNT))
1000  PRINT D$;O$
1001  PRINT D$;R$
1060  INPUT MDOC
1110  INPUT MFEED
1160  INPUT W1CC$
1210  INPUT W2CC$
1260  INPUT H1S$
1310  INPUT B11S
1360  INPUT S1
1410  INPUT I1
1460  INPUT N1S$
1510  INPUT B21S
1560  INPUT S2
1610  INPUT I2
1660  INPUT T1S$
1710  INPUT B31S
1760  INPUT S3
1810  INPUT I3
1860  INPUT SL
1910  INPUT IL
1960  INPUT KS
1970  INPUT HK
2010  INPUT S4
2060  INPUT I4
2110  INPUT KD
2111  FOR ZZ = 1 TO 4
2112  INPUT ST(ZZ)
2113  INPUT FT(ZZ)
2114  INPUT DC(ZZ)
2115  NEXT ZZ
2116  INPUT H
2117  INPUT HM
2160  PRINT D$;C$
4465  HOME
4485  PRINT "M/CABILITY GROUP NO:-";MG(COUNT): PRINT "*****
```

```
     ####################################"
4486  PRINT : PRINT "RECCOMENDED CARBIDE CLEARANCE <'S:-";W
     ICC$
4487  HTAB 36
4488  PRINT W2CC$
4490  PRINT
4493  PRINT "APPLICABLE 'HARD' GRADE:-";HIS$
4494  PRINT : PRINT "APPLICABLE 'STANDARD' GRADE:-";NIS$
4495  PRINT : PRINT "APPLICABLE 'TOUGH' GRADE:-";TIS$
4497  PRINT : INPUT "IS BATCH HARDNESS KNOWN (Y OR N):-";AA
     $
4498  IF AA$ = "Y" THEN  PRINT " ": INPUT "GIVE FIGURE (HB)
     :-";MH
4499  PRINT : INPUT "SELECT TOOL GRADE:-";G$
4500  IF G$ = HIS$ THEN 4504
4501  IF G$ = NIS$ THEN 4504
4502  IF G$ = TIS$ THEN 4504
4503  PRINT "GRADE NOT RECOGNISED=RE-INPUT !": GOTO 4499
4504  PRINT : INPUT "INPUT MACHINE TOOL FACTOR:-";FA$
4505 FB$ = "1":FC$ = "1"
4510  INPUT "DO YOU WISH TO ALTER DATUM SPEED ?(Y/N) :-";AA
     $
4520  IF AA$ <  > "Y" THEN 4900
4525  PRINT " "
4530  INPUT "INPUT FACTOR BY WHICH TO MULTIFLY:-";M
4540 B11S = B11S * M:B21S = B21S * M:B31S = B31S * M
4900  PRINT : PRINT "HIT 'RETURN' TO CONTINUE:-";
4901  GET AA$
4999  REM  ============================================
5000  REM  FINISHING ROUTINE SECTION
5001  REM  ===================================
5005 CNTR = 1: REM  THIS IS THE COUNTER TO TELL YOU HOW MAN
     Y TIMES YOU'VE BEEN THROUGH THE VARIOUS PARTS OF THE P
     ROGRAM
5010  HOME
5020  INPUT "GIVE FINAL SURFACE FINISH REQ'D(UM):-";FSF
5030  INPUT "GIVE FINAL SIZE TOLERANCE TO BE ACHIEVED (+/-)
     MM:-";TSF
5035  PRINT " ": PRINT " "
5040  INPUT "GIVE START OD FROM ROUGH(MM):-";SOD
5045  PRINT " "
5050  INPUT "GIVE FINAL FINISHED O/D(MM):-";FFOD
5060  IF FFOD >  = SOD THEN  PRINT "ERROR HAS BEEN MADE (FI
     NAL O/D >START O/D)": GOTO 5040
5065  REM  ============================================
     ==
5070  REM  SECTION TO DECIDE UPON FINISHING OF STOCK REMOVA
     L
5080  IF FSF <  = FT(1) THEN C1 = 1: GOTO 5130
5090  IF FSF <  = FT(2) THEN C1 = 2: GOTO 5130
5100  IF FSF <  = FT(3) THEN C1 = 3: GOTO 5130
5110  IF FSF <  = FT(4) THEN C1 = 4: GOTO 5130
5120 C1 = 5: REM  DUMMY VALUE
5130  REM  C1 IS THE 'CRITICAL INTERVAL' AS DICTATAED BY SU
     RFACE FINISH CRITERIA
5140  IF TSF <  = ST(1) THEN C2 = 1: GOTO 5190
5150  IF TSF <  = ST(2) THEN C2 = 2: GOTO 5190
5160  IF TSF <  = ST(3) THEN C2 = 3: GOTO 5190
5170  IF TSF <  = ST(4) THEN C2 = 4: GOTO 5190
5180 C2 = 5: REM  DUMMY VALUE
5190  REM  C2 IS THE 'CRITICAL INTERVAL' AS DICTATED BY SIZ
     E TOLERANCE CRITERIA
5200  IF C1 <  = C2 THEN C = C1: GOTO 5220
5210 C = C2
5220  REM  C IS THE MORE CRITICAL INTERVAL OF C1 AND C2
5245  HOME : HTAB 12: PRINT "FINISHING ROUTINE"
5246  HTAB 12: PRINT "================="
5247  PRINT " "
5250  IF C = 5 THEN  PRINT "DO NOT HAVE A CRITICAL FINAL D.
     O.C.": PRINT "TOTAL STOCK TO REMOVE=";(SOD - FFOD) / 2
     ;" MM": INPUT "SELECT A FINISHING D.O.C (MM):-";D(1): GOTO
     5290
5260  PRINT "CRITICAL FINAL D.O.C": PRINT : PRINT "": PRINT
     "RECOMMEND A D.O.C. OF :-";DC(C);" MM"
5262  PRINT " ": PRINT " "
5265  INPUT "SELECT FINAL OP. D.O.C.(MM):-";D(1)
5270  IF C = 5 THEN 5290
5275  IF D(1) > DC(C) THEN  PRINT " ": PRINT "THIS VALUE IS
      GREATER THAN RECOMMENDED  -DO YOU WISH TO CHANGE IT?(
     Y OR N):-";: INPUT AA$: PRINT " "
5276  IF D(1) <  = DC(C) THEN 5290
5277  IF AA$ <  > "N" THEN 5265
5290  INPUT "HIT 'RETURN' TO CONTINUE:-";AA$:OD(1) = FFOD +
     (2 * (D(1))): GOTO 10000: REM  FACTORING ROUTINE
5299  REM  **** SECTION TO DEAL WITH NON-FINISHING D.O.C. D
     ETAILS ****
5300  HOME
5310 CNTR = CNTR + 1
5320  IF CNTR = 2 THEN  PRINT "STOCK REMAINING TO BE REMOVE
     D=";((SOD - (FFOD + (2 * (D(1))))) / 2):OD(CNTR) = SOD

5330  IF CNTR >  = 3 THEN OD(CNTR) = (OD(CNTR - 1)) - (2 *
     (D(CNTR - 1))): PRINT "STOCK REMAINING=";((OD(CNTR) -
     OD(1)) / 2);" MM"
5335  IF (FFOD + (2 * D(1)) = SOD) THEN  PRINT "ALL STOCK H
     AS BEEN REMOVED IN ONE PASS": GOTO 60000: REM   BRANCH
      TO OP SHEET SUMMARY PRINTOUT ROUTINE FROM HERE
5336  IF OD(CNTR) = (FFOD + (2 * (D(1)))) THEN  PRINT "ALL
     STOCK HAS BEEN REMOVED": GOTO 60000: REM  THIS IS THE
     POINT AT WHICH WE MUST BRANCH TO A SUBROUTINE TO PRINT
      OUT AN 'OP SHEET'-TYPE SUMMARY
5340  INPUT "SELECT D.O.C.:-";D(CNTR)
5350  REM  WE NEED TO PUT IN A CHECKING ROUTINE HERE TO ENS
     URE THAT WE DO NOT REQUEST TO REMOVE MORE STOCK THAN A
     CTUALLY REMAINS
10000  REM  *****THIS IS WHERE THE'FACTORING'ROUTINE WAS***
     *
10749  IF CNTR <  > 1 THEN 10950: REM  DON'T WANT TO GO THR
     OUGH THE FINISH DISPLAY ROUTINE FOR ROUGHING CUTS
10750  HOME
10752  PRINT "APPROPRIATE FEED/NOSE RAD COMBINATIONS"
10754  PRINT "======================================="
10756  PRINT "(SURFACE FINISH=";FSF;" UM C.L.A.)"
10758  PRINT "*--------------*---------------------*"
10760  PRINT "! NOSE RAD(MM) ";"!";"  FEED RATE (MM/REV)  "
```

```
10762  PRINT "*---------------*------------------------*"
10764  FOR ZZ = 1 TO 7
10766  PRINT "!               !                        !"
10768  PRINT "*---------------*------------------------*"
10770  NEXT ZZ
10772  FOR ZZ = 0.4 TO 3.2 STEP 0.4
10774  HTAB 6
10776  VTAB ((ZZ * 5) + 6)
10778  PRINT ZZ
10780 F =  SQR ((FSF / 1000) * (18 * ( SQR (3)) * ZZ))
10782  HTAB 26
10784  VTAB ((ZZ * 5) + 6)
10786 F$ =  LEFT$ ( STR$ (F),3): PRINT F$
10788  NEXT ZZ
10790  PRINT
10792  INPUT "HIT 'RETURN' TO CONTINUE:-";AA$
10950  HOME
10952  PRINT "I.M.P.S. MACHINING PARAMETER SELECTION"
10953  PRINT "======================================"
10954  PRINT
11010  PRINT ""
11060  INPUT "GIVE LENGTH OF CUT (MM):-";L(CNTR)
11080  PRINT ""
11110  INPUT "SELECT FEED RATE (MM/REV):-";F(CNTR):F = F(CN
     TR)
11111  IF CNTR = 1 THEN RAD = (((F(CNTR)) ^ 2) * 1000) / (1
     8 * FSF * ( SQR (3))): PRINT " ": PRINT " APPROPRIATE
     TOOL NOSE RADIUS IS:-"; INT (RAD * 10): PRINT " TENTHS
      OF A MILLIMETRE OR GREATER": PRINT " "
11120  IF F > (MFEED *  VAL (FA$) *  VAL (FB$) *  VAL (FC$)
     ) THEN  FOR XX = 1 TO 3: FOR YY = 1 TO 60:Z1 =  PEEK (
      - 16336): NEXT YY: NEXT XX: PRINT "MAX FEED ACHIEVABL
     E IS:-";(MFEED *  VAL (FA$) *  VAL (FB$) *  VAL (FC$))
     : GOTO 11110
11159  PRINT
11160  INPUT "SELECT TOOL LIFE (MINS):-";T(CNTR):T = T(CNTR
     )
11210  REM  ********************
11260  REM  CALCULATING SECTION
11310  IF G$ = HIS$ THEN S = B11S * ( EXP (( LOG (F) - I1) /
     S1)): GOTO 11530
11360  REM  SPEED IS NOW GENERATED FROM FEED
11410  IF G$ = NIS$ THEN S = B21S * ( EXP (( LOG (F) - I2) /
     S2)): GOTO 11530
11460 S = B31S * ( EXP (( LOG (F) - I3) / S3)): GOTO 11530
11510  REM  ******** HAVENT GOT THE HSS CALCULATION IN YET
     ************
11530  HOME
11535  PRINT "I.M.P.S. INITIAL RESULTS"
11536  PRINT "========================"
11537  PRINT
11540  PRINT "SPEED FROM FEED="; INT (S);" M/MIN"
11610  REM  **********************
11660  REM  NOW MODIFY FOR TOOL LIFE SELECTED
11710 S1 = S *  EXP (IL + (SL * ( LOG (T))))
11763  PRINT "SPEED MODIFIED FOR TOOL LIFE:-"; INT (S1)
11770  REM  SECTION TO FACTOR DOWN SPEED AS PREDICTED FROM
     LOGARITHMIC EQUATIONS
11772 S2 = S1 * ( VAL (FA$)) * ( VAL (FB$)) * ( VAL (FC$))
11778  PRINT "FINALLY FACTORED SPEED (M/MIN):-"; INT (S2)
11780 S2(CNTR) =  INT (S2 * (1 + (((H - MH) / 10) * HM))): REM
      HARDNESS MODIFICATION
11782  PRINT "SPEED MODIFIED FOR COMPT HARD NESS:-";S2(CNTR
     )
12010  REM  NOW IN A POSITION TO CALCULATE ROGH ESTIMATES
12060 N(CNTR) = (1000 * S2(CNTR)) / (60 * 3.142 * OD(CNTR))
12110 STDTIME(CNTR) = L(CNTR) / (F(CNTR) * N(CNTR) * 60): REM
      STANDARD TIME IN MINUTES
12160 K1S(CNTR) = KS * ( EXP (( LOG (F(CNTR)) - I4) / S4))
12170 K1S(CNTR) =  INT (K1S(CNTR) * (1 + (((MH - H) / 10) *
     HK))): REM  MODIFY FOR HARDNESS
12210 POWER(CNTR) = (D(CNTR) * F(CNTR) * S2(CNTR) * K1S(CNT
     R)) / 6120: REM   POWER IN KW
12258  PRINT "----------------------------------------"
12259  PRINT
12260  PRINT "DEPTH OF CUT(MM):-";D(CNTR)
12310  PRINT "FEED RATE(MM/REV):-";F(CNTR)
12360  PRINT "SURFACE CUTTING SPEED (M/MIN):-"; INT (S2(CNT
     R))
12388  PRINT "ROTATIONAL SPEED (REVS/SEC):-"; INT (N(CNTR))
12410  PRINT "TURNED LENGTH(MM):-";L(CNTR)
12460  PRINT "TOOL LIFE SELECTED (MINUTES):-";T(CNTR)
12465 TCF(CNTR) =  INT (T(CNTR) / STDTIME(CNTR))
12466  PRINT "TOOLCHANGE FREQUENCY(COMPTS):-";TCF(CNTR)
12470 ST$(CNTR) =  STR$ (STDTIME(CNTR))
12472  FOR ZZ = 1 TO  LEN (ST$(CNTR))
12474  IF  MID$ (ST$(CNTR),ZZ,1) = "." THEN 12478
12476  NEXT ZZ
12478 ST$(CNTR) =  LEFT$ (ST$(CNTR),(ZZ + 3))
12500 PO$(CNTR) =  STR$ (POWER(CNTR))
12502  FOR ZZ = 1 TO  LEN (PO$(CNTR))
12504  IF  MID$ (PO$(CNTR),ZZ,1) = "." THEN 12508
12506  NEXT ZZ
12508 PO$(CNTR) =  LEFT$ (PO$(CNTR),(ZZ + 2))
12510  PRINT "STANDARD TIME (MINUTES):-";ST$(CNTR)
12558  PRINT "'KS' SPECIFIC FORCE VALUE(KG/MM):-"; INT (K1S
     (CNTR))
12560  PRINT "POWER (KW):-";PO$(CNTR)
12570  PRINT
12580  PRINT "----------------------------------------"
12584  IF ZY = 100000 THEN ZY = 0: GOTO 13260
12585  INPUT "IS HARD COPY REQ'D?(Y OR N):-";AA$
12590  IF AA$ = "Y" THEN  PR# 1:ZY = 100000: GOTO 11530
13260  REM  END OF SECTION ******************************
13304  PR# 0
13305  REM  SECTION TO QUESTION SPINDLE SPEED
13310  INPUT "IS SPINDLE SPEED ACHIEVABLE(Y OR N):-";AA$
13312  IF AA$ = "Y" THEN 15000
13314  IF AA$ = "N" THEN  GOSUB 30000
13315  REM  HAVE NOW RETURNED FROM SPINDLE SPEED ALTERATION
      SUBROUTINE
13316  HOME
```

```
13317  PRINT "I.M.P.S RESULTS (SPINDLE SPEED REDUCED)"
13318  PRINT "##########################################"
13319  PRINT "PLEASE NOTE CHANGES TO STANDARD TIME,   TOOL
     LIFE ,TCF ,AND POWER ": PRINT ""
13320  GOSUB 20000: REM  PRINT OUT DETAILS
13333  REM  HAVE NOW RETURNED FROM PRINTING DETAILS ON SCRE
     EN
15000  REM  ###############################################
     ##########################
15010  REM  SECTION TO DETERMINE WETHER POWER IS AVAILABLE
15015  INPUT "IS POWER AVAILABLE ?:-";AA$
15020  IF AA$ = "Y" THEN 16000
15030  IF AA$ = "N" THEN 15040
15035  GOTO 15015
15040  REM  WE NOW KNOW THAT INSUFFICIENT POWER IS AVAILABL
     E,MUST ASK FOR MAX SPEED & MAX FEED
15050  INPUT "GIVE MAX SPEED(REVS/SEC):-";MS
15060  INPUT "GIVE MAX FEED(MM/REV):-";MF
15070  INPUT "GIVE MAX POWER(KW):-";MP
15080  REM  THERE ARE 2 WAYS TO CALCULATE POWER REDUCTION-(
     A)REDUCE DOC ONLY,(B) OPTIMISE A/C TO CERTAIN GROUND R
     ULES OF PRECEDENCE
15090  GOSUB 35000: REM  SUBROUTINE TO CALCULATE NEW DOC
15100  REM  HAVE NOW CALCULATED NEW DOC AND PRINTED ON SCRE
     EN
15110  GOSUB 40000: REM  SUBROUTINE FOR PSEUDO-OPTIMISATION

15120  REM  HAVE NOW RETURNED
15130  HOME
15140  HTAB 10
15150  PRINT "I.M.P.S. RESULTS"
15155  PRINT "##########################################"
15160  PRINT "NOTE ALL-ROUND CHANGES": PRINT
15170  GOSUB 20000: REM  PRINT OUT DETAILS
15175  REM  HAVE NOW RETURNED FROM PRINTING
15177  PR# 0
15180  REM  NOW SELECT TOOL AT 16500-
16000  INPUT "ARE PARAMETERS ACCEPTABLE? (Y OR N):-";AA$
16010  IF AA$ = "Y" THEN 5299
16020  IF AA$ = "N" THEN 16100
16030  GOTO 16010
16100  INPUT "TRY ANOTHER M/C (Y OR N):-";AA$
16110  IF AA$ = "Y" THEN 10000
16120  IF AA$ = "N" THEN 10735
16130  GOTO 16100
16650  GOTO 5299
19999  REM  ###############################################
     #####################
20000  REM  PRINTING ON SCREEN ROUTINE
20026  PRINT
20030 DD$ =  STR$ (D(CNTR)): FOR ZZ = 1 TO  LEN (DD$): IF  MID$
     (DD$,ZZ,1) = "." THEN DD$ =  LEFT$ (DD$,(ZZ + 2)): NEXT
     ZZ
20040  PRINT "DEPTH OF CUT(M.M.):-";DD$
20050 F$ =  STR$ (F(CNTR))
20052  FOR ZZ = 1 TO  LEN (F$)
20054  IF  MID$ (F$,ZZ,1) = "." THEN 20058
20056  NEXT ZZ
20058 F$ =  LEFT$ (F$,(ZZ + 2))
20060  PRINT "FEED RATE(MM/REV):-";F$
20080  PRINT "SURFACE CUTTING SPEED (M/MIN):-"; INT (S2(CNT
     R))
20090  PRINT "ROTATIONAL SPEED (REV/SEC):-"; INT (N(CNTR))
20100  PRINT "TURNED LENGTH(MM):-";L(CNTR)
20105 T$ =  STR$ (T(CNTR))
20106  FOR ZZ = 1 TO  LEN (T$)
20107  IF  MID$ (T$,ZZ,1) = "." THEN 20109
20108  NEXT ZZ
20109 T$ =  LEFT$ (T$,(ZZ - 1))
20110  PRINT "TOOL LIFE SELECTED (MINS):-";T$
20120  PRINT "TOOLCHANGE FREQUENCY (COMPTS):-"; INT (TCF(CN
     TR))
20130 PO$ =  STR$ (POWER(CNTR))
20132  FOR ZZ = 1 TO  LEN (PO$)
20134  IF  MID$ (PO$,ZZ,1) = "." THEN 20138
20136  NEXT ZZ
20138 PO$ =  LEFT$ (PO$,(ZZ + 2))
20140  PRINT "POWER REQ'D (KW):-";PO$
20150  PRINT "'KS'SPECIFIC FORCE VALUE(KG/MM):-"; INT (K1S(
     CNTR))
20155 ST$ =  STR$ (STDTIME(CNTR))
20156  FOR ZZ = 1 TO  LEN (ST$)
20157  IF  MID$ (ST$,ZZ,1) = "." THEN 20159
20158  NEXT ZZ
20159 ST$ =  LEFT$ (ST$,(ZZ + 3))
20160  PRINT "STANDARD TIME (MINS):-";ST$
20165  PRINT
20170  PRINT "========================================"
20174  IF ZY = 200000 THEN  PR# 0: GOTO 20200
20175  INPUT "IS HARD COPY REQ'D (Y OR N):-";AA$
20180  IF AA$ = "Y" THEN  HOME : PR# 2:ZY = 200000: GOTO 20
     030
20200  RETURN
20201  REM  ###############################################
     #####################
29999  REM  ===============================================
     ============
30000  REM  SUBROUTINE FOR RECALCULATION GIVEN INSUFFICIENT
      SPINDLE SPEED
30005  INPUT "GIVE MAX SPINDLE SPEED(REVS/SEC):-";NN
30006 SS = (60 * NN * 3.142 * OD(CNTR)) / 1000: REM  THIS I
     S NOW THE  MAX  ACHIEVABLE CUTTING SPEED IN M/MIN
30007 S2(CNTR) = SS: REM   DO THIS SIMPLY TO MAINTAIN CONFO
     RMITY WITH PREVIOUS NOMENCLATURE IN CALCULATIONS
30008  REM  WE MUST NO 'UN-FACTOR' THIS TO ARRIVE AT 'THEOR
     ETICAL' CUTTING SPEED TO DETERMINE TOOL LIFE
30009 S1 = S2(CNTR) / ( VAL (FA$) *  VAL (FB$) *  VAL (FC$)
     )
30010 T(CNTR) =  EXP ((( LOG (S1 / S)) - IL) / SL)
30012 N(CNTR) = NN:STDTIME(CNTR) = L(CNTR) / (F(CNTR) * N(C
     NTR) * 60):TCF(CNTR) =  INT (T(CNTR) / STDTIME(CNTR)):
     POWER(CNTR) = (D(CNTR) * F(CNTR) * S2(CNTR) * K1S(CNTR
     )) / 6120
30013 ST$(CNTR) =  STR$ (STDTIME(CNTR))
30014  FOR ZZ = 1 TO  LEN (ST$)
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30015  IF  MID$ (ST$(CNTR),ZZ,1) = "." THEN 30019
30016  NEXT ZZ
30019 ST$(CNTR) =  LEFT$ (ST$(CNTR),ZZ + 3)
30030  RETURN
30031  REM  ================================================
     =============
35000  REM  ******************************************
35010  REM  TEMPORARY                    SUBROUTINE FOR DREWS L
     ANE DEMO
35020 DTEMP = (MP * 6120) / (F(CNTR) * S2(CNTR) * K1S(CNTR)
     )
35030  HOME
35040  HTAB 10: PRINT "I.M.P.S. RESULTS"
35050  PRINT "******************************************"
35060 DT$ =  STR$ (DT)
35070  FOR ZZ = 1 TO  LEN (DT$)
35080  IF  MID$ (DT$,ZZ,1) = "." THEN 35100
35090  NEXT ZZ
35100 DT$ =  LEFT$ (DT$,(ZZ + 2))
35110  PRINT : PRINT "EITHER REDUCE D.O.C. TO:-";DT$;"MM"
35120  PRINT
35130  INPUT "OR:-";AA$
35137  HOME
35140  RETURN
39999  REM  ********************************************
     ****
40000  REM  SUBROUTINE TO CALCULATE POWER ,ITERATIVELY REDU
     CING FEED AND HOLDING SPEED 'CONSTANT' THEN ALTER TOOL
      LIFE IF NEED BE
40010  REM  THIS S/R IS TEMP METHOD FOR D/L PRESN. SINCE WE
      SHOULD NEED TO STORE ALL ORIGINAL VALUES CALCULATED T
     O DO THE THE NEXT S/R WHICH HOLDS FEED 'CONSTANT' ANDR
     EDUCES SPEED ITERATIVELT BY 10 M/MIN
40015 F1 = F(CNTR): REM  STORE  1ST EVER FEED SELECTED AFTE
     R ANY SPEED RESTRICTIONS HAVE BEEN CATERED FOR
40020 F(CNTR) = F(CNTR) - 0.01
40030  IF REC$ = HARD$ THEN S = B11S * ( EXP (( LOG (F) - I
     1) / S1)))
40040  IF REC$ = STD$ THEN S = B21S * ( EXP (( LOG (F) - I2
     ) / S2))
40050  IF REC$ = TGH$ THEN S = B31S * ( EXP (( LOG (F) - I3
     ) / S3))
40060 S1 = S *  EXP (IL + (SL * ( LOG (T))))
40070 S2(CNTR) = S1 * ( VAL (FA$)) * ( VAL (FB$)) * ( VAL (
     FC$))
40080 N(CNTR) = ((1000 * (S2(CNTR))) / (60 * 3.142 * OD(CNT
     R)))
40090 STDTIME(CNTR) = (L(CNTR)) / (F(CNTR) * N(CNTR) * 60)
40091 ST$(CNTR) =  STR$ (STDTIME(CNTR))
40092  FOR ZZ = 1 TO  LEN (ST$(CNTR))
40093  IF  MID$ (ST$(CNTR),ZZ,1) = "." THEN 40095
40094  NEXT ZZ
40095 ST$(CNTR) =  LEFT$ (ST$(CNTR),(ZZ + 3))
40100 K1S(CNTR) = KS * ( EXP (( LOG (F(CNTR)) - I4) / S4))
40105 K1S(CNTR) =  INT (K1S(CNTR) * (1 + (((MH - H) / 10) *
     H)))): REM   THIS HAS MODIFIED K1S TO TAKE INTO ACCOUN
     T THE DIFFERENCE BETWEEN MEAN GROUP HARDNESS AND ACTUA
     L MATERIAL HARDNESS
40110 POWER(CNTR) = (D(CNTR) * F(CNTR) * S2(CNTR) * K1S(CNT
     R)) / 6120
40115 TCF(CNTR) =  INT (T(CNTR) / STDTIME(CNTR))
40120  IF N(CNTR) > MS THEN T(CNTR) = T(CNTR) + 1:F(CNTR) =
     F1: GOTO 40020
40130  IF POWER(CNTR) > MP THEN 40020
40140  REM  SHOULD NOW HAVE SOLVED THE PROBLEM. GO AND PRIN
     T OUT THE ANSWER
40150  RETURN
49999  REM  ************************************************
     ************************************
50000  REM  SUBROUTINE TO PREDICT SURFACE FINISH ACHIEVABLE
      FROM THE INITIAL FEED RATE ARRIVED AT FOLLOWING ALL M
     ODIFICATIONS
50010  HOME
50020  PRINT "SURFACE FINISH ESTIMATES"
50030  PRINT "======================================="
50035  PRINT "(FEED RATE =";F;" MM/REV)"
50045  PRINT "*--------------*----------------------*"
50050  PRINT "! NOSE RAD(MM) ";"!";" SURF FINISH(MICRO-M) !
     "
50060  PRINT "*--------------*----------------------*"
50070  FOR ZZ = 1 TO 7
50075  PRINT "!              !                      !"
50080  PRINT "*--------------*----------------------*"
50090  NEXT ZZ
50100  FOR ZZ = 0.4 TO 3.2 STEP 0.4
50110  HTAB 6
50120  VTAB ((ZZ * 5) + 6)
50130  PRINT ZZ
50140 RA = (F * F) / (18 * ( SQR (3)) * ZZ)
50145 RA = RA * 1000: REM  CONVERSION OF UNITS TO MICROMETR
     ES
50150  HTAB 26
50160  VTAB ((ZZ * 5) + 6)
50170 RA$ =  LEFT$ ( STR$ (RA),3): PRINT RA$
50180  NEXT ZZ
50185  PRINT
50190  INPUT ZX$
50200  GOTO 16502
59999  REM ************************************************
     ******************************************
60000  REM  SECTION TO PRINT OUT 'OP SHEET-TYPE'SUMMARY
60001  REM  ********************************************
     *************
60002 D$ = ""
60003  PR# 2
60004  PRINT D$;"          "
60010  PRINT  TAB( 23);
60020  PRINT "OPERATIONS SUMMARY SHEET"
60025  PRINT  TAB( 23);
60030  PRINT "************************"
60040  PRINT " "
60042  PRINT " MATERIAL TYPE:-";XX$
60043  PRINT " ----------------------"
60045  PRINT " ": PRINT " "
60050  PRINT "OP.NO. START OD   DOC  SPEED   FEED   LENGTH   STD.
```

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                T.C.F."
60060  PRINT "=======================================================
     ==================="
60065 ZZ = 0
60067  IF CNTR = 2 THEN 60260
60070  FOR NZ = 2 TO (CNTR - 1)
60080 ZZ = ZZ + 10: REM  DUMMY OP.NO.
60090  PRINT ZZ; TAB( 8)
60110  PRINT OD(NZ); TAB( 9);
60130  PRINT D(NZ); TAB( 5);
60150  PRINT  INT (S2(NZ)); TAB( 6);
60170  PRINT F(NZ); TAB( 7);
60190  PRINT L(NZ); TAB( 8);
60210  PRINT ST$(NZ); TAB( 11);
60222  PRINT TCF(NZ)
60225  PRINT ""
60230  PRINT "-------------------------------------------------------
     -------------------"
60240  PRINT ""
60250  NEXT NZ
60260  REM  THIS IS THE FINISHING OPERATION DETAILS
60270  PRINT (ZZ + 10); TAB( 8);
60280  PRINT OD(1); TAB( 9);
60290  PRINT D(1); TAB( 5);
60300  PRINT  INT (S2(1)); TAB( 6);
60310  PRINT F(1); TAB( 7);
60320  PRINT L(1); TAB( 8);
60330  PRINT ST$(1); TAB( 11);
60340  PRINT TCF(1)
60350  PRINT ""
60360  PRINT "*******************************************************
     *******************"
60365  PRINT " "
60370  PRINT "": PRINT "SUMMARY ENDS"
60372  PR# 0
60375  RUN
```

TITLE A SYSTEMS APPROACH TO THE CONTROL OF CUTTING TOOLS WITHIN A LARGE-SCALE MANUFACTURING ENVIRONMENT

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