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**A Distributed Decision Support System
For Turning And Milling Operations
Using The Internet**

**A thesis submitted to the
University of Durham
for the degree of
Doctor of Philosophy**

by

Kelvin Mark Revere

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**School of Engineering
University of Durham**

January 2000



13 JUL 2001

Declaration

This thesis is the result of my own work. No part of this thesis has been submitted for any other degree in this or any other University.

Kelvin Mark Revere

Durham University

January 2000

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Abstract

The machine tool industry is highly dependent on the tooling which is needed to machine the components used to make the range of products seen in today's society. The range of tooling available to machinists is prolific and subject to continual growth. Those engineers faced with the task of process planning require advanced systems to support the decisions that need to be made for the production process to operate smoothly. The tooling data made available by these systems is a key factor in defining the efficiency with which the production processes can be carried out.

This research examines the technical decision support systems made available to industrialists and highlights the scope to provide tooling engineers with up-to-date tooling performance and use data that can be used both in the planning stages as well as dealing with problems encountered during production. Specifically, this research identifies the role performed by widespread tool trials, associated with new tools or new materials, and goes on to show how the information obtained from tool trials can be collated in a structured manner and used to enhance the provision of data with which to carry out the process planning task.

The goal of this research was to develop and implement a framework capable of collecting and disseminating data related to tool trials in a coherent and supportive fashion using distributed methods. This target resulted in the deployment of a system named JadeT, which is capable of receiving and analysing data from tool trials and subsequently enhancing the process planning task by basing cutting parameter selection on a combination of fundamental cutting parameter algorithms in parallel with using the approved data generated from tool trials. The JadeT system was tested via the creation of a database using actual tool trial reports, and the manner in which this data was used to provide cutting parameters was analysed.

The JadeT system has been developed, deployed and evaluated. The opportunity to use data contained within tool trial reports to support process planning tasks has been identified and exploited. The testing of JadeT indicates that the system fulfils the initial goals and was able to provide suggestions for further research in this area.

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Chapter 1 : Introduction

This chapter reviews the historical background of metal cutting operations within manufacturing industry, and goes on to highlight the key features of the manufacturing systems in use today. Brief consideration will also be given to the changing priorities within industry when attempting to keep pace with technological advances within the tooling arena. This will be followed by a statement of the research objectives and an outline of the thesis structure.

1.1 The evolution of metal cutting

Since the beginning of the industrial age there has been an ever increasing need to perform metal cutting operations due to the continuous developments and advances that have been made in engineering design as well as the similar advances in producing highly efficient and reliable semi-automated machine tools. In general, cutting operations are needed to achieve the following requirements;

1. To achieve closer dimensional accuracy.
2. To create external and internal profiles which could not be produced by casting, forging or shaping operations.
3. To create sharp corners and flatness unobtainable by casting, forging or shaping operations.
4. To perform finishing operations on heat-treated components which may have undergone distortion as a result of the heat treatment.

Until the middle of this century the majority of manufacturing operations were carried out manually by skilled engineers based in workshops equipped with lathes, milling machines and the like. At this time the labour market was rich with people possessing such technical engineering knowledge and practical engineering skills so there was no salient justification in trying to reduce the amount of time and labour required to produce any given component.



Once the economic effects and market depression associated with World War II diminished within Europe the global roots for mass consumerism were sewn. Such developments saw a rapid increase in not only the volume of consumer goods which were being demanded but also the quality and reliability of these goods. It soon became apparent that these traditional approaches to product manufacture were unable to meet the demands placed upon them from the market place.

The dawn of manufacturing automation had arrived and with it came new principles for industrial manufacture. The need to produce high quality interchangeable parts demanded consistent methods of manufacture; labour intensive workshops needed to be replaced with automated processes capable of meeting these more stringent needs.

The manual machine tools which had been commonplace in the manufacturing workshops became the focal point of the emerging age of computers. During the course of the 1950's much effort was focused on integrating new computing ability with traditional machine tools. Numerical Control (NC) machine tools gradually evolved and subsequent to this Computerised Numerical Control (CNC) machine tools were introduced, both of which were capable of being programmed to perform a variety of operations. These computerised machine tools were efficient at performing repetitive tasks in a consistent manner and hence they were widely adopted by manufacturing organisations.

Despite the impressive capability of modern machine tools, the efficiency achieved in performing the machining operations is offset when the capital investment aspect is considered. In order for a CNC machine tool to be of true benefit within a manufacturing organisation the way in which the machine tool is utilised has to be considered in great detail. This has resulted in engineers having to plan all aspects of the manufacture of components as soon as possible during the design phase. The alterations to component geometry at the manufacture stage which were prolific fifty years ago are now entirely unacceptable and could lead to a sizeable financial loss. The rapid material removal rates possible with modern machining centres and the financial implications of running such machines has led to a situation where the planning phase can account for 40% of the overall preparation time of any given component.

It should not be assumed that solely the machine tools have developed significantly in the latter half of this century. Indeed, a consequence of this increasing need to perform a greater volume and variety of cutting operations with more consistency has been the marked change in the tooling which is used to perform the machining operations.

The traditional machining environments saw engineers making their own tools by grinding them from High Speed Steel (HSS) bar stock. Each tool was unique and of course this is not conducive to enhancing machining consistency. The tooling market saw this approach diminishing rapidly and being replaced with toolholders capable of holding precisely formed inserts which performed the metal cutting actions.

In recent decades the tooling market has seen the proliferation of such tools and indexable inserts for operations performed on various component materials. New cutting edge materials and geometric designs are being developed to take advantage of the capabilities of new machining centres.

As a result of these considerations manufacturing organisations need to be able to plan both the tooling and machine tool resources which are necessary to produce any given component. With such poignant emphasis now placed on the planning stage of manufacture, the utilities which are made available to assist the engineer in performing these tasks can be vital.

1.2 The needs of modern machining industries

The technological advances which have been made in the machine tool and cutting tool industries have provided manufacturing organisations with a wide variety of products which are able to machine engineering components. Whilst the manufacture of components is a key part of any manufacturing organisation, this is not to say that there are not other functions which have an equally important role to play. Indeed, in recent times industries have realised that the total time taken to bring a new product to the market place has an important effect on the overall profitability of that product.

This need to reduce the product development cycle time saw the 1980's giving birth to the concept of *concurrent engineering*. Rather than the sequential progression of product design through to manufacture, concurrent engineering proposes that all the aspects of a product's design and manufacture can be carried out simultaneously. A significant amount of the research which focuses on concurrent engineering addresses the interaction of the various design elements with process planning and production facilities. A fully integrated concurrent engineering system would consider design criteria, materials, manufacturing methods, process planning, assembly, quality and, indeed, many other issues.

Consideration of such a fully integrated concurrent engineering system makes it clear that the efficiency of successfully employing such principles will result in the reduction of the product cycle time and hence lead to a more competitive manufacturing organisation. However, it is not the philosophy of concurrent engineering which raises doubts about the competitiveness of manufacturing companies; it is the provision and exchange of information in the utilities which are used to support the rudimentary elements of concurrent engineering. During the product development cycle the engineer must have access to the information which is required to make the necessary decisions.

Process planning is a significant task within the whole product development cycle. The process planning function refers to those tasks which ultimately provide the information necessary to machine the component. In effect, the remit of the process planning activity is to perform all tasks within the product development cycle which involve tooling related considerations. The first stage in process planning is to outline the sequence of operations which are required to produce the required component features. The completion of the process planning phase will yield detailed data about the machine tools to be used, the cutting tools to be used and the cutting parameters associated with each machining operation.

It is likely that the majority of manufacturing organisations are aware that the tooling market is highly dynamic and that the range of tooling products and their capabilities is subject to continual change and advancement. Because of competition between rival manufacturing establishments it is important for process planners to be continually aware of new tooling developments.

Within industry there is not only a need to engineer plans which will ensure the provision of the right tool at the right place at the right time, but it is crucial to have the data which is necessary to maximise the potential of that tool as well. Of course there are no companies which can claim to have developed a perfect management of machine tool and cutting tool resources. Throughout the engineering world it is commonplace for engineers to be consulted when difficulties arise during the production stage. In these situations it is necessary to resolve such problems quickly and effectively, so as to limit disruption to production.

It has already been noted that the main way to be a successful competitor within the manufacturing sector is to employ techniques that ensure a product development cycle which is as short as possible and a workshop set-up which is capable of responding to design changes and new components in an agile manner. When these global concepts are then examined in terms of the effects on the process planning activity, a number of key tooling requirements are made apparent, viz.;

- To be kept aware of the variety and availability of products in the tooling market.
- To have access to the information needed to maximise the capability of that tooling.
- To have rapid access to knowledge capable of resolving any problems encountered during the use of that tooling.

The efficient use of metal cutting tooling products can be seen to depend upon not only the physical properties and capabilities of that tooling; the dissemination and application of tooling knowledge is also a key factor when assessing the overall effectiveness of the process planning activity.

1.3 The evolution of computing technology

The early decades of the twentieth century saw noticeable advances in the variety and quality of machine tools. These advances led to a gradual increase in the productivity of manufacturing companies, and the first realisation that productivity is a measure of the overall manufacturing efficiency.

With efficiency having established itself as an important consideration, a more detailed analysis was undertaken. This resulted in efforts to reduce the labour costs and improve the efficiency and flexibility of manufacturing processes. These advances were achieved by the application of mechanisation techniques. The central role of mechanisation is to use mechanical devices fitted to machine tools which reduced the labour effort. However, labour costs are still significant even with the introduction of mechanised machine tools, as the operators still directly control the machining process. Mechanisation peaked around 1940, although the need for improving efficiency had by no means diminished.

The beginning of the 1940's saw the emergence of another industry which would prove to be vital in the context of the development of manufacturing systems. This industry was of course the computing industry and resulted in an exponential growth of manufacturing capability. In 1940 the first electronic computing machine was announced, and by 1943 the first digital computer had been developed.

The concept of using digital computers in performing traditionally manual tasks was born, and from the peak of mechanisation techniques were founded the roots of manufacturing automation. The word automation was first used in 1945 and is derived from the Greek word *automatos*, which means self-acting. A period of fevered development ensued, and by 1952 a prototype numerical-control (NC) machine tool was displayed. For the first time, various operations in component manufacture could be carried out by machines rather than people.

Since this breakthrough in machine tool control, rapid progress has been made in automating a significant number of the tasks involved in component manufacture. The development of NC machine tools was followed by the arrival of Computerised Numerical Control (CNC) machine tools. The main distinguishing feature between NC and CNC machines is that NC machines are controlled by a computing device which is remote from the machine tool whilst CNC machine tools are controlled by an integral computing facility.

Not only did the speed and accuracy of the machine tools improve, but parallel development work resulted in the design of adaptive control techniques which used data feedback from sensors to automatically control the machining process. In addition to this robots were introduced in the 1960's allowing automatic welding operations to be employed by the major car manufacturing organisations. These robots were then extended to provide automatic material handling, and eventually automated assembly tasks which further reduced the level of human involvement in the manufacturing process.

The use of computers in aiding the process of component manufacture has not been restricted to the shop floor. Indeed, computers have helped engineers in a number of manufacturing planning tasks for efficiently processing high volumes of complex data. One of the most powerful features of computing technology has been its ability to provide manufacturing organisations with a series of tools which can integrate virtually all the phases of product manufacture. The ideological integration of design and manufacturing activities proposed by concurrent engineering principles can be realised with the use of computers, and the level of computer integration will be an important consideration when evaluating the overall efficiency of the manufacturing task.

The development of digital microcomputers in the 1960's gave rise to the idea of Computer-Integrated Manufacturing (CIM). The primary goal of the CIM concept was to apply computers in integrating all the phases of the product development cycle. CIM can be broken down into three primary regions, namely Computer Aided Design (CAD), Computer Aided Process Planning (CAPP), and Computer Aided Manufacture (CAM). Computers would be used within each region to carry out the necessary tasks, and they would also be employed to facilitate the exchange of information between the traditionally separate activities.

Process planning within CIM is the link between the design and manufacture functions, as in the traditional architecture. However, during the research and development effort applied to the CIM concept it was the tasks of design and manufacture that received the initial attention, with CAPP development following behind. As the level of machining efficiency has improved, so has the variety of materials which are being machined and the tools which are used to machine them. These facts have made the tool selection and optimisation procedures within CAPP systems become increasingly more complex.

1.4 CAPP support from tool manufacturers

Traditionally it has not been the remit of tooling manufacturers to develop tool and cutting data selection utilities for industrial machinists. CAPP systems were capable of assessing tooling requirements, and the input of tooling knowledge from the planning engineer would provide sufficient information to perform the tool selection task.

As the demands placed upon the CAPP systems have heightened and the portfolio of cutting tools has increased significantly a gap has emerged in the traditional CAPP system. The CAPP system is sufficiently abstracted so as not to contain specific tooling data, whilst the planning engineer has been unable to keep pace with the developments and additions to the tooling range.

Those companies involved with the manufacture of metal cutting tooling products have seen this gap within the process planning domain and hence developed their own miniature CAPP systems. These systems would be based upon the products of a single manufacturer and would typically provide functionality allowing the tasks of tool selection and cutting data selection to take place.

At the current point in time it is the case that software provided to industrial machinists by tooling manufacturers contains static databases of information. This is to say that software may be supplied on floppy diskettes or CD ROM's intended for use on any general IBM compatible PC. Whilst the software provided on these media may be powerful in terms of its ability to aid industrialists on the technical side of planning the cutting operations, it should be noted that the databases of tools and their associated information is relatively static. The only way to maintain the accuracy of the data used by the software is to regularly update these databases of information; this course of action then requires the new databases to be distributed to the relevant machinists.

The battle to increase manufacturing efficiency and competitiveness is ongoing, and the laborious nature of updating tooling manufacturers' software seems not only antiquated, but incapable of reaching the same performance levels as the application of newly emerging technologies could achieve.

1.5 Web-based CAPP support

Recent years have seen a huge expansion in the volume of on-line information that is available via the 'information superhighway' or 'Internet'. The World Wide Web (or Web as it is more commonly known) can be considered as a huge interconnected web of pages - the difference between the Web and traditional media being that the Web provides a seamless and consistent way of displaying information from a plethora of sources.

Hypertext is the fundamental concept of the Web and allows information to be linked in a flexible manner. Hypertext author and theorist, Michael Joyce, distinguishes two varieties of hypertext, namely 'exploratory hypertext' and 'constructive hypertext'. The former of these may be considered as a 'read only' information source - the reader is presented with a finite set of choices from which they must choose in order to continue the process of reading.

Constructive hypertext is more flexible in its functionality, and is often considered as the 'read-write' form of hypertext. By allowing a reciprocal exchange of information between author and reader, the text is no longer a rigid collection of rules. The reader is able to find out information which is far more specific to their given needs, and, in addition to this, information provided by the user can be utilised in creating a developing body of knowledge which can then be extended to subsequent readers.

To say that tooling manufacturers have not taken advantage of the marketing opportunities made available by the existence of the World Wide Web would be a rather stringent way of assessing the situation, as several of the major tooling manufacturers do provide basic information regarding their products on the World Wide Web. However, it would be fair to say that the information given in these Web sites is based upon exploratory hypertext, and it is the responsibility of the user to navigate a number of pages in order to find the required information. The use of constructive hypertext is low, and within the tooling industry Web sites providing powerful user interfaces allowing dynamic data exchange between machinist and tool manufacturer are rare.

1.6 Research objectives

The targets of this research were as follows;

- To investigate and develop a database of tool trials¹ carried out by tool manufacturing engineers when solving industrial tooling problems.
- To provide a Web-based interface, based upon constructive hypertext, for accessing data stored in the tool trials database in an effort to solve a tooling problem whilst also reducing the need for tool trials.
- To provide a standardised Web-based tool trial form, again based upon constructive hypertext, for submitting tool trial data to a central database.
- To provide Web-based process planning utilities, for industrial machinists, which would avoid the creation of distributed tooling data by using a central database of tooling products.
- To identify trends within approved data from tool manufacturing engineers for enhancing the applicability and confidence of data sourced from standard catalogues.

A system was developed at the University of Durham called JadeT (Java Assisted Development for Engineering Tooling) which provided the functionality described above in relation to tool trials. This system was designed with the intention of being solely for the use of remote tooling engineers. An extension of the JadeT system was used to develop process planning utilities for the use of industrial machinists.

The author is pleased to report that the technical functions developed during the course of this research have been adopted by the Seco group of companies in their programme to consolidate opportunities afforded by e-commerce.

¹A tool trial is a trial which is instigated when a machinist is unable to solve a tooling problem by using the technical information provided in tooling guides. A tooling engineer from the tool manufacturer will visit the company and carry out a series of trials to find a solution to the problem.

1.7 Thesis structure

An outline of the remaining chapters in this thesis is given below:

Chapter 2 presents a review of literature in areas related to this research and includes consideration of areas such as process planning activities from initial tool selection through to tool-set rationalisation. Also, the ways in which the Internet can be exploited as a new media for conducting business are discussed.

Chapter 3 discusses the development of the industrial survey and the variety of methods and industries that were contained within the survey. This chapter also presents the direct results obtained from the survey and discussion of how these results were collated and used to suggest areas of productive research.

Chapter 4 presents a number of technical tooling support systems provided by tooling manufacturers and examines their strengths and weaknesses.

Chapter 5 will give an overview of the JadeT system which was developed during this research, and discuss its implications for tooling manufacturers and industrial machinists.

Chapter 6 will look in detail at the design and implementation of the tool trials database.

Chapter 7 continues with the theme of the tool trials database and goes on to discuss the methods and intelligent data handling routines that were applied to the tool trials database. The aim of these methods was to provide tooling engineers with highly specific data relating to a given tooling problem.

Chapter 8 provides details of the design and implementation of a web-based tool and cutting data selection system for turning and milling operations. In addition to this the integration of cutting data obtained from the tool trials database will be examined.

Finally, Chapter 9 will draw conclusions from this research work and will go on to make recommendations regarding other areas in this field suitable for the concentration of further research.

Chapter 2 : Literature review

2.1 Introduction

Before the Industrial Revolution goods had been produced in batches, and a large emphasis was placed on manual labour in all the stages of manufacture associated with any given product. It was the development of textile machinery and machine tools for cutting metals during the Industrial Revolution that saw the beginning of mechanisation in England and the rest of Europe. It was not long before this technology became available in the United States where it saw further development. It was especially in the US where important advances were made in the areas of design and manufacture resulting in a surfeit of products that today we could not imagine having to live without.

It is the relationship between design and manufacture that causes advances to be made in the engineering world. As designs became more complex and more demanding in their manufacture, the machine tools also experience improvement and this of course initiates the cycle of designing yet more complex products, and so on.

Up until the 1950's the emphasis on manual labour to produce components was still very high and labour strikes during the period between World War I and World War II forced manufacturing organisations to be aware of the power that their labourers had, when shielded by the Unions of which they were members. As a result of this, and the initial development of computing ability that allowed the development of computer controlled machine tools, it was possible for manufacturing organisations to radically change their environment. There was a move away from highly intensive labour-based industries towards those which saw less reliance on human labour and an increase in the use of computer controlled machine tools capable of rapidly producing high quality parts.

As these computer controlled machine tools improved, the balance between the time spent designing a product and the time spent manufacturing that product changed, and it is now the case that the activity of planning how to manufacture a product can account for 40% of the total preparation time [Colding (1992)].

During the 1970's and 80's, the power and speed of computers that were being designed experienced remarkable growth. In addition to this work was also being carried out into the concept of linking a number of computers together to form a computing network. A number of years on from this work the success of the Internet and the World Wide Web has opened up a series of possibilities for the manufacturing industries of today.

This chapter presents a review of published literature relating to the tasks associated with process planning, the technical support that is needed to carry out process planning tasks, and the extent to which computers and more recently the World Wide Web can be utilised by manufacturing industries.

2.2 Process planning

The aim of process planning is to determine a sequence of machining operations that when performed on the workpiece will produce the part as required by the design description [Luscombe and Toncich (1996), Chang (1990), Aldakhilallah and Ramesh (1997), Marefat and Britanik (1997), Horváth, *et al.* (1996)]. The process plans detail the routes and process parameters in addition to the machine tools and the cutting tools required for production. Process planning has a central role in manufacturing as it is an area that interfaces with product design, production planning and manufacturing system design [Kim and Cho (1994), Mamalis *et al.* (1996)].

Process planning has been the topic of investigation in a wide variety of research institutions during recent times. Whilst this research has focused on many diverse features of process planning there remains a significant level of agreement concerning the definition of process planning and the tasks it involves as well as the importance it has when considered in terms of the life-cycle of any machined component or product.

Before the implementation of powerful computers into industry, the majority of process planning was carried out manually. There are two categories of manual process planning that have been used to generate the process plans, namely to use handbooks and tables of data or alternatively to use mathematical techniques to model the cutting operations.

The use of handbooks and data tables to carry out process planning is historically the oldest method used to establish a process plan for a component. This approach involves the selection of cutting conditions from a variety of sources of data. Tables of cutting data are numerous and can range from small tables of data such as those printed in tooling catalogues [Seco Tools AB (1997a, b), Sandvik Coromant (1997a, b)] up to large sources of data which can be found in engineering handbooks, such as the Machinery's Handbook [Oberg and Jones (1954)]. This handbook contains almost two thousand pages of information relating to tooling, a high percentage of the information being printed in tables. The data presented in this handbook covers a wide range of topics and in most cases will contain all the information needed to carry out process planning tasks. In general the stages involved in creating a process plan are to select the following [Carpenter (1996)];

1. Workpiece material
2. Type of operation
3. Tool-holder
4. Cutting tool material
5. Other parameters (coolant etc.)
6. Look up cutting conditions in handbook

During the infancy of process planning there was little alternative to using handbooks in preparing a selection of process plans. Such a method of process planning is time consuming due to the significant volume of data that is contained in the handbooks, and the variations in the data specifications they quote. In addition to this, as the data is published explicitly, there is no way of knowing how that data was obtained and whether any constraints were applied during the evaluation of the data. Caution is therefore required when adopting machining data from a handbook when the source of the data is unknown.

As an alternative to manual process planning the cutting processes can be modelled mathematically [Smith and Tlusty (1991), Tan and Creese (1995)]. In general, tool life, power consumption and cutting force can be represented in algebraic equations rather than explicit data tables and so the space required to store the information is dramatically reduced.

2.3 Computer Aided Process Planning (CAPP)

Before computers were introduced into the manufacturing industry it was the responsibility of manual process planners to carry out the tasks and calculations associated with producing a given component. These manual process planners developed their skills through many years of experience and gained a significant amount of knowledge.

Even when computers did become available with the necessary speed and ability to carry out the calculations, there was a necessity for the computer to also be able to use the knowledge and experience of a manual process planner. For example, a computer would have to know factors such as;

- Available processes
- Process capabilities
- Size limitations
- Jigs and fixtures available
- Dimensional and geometric tolerances
- Surface finish

The history of computer development shows that the early microcomputers of the 1960's and early 70's were large, expensive and not well suited to carrying out calculations based on the wide variety of data available. The first use of a computer to carry out process planning activities was in the late 1970's. As the 80's arrived, computers were becoming more widely available and with enhanced levels of processing ability. In addition to this, the tooling market itself was expanding and it became difficult for process planners to have the knowledge necessary to use this ever increasing range of tooling. As computers became a realistic way of carrying out the calculations needed when undertaking process planning tasks, the mathematical equations used to calculate the cutting parameters became more and more complex, always taking into account an increasing number of parameters which affected and constrained the machining operation.

It should be noted that a Computer Aided Process Planning (CAPP) system is not a standalone piece of software that will carry out process planning with no human interaction (this partly explaining the emphasis of 'aided' in CAPP rather than 'automated'). A CAPP system is an expert piece of software that provides a process planner with assistance during the process planning stage of any component or product. As CAPP systems evolved there remained a central core of common objectives, namely [Luscombe and Toncich (1996)];

- Reduction in time to produce plans
- Reduction in number of human experts required
- Ensure consistency in plan preparation
- Optimisation of the plans.

Whilst reviews of process planning [Weill *et al.* (1982), Eversheim and Schulz (1985), Alting and Zhang (1989), Maropoulos (1995a, 1995b)] have shown agreement as to the tasks that should be performed, there is still debate as to the order in which these tasks should be carried out. The survey by Alting and Zhang (1989) covers the state-of-the-art of process planning and most CAPP systems world-wide at that time. Since then, agreement on process planning approaches and techniques seem to have been achieved [Zhao (1997)]. Alting and Zhang list the ten main functions of a CAPP system as being;

1. Interpretation of product design data
2. Selection of machining processes
3. Selection of machine tools
4. Determination of fixtures and datum surfaces
5. Sequencing of operations
6. Selection of inspection devices
7. Calculation of tolerances
8. Determination of reasonable tools and cutting conditions
9. Calculation of overall process times
10. Generation of process instructions (including NC data)

2.3.1 Classification of CAPP architecture

As CAPP gained momentum during the early stages of development, two broad categories of CAPP system became evident, namely the generative and the variant approaches, [Zhao (1997), Marefat and Britanik (1997)].

Generative process planning systems automatically create a new process plan for any new component that needs to be machined. The process plan for a part is started from scratch, and does not refer to any previous process plans. Instead, a generative CAPP system bases the process plans on manufacturing information stored in a database and decision making logic and algorithms [Marefat and Britanik (1997)] are used in order to prepare a process plan that will transform a blank workpiece into a finished component [ElMaraghy *et al.* (1993)]. Whilst a generative process planning system requires little user intervention in creating the process plans there are a number of limitations of adopting such a technique. A generative CAPP system does not utilise data obtained from existing process plans and in addition to this CAPP systems generally lack the ability to generate a variety of process plans for a given component [Marefat and Britanik (1997)]. This leads to the conclusion that a generative CAPP system can only optimise the process plans associated with a given component for a single objective function.

Having noted the way in which a generative system carries out the task of producing process plans for a given component, it should be clear that such a system does have the advantage of being able to calculate process plans for a part which is not similar to any previous process plans, as generative systems do not rely on previous work. If a generative process planning system has to prepare process plans for two similar parts, it is probable that a substantial amount of information in the first process plan could be utilised in producing the process plans for the second part, without the need for carrying out a completely new process planning exercise. A process planner which considers information within previous process plans and uses this information in the calculation of new process plans is referred to as a variant process planner. Essentially, old process planning solutions are retrieved and then modified to meet the needs of the new scenario [Marefat and Britanik (1997)].

The basis of the variant approach to process planning is to classify each part according to a number of its important attributes, these attributes being used to create a code for that part in accordance with a precise coding system. When a part has been allocated a code it will be stored in a database along with the process plan. Once the database of codes and process plans has been established, it is then possible to search the database when a process plan is needed for a new component. The way in which this is carried out is to assign a code to the new part and then search the database for previous plans whose codes match that of the current component. If a similar plan is found then it will be retrieved from the database for the user to either use the process plans *per se* or to modify them slightly in order to machine the new component.

The way in which the coding system operates is to cluster parts into part families, each part family having a similar selection of process plans. This coding process can be complex to carry out, and this is the situation where the computer excels, as it can be used to quickly process the data that needs to be assessed during the process planning phase of a part. A computer also has the ability to quickly calculate the changes that need to be made to an existing plan to machine a new component. The advantages of a variant process planning system are that the standardisation of plans leads to a reduction in the volume of duplicate plans being made and leads to more consistent and reliable plans. The disadvantages associated with variant systems are that any errors in original process plans may be inherited by future process plans. In addition to this variant systems are expensive to implement primarily because they are labour intensive during the installation phase within a manufacturing environment [Marefat and Britanik (1997), Carpenter (1996)]. Additionally, variant systems are not generally used within industries that manufacture a high variety of products, as this leads to a large number of standard plans being available within the database and only a few variant plans being constructed from them. Despite these drawbacks, Alting and Zhang (1989) report that variant CAPP systems have increased their presence within industry due to them requiring less capital investment and being far simpler to install than comparable generative systems.

Whilst the majority of process planning systems fall neatly into being classified as either generative or variant, there are a few hybrid methods that utilise the advantages from generative and variant systems and try to minimise their disadvantages. Such systems are called semi-generative systems or case-based systems. These types of CAPP system

firstly analyse the database of process plans established by a variant system. If the hybrid process planning system is unable to find a previous process plan that matches the new one, then the generative process planning architecture will be used to create a new process plan which will then be added to the database of previous work. Another purpose served by these semi-generative system is in bridging the gap for any company who wants to change from a generative to a variant system, or vice versa.

2.3.2 CAPP integration

In the last two decades, there has been an ever strengthening push towards establishing a fully integrated CIM (Computer Integrated Manufacturing) factory [Luo *et al.* (1997), Leung (1996), Aldakhilallah and Ramesh (1997)]. CIM may be defined as being a global information system for computerised manufacturing. This information system would provide a basis for integrating information flow through the whole manufacturing environment by means of a common data link [Luo *et al.* (1997)].

The CIM factory utilises CAPP in order to create a link between the CAD function, where products are conceived and designed, with the CAM function, where the products are manufactured according to the design specifications. This form of CAPP integration serves to unite all elements within the life-cycle of a product from initial design through to finished product. In addition to the role of CAPP within the CIM environment it should also be noted that CAPP has a significant role to play in the area of concurrent engineering where the design, process planning, and manufacture stages associated with a given component are merged [Maropoulos (1995c), Luo *et al.* (1997)]. This serves to shorten the manufacturing lead times, and to reduce the number of errors by enhancing the exchange of data between different business functions.

During the initial stages of CAPP research much effort was made in developing the functionality within the CAPP system, and little attention was paid to how the CAPP system would integrate with CAD and CAM functions. Because of this limited development in the area of interfacing CAPP with CAD and CAM, it became true to say that the CAD and CAM areas had overtaken the CAPP systems available at the time, and so the potential of CAPP to link CAD and CAM in an effective manner was reduced.

Within the research community there are a wide range of opinions as to what has been the significance so far of work carried out in the area of CAPP, and indeed what is required for the future [Maropoulos (1995b), Marefat and Britanik (1997)]. Barakat and Dutta (1996) describe CAPP as being a major step towards bridging the gap between the design and manufacture of a component. Whilst this cannot be denied in theory, the practicalities of the situation are somewhat different. Luo *et al.* (1997) believes that CAPP systems have not been able to keep up with the rapid developments in the CAD and CAM areas, and further to this they state that CAPP systems developed so far cannot play an important part in bridging the gap between CAD and CAM. Maropoulos (1995b) concurs with the beliefs of Luo *et al.* and states that process planning research in its present form has been saturated. Further to this it is noted that there are a large number of prototype CAPP systems, generally modelled using prismatic parts, and that additional research into this area will be of little value as a whole. In conclusion it is reported that there remains potential for applied research in the integration of CAPP with CAD and CAM functions.

2.3.3 The CAPP / CAD interface

The first stage of creating the process plan, as defined by Alting and Zhang, is referred to as 'Interpretation of product design data'. This stage encompasses feature recognition procedures that are able to analyse an engineering drawing and define a series of cutting operations that can be carried out in order to produce the finished part as specified in the initial design. In general, the CAD drawing of a component is analysed and various features within that part are identified. It is these features that can then be used to define which operations are needed in order to machine the workpiece and produce the finished component.

Since the CAD generated model of a product is the starting point for performing process planning activities, it follows that the main emphasis of any CAPP system is to be able to extract manufacturing features from that CAD generated product model. The subject of features receives the attention of many researchers and is a crucial element of the CIM concept. The three main techniques for carrying out the conversion from a CAD drawing to a series of manufacturing operations are [Salomons *et al.* (1993), Shah (1991)];

- Design by features
- Feature recognition
- Interactive feature definition

Design by features is the most recent development in the area of features and Maropoulos (1995b) suggests that design by features is the most promising technique regarding the interfacing of CAPP with CAD. Feature based modellers use pre-defined form features to construct the product that is being designed [Lenau (1993)]. These form features can then be converted into manufacturing features in preparation for the production phase. Manufacturing features are defined by considering form features from the viewpoint of manufacture, assembly and inspection [Krause *et al.* (1993)].

A problem has been identified in the conversion of form features to manufacturing features [Hummel and Brown (1989)] and various methods have been developed in order to try and correctly convert form features into manufacturing features [Rosen *et al.* (1991), Fu and de Pennington (1991)]. With an environment that only allows design through the use of a finite series of features, the designers may argue that their freedom in creating a new product is being suppressed. Whilst this may be partially true it was felt that the positive effects of linking CAD with CAPP outweighed this consideration.

The second method used to carry out the conversion of CAD drawings into a series of manufacturing operations is feature recognition. Research in the area of feature recognition is extensive [Aldakhilallah and Ramesh (1997), Lenau (1993), Kao (1992)].

Given the task of feature recognition, three key stages can be identified in applying the principles of feature recognition, viz.;

1. To recognise the features of a product from the CAD generated design specification.
2. To determine the set of component features required to manufacture the product.
3. To determine production plans consisting of sets of features that would provide the finished component.

The traditional approach to feature recognition is to classify features as either rotational, rotational with deviation, or non-rotational forms, although researchers have developed

a wide variety of methods to identify and specify features. Gindy (1989) suggests that features can be modelled as boxed-in volumes which are defined by entry, exit and depth boundaries. In an alternative approach, Requicha and Vandenbrandem (1989) suggest that design features can be linked to machining features via the specification of surface features and volumetric features respectively. Incorporated into this method are a series of rules to validate the identification of features. A survey of the variety of methods by which feature recognition can be carried out is presented and discussed by Subrahmanyam and Wozny (1995).

Whilst there are several recognised methods for carrying out feature recognition tasks, there is agreement that the main drawback of feature recognition is that complex shapes may not be recognised as a series of features [Salomons *et al.* (1993)]. This area has seen a number of research initiatives. Gao and Case (1993) discuss the practicalities associated with producing a series of manufacturing features from design features as defined by a Brep (boundary representation) modeller. Mill *et al.* (1993) have developed a composite component, referred to as an Edinburgh component, that is designed to assess the robustness of feature recognition as well as feature based design.

In addition to the problems posed by complex shapes, Kruth *et al.* (1994) identify and discuss the nature of the search space which supports the feature recognition task. Given the complexity associated with the systems designed to produce process plans from a series of features, they suggest that it is important to be able to discretise search space. In addressing this issue they seek to minimise the time spent identifying and collating relevant process planning information.

The third general method that is used to carry out process planning tasks from CAD drawings is referred to as 'Interactive feature definition'. This arose from a suggestion that feature based design and feature recognition should be used together to improve the interface between design and process planning [Wingard (1991), Wang (1991)]. Reliance on one method only may result in a greater complexity when producing the sequence of operations from the CAD drawing, and it is debatable as to whether the limited gains achieved by using one method is not outweighed by the use of two models side by side, as in the case of interactive feature recognition.

2.3.4 CAPP and product manufacture

Whether a CAD drawing is interpreted, or whether a product is designed by features, the same point in the process is reached; the machining operations required to produce the finished component will be known. The next step in generating the process plans is to select machining processes that will produce the required features in the blank part. At this point during the process planning phase it is not necessary to know in detail what tooling will be available. The operation generation phase simply quotes the operations that need to be performed in order to produce the finished component. For example consider a cylindrical workpiece clamped in a 3 jaw chuck in a lathe, the workpiece being 100mm in length and 40mm in diameter. If it was necessary to have a length of 50mm turned to a diameter of 38mm, then the operation would simply be quoted as needing a longitudinal external turning tool to provide a depth of cut of 1mm.

Subsequent to the machining processes having been selected, it is necessary to choose the machine tools that will be used to carry out the machining operations. This stage will involve consideration of conditions imposed by a given machine tool - for example, maximum workpiece diameter, maximum workpiece length, and the maximum power output of the machine tool would all be examples of constraints that need consideration. To sequence the operations which have been selected, each operation must be considered in terms of the type of cutting tool that will be used to perform it, the machine tool in which the operation will be performed, and finally, where the operation is placed with regard to the other machining operations.

Once initial operations and their process parameters have been defined it is possible to undergo a series of optimisation procedures. These optimisations are usually to maximise production or to maximise tool life. In addition to this it is also possible to vary cutting conditions in an attempt to optimise tool replacement strategies. With optimisation completed sufficient data will be available to calculate overall process times and finally process instructions will be generated. The next sections in this review of literature will consider a number of the core process planning activities that have been introduced in considerably more detail. Those activities to be considered are tool selection, cutting data selection and the application of cutting parameter optimisation techniques.

2.4 Tool selection

Tooling technology has a strong interface with process planning [Maropoulos (1995a)], since the key tasks of tool selection and the subsequent definition of how the tools should be used (i.e. the calculation of cutting conditions) are essential elements of the overall activity of process planning. Further to this, cutting tools are central to the machining of a component, since the characteristics of the tools and how they are used to produce the component have a direct effect on the quality of the components to be machined and the overall economics of the operation [Dhage and Usher (1993)].

Whilst the overall subject of process planning has received much attention over the past few years, the same cannot be said of the activity of tool selection. This is to say that tool selection is mentioned in research pertaining to CAPP systems but is rarely investigated in any worthwhile detail necessary to optimise the process. Further to this, a high proportion of the research carried out into tool selection considers only single-point machining applications (i.e. turning, and boring) [Arsecularatne *et al.* (1992), Agapiou (1992a-d), Wang (1993), Yeo (1995), Matos and Mesquita (1996)] - the area of multiple-point cutting operations (i.e. milling) has been neglected, perhaps due to the added complexity associated with having multiple cutting edges with each cutting tool, as suggested by Carpenter (1996).

Before the concentration of research in the area of process planning, it was common for tool selection activities to be carried out manually. This method of tool selection relies extensively on the knowledge of the person performing the tool selection activities and assumes that he or she is familiar with a wide variety of tooling from different manufacturers. It is suggested that the continual growth in the range of tooling products and the improvements in tooling technology make the task of manual tool selection unenviable [Dhage and Usher (1993), International Carbide Data (1990)].

Whilst a manual process planner may have the ability to select a set of tools capable of machining the component as required by the design, it is unlikely that this set of tools will be the optimum tool set. This can be asserted from consideration of the high number of tools which are available today to carry out any chosen operation. Further to

this, the task of calculating cutting conditions and carrying out even the most basic optimisation procedures would lead to the process planner taking an excessive amount of time to produce the final process plans. With the high cost of purchasing and running machine tools [ElMaraghy *et al.* (1993), Bard and Feo (1989), Houtzeel (1981)] this is by no means a cost-effective solution. Modern machine tools can cost £500,000 to purchase and accrue running costs of £300 per hour; utilisation of such investments is of critical importance in determining whether a manufacturing organisation is to be successful.

Because of these factors, research work has been guided into the development of CAPP systems which are capable of carrying out the majority of the procedures involved from initial tool selection all the way through to tool optimisation procedures. Despite this focus of research effort into the area of CAPP systems, such systems are fragmented and inadequate [Maropoulos (1995a)] at providing a truly efficient and comprehensive automated process planning system. Dhage and Usher (1993) examines the various methods available to an industry which can supplement any CAPP system when new tooling is needed and summarises these as being to;

- Gather advice from a representative of a tool manufacturer.
- Hire a tool consultant to evaluate the problem.
- Rely on in-house tooling engineers

Dhage and Usher discard the first two methods as primary solutions to the problem on the grounds of the limitations they suffer from and the risks associated with following their advice. Because of this and the apparent lack of functionality and efficiency associated with CAPP systems, the industrial utilisation of CAPP systems is currently supplemented by internal staff who are knowledgeable in the tooling field. Whilst this balance between CAPP systems and tooling engineers may seem a suitable compromise in the efforts for fully integrated CAPP systems, other factors have to be considered;

- The increases in the cost of machine tools means that the time spent performing operations planning should be kept to a minimum, and this is achieved by maximising the utilisation of CAPP systems and reducing the volume of manual work involved in the generation of process plans.

- The availability of tooling engineers is becoming limited [Allen (1987)] and so it is crucial that the work carried out by tooling engineers should be captured in such a way as to be incorporated into future CAPP systems.

Arising from this need for CAPP systems to increase the functionality they offer and the efficiency with which they operate is that the tooling features within such systems should be considered in more detail than the research indicates they have done to date.

The importance of tool selection and related activities within CAPP systems has been discussed and reviewed extensively [Maropoulos (1991, 1992), Maropoulos and Gill (1995), Maropoulos and Alamin (1995)]. This analysis has not been limited to the academic community and consideration of the technical literature made available to industrial machinists reveals that the topic of tool selection is covered in a variety of publications from the tooling manufacturers themselves [Seco Tools AB (1997a, b), Sandvik Coromant (1997a, b), Kennametal-Hertz (1996a, b), Walter (1996)].

2.4.1 Tool management

Collaboration with Seco UK and other tooling manufacturers during this and previous research has revealed that the instructions for carrying out tool selection presented within tooling catalogues have to be suitable for a wide (and unknown) variety of users. As a result the processes used to evaluate the data are simplified and the additional cutting data associated with a particular tool is conservative when compared to the theoretical potential of the given tool. Whilst the information regarding the selection of cutting conditions for any given tool is detailed (even if conservative), little consideration is given as to how tools should be chosen to perform a certain operation.

The portfolio of tooling made available to industrial machinists by the tooling manufacturers is forever increasing in both variety and cost, as is the number of tooling manufacturers themselves. Because of this trend, the last decade saw a gradual but significant number of researchers diverting their attention towards issues associated with tool management in an effort to utilise tooling resources in a more efficient manner [Macchiaroli and Riemma (1996), Park and Khoshnevis (1993), Gayman (1987)].

In a review of the state of the art of tool management by Eversheim *et al.* (1991), the aim of tool management is identified as being to ensure that the right tool is at the right place at the right time. The benefits to be derived from the successful attainment of this goal include high levels of machine tool utilisation courtesy of reduced setting up and idle times associated with tooling related issues, as well as a rationalisation of tooling as a source of cost. The authors suggest that tooling can account for 14% of manufacturing cost and is therefore an area that merits applied research in pursuing an efficient tool management strategy.

In terms of the methods that can be used to optimise tooling resources Eversheim reports that the key concept is that of managing tooling technology. The first step towards an effective tool management system is the development of a tool selection system that is able to provide tooling information at the pre-production stage. The basis of this statement is that it would be impossible to control the tooling inventory unless the tool selection phase is executed in a controlled and calculated manner. Once the tool selection task has been rationalised it will be possible to consider the topic of manufacturing control, namely the way in which the tooling resource is managed within the shop floor environment. By planning and executing a calculated approach to the purchase, storage and transportation of tools within the production environment the goals of tool management can be realised.

During the infancy of tool management in the late 1980's there existed a variety of opinions as to how the topic should be approached and the most promising methods that should be pursued. Gayman (1987) highlights this when he states that 'One of the problems is that there are so many tools in any operation, each with some variant to its life, that an overall program of rational management is exceptionally tough to put into place'. Whilst these comments may seem defeatist in nature, they are not unsubstantiated, especially considering the situation regarding CAPP, tool selection and tool management when this article was written in 1987. Looking back to the state of developments in the areas of these three research fields, it should be noted that in the early 1980's CAPP itself was in the preliminary stages of research along with tool selection. Whilst the vision of tool management may have been a realistic goal, it was simply the case that the building blocks necessary for effective tool management were not present.

Although the period associated with the conception of tool management was perhaps rather jaded, it would be incorrect to say that the concept of tool management has left the manufacturing arena. Despite initial scepticism, it was during the 1990's that research into CAPP and tool selection let some of the concepts and ideas of tool management be implemented into various computer based products for industrialists, even though the words 'tool management' are not used to describe the systems.

2.4.2 Tool selection systems

In the remainder of this section the various systems which have been developed to carry out tool selection under the hood of process planning will be discussed. Most of the systems reported are concerned with the problems arising from tool and workpiece geometry, and only a limited number of systems include technical aspects of the cutting tool as a criteria for tool selection.

The tool selection system by Mathieu and Bourdet (1987) proposes a method for the selection of tools for cylindrical turning operations based upon matching definition parameters of the operation with parameters of the tool which are based upon both geometric and technological considerations. Whilst this system proposes consideration of both technological and geometric features of the tool, the geometric capability of the system is only limited since it performs collision checks but it cannot provide a multi-tool solution for machining a profile containing either a recess or a shoulder.

Chen *et al.* (1989) base their analysis of the tool selection problem upon the various cost equations associated with this task. The authors' demonstrate that for any given tool and workpiece material, the only tool parameter that affects the operation cost is the cost per cutting edge. Their method for tool selection also takes into account the constraints which act during rough turning operations. The system is efficient in terms of the computational effort required as tools are ranked by the cost parameter and the system carries out detailed cost and cutting condition calculations for the top tool in the list (i.e. the one with the lowest cost per cutting edge). The other tools are examined in order to determine if their parameters will affect the constraint curves. It is possible that a tool with a higher cost per cutting edge may be able to satisfy the constraint tests and hence

be worthy of a full calculation of costs and cutting conditions. All the other tools in the list which would not lead to improved cutting parameters are discarded at this point and undergo no further analysis or consideration. Despite the technological approach to this method of tool selection it exhibits a number of weaknesses, the most significant of these being that the system can only deal with situations where one tool is capable of performing all the operations on a given workpiece.

The expert system presented by Giusti *et al.* (1986), called COATS, is for the optimised selection of tools for turning operations. The COATS module deals only with the tool selection task within process planning. COATS forms part of a larger generative process planning systems called PICAP. The COATS system includes a certain amount of technological consideration as the structure of the manufacturing system is stored in a rule-base and individual tools are assessed in terms of their ability for performing the cutting operations by assigning a 'weight' to each rule in the knowledge base, dependent upon the parameters of the tool. The assigning of arbitrary weights is noted by the authors as being not only a function of the importance of the particular parameter but also of the user's knowledge and experience. Further to this it has been argued by Maropoulos (1988) that the weight assigned to any given parameter is also a function of the operation being considered. As an example of this, consider face milling, where the machine power can limit the axial depth and feed rate and thus a smaller diameter tool might be capable of producing a higher metal removal rate than a larger diameter cutter. Whilst the power of the machine tool may constrain the choice of cutter diameter in this way, if the active constraint is tool stability (to avoid the onset of chatter) then a stiffer tool, that is to say the tool with the larger diameter, will be more suitable. Considering this apparent dichotomy between the application and weighting of different rules, it is apparent that the COATS system relies heavily on the expertise of the developer / user for defining an efficiently structured rule base.

Plummer and Hannam (1983) take both the workpiece material and profile geometry into account during tool selection but ignore a number of key aspects parameters associated with the insert; these include the carbide grade, chipbreaker, cutting edge length and nose radius. These parameters are significant during the selection of any tool as to a large extent they determine the overall performance of the tool.

In the system proposed by Sakamoto *et al.* (1987) the insert shape and material (carbide grade) are selected during the operation definition phase whilst the holder is selected using a collision checking module. Selecting the insert parameters at such an early stage does not give the system an opportunity to consider important parameters such as the power of the machine tool used to perform the machining operations, and the cutting parameters and forces. This leads to a situation where in the latter stages of the tool selection procedure the insert might be identified as being technically poor at performing the operation required and so the tool selected will not be the optimum one for the job.

The knowledge based system, called SIPS, presented by Nau and Luce (1987) carries out the activity of tool selection by determining the type or family of tools which can successfully machine the part, which tool size fits the constraints of the parts and finally the material from which the tool should be made.

The system developed by van Houten (1986) selects tools by applying dynamic programming to all the paths of a uni-directional network. The essence of this method is based upon the use of pre-defined tool set, an activity which is of course contrary to the existence and support of a complete tool database. An initial set of tools is chosen based upon which tools can feasibly perform the required machining operations. The optimal set of tools from this initial tool set is found by relating the total costs attributed to each tool with the number of available tool turret positions. Further to this, tool types are analysed in terms of their frequency of use. This analysis is then used to produce a list of tools which can feasibly be used with each given machine tool. The batch size will then be used to determine whether the tools are sourced from either this reduced set of feasible tools or from the whole tool store. The application of such logic within industries where the volume of tools is significant would be costly in terms of the time taken to perform this analysis. As is implied by the tool selection criterion, the aim of this system is not to produce highly optimised cutting data. Rather, the aim is to produce reasonable tool selections which will operate reliably and thus the objective function is simply a rough cost estimate rather than a complex economic model incorporated within process planning.

It should be added that the constraints imposed by the system are low in number, but high in terms of their importance relative to the machining operations being considered. However, when a system takes no account of factors such as the risk of the part being thrown out of the chuck, the axial and circumferential slip within the chuck, the workpiece deflection or the risk of tool breakage during machining, it is clear that the author's decision to propose this model as a basic economic model rather than a complex process planning system incorporating financial management was a wise one.

Consideration of one of the small number of systems dedicated to milling, Melkote and Taylor (1988) report an expert system for selecting milling cutters and determining the optimised feed rate and spindle speed. In this system it is necessary to provide information regarding the geometry of the workpiece and details of the operations to be performed. This data is subsequently used to assess the desired characteristics of the tool which can perform the operation, and generates information such as the cutter type, critical rake angles, diameter, pitch and insert shape. This technical information about the required tool is then used to select a suitable tool from the database of available tools. Finally the cutting conditions are determined based upon objective functions such as the cost of the operation and the production rate whilst constraining the solution by giving due consideration to cutting force, tool rigidity, surface finish and machine power.

Maropoulos and Hinduja (1990, 1991) present a refined and comprehensive method of performing tool selection. The method they present, unlike so many previous systems, is capable of considering both roughing and finishing turning operations. These two modules form an Automatic Tool Selection (ATS) program, a selection program which forms part of a CAM system called TECHTURN. The module associated with the selection of the optimum tools for rough turning operations initially selects all the tools that can feasibly machine the given component based on geometric considerations alone. For each of these tools the system calculates the machining cost based on approximate cutting data for the first and last pass in a multi-pass operation. The cutting parameters are chosen based upon an extensive variety of technical considerations; namely, machine tool power, work holding method, insert chipbreaker, workpiece deflection and tool breakage.

The system presents several alternative solutions, arranged in increasing order of cost, to the user who has the responsibility for making the final decision as to which tool set is chosen. In addition to both the technological and geometric considerations in performing the activity of tool selection, Maropoulos and Hinduja present a novel way of dealing with components which feature either a recess or a shoulder. Such features are dealt with by applying a technique known as 'feature splitting', which provides the ability to machine a single feature using more than one tool. For example, a recess may be formed by using a right handed tool to machine one side of the recess and a left handed tool for the other side. For the area of finish turning, the authors decide that rather than making extensive calculations to determine a precise machining cost, the approximate cost of machining with a tool is based on a nominal length and an average profile diameter, and on cutting parameters which, although approximate, are realistic because the procedure takes into account constraints such as chipbreaking, surface finish and diametral tolerance. The precise way in which tools are ranked uses a method which assigns each tool with an 'effective unit cost' (e.u.c.). The e.u.c. is the cost per unit of machined length and forms a stable and objective basis for comparing the relative performance of tools. Tools are then ranked according to e.u.c. and again, the user is presented with this information allowing a final decision to be taken as to the tooling that will be used.

Whilst none of the aforementioned systems can claim to provide a foolproof system which guarantees the selection of the optimal set of tooling for any component, it is fair to say that collectively the systems do consider a good variety of geometric and technical considerations when performing the tool selection activities. However, the expert system EXCAP (Wright *et al.* 1987) is a perfect example of how little tooling ability some systems offer, since it associates an operation with one or two recommended tools, and yet never performs any tool selection. Similarly, no details of the tool selection method employed by KAPPS (Iwata and Fukuda 1987) are given, and in this system the stage of determining the cutting conditions occurs before the selection of cutting tools.

Consideration of a variety of tool selection systems for both turning and milling illustrates that a number of systems perform extensive analysis on individual tools which are used to perform a single operation, and these systems are adept at producing

highly optimised machining parameters. Whilst the output of these systems may indeed be highly optimised, the practical implications of such calculations are that the optimised tool sets will contain a large number of unique tools. Most modern machining centres hold a limited number of pre-set tools so it would be advantageous if the number of unique tools required were to be less than the number of available tool posts - an important criterion that is not considered in the systems just described.

From consideration of the various factors that the different tool selection systems are constrained by, it can be seen that the majority of systems adhere to at least some of the geometric and technical constraints in tool selection. Whilst the adherence to these constraints is of importance, it should be remembered that many of these prototype systems rely on complex equations using obscure constants, some of which are only obtainable through a series of experimental tests, and of course this is a severe limiting factor when the systems are considered in the context of their industrial applicability.

It is suggested that any future tool selection system should incorporate as much tool and workpiece data as is freely available, particularly with regard to tool and workpiece material. Complete catalogues of tools and material standards are widespread, and current PC-based relational database management software is adept at handling high volumes of data and processing complex algorithms.

2.5 Cutting data selection and optimisation

As most components have a variety of features, it is probable that in order to manufacture a component more than one tool will be needed. Once a set of tools has been selected to carry out the machining of a component there is scope for optimisation of that tool set [Arsecularatne *et al.* (1992)]. This optimisation may consider whether the complete tool set is really needed in order to produce the finished component, and whether the cutting conditions may be altered in order to reduce the time taken to machine a component or to maximise the tool life of any given tool [Agapiou (1992a-c), Domazet and Lu (1992), Hati and Rao (1976), Ermer and Kromodihardjo (1981), Shalaby and Riad (1988), Boothroyd and Rusek (1976)]. It is also possible to optimise tool sets in order to make provision for the most efficient tool replacement strategy [Alting and Zhang (1994), Lambert and Walvekar (1978), Hitomi (1977, 1976, 1971)].

2.5.1 Historical cutting data selection

Before the recent advances in computer technology which yielded systems capable of processing the vast stores of information necessary to carry out process planning activities with any degree of efficiency, it was traditionally the case that the determination of process parameters was the task of machinists and machine operators [Mesquita *et al.* (1995), Wang and Wysk (1987)]. These engineers performed the selection of cutting conditions based upon years of experience with little consideration being given to their optimisation so as to adopt the most efficient method of manufacture. Two distinct approaches for performing the task of cutting data selection could be identified, namely data retrieval and empirical equation based methods.

Data retrieval methods function by obtaining cutting conditions from tables of values found in technical guides. This data has commonly been sourced from industrial environments and tends to be categorised by specific combinations of workpiece material, tool material and machining operation.

Empirical approaches to selecting cutting conditions are based upon the expanded Taylor tool-life equations. Whilst empirical approaches can yield reliable and consistent cutting parameters, it is common to encounter parameters which can only be estimated once an extensive series of tests have been performed; hence the practical suitability of this method is limited.

Today, both the data retrieval and empirical approaches would be of little practical use in obtaining financially efficient manufacturing operations. This is a consequence of not only the absence of optimisation techniques but also the need for performing extensive series of cutting tests is highly inappropriate in a field where the emphasis is on maximising machine utilisation and reducing down-time and other unproductive machine time.

2.5.2 The need for cutting parameter optimisation

Tan and Creese (1995) state that 'The selection of optimal machining parameters is a key factor in achieving machining efficiency.' Mesquita *et al.* (1995) concur with this and have stated that 'Improving efficiency of metal cutting operations can lead to considerable savings. For that purpose, selection of optimum machining parameters is a key issue.'

The instances where the importance of cutting data selection and optimisation are noted as being important in terms of overall manufacturing efficiency are extensive. Whilst the analysis of any given part of the process planning system is of interest, it is the complexity of these functions and their technical demands that place the emphasis on both the software systems and engineers that interact to perform these tasks efficiently [Sakal and Chow (1994), Lenau (1993), Larsen (1993), Wang and Wysk (1986)].

2.5.3 The cutting parameter optimisation task

Consideration of published literature makes it apparent that the number of factors which affect the overall result associated with a given machining operation is high, and that further to this the relationships that exist between process parameters are not linear. As a result it is not possible to apply simple methods to the highly complex task of optimising process parameters [Prasad *et al.* (1997), Zhang and Mallur (1994)].

Before examining the variety of methods applied to the task of optimising process parameters, it will be useful to define what is meant by the term 'optimisation' in respect of machining operations. Three objective criteria are recognised as being those which can be optimised by modifying cutting parameters associated with the machining of a component [Cho *et al.* (1994), Hitomi (1979)]. These are;

1. Maximum production rate (minimum cycle time)
2. Minimum cost (of machining the component)
3. Maximum profit

Prasad *et al.* (1997) identify two of the key considerations in any automatic optimisation technology as being the complexity of the mathematical models and the flexibility of those models. In both the areas of turning and milling, there exist a variety of clearly defined equations for calculating the time and cost of a machining operation based upon the process parameters and the technical and fiscal parameters of the cutting tool.

Whilst the fundamental equations derived for the calculation of machining times and costs are not of a complex nature, the constraints which are inherent in any machining operation are far more complex, and it is the way in which any system deals with these constraints that determines its effectiveness in a real manufacturing environment.

In a roughing operation, for example, constraints such as the spindle power of the machine tool, and maximum depth of cut and feed rate associated with a given insert will all be of importance, whilst the surface finish of the component will be of no interest. By contrast, a finishing operation will be keenly concerned with surface finish whilst the maximum spindle power and maximum process parameters that can be used with a given insert will be inconsequential.

2.5.3.1 Optimisation of parameters for turning operations

In terms of turning operations and the variety of methods that have been developed, a block diagram showing the breakdown of these methods is shown in Figure 2.1.

The methods which are based upon unconstrained optimisation consider purely machining parameters and no consideration is given to process constraints; as a result this method does not present a realistic representation of a practical machining situation.

As noted earlier, the three commonly accepted ways of optimising unconstrained methods is to strive for the maximum production rate (minimum production time), minimum cost per component or maximum profit (this situation occurring somewhere in the range between the other two extremes). These optimisation methods are carried out by the application of differential calculus techniques to equations for machining time and machining cost.

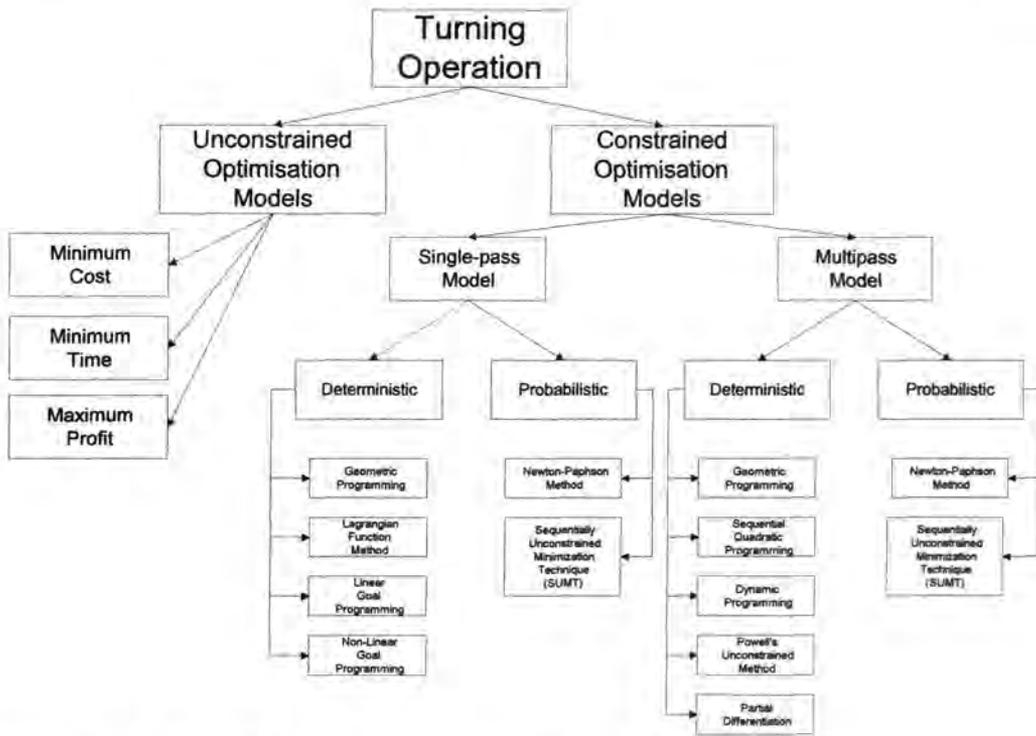


Figure 2.1 : Classification of optimisation models for turning

From Figure 2.1 it can be seen that the other branch is classified as being the group containing models which do consider process constraints. Constrained models are subdivided into single and multipass groups, each of these being further subdivided into probabilistic and deterministic models. The probabilistic group considers uncertainties in the process models whilst the deterministic group applies empirically known equations in the creation of a process model.

Whilst those models falling into the category of constrained optimisation models differ from the unconstrained models insofar as the techniques they use to perform the optimisation, it should be remembered that the overall goal of the constrained optimisation models is no different to the goal of the unconstrained models.

Whilst Figure 2.1 shows the various classifications for optimisation models, it should not be assumed that all manufacturing organisations even employ optimisation procedures during the selection of cutting conditions. Whilst the evidence from the research shows the importance of effective optimisation in achieving efficient machining operations, discussions held with a variety of manufacturing organisations (which will be discussed in significantly more detail in the following chapter) asserted that these methods were not always employed.

Table 2.1 summarises published literature for each of the various models.

Single / Multi Pass	Probabilistic / Deterministic	Modelling Method	Literature
Single pass	Deterministic	Geometric Programming	Phillips & Beightler (1970), Gopalakrishnan <i>et al.</i> (1991)
Single pass	Deterministic	Lagrangian Function Method	Bhattacharya <i>et al.</i> 1970
Single pass	Deterministic	Linear Goal Programming	Sundaram (1978)
Single pass	Deterministic	Non-linear Goal Programming	Satyanarayana <i>et al.</i> (1986)
Single pass	Probabilistic	Newton-Raphson and SUMT	Iwata <i>et al.</i> (1972)
Multi pass	Deterministic	Geometric Programming	Ermer and Kromodihardjo (1981)
Multi pass	Deterministic	Sequential Quadratic Programming	Chua <i>et al.</i> (1991)
Multi pass	Deterministic	Dynamic Programming	Hayes and Davis (1979)
Multi pass	Deterministic	Powell's Unconstrained Method	Yang and Seireg (1992)
Multi pass	Deterministic	Partial Differentiation	Kals and Hijink (1978), Hinduja <i>et al.</i> (1985)
Multi pass	Probabilistic	Newton-Raphson and SUMT	Iwata <i>et al.</i> (1977), Hati and Rao (1976)

Table 2.1 : Published literature for various process optimisation methods

The reader may be curious as to why no mention has been made of relatively new technologies such as fuzzy logic and neural networks. The reason is that both of these methodologies fall into a pool of research which assumes the title of 'adaptive control techniques'. Whilst it is theoretically possible to apply these techniques to off-line machining analysis, it is generally the case that they are used to perform on-line process monitoring. This allows real time analysis of the machining operations and in-process control to be undertaken. This on-line form of cutting parameter optimisation falls outside the remit of this work.

2.5.3.2 Optimisation of parameters for milling operations

Whilst the actual cutting processes involved in milling operations are more complex physically and mathematically, there remain a number of recurrent themes in the selection and optimisation of cutting data for milling, the four primary categories being;

- Empirical equation methods incorporating no constraint application or optimisation procedures. The empirical equations are, as in the case of turning, derived from expanded Taylor tool-life equations.
- Data retrieval methods incorporating no constraint application or optimisation procedures.
- Unconstrained mathematical modelling based on the solution of differential equations (DE's) generated from machining cost and machining time equations using mathematical models of machining operations. The DE's are solved for the cases of minimum production time per component, minimum cost per component, and maximum overall profit.
- Constrained mathematical modelling based on a variety of modelling techniques which also apply machining operation constraints. Optimisation is carried out on these constrained cutting parameters to achieve minimum time or cost, or maximum profit.

Whilst these categorisations are the same as those found in turning, the constrained mathematical models for milling are highly complex and contain a variety of both independent and dependent variables making the solution of multi-variate situations technically challenging.

2.5.4 Cutting parameter optimisation systems

With the high number of factors that are inherent in cutting processes and the complex relationships that exist between them, there are a wide variety of approaches used by researchers to attempt the optimisation of cutting conditions, irrespective of the objective function of the optimisation.

Field *et al.* (1969) perform the calculation of cutting conditions by assuming the parameters satisfy Taylor's equation. The parameters are calculated by considering three pairs of velocity and tool life data which are obtained from approved data sources and provided by the user. From these cutting data a series of detailed cost equations are presented, the objective functions being minimum cost or maximum production rate.

Friedman and Tipnis (1976) use the concept of R-T characteristic functions. In this approach the number of critical parameters for an operation is reduced to two; the material removal rate (R) and tool life (T). For a given material removal rate, the points on the R-T curve represent the cutting conditions that produce the longest tool life. It was shown that the cutting conditions associated with the three common objective functions all lie on the R-T curve.

Metha and Singh (1980) perform an optimisation procedure where the objective function is minimum tool wear. This is achieved by relating the optimum tool life to other variables such as tool changing time, machining time and non-machining time, which are all time dependent variables. The only constraint applied to this method is that the range of values of independent cutting variables adopted during the experimental tests to determine tool life parameters are within the range of values for which the equations for tool life and tool wear are valid. This approach is rather limited in both practicality and confidence in the data produced, as the method relies not only on experimental tests, but also no other process constraints besides tool wear are considered.

Reitz (1981) presents a series of suggestions as to the influences that cutting variables in milling have on the production times and costs. In addition to this a number of strategies are suggested for the order in which milling process parameters should be selected according to the influence each of them has on tool life. Typical process parameters considered are cutting velocity, feed per tooth and depth of cut, and the constraints on each of these variables are also given.

Ostafiev (1983) presents an optimisation procedure that generates not only cutting conditions, but tool geometry parameters and a tool path as well, with the objective function being maximum production rate. The overall procedure is carried out in two distinct parts;

1. Number of passes, cutter diameter and tool path are defined.
2. Cutting parameters are calculated.

Whilst the method contains two separate parts, there is an iterative process between the two parts until the maximum production rate criteria is obtained. During the first part of the method, the area to be removed is assumed to be distributed uniformly, allowing a constant depth and width of cut to be assumed. The tool path and number of passes are defined by imposing the objective function for this part as being to achieve the minimum cutting time per part. Whilst limits on the cutter diameter are shown, the method used to obtain these values is unclear. Analysis of the methods adopted in the selection of process parameters during the second part of this optimisation method shows that the author has considered a significant number of sets of variables;

- The optimised process parameters
- Input parameters such as material type, machining methods and machine tool
- Physical parameters such as cutting forces, contact load and surface roughness
- Economic indicators such as manufacturing costs, productivity and calculated time per part
- Uncontrolled disturbing factors such as variations in mechanical properties
- The feasible region of process parameters

Optimised parameters are obtained from the use of tool life and force equation models and the method of obtaining these parameters is to use successive unconditional minimisation or the combined method of penalty functions.

It is not only the area of turning where research has highlighted the importance of reducing machining costs in achieving overall economic production. Both Aggarwal (1985) and Thompson (1985) comment on the relevance of reducing the contribution of machining time to overall manufacturing costs. Aggarwal discusses the reduction of machining costs in the context of high speed machining (HSM). The focus of this work is directed towards those industries machining large components where the importance of reducing machining costs is even more prevalent. The determination of process parameters is effected by using diagrams showing spindle speed and cutting power for

various depths of cut and feed rates. A variety of constraints are considered in this method, the overall method summarised as being;

- To select the shortest length cutter which is capable of performing all the operations on a part.
- Referring to the HSM diagram for a particular end-mill to select process parameters for each operation.
- To ensure that the spindle speed, power and material removal rate are all towards the maximum capacity of the machine tool.

Thompson (1985) repeats the established truth that the main factor which influences the cutting process and its efficiency is tool life. Hence he proposes that cutting parameters are selected in an order such that their importance in terms of affecting tool life decreases. The selection of parameters becomes a three stage process;

- Select the maximum possible radial width of cut.
- Select the largest possible feed rate.
- Optimise the cutting velocity.

2.5.5 Summary of optimisation techniques

The past two decades have seen the development of computer software capable of carrying out optimisation procedures based upon extensive use of mathematical modelling of machining processes. Carpenter (1996) concurs with other researchers in the field of cutting data optimisation and concludes that recent research in this area has focused on turning operations to a far greater extent than milling. He suggests that this is due to the lower complexity of the cutting tool and workpiece geometry found in turning and in addition to this the uninterrupted nature of the cutting.

The variety of systems which have been developed suffer from a number of commonly occurring problems when applied to practical situations;

- The model is too complex and relies on data not readily available in a practical manufacturing environment.
- The model is too simple and considers few or no constraints leading to the risk of catastrophic failure during a machining operation.
- The model is too rigid and applies unimportant constraints to different classes of operation.

During the previous decade the effectiveness of performing the selection and optimisation of process parameters via the use of data retrieval has been limited. The inherently complex nature of machining operations requires that any databases of specific combinations of cutter, process parameters and material are extensive in order to cover commonly used tools and workpiece materials. At the beginning of this period it was not simple to either store or process such large volumes of data and hence the practicality of such systems was limited, and focus was given to the use of mathematical modelling in order to select and optimise process parameters. Whilst this focus on mathematical modelling resulted in the development of a number of systems claiming to carry out parameter selection and optimisation, neither the selection or optimisation algorithms were always robust or sufficiently constrained by the practicalities of real-life machining.

In light of previous work in this area and the significant advances that have been made in computing technology it is suggested that there are merits in using a system which is capable of limited mathematical modelling substantiated by data from real-life machining operations.

2.6 A brief review of the Internet

Recent times have seen a huge growth in not only the number of users found on the World Wide Web but also the number of companies both providing Internet services and also those establishing sites via the purchase of dedicated Web-servers [Pant and Hsu (1996), Yang and Keiser (1996), Berners-Lee and Cailliau (1990)]. Whilst this exceptional growth has created a number of problems for the Web and its users

[Baentsch *et al.* (1996)], it has also opened exciting opportunities to businesses as providing another way of reaching potential customers. Pant and Hsu (1996) suggest that the use of the Internet as a business tool may have the same effect on businesses as the rapid spread of personal computers during the 1980's.

The way in which navigation is made possible on the World Wide Web is via the use of Uniform Resource Locator's (URL's). Every page on the Web will be identified by having a unique URL, each URL comprising of three distinct parts, as illustrated below;

- **URL Format : Protocol / Server / File**

The protocol refers to the transmission type of the HTML (HyperText Markup Language) file, the three common options being **ftp** (File Transfer Protocol), **http** (HyperText Transfer Protocol) or **file** (for local HTML files). The server part of a URL is a unique name that refers to the server where the files are stored. The file part of the URL refers to the name of the HTML file as well as the directory in which it is contained.

A browser is the common name given to a software package that is capable of viewing HTML at a given URL address. By typing a URL into a browser the file referred to by the URL will be downloaded to the user's machine (the client system) from the specified server and can then be viewed by the user.

2.6.1 Hypertext fundamentals

As briefly stated in Chapter 1, hypertext theorist, Michael Joyce (1995), distinguishes two varieties of hypertext, namely 'exploratory hypertext' and 'constructive hypertext'. The former of these provides users with a 'read only' information source, navigation being possible by the user being presented with a finite set of choices from which a selection must be made in order to continue the process of reading.

These types of pages are written in HTML and allow a static display of information to the user [Duan (1996)]. Significant research has been carried out to investigate the effect that static pages have on the users of those pages [Nielsen (1990)].

One of the first issues to be highlighted by Strain and Berry (1996) is the high dependence on the architecture and format adopted by any given browser. It is noted that there is a division that exists between the page designer and the browser (and hence the end user). The nature of HTML allows page designers to define the logical structure of any page, but the designer will have no control over how this structure is implemented by the browser. Whilst a designer may define a certain piece of text within the page to be a level one heading, it is the browser that will define the font size and style that will be used to display all level one headings. In this way, it is possible for the designer's view of the page to be significantly different to the way in which the browser displays the page to the user.

Because of the static nature of pure hypertext pages, it is the responsibility of the reader to determine the route taken through the web of pages in order to (try and) arrive at the information required. The nature of this emphasis on the user at navigating a course to the desired information has been named the 'Navigation Problem' (Nielsen 1990). There are two major factors which can lead any given user to experiencing problems when carrying out Web navigation;

- The rapid growth in the number of pages available
- The unconstrained nature of the Web arising from the lack of a governing authority

Research into disorientation is prolific, and publications by Nielsen (1990), Conklin (1987), Kahn and Landow (1993), and Foss (1989) all conclude that the navigation of static pages can lead to a significant number of users feeling unsure of their location in cyberspace. In particular, a study conducted by Nielsen (1990) found that 56% of people agreed with the statement '*I was often confused about where I was*'.

2.6.2 The use of constructive hypertext

Whilst HTML itself may allow only static display of information, the whole nature of the Web is far from static, and recent times have seen significant advances being made in the availability of 'constructive hypertext'. i.e. hypertext pages that contain elements allowing direct user-interaction - akin to the remote use of software on a central server.

It should be stressed that one of the fundamental keys to the overall success of the World Wide Web on the Internet is the way in which the gap between different computer architectures has been bridged. A browser may be used on a UNIX based computer, a standard IBM PC, an Apple Macintosh PC or any other supported standard. Irrespective of the format of the user's hardware it is possible for all of them to view the same Web-pages, and this concept of 'platform independence' has gone a long way to removing the shroud of using dedicated software on each distinct platform. Not only is hypertext itself portable across different platforms, but these new technologies providing interactive features also offer platform independence.

It is the situation now that technologies are available for producing fully interactive Web-pages. A number of researchers have investigated the effect these technologies have in reducing the Navigation Problem associated with static pages. In addition to reducing the navigation problem, research is being carried out in the area of implementing distributed database access and data processing capabilities on the Web. This research has paid significant attention to data processing in the context of corporate environments and the effect the Web can have on businesses employing these techniques.

Whilst the introduction of new techniques which allowed user-interaction with a given Web-page was a significant step forward for the World Wide Web, thought needs to be given as to why user-interaction may be so important. The research on static pages and the limitations of these pages has shown that significant work is needed by the user in order to arrive at the required information, and the process of reading several pages in order to end up at the required destination is one of the most important reasons why disorientation may occur and the user may never reach the required information.

One of the advantages of user-interaction is that if a user can specify a few key criteria which will allow far more precise location of the required information then the risk of disorientation being experienced is reduced. Further consideration of this point makes it apparent that if a user is providing information particular to their data needs, the information must be generated specifically for that user. This requires capability for database access and data processing to be available to such interactive Web elements. As a result of this, the development of interactive Web capabilities was existing in parallel with the development of distributed database access on the Web.

2.6.3 Tools supporting user-interaction

The two commonly occurring methods for developing distributed database access applications are CGI (Common Gateway Interface) and Java. Both these methods are categorised under the heading of Distributed Object Computing (DOC). The analysis of traditional corporate environments revealed that the information repository utilised a wide variety of storage methods from mainframe based systems to UNIX workstations and personal computers (IBM PC's, Apple Macintoshes etc.) [Duan (1996)]. The ideology behind the DOC culture was to provide methods capable of allowing the seamless integration of data sources on differing platforms whilst still maintaining the overall goal of distributed objects [Schmidt and Vinoski (1995)]. The remainder of this section will present an overview of CGI and Java and the way in which they strive to achieve distributed database access.

2.6.3.1 The Common Gateway Interface (CGI)

Figure 2.2 illustrates a typical database application on the Web and the three main components of which it consists. These components are the Web browser, commonly referred to as a Web client, an HTTP server with a CGI program, and a database server. The whole process is initiated by the user generating a request, the information provided by the user normally being contained within HTML forms. Once the request is initiated, the query will be sent to the HTTP server thereby invoking the CGI program which is resident on that HTTP server. The CGI program converts the information contained within the HTML form to a specific database query and submits this query to the database for processing. Once the query has been processed by the database server the results will be returned to the CGI program, and finally passed to the Web client through the HTTP server.

CGI was developed from the need to provide a generic interface between an HTTP server and server applications being run by a Web user. Historically, CGI programs used to be the only option that was available to provide database access on the Web and hence CGI became the *de facto* standard for establishing a link between HTTP servers

and external applications [Duan (1996)]. As a result, CGI is the most common method of database access on today's Web.

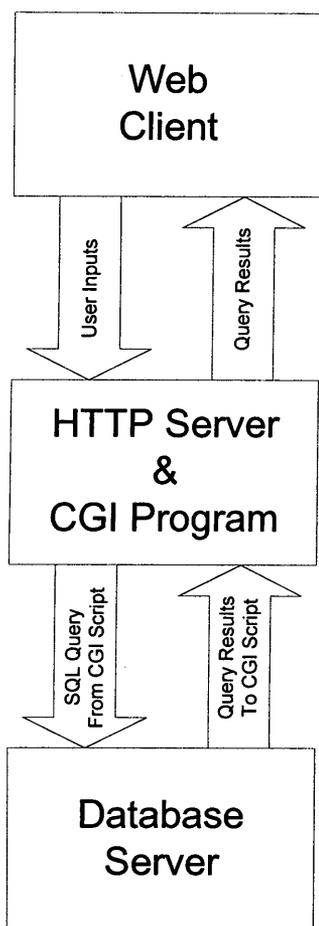


Figure 2.2 : CGI and database access

Although CGI applications are widespread and the concept of CGI is relatively simple in nature, the overall architecture of CGI suffers from a number of drawbacks which can be especially significant in an era when Web traffic is showing no signs of decreasing.

The first problem is that the use of CGI on an HTTP server means that the possibility of direct SQL¹ submission to the database is removed. This is to say that communication between the Web client and the database server must always go through the HTTP server. In times of busy traffic to the server this will be a significant bottleneck in the overall process as the HTTP server has to convert every user request to an SQL query via the CGI script and then convert the data back to HTML format before transmitting it to the user.

The second problem identified by Duan (1996) in his analysis of CGI programs is another one created during times of busy traffic, but emanates from a lack of efficiency in a CGI based database access script. In order to try and introduce some semblance of security measures into CGI scripts accessing databases on behalf of remote users, it was made necessary for every transaction submitted to the database server to undergo a logon and logoff procedure; this is true even for subsequent queries submitted by the same user. The logon and logoff procedures take system resources, and in times of heavy traffic the resources used are significant.

Whilst the provision of logon and logoff procedures may appear to enhance security, this is only true to a limited extent. Because of the statelessness of HTTP, the database query and the user ID and password have to be sent in one batch. As this transmission is

often in plain ASCII format the overall process is not considered as being secure. A workaround to this was for user ID and passwords to be embedded in the CGI program, whereby user authentication and access is handled by the HTTP server. Whilst this adds an additional level of security, a side effect is the additional demands on system resources to carry out these additional routines.

2.6.3.2 Java

Now consider the architecture associated with the use of Java to provide remote database access to a Web client. Figure 2.3 shows the same three components that were present for CGI based transactions, but the way in which Java links these components is fundamentally different as the HTTP server no longer acts as a stepping stone between the Web client and the HTTP server.

Java is a platform independent object oriented programming language based on C++, but designed to be fully portable over the Web. Java can be used to create interactive applications which can be imbedded in standard HTML documents.

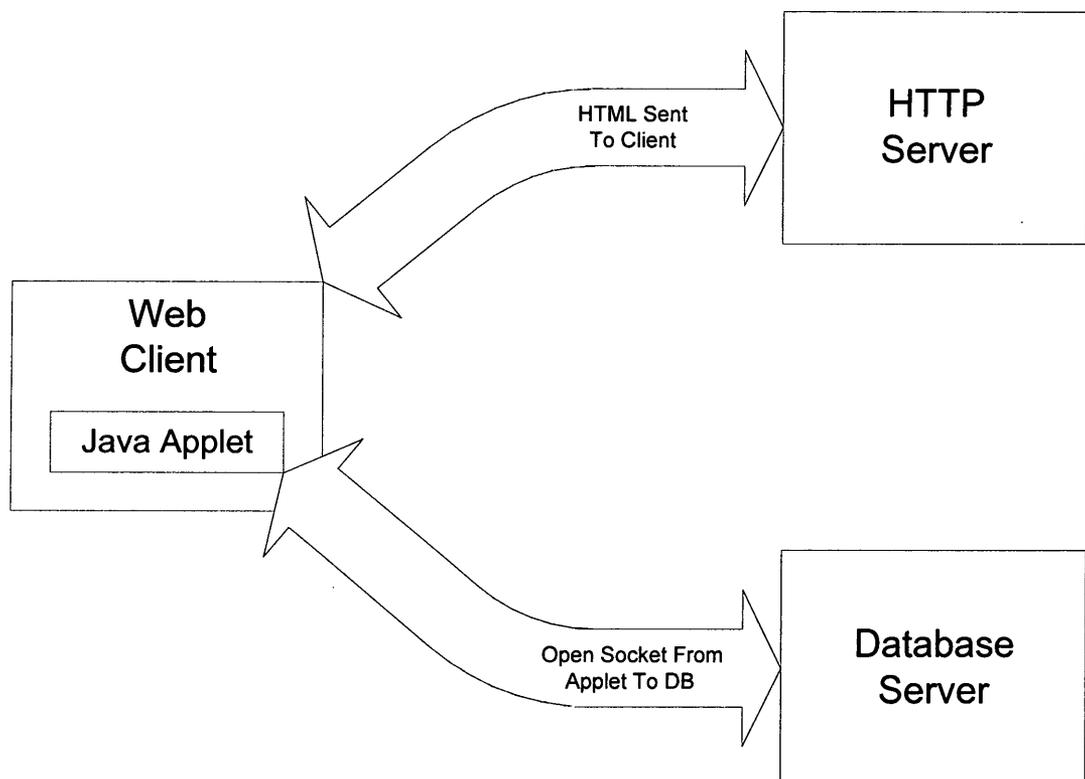


Figure 2.3 : Java and database access

Once the Java applet¹ has been initiated on the Web-client, it has the ability to make its own connection to the database server via the use of sockets. It is possible for a Java applet to communicate directly with the database, thus eliminating the bottleneck which CGI imposes on the HTTP server. In addition to this an applet has the ability to provide session-oriented communications with the database. This is to say that once an applet connects to a database, the connection can be kept open as long as the applet is alive and the user is in session. As a result of this, interactive queries and multiple database transactions can be supported, an advance on CGI which closes a connection as soon as an individual query has been processed irrespective of whether another query is queuing to be sent by the same user.

Not only does an applet have the ability to communicate directly with a database server, but it also has a full set of drawing functions made available through the AWT (Abstract Window Toolkit). Hence Java can handle sophisticated graphics and provide a comprehensive distributed computing arrangement all sewn neatly into an object oriented environment. Having overcome problems encountered with CGI and incorporating distributed database access with a professional GUI² created by the AWT, Java offers impressive scope for industries wishing to deploy interactive Web applications.

2.7 Summary and conclusions

The review of literature presented in this Chapter shows that research into machining issues and in particular computer aided machining issues has been receiving the attention of a number of researchers. The need for this type of research has been borne out of the changing face of manufacturing industry and the ever increasing need to produce higher quality products with shorter lead times. Whilst the research has been prolific, Maropoulos (1995a) suggests that this research has become fragmented and that the rate at which industries are adopting new methods and systems designed to enhance and optimise cutting processes has been disappointing.

¹ A Java applet is the name given to the interactive element of the Web page.

² GUI is an acronym for Graphical User Interface and is the part of the software with which the user interacts during use of the software.

The fragmentation of research is shown in the consideration of systems that have been developed to aid industrialists in the task of process planning. Such systems whilst perhaps presenting an efficient way of carrying out a particular aspect during the process planning phase lack the ability to attempt an overall solution to the process planning area, the consequence of which has been the low uptake of these systems by the industrialists for whom they were designed.

The next Chapter will analyse in detail the level of knowledge that appears to exist within manufacturing industry for carrying out the process planning task. It is fair to say at this point that the survey carried out as part of this research project in addition to the conclusions of other researchers has concluded that the level of knowledge amongst tooling customers is decreasing.

In addition to this it should be remembered that the level of computer processing power and data storage capacity has been significant during the last few years and that computer systems are now capable of performing complex analyses on a high volume of data with speed and efficiency. It is therefore suggested that in order to take advantage of this distributed computing technology, whilst trying to halt the decline in the technical knowledge amongst industrialists, future systems should utilise mathematical modelling of machining operations in combination with data storage and knowledge capturing systems.

Whilst it is not feasible for any system to reliably model the complete variety of constraints affecting any given machining operation, it is proposed that rather than trying to accurately model a single aspect of the machining of an entire component or assembly that a broader vision needs to be adopted. This is to say that whilst still employing a reasonable number of process constraints for the purposes of practical applicability, the focus of research should be to develop systems which can consider a wider section of the whole process planning activity. It is only through the development of systems capable of dealing with multiple aspects of process planning that it will be feasible to produce a fully computer-aided process planning system.

In addition to this Chapter 3 will discuss the results that were obtained from the survey of manufacturing industry and in particular the significant expression of interest from

industrialists in using the World Wide Web as a practical method for obtaining technical information, technical support and also providing a direct method of performing logistical tasks such as tool ordering. This need will be discussed in terms of the benefits it may yield for customers and manufacturers of tooling products alike and whether such systems would advance the level of technical support currently made available to industrialists.

Chapter 3 : A survey of manufacturing industry

3.1 Introduction

The manufacturing industry has experienced significant development in recent times and it would be difficult to accurately assess the engineering needs of such organisations without up to date and relevant knowledge. To satisfy this need it was suggested that a direct study of manufacturing companies would yield valuable information in terms of complementing the review of literature and hence defining a suitable research programme. In order to carry out this study a survey of engineering companies was instigated with the aim of establishing the tooling needs and priorities of a wide range of manufacturing industries.

When a product is considered in terms of the market for which it has been designed it is necessary to give attention to;

- Information needed to choose and order the correct product
- Functions the product can be expected to perform
- Dealing with problems encountered when using that product

In defining the aspects that the industrial survey would seek to address these three key areas served as a platform from which the survey could be built. When considered in the context of industrial tooling needs these three functions were identified as;

- Logistical considerations and requirements
- Tooling performance requirements
- Technical support requirements

A questionnaire was developed to gather the required information via both a series of industrial visits to leading manufacturing organisations as well as a more general mail-shot to companies throughout the UK. This chapter will examine the development of the survey and will be followed with a presentation and discussion of the results obtained.

3.2 Methods adopted for the industrial survey

3.2.1 Selection of survey group

Before being able to select those companies which would form the basis of the industrial survey there was a requirement to categorise manufacturing industry so that the sample of industries chosen would be wide ranging. In order to achieve this it was decided to initially use the 'volume / variety' classification system. This method takes the volume and variety of products made by a variety of manufacturing industries and places groups of similar companies on a chart of volume vs. variety. An illustrative volume / variety chart is shown in Figure 3.1.

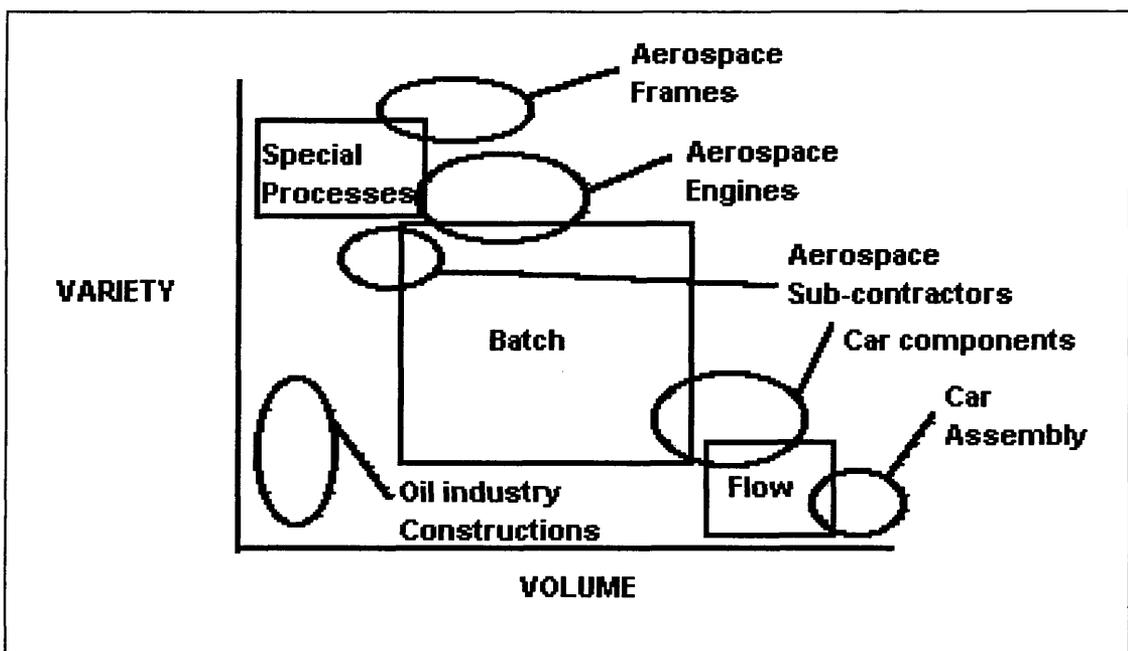


Figure 3.1 : Volume / variety classification of industry

From Figure 3.1 it can be seen that in general manufacturing companies are expected to fall into one of three major categories of machining environment, namely, 'flow', 'batch', or 'special processes'. These categories can be briefly defined as follows;

Flow

This group contains companies who produce a very high volume of products which are of low variety. Typical industry groups which fall into this categorisation are assembly plants for automotive vehicles and the manufacturers of automotive components. As

suggested by the name, production is carried out on highly automated flow lines offering limited flexibility.

Batch

This group is the largest of the three and contains industries which manufacture an average volume and variety of products. Because of the increased variety of products there is a need for the manufacturing environment to be more flexible, and a scheme of batch production is adopted.

Special Processes

This group occupies the position in the top left hand corner of the chart. As the name suggests, the group encompasses those manufacturing industries who operate in a relatively specialised field of manufacturing and hence make a low volume of highly varied products. Typical examples of such companies would be those associated with the aerospace industry.

Whilst the volume / variety chart provides an indication of the relative location of major industrial groups, it is necessary to ascertain the ways in which individual companies are categorised so that a representative sample of single companies could be selected to take part in the industrial survey. An analysis of company directories published by HMSO revealed a universally accepted method of categorising individual companies is via the allocation of SIC (Standard Industrial Classification) codes. The list of SIC codes for manufacturing industries is extensive and provides a more in-depth description of the activities of the companies than the broad groupings shown in the volume / variety chart. A sample of the SIC groups listed in the HMSO publication is shown in Table 3.1.

SIC Code	Description of Industrial Classification
3204	Fabricated constructional steelwork
3205	Boilers and process plant fabricators
3211	Agricultural machinery
3221	Metal-working machine tools
3222	Engineers' small tools
3251	Mining machinery
3254	Construction and earth moving equipment
3255	Mechanical lifting and handling equipment

Table 3.1 Sample of SIC codes

A complete list of all SIC codes relating to manufacturing industries was obtained and then sifted in order to eliminate those groups which would not have a need for the tooling of interest to this research. The resulting list of industrial groups hence contained those industries which did have a need for traditional tooling. Further referencing was carried out on the remaining thirty or so SIC groups, in order that each group could be assigned a position on a new volume / variety chart, as shown in Figure 3.2.

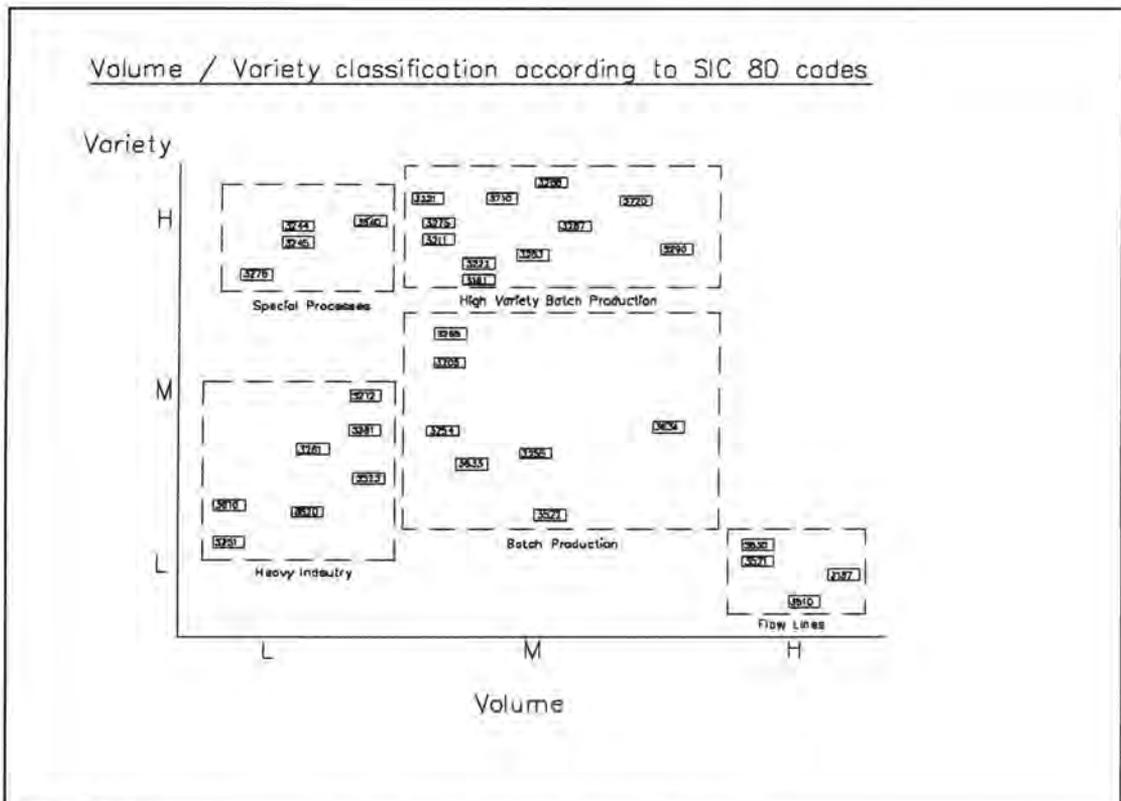


Figure 3.2 : Volume / variety chart according to SIC groups

It should be noted that whilst each SIC code in Figure 3.2 appears to occupy a small, well defined region of the volume / variety chart this is solely a representation of the overall group of companies relative to other groups of companies within the manufacturing sector. If individual companies in each SIC group had been considered, the area covered by each of the SIC groups on the volume / variety chart would be greater. The description of each of the SIC groups shown in Figure 3.2 can be found in Appendix A. This new volume / variety chart shown in Figure 3.2 can be seen to contain two additional clusters, namely 'high variety batch production' and 'heavy industry', the names of which should be self-explanatory in terms of the industries they are each likely to contain.

Once each of the SIC groups of relevance had been assigned a position on the volume / variety chart, it was possible to obtain a list of all the companies within each of the chosen SIC categories. The result of this was to obtain the details of approximately four and a half thousand companies.

3.2.2 Development of information gathering methods

With the survey group having been identified it was necessary to specify the methods which would be adopted to gather the required information and carry out a development process with the chosen information gathering methods. It was decided that a questionnaire would be designed to facilitate both a series of industrial visits by the author as well as a broader mail-shot. The questionnaire was developed with assistance from the collaborating company as they had a wealth of knowledge and experience in this area from a history of customer surveys. It should be noted that the name of the collaborating company was withheld from those people completing the questionnaire; the aim of the survey was to establish the tooling needs and priorities of manufacturing industry independently of any given tooling manufacturer.

A copy of the questionnaire can be found in Appendix B, from which it can be seen that the questionnaire is split into four sections;

1. General company details
2. Tooling performance requirements
3. Technical support requirements
4. Logistics requirements

For the mail-shot part of the survey it was felt that the questionnaire as it stood was too long and would draw a limited response from industry. It was decided to create three smaller mail-shot questionnaires, each of which would contain the 'General company details' section in addition to just one of the sections numbered 2 - 4 in the above list.

3.3 Results obtained from the industrial survey

The industrial visits were carried out in the North-East and the Midlands, whilst the mail-shot was nation-wide. It was noted earlier that the details of approximately four and a half thousand companies were obtained during the referencing of the directories of manufacturing industries. It was not possible to extend the mail-shot to all of these companies and hence a selection procedure had to be adopted.

The first stage of this selection process was to assess the number of companies within each of the SIC groups and hence calculate the proportion of the overall sample that each SIC group accounted for. The number of questionnaires sent to each SIC group was then decided according to the relative size of that group in terms of the number of companies it contained. Within each SIC group, an equal number of the three versions of the mail-shot questionnaire were distributed. A summary of the number of industrial visits performed and the response from the mail-shot questionnaire are summarised in Appendix C.

3.4 Discussion of results

This section will analyse and discuss the results that were obtained for each of three main sections of the questionnaire in terms of industrial tooling needs and priorities. The aggregate results from the questionnaire can be found in Appendix D.

3.4.1 Analysis of results for ‘tooling performance requirements’

As an initial indication of the results, it will be useful to consider a representation of the results in the form of a histogram, as shown in Figure 3.3. The scale for a number of questions has been reversed in order that all those questions with an average of above three indicates an industrial need or problem whilst those with an average response of below three indicates a low industrial need or above average satisfaction. Those questions which have been reversed are indicated on the histogram with a *.

From the first three questions it can be seen that companies are able to predict both the content and volume of their machining work as well as having a long time span for production planning. In terms of material machinability, companies have a relatively high number of materials to machine and yet experience few problems when assessing the machinability of these materials. Questions seven through to ten show that companies have to spend only a short time selecting tooling and cutting data and that they encounter few problems when performing these activities.

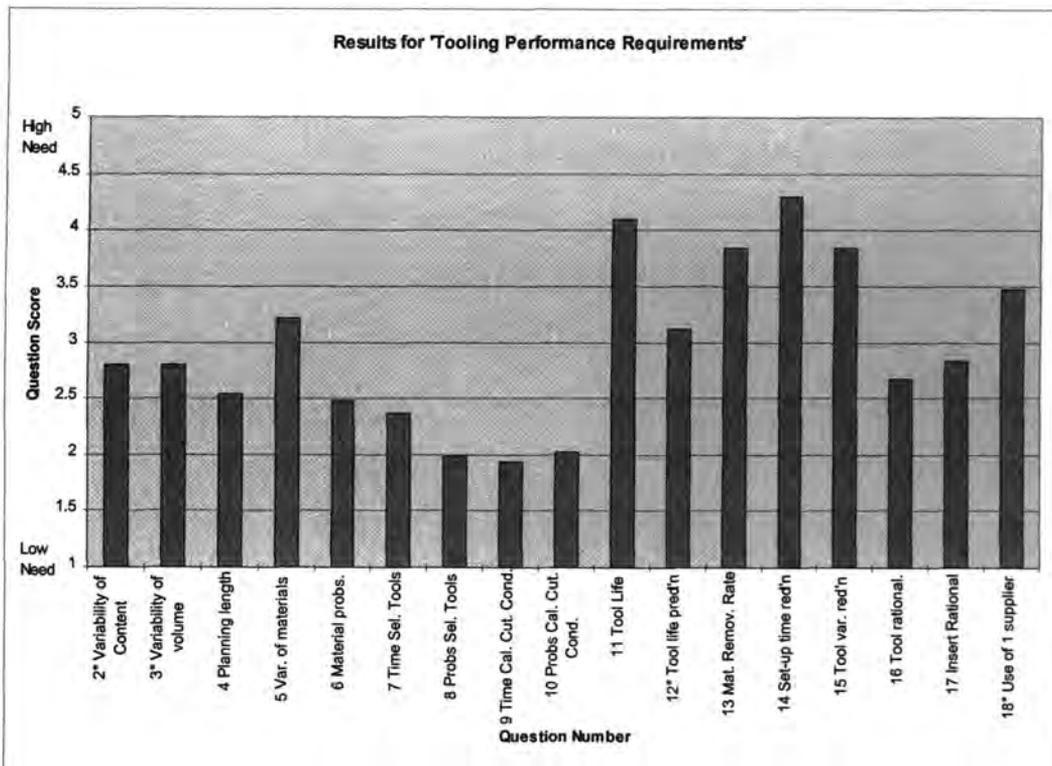


Figure 3.3 : Results for tooling performance requirements

The above conclusions were confirmed during the course of industrial visits. In general, the companies visited had a good knowledge of the technical parameters which have to be considered when performing these tasks and hence were able to carry out the preliminary stages of process planning successfully and with few problems.

An important area to be examined as part of the survey was that of tool life. The result was to find out that companies regard tool life to be very important. However, the number of problems associated with the task of predicting tool life were high, and during the discussions it was made apparent that a system which would provide an accurate way of predicting tool life would be of great interest.

Companies also attributed a high importance to material removal rate, set-up time reduction and tool variety reduction. The importance of tool variety reduction was emphasised during the industrial visits and it was generally the case that the majority of companies had recently undergone or were currently undergoing tool rationalisation procedures. Because of this activity the opportunities for tool-holder and insert rationalisation within companies were rather limited.

3.4.2 Analysis of results for ‘technical support requirements’

This section of the questionnaire was designed to look at;

- General requirements for the level of technical support from tooling manufacturers.
- Importance and effectiveness of a variety of technical support aids when performing a selection of process planning activities.
- Importance of various factors when tooling up a new machine tool and preferred methods for specifying tooling.
- Industrial interest in a variety of training courses provided by tooling suppliers.

The first two questions in this section were to assess the frequency and variability of technical queries - technical queries, in this situation, being defined as those where it was necessary to contact the tool manufacturer for technical advice. The results of these questions showed that the frequency of technical queries was quite high, whilst the variability of these queries was relatively low. This indicates that there is an industrial need for the tooling manufacturers to provide technical support. From the tool manufacturers view point, they can expect the nature of those queries to be predictable and hence easier to prepare for to give faster response times. The time taken to receive technical support from tooling suppliers, whilst not explicitly questioned in the survey, was regarded as important to the majority of companies visited.

Questions three through to ten, fourteen and fifteen were designed to examine the importance and effectiveness of tool catalogues and guides, tooling engineers, telephone technical support, software systems (CAD/CAM) and employee experience when performing a variety of process planning activities. Histograms showing the results for

the importance and effectiveness of the five technical support aids when performing each of the tooling related activities can be seen in Figures 3.4 and 3.5 respectively.

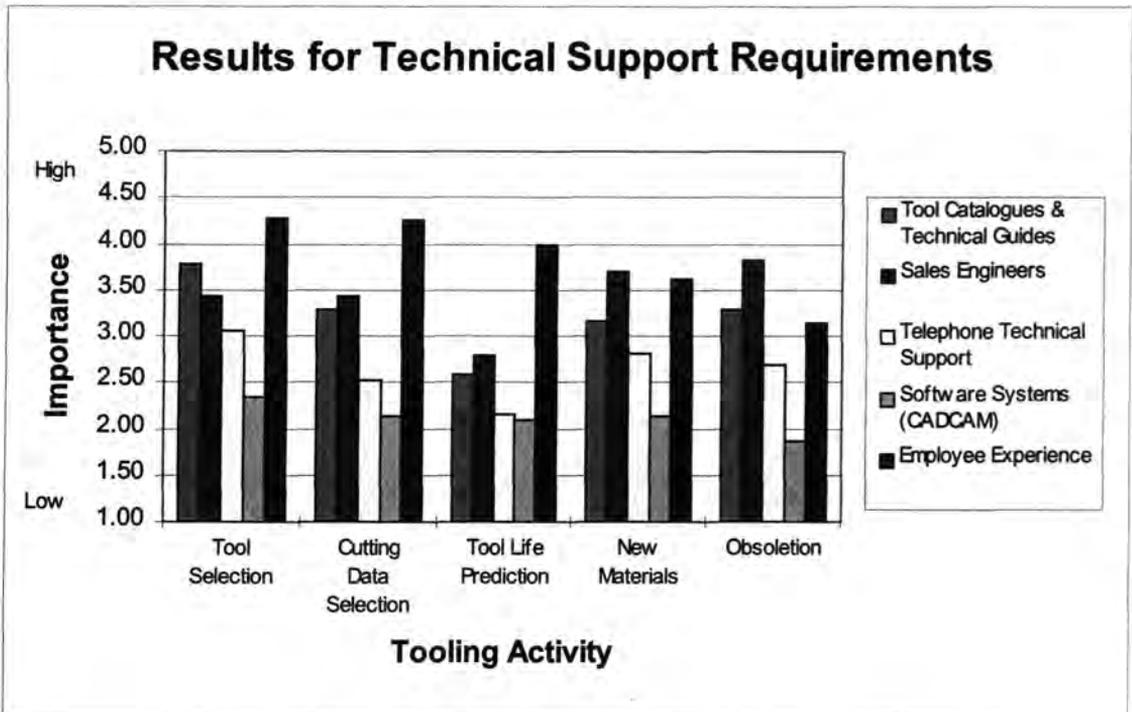


Figure 3.4 : Importance of various technical support aids

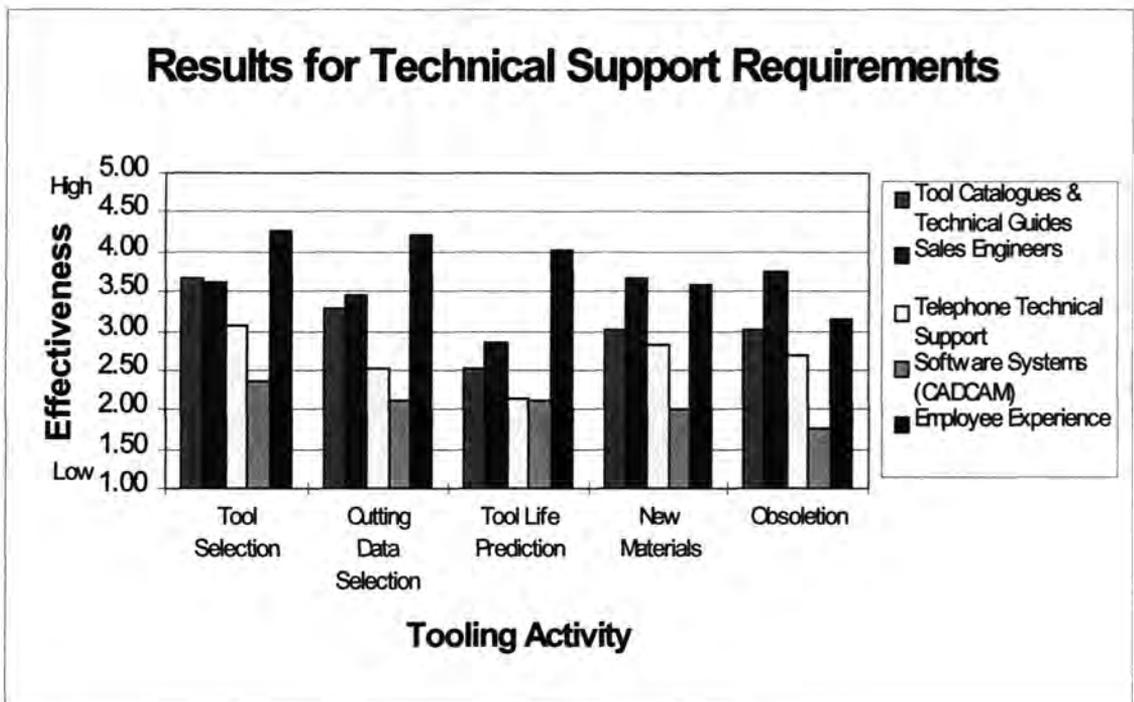


Figure 3.5 : Effectiveness of various technical support aids

From Figures 3.4 and 3.5 it can be seen that the results for importance (Figure 3.4) and the results for effectiveness (Figure 3.5) are almost identical, and hence all future references to the importance indicators are equally applicable to the effectiveness indicators as well. This is to say that the effectiveness of a technical support aid is directly linked with the level of utilisation of that aid by industry.

Figures 3.4 and 3.5 show that companies rely heavily on their own employees experience when dealing with the routine tooling activities of tool selection, cutting data selection and tool life prediction. This indicates that people within the companies have a good technical knowledge of the factors to be considered when performing these activities and this indication was asserted during the course of industrial visits. Figures 3.4 and 3.5 show that the importance of employee experience is reduced when it comes to machining new materials and especially so in the case of tooling obsolescence.

In terms of the services provided by tooling companies (tool catalogues and technical guides, tooling engineers, telephone technical support and software systems / CAD/CAM), Figures 3.4 and 3.5 show that tooling engineers from the tooling companies are regarded as being very important when dealing with the complete spectrum of tooling activities that need to be performed by companies. It should be noted that the term 'sales engineer' quoted in the Figures is something of a euphemism, and the people from tooling manufacturers with this job description are far more technically oriented than their title might suggest. Indeed, strong relationships can be formed between tooling suppliers and their customers based solely upon the confidence a customer has with the technical input from the tooling engineer.

By looking at the responses for the importance of tool catalogues and guides, it can be seen that they are an important source of information for all of the tooling activities given. They are particularly important for tool selection and cutting data selection, whilst being less important when dealing with new materials and tooling obsolescence.

The results also show that the importance of telephone technical support is rather low as compared with tooling engineers and the technical catalogues and guides. Despite this trend, it can be seen that telephone technical support is better favoured when it comes to the activities of tool selection and tool obsolescence. This result is expected, as sales staff

of the major tooling manufacturers receive training for these activities and can hence provide both an efficient and quick source of technical support for customers. During the course of discussions in the industrial visits it was made clear that the service of telephone technical support was limited when used for cutting data selection and tool life prediction activities. This again is expected, for the following reasons;

- Staff - The number of people within tooling companies who are able to provide solutions to these types of queries is more limited when compared with the number of people who are trained to deal with tool selection and obsolescence queries.
- Complexity - Both cutting data selection and tool life prediction are far more specific to individual customers due to the wide variety of factors that they are influenced by.

The result of this is that it takes longer for customers to receive answers to these particular types of technical query, and this is reflected in the results obtained. Figures 3.4 and 3.5 also show quite clearly that software systems are ineffective for all of the tooling activities selected. This result identifies the opportunity for producing software to cater for the tooling activities considered.

Tool life prediction is a complex area of tooling [Maropoulos (1995)] and involves consideration of a wide variety of company-specific factors. As a result of this, employee experience is relied on to a far greater extent than any service provided by the tooling suppliers to aid tool life prediction. For the situations where it is necessary to machine new materials, it is again the case that a combination of the technical knowledge of the tooling (via the tooling engineer) and the operations to be performed (via the industrial machinist) are used. The final tooling activity to be considered was obsolescence whereby older items of tooling are discontinued by the manufacturers. In this situation companies have to rely on the technical expertise of the tooling engineer in order to assist with the variety of technical considerations when changing tooling.

To summarise the results shown in Figures 3.4 and 3.5, it can be seen that companies tailor their use of technical support aids available to them according to their needs in respect of a particular tooling activity. For example, the activity of tool selection is relatively straightforward in terms of the factors that have to be considered. This is shown by the results insofar as companies rely on employee experience combined with

the tool catalogues and technical guides provided by the tooling companies. For the activity of cutting data selection, a greater number of factors have to be considered, and hence a combination of the technical knowledge of the tooling (via tooling engineers) and the operations to be performed (via the tooling customer) are used.

Whilst Figures 3.4 and 3.5 show us that companies rely heavily on the knowledge of their own employees, it would be unjustified to assume that these people are experts in their field who are always able to consistently obtain the best possible performance from their tooling. Due to the ever advancing face of the tooling industry and the wide variety of factors which influence tooling based decisions, it was decided to include a section in the questionnaire relating to training. A wide variety of tooling issues were considered in order to arrive at a list of ten training courses that could be organised by tooling manufacturers for the benefit of machinists. Companies were then asked to indicate their interest in attending each of these ten training courses. The results for this part of the 'technical support requirements' section can be seen in Figure 3.6.

From Figure 3.6 it can be seen that in general terms there is significant corporate interest in attending training courses organised by the tooling suppliers. It should be noted that a number of the tooling suppliers already have such training courses in operation. These results give a justification for the investment made by tooling manufacturers in the area of tooling training courses and also display the opportunity for work to be carried out in the development of corporate training modules for a wide variety of tooling issues. There is significant interest from industry in attending courses on tool selection, machinability assessment, cutting condition selection and tool life control. It was previously noted that companies rely extensively on their own internal knowledge to perform these activities. This result shows, for the next period at least, that they wish the emphasis to remain this way and are prepared to invest in the necessary training. From the viewpoint of the tooling manufacturers this is an advantage, as at the current point in time the tooling manufacturers provide free advice relating to these topics to individual companies as and when it is required. With the use of organised training courses, an opportunity is provided for tooling supplier to 'sell' this advice to a larger number of people. This is a better situation for the tooling manufacturers due to the extra revenue created, and may also serve to reduce the number of queries from individual machinists who rely on advice being given free of charge.

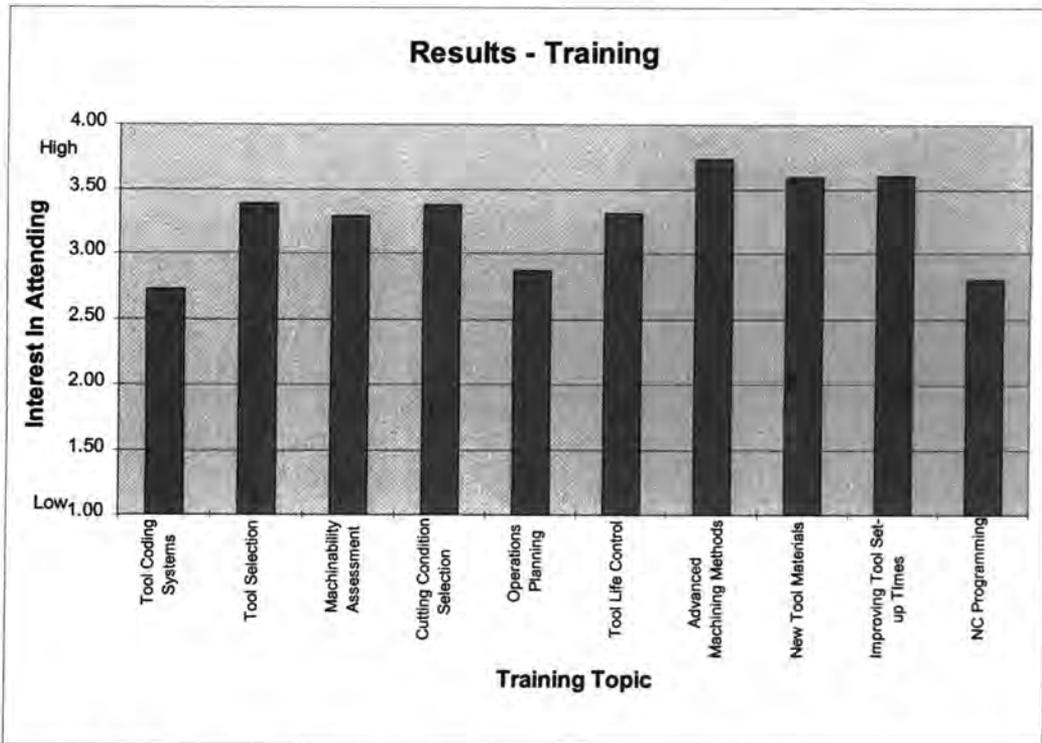


Figure 3.6 : Corporate interest in training courses

Companies also expressed significant interest in receiving training which focuses on advanced machining methods, new tool materials and improving tool set-up times. This indicates that companies appreciate the highly dynamic nature of the tooling industry and the importance associated with producing high quality components as quickly as possible in order to meet the general need of reducing product lead times and product cycle times. As a result of this important consideration companies are again prepared to invest in training for its employees, with the overall need to remain ahead in what is becoming a market of ever increasing competitiveness.

The interest expressed in attending training courses on operations planning, NC programming and tool coding systems was rather lower than for other training courses. Discussions during the industrial visits revealed that there was a consensus of opinion that both operations planning and NC programming were not the domain of the tooling manufacturers, and that the latter of these two areas was more the responsibility of the machine tool manufacturers. It is suggested that the reason for the relatively low interest in tool coding systems was due to the experience of companies own engineers being familiar with the available tooling through their work on tool selection and cutting data selection.

The remainder of the questions in this section on technical support requirements examined what factors companies considered when tooling up new machine tools and what methods they preferred for specifying the tooling packages for new machine tools. Question eleven focused on the importance of a variety of factors when tooling up a new machine tool. The results for this question are shown in Figure 3.7, from which it can be seen that the factors which are attributed to be of high importance are the reputation of the tooling supplier, experience with the tooling supplier and the cost of the tooling package. During the course of discussions it was made apparent that companies attributed a high importance to their trust of tooling manufacturers and hence the reputation of, and experience with tooling manufacturers are highly regarded.

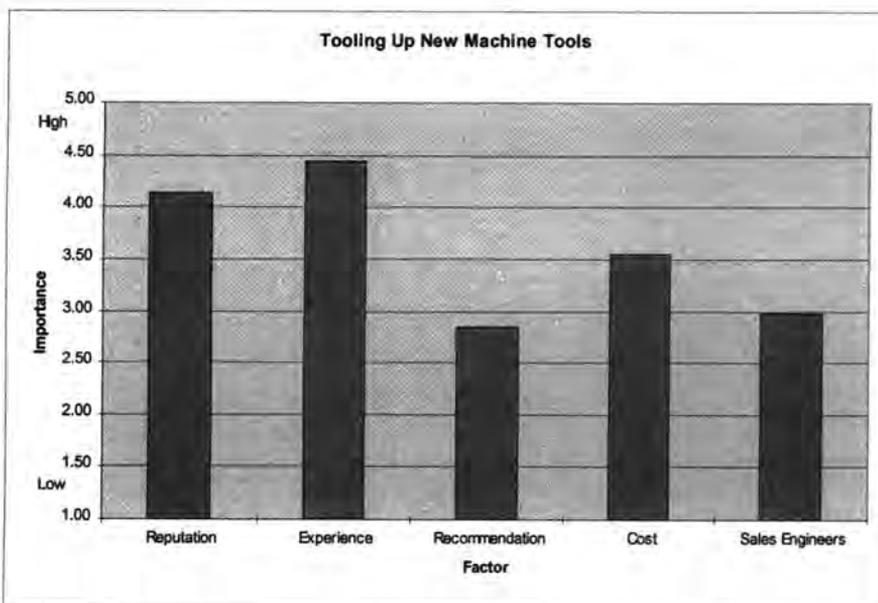


Figure 3.7 : Considerations when tooling up a new machine tool.

Two factors which were attributed to be of relatively low importance were a recommendation from the machine tool supplier and the advice from the tooling manufacturers tooling engineers. Companies believe that specific machine tool manufacturers were operating on a commission basis to recommend and supply a particular brand of tooling. As a result of this, no significant importance was attached to the advice received from machine tool manufacturers.

Question twelve in the section on 'Technical Support Requirements' examined how companies specified the tooling for new machine tools. There are three general options available when specifying how a new machine tool is to be supplied;

1. Machine builder specified turnkey package - This is a tooling package specified by the machine tool manufacturer and is pre-installed on the new machine tool.
2. Company specified turnkey package - This is a tooling package specified by the industrial machinist and is also pre-installed on the new machine tool.
3. Machine supplied without tooling - As the name suggests, the new machine tool is supplied without any tooling, and the machinist will then tool up the machine tool themselves (usually via interaction with a variety of tooling manufacturers).

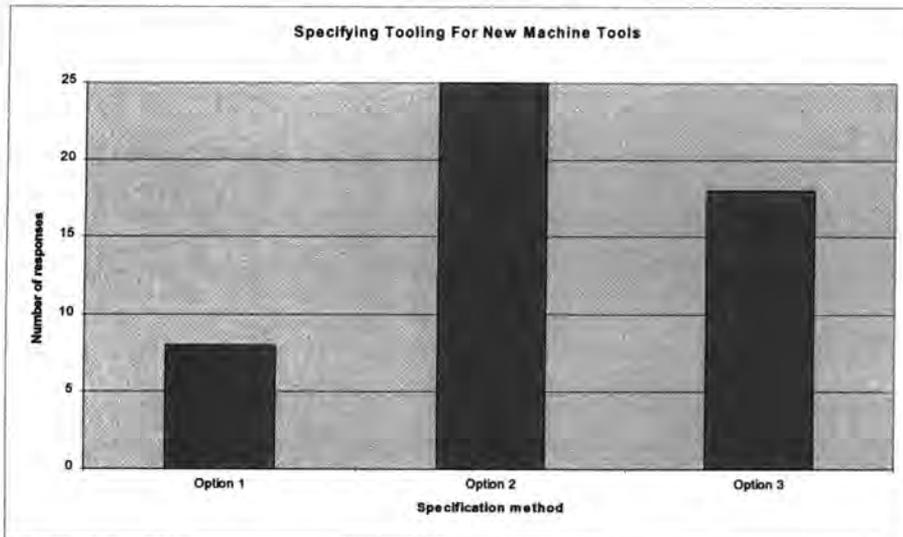


Figure 3.8 : Specifying tooling for new machine tools.

From Figure 3.8 it can be seen that the preferred method for specifying tooling for a new machine tool is option 2, a company specified turnkey package. The next most popular option is for the machine to be supplied without tooling and to be tooled up post delivery. The least popular option is to order tooling specified by the machine tool manufacturer. These results are as expected from the discussion relating to the importance of various factors when tooling up a new machine as shown in Figure 3.7.

3.4.3 Analysis of results for 'logistics requirements'

This section of the questionnaire looked at a number of factors associated with logistical considerations of tooling, and a summary of the results is shown in Figure 3.9. From these results it can be seen that;

- Tooling delivery is regarded as being of high importance.

- The average variety of tooling used by a company is high.
- Companies neither find it simple nor complex to control their tooling inventory.
- Tool requirement planning is important, and in general companies are able to predict their tooling requirements accurately.
- Companies have expressed a need for effective tool management systems. It was apparent that companies were aware of the availability of tool management systems (TMS) but were unable to find a TMS that worked efficiently for them.
- In terms of the methods of ordering tools, both the telephone and fax are regarded as being highly important and the most commonly used. Traditional mail is useful, but in general is only used for confirmation of orders transmitted via fax or telephone. The use of electronic mail is very limited although almost all companies expressed significant interest in this method of tool ordering should it become available to them.
- In general companies expressed little interest in tool suppliers having the responsibility for handling their tool ordering. A number of companies had used this facility on a trial basis and found it unsuccessful.
- Companies do experience problems when trying to identify obsolete tools.

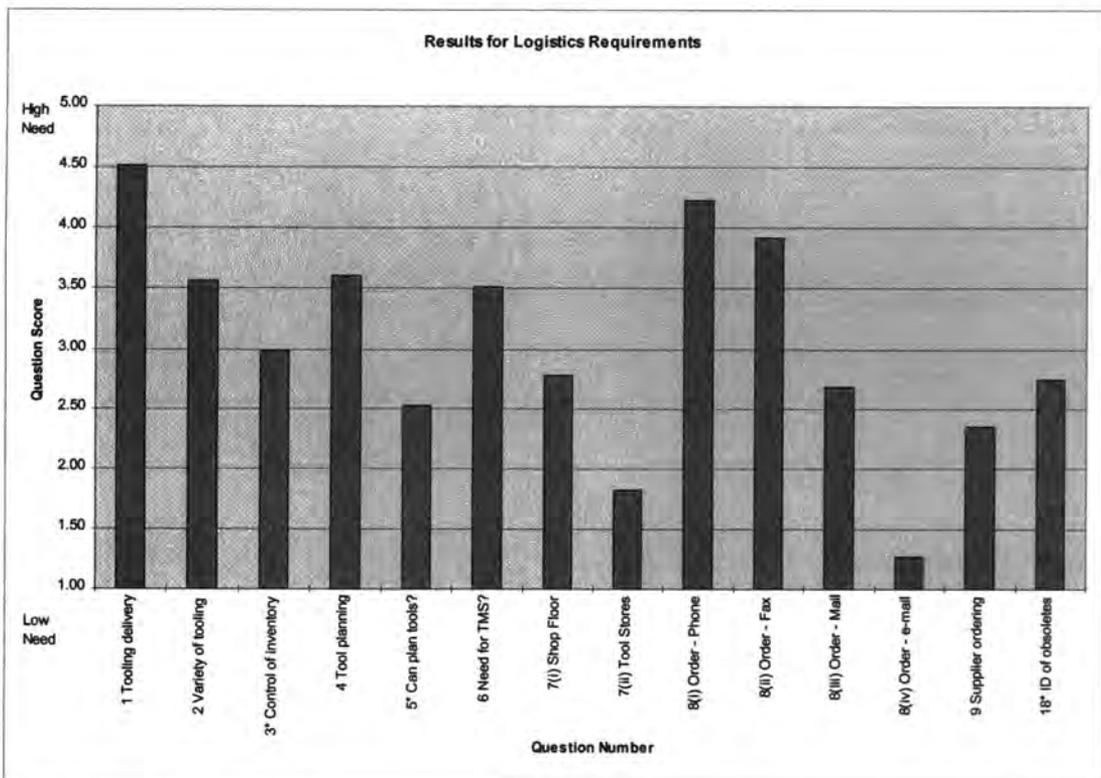


Figure 3.9 : Results for logistics requirements.

Because of the dynamic nature of the tooling industry, new products are continually being introduced into the product range of tooling manufacturers. In order to accommodate these new tools, it is necessary for tooling manufacturers to make a number of older items of tooling obsolete. One of the questions in the survey focused on this area and asked companies to rate a number of factors which might affect them as a result of tools being made obsolete. The results for this question are shown in Figure 3.10.

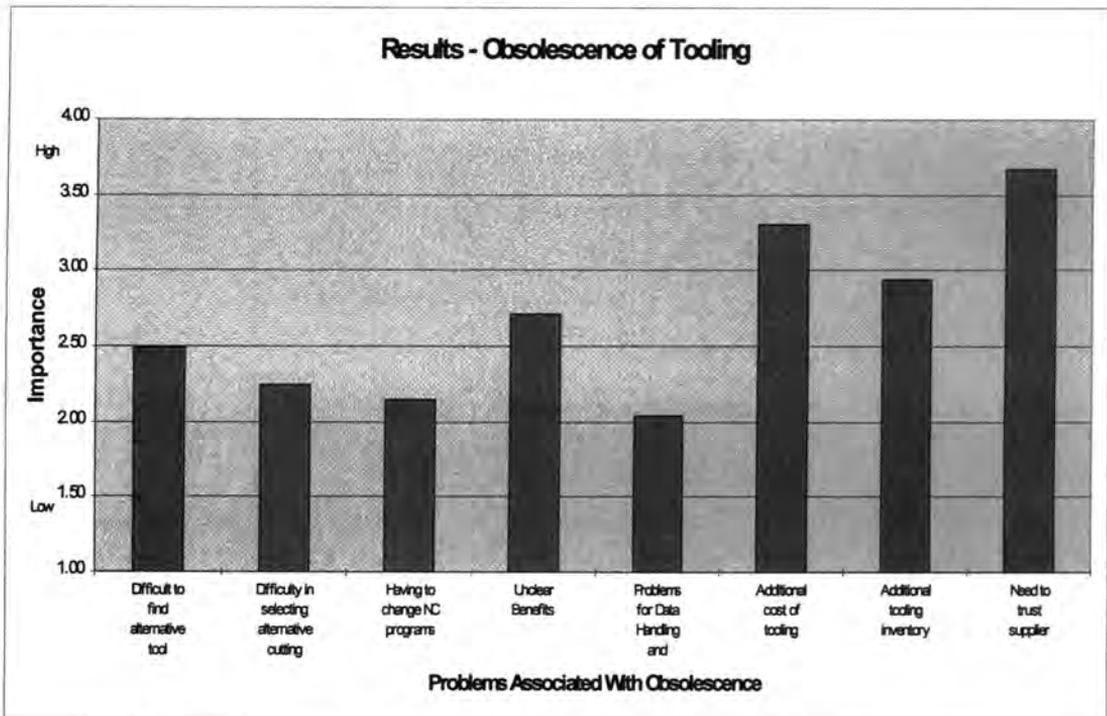


Figure 3.10 : Importance of factors associated with tooling obsolescence.

From the results in Figure 3.10 it can be seen that a number of suggested problems associated with obsolescence are not of significant importance to companies. From earlier results which showed that companies were able to perform tool selection and cutting data selection activities quickly and with new problems, the results for this question are not unexpected.

Those factors which are significant to companies are primarily;

- The cost of purchasing new tooling.
- The additional tooling inventory that is created.
- Unclear benefits.

During the series of industrial visits, it became apparent that dealing with obsolescence was expensive not only in terms of purchasing the new tooling but also in evaluating the required cutting parameters needed to be able to adopt the new tooling. An additional complaint from industry was that the new tooling was in general more expensive than the previous tooling and yet the improvement in performance was limited, and hence the companies found it difficult to justify why the change should have been made.

From Figure 3.10 it can be seen that companies found it crucial to be able to trust their tooling manufacturer(s). A number of engineers commented that in some circumstances they believed the tooling manufacturers were asking them to change to new tooling simply to increase their revenue and not due to the old tooling becoming obsolete. As a result of this the interest in tool manufacturers having the responsibility for ordering tools on behalf of industrial machinists was very low.

Another important logistical consideration to be investigated was the number of tooling manufacturers that companies used and their reasons for choosing to do this. Question eleven highlighted that the average number of tooling suppliers used by companies was 4.7. The next question then suggested a number of reasons as to why companies choose to have multiple tooling suppliers. The results for this are shown in Figure 3.11.

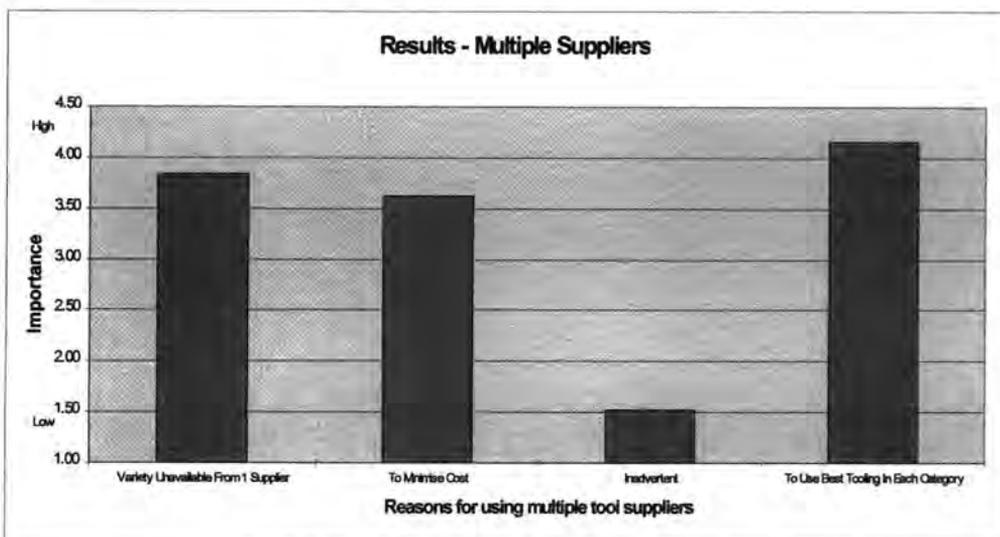


Figure 3.11 : Reasons for using multiple tool suppliers.

These results show that the primary reason for companies choosing to use multiple vendors is to use the best available tooling for each category of machining. An earlier question relating to tooling performance requirements requested four of the major

tooling manufacturers to be rated for the major categories of machining operation. There was close correlation between the responses of all those surveyed, and hence the importance attached to using the best tooling in each category is expected. Besides this requirement, it was also found that companies were sometimes unable to obtain all the tooling that they needed from a single supplier. Again, this is in keeping with the result that on average companies tended to use a high variety of tooling. In addition to this companies also tried to minimise their tooling expenditure by using a variety of suppliers.

Special tooling was another area to be considered in this section of the questionnaire. It was found that almost all companies found it important to be able to obtain special tooling and that the tooling manufacturers should adhere to their quoted delivery times without fail. On average, only fifty percent of companies claimed to have regularly received their special tooling orders either on or before the quoted delivery date. At the current time, it is standard practice for special tooling orders to have an 8-10 week turnaround time. When questioned regarding delivery times, companies said that they would ideally like this to be reduced to four weeks.

Figure 3.12 shows the results for a question that examined various factors associated with new products from the tooling manufacturers.

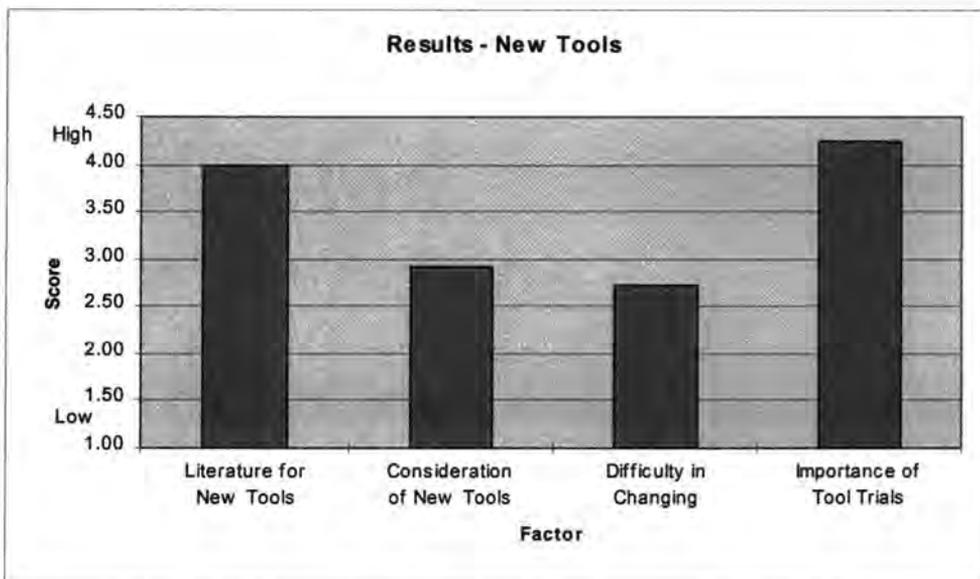


Figure 3.12 : Factors relating to new tooling products.

The results from this question showed that companies were well informed of the introduction of new tooling and they spent a reasonable amount of time considering these new products. Companies indicated that they did experience a moderate amount of difficulty when changing to new tooling and that tool trials are extremely important when deciding whether or not to adopt a new tooling product.

3.5 Conclusions from the industrial survey

This review has identified the need for up to date information about a variety of activities in the area of metal cutting tooling, and further to this has developed and carried out a survey of manufacturing industries within the UK via the use of a mail shot questionnaire and a series of industrial visits. A large volume of data has been gathered which has revealed specific needs and priorities within manufacturing organisations.

In terms of the knowledge needed to carry out process planning activities concerning tooling, companies appeared to have sufficient understanding to carry out tool selection and cutting data selection with few problems, but it was found to be difficult to predict tool life with any degree of accuracy. Further to this, companies were found to tailor their use of technical support aids according to their needs in respect of a particular activity. In general it was found that companies wish to rely on their own employees experience for carrying out process planning activities, but information from tool catalogues and advice from tooling engineers is also regarded as being important.

In order for companies to maintain their base of technical skills, their awareness of the importance of training and their willingness to invest in this training was clearly demonstrated. This highlighted the opportunities for work to be carried out in the development of training modules for a wide variety of tooling issues. Companies encountered few problems when performing process planning activities and this is supported by the endorsement of technical training. Further analysis of the variety of technical support aids available to companies highlighted a niche in the areas of CAD/CAM software systems. There was significant corporate interest in Internet-based interactive software for supporting the tasks involved in process planning.

Chapter 4 :Technical tooling support systems

The earlier chapters which examined both previous literature in the area of process planning activities and the results from the industrial survey demonstrated that there is a need for more competent systems to support the process planning task. This chapter will present a number of technical tooling support systems provided by tooling manufacturers and examine their strengths and weaknesses.

4.1 Coroguide from Sandvik Coromant

The Coroguide system [Sandvik Coromant (1997c)] from Sandvik Coromant is a Windows based software system for the selection and assembly of tools as well as the selection of cutting data based upon component geometry. Whilst the system only allows the analysis of Sandvik's own products, it is useful in terms of the variety and depth of information made available to the user. The three main functions to be performed by the Coroguide package are;

- Tool component selection
- Tool assembly
- Cutting data selection

The component selection is implemented for turning, milling, drilling and adapter product types. The provision of the material selection utility is beneficial insofar as it eliminates all those inserts which are incapable of machining the specified material, and also allows the cutting data to be specific based upon a clearly defined material identification system.

The first stages in the use of the system require the workpiece material and the general tooling group to be specified. The material selection utility is robust and provides several methods for specifying the workpiece material. Once the component material has been identified it is necessary to specify the general product area for the tool selection phase. The way in which the products are categorised is via a product tree, as illustrated in Figure 4.1.

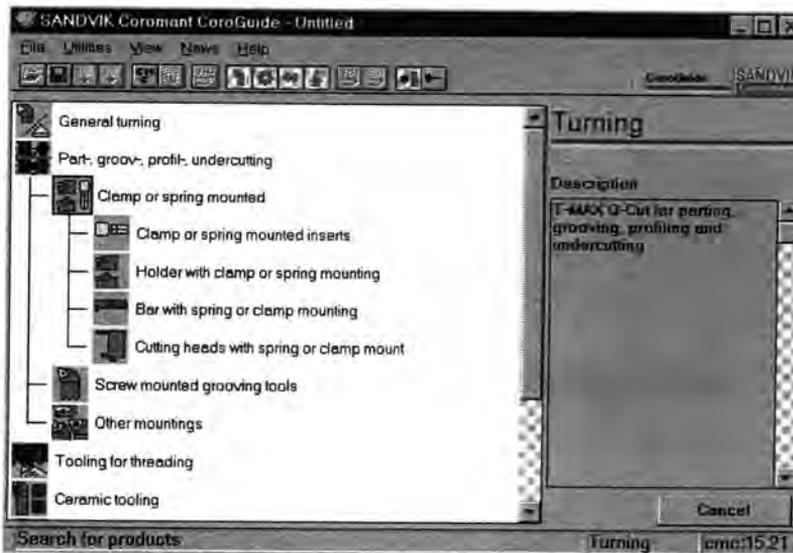


Figure 4.1 : Product tree for turning operations

The system presents increasingly specific categories of tooling until a discrete product type is identified. A list of the products of the selected type are displayed, each product being specified by its ordering code and the important dimensions. It is the responsibility of the user to select a product suitable for the operation to be performed. Upon selecting an individual tool holder the tool assembly utility is presented in order to select a compatible adapter and insert combination.

In the case of insert selection, the list of inserts displayed to the user is based upon knowledge of the holder geometry and the workpiece material. Each insert in the list is shown with its product code and key dimensions. It is the task of the process planner to decide on an insert geometry taking into account the precise operations the insert is expected to perform. When a specific insert type has been selected a list of available grades will be displayed again requiring the selection to be made by the user. In a similar manner a list of compatible adapters will be displayed requiring the process planner to have knowledge of the back-end¹ tooling associated with the machine tool which will perform the machining tasks.

Subsequent to the insert and adapter having been selected the cutting data analysis utility will be displayed as illustrated in Figure 4.2. The cutting data is presented for the insert type and material combination defined by the user.

¹Back-end tooling refers to the items of tooling which are used to mount tool holders on the machine tool.

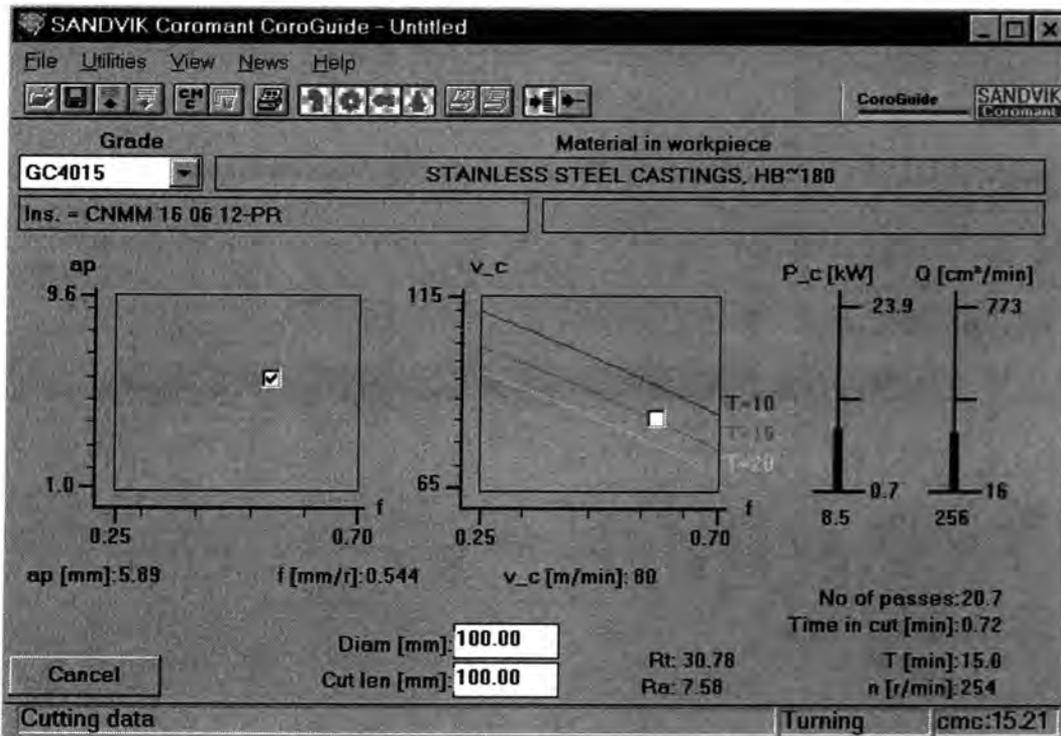


Figure 4.2 : Cutting data analysis utility

The cutting data analysis utility as shown in Figure 4.2 is a visual way of assessing the impact of variations in the cutting parameters of the options. The graphs of depth of cut and cutting velocity against feed rate are not static in terms of the data they display. Each graph has a pointer which can be moved within the limits of the graph to see what effect it has upon the other parameters associated with the operation.

Whilst the Coroguide system provides ample data in assessing suitable cutting conditions, it is not able to calculate the specific cutting parameters associated with maximum production rate (minimum cycle time) or minimum cost (of machining the component). Whilst the maximum production rate is never explicitly mentioned, a process planner with a knowledge of the power of the machine tool would be able to find cutting parameters that result in the shortest machining time corresponding to the maximum production rate.

A limitation of the cutting data utility is with regard to the range of depth of cut and feed rate values. In general, the range of values for depth of cut and feed rate for which an insert is valid is specified by the use of an 'a-s chipbreaker diagram', as illustrated in Figure 4.3.

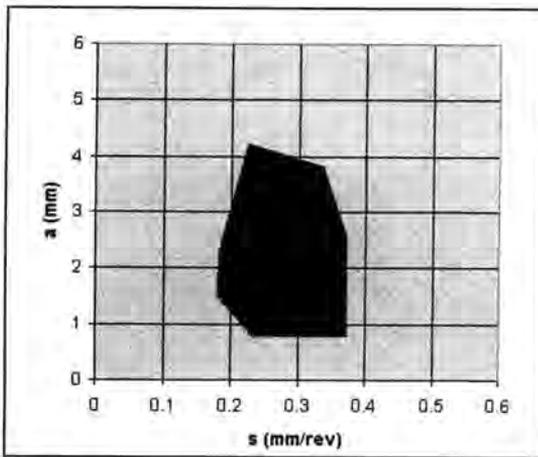


Figure 4.3 : An a-s chipbreaker diagram

The Coroguide system does not define limits for the depth of cut and feed rate based upon the insert selected, and so the user must cross-reference the technical specification of the insert with catalogue information to ensure the cutting parameters are appropriate in the given situation.

4.2 IscarXP from Iscar Tooling

IscarXP [Iscar Tooling (1997)] is intended for use as an electronic catalogue which operates from a Windows platform and offers navigation through product information and technical data. The system incorporates a series of functions which are referred to as 'atoms', providing the user with the ability to search for products, assess the compatibility of products and analyse the cutting data for which the products are suitable. In addition to this provision is also made allowing the comparison of products in terms of their technical specifications. A summary of the various functions (atoms) now follows;

- **Tool / Insert Atom** Figure 4.4 shows an illustration of this function for a family of tools designed to perform internal turning operations. Each of the parts within the chosen part family is listed along with their key dimensions, a basic drawing and an illustration of the intended application of the tool. It is the responsibility of the user to select tool holders and inserts from a knowledge of the operations to be performed. No consideration is given to back end tooling. Additionally this function provides direct links to an accessory list, a fully rendered picture of the tool and details of the inserts that are compatible with the chosen tool holder.
- **Alternatives Atom** This is a function which generates a list of alternatives to any specified tool. The alternatives listed will be those components within the part family from which the original tool was selected.

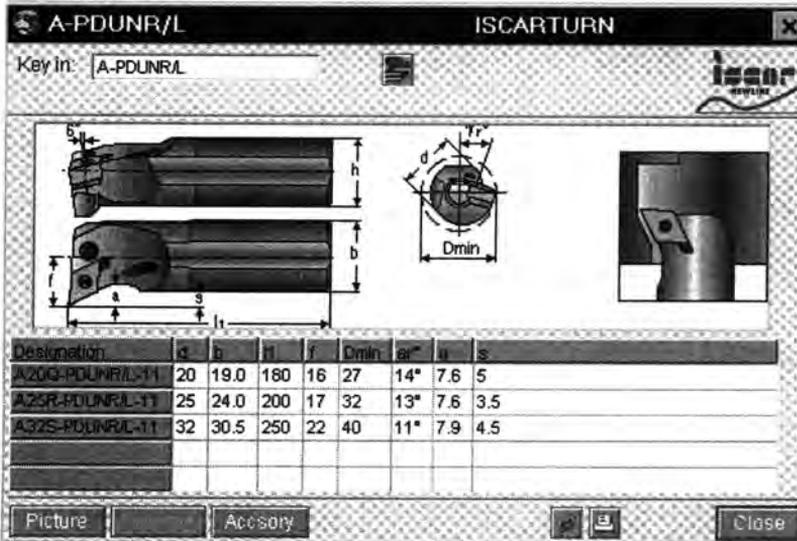


Figure 4.4 : Family of turning tools in the tool / insert atom

- Compare Atom** If the user had identified two tool holders or two inserts which were both appropriate to perform the required machining operation it is possible to automatically generate a list of technical differences between the two items. These differences are presented to the user in three sections; the differences between the dimensions of the products, the appearance of the products, and the intended application area of the products, as shown in Figure 4.5. This feature is particularly helpful in succinctly summarising the differences between two similar products and would assist the user in selecting the appropriate tooling for the machining task.

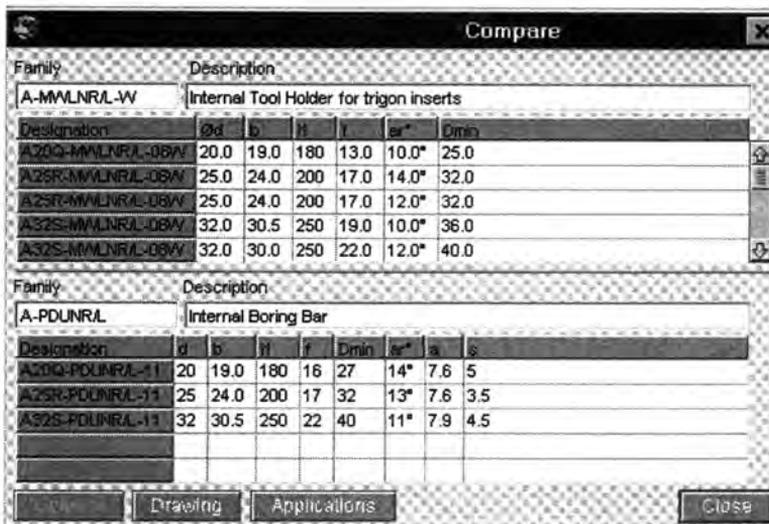


Figure 4.5 : Illustration of compare atom

- Grades Atom** This atom displays technical information for each carbide grade. This data comprises workpiece material, the recommended applications as well as the chemical content of the insert grade. In addition to the entire list of insert grades, it is possible to 'drag and drop' any particular insert or insert family to this atom and the grades in which the chosen part is available will be displayed.
- Cutting Data Atom** Once the application has been defined, the workpiece material selected, and the tool holder / insert combination specified it is possible to view the machining data atom which displays key cutting parameter information to the user. A comprehensive and interactive a-s chipbreaker diagram is provided for each insert alongside a graph of cutting speed versus tool life, which is also interactive courtesy of a floating cursor. It is possible for the user to manually enter a number of key parameters for the operation being carried out, as shown in Figure 4.6.

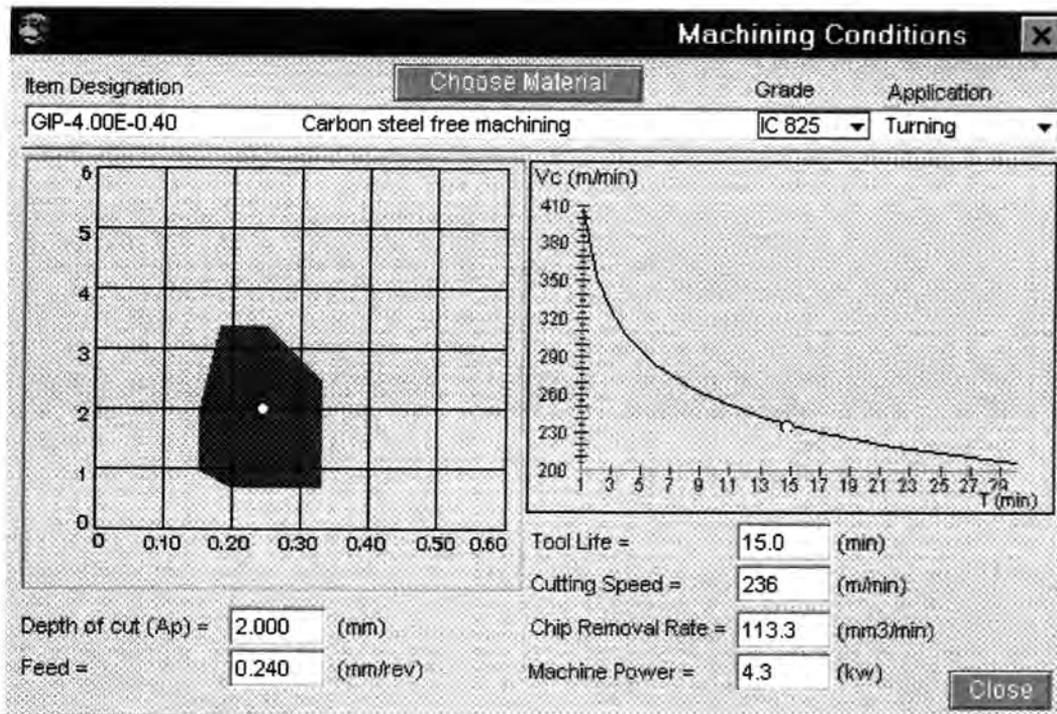


Figure 4.6 : Presentation of cutting data in IscarXP

- Other Atoms** In addition to the technical elements of the software described, a comprehensive help utility is provided giving guidance on all of the functions contained within the system. In addition to this there is a Help Atom which provides advice of a more general nature regarding product application and courses of action in the event of any difficulties being encountered.

4.3 SecoTurn from Seco Tools

Seco have produced a number of software packages to aid their customers in carrying out tool and cutting data selection activities. Rather than a single integrated software package, independent provision is made for each of the major product areas, namely milling, turning, drilling and threading. Despite this approach each system is functionally similar and so this section shall only detail the system dedicated to the support of turning operations.

The first stage in the SecoTurn [Seco Tools (1998b)] module is to specify a general category of machining operation, as illustrated in Figure 4.7. Once a general operation specification has been made, a list of tool holders that can be used to perform the required operation is presented, as shown in Figure 4.8. This list contains different holder type standards and requires the user to specify which holder type is required. Upon selection of a holder type a list of tool holders will be displayed, although no specific data regarding an individual holder is displayed, or indeed is obtainable. It is necessary for the user to be familiar with the Seco coding system (which in the case of turning is an ISO coding system) in order to be able to select the holder required. Finally a list of holder sizes will be displayed, again requiring user interpretation before a choice can be made.



Figure 4.7 : Operation categories in SecoTurn

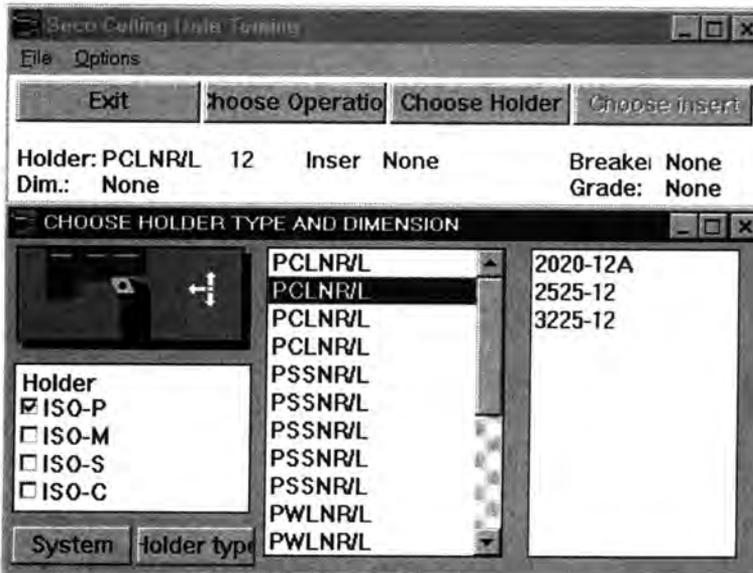


Figure 4.8 : Holder specification in SecoTurn

Once the holder size has been selected a 3x3 grid will be presented to the user, as illustrated in Figure 4.9. This 3x3 concept is unique to the manufacturer concerned and allows a basic specification of the duty of machining operation and workpiece material. The three operation types are finishing, medium and roughing, whilst the material types are steel, stainless steel and cast iron.

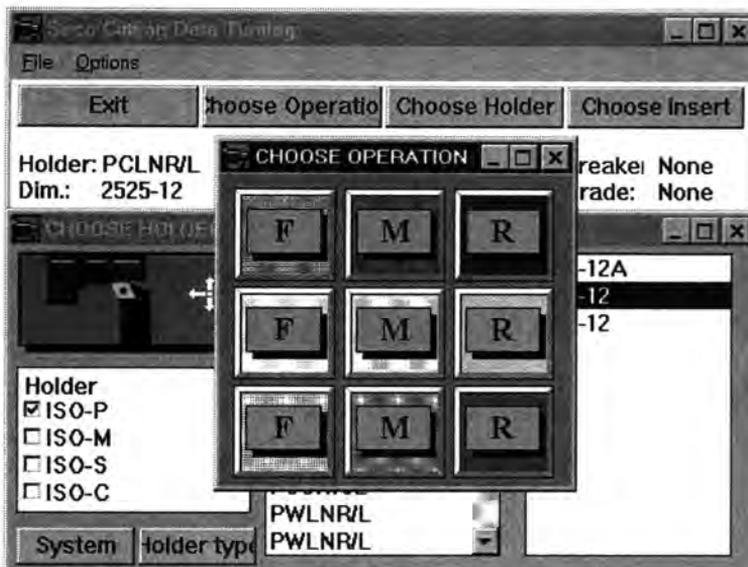


Figure 4.9 : Seco's 3x3 matrix

Based upon the holder specification and the element in the 3x3 matrix having been selected, a list of compatible inserts is generated. This compatibility encompasses the physical geometry of the tool holder as well as material to be machined.

The final stage involves the selection of an appropriate insert. This choice is graphically similar to the tool holder selection screen, as shown in Figure 4.10, although it can be seen that the user is solely provided with the insert code upon which to make the choice.

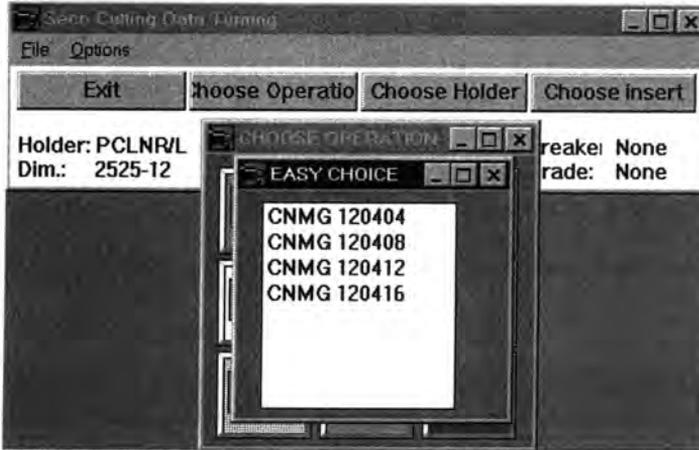


Figure 4.10 : Insert selection in SecoTurn

Once the tool holder and insert have been selected the cutting data screen will be displayed. This final screen allows the completion of the selection process, as so far neither the grade nor chipbreaker of the insert have been specified. As illustrated in Figure 4.11, all of the available insert grades and chipbreakers for the specified insert are displayed on the cutting data screen from which the user can select.

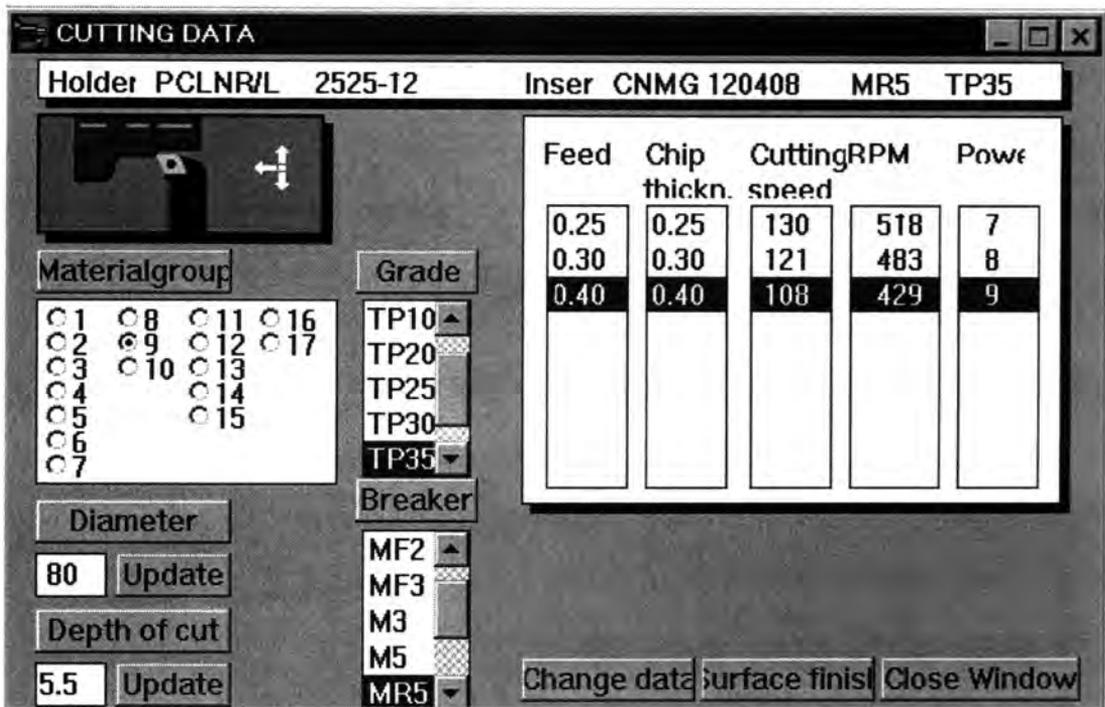


Figure 4.11 : Cutting data in SecoTurn

The other parameters which can be set by the user are the material group (based upon a classification specific to the manufacturer), the diameter of the workpiece and the feed rate. Specification of these parameters produces a table of cutting data for specific discrete values of the feed rate. This requires interpolation or a similar numerical technique to be applied when assessing other cutting parameter combinations. It is also evident that depth of cut and feed rate combinations need to be cross referenced with chipbreaker diagrams presented in technical catalogues to ensure compatibility with the operations being performed.

4.4 WinTool from Datos

In addition to the technical tooling support systems described, investigations were undertaken to identify any commercial systems which offered the same general range of functions but provided specific tooling data for multiple product manufacturers. At the time of writing, only one notable software package had been identified which met the criteria stated; namely WinTool [Datos (1998)], which is developed and marketed by a company named Datos based in Zurich, Switzerland. The system is designed for use within a Windows environment operating on an IBM compatible PC.

WinTool is available in two formats; WinTool Compact and WinTool Professional. The only difference between these versions, that the user will be aware of, are the number of functions which can be performed. In addition to this the WinTool licensing agreement and regulations vary between the two formats. WinTool Professional can only be used with a legally obtained licence whilst the Compact version may be copied and used as often as required. The relaxed licensing rules applying to the Compact edition of WinTool make it ideal for a tooling manufacturer to simply upload their own product database to the system for distribution directly to their customers. The end user can then decide whether to upload further product databases from additional tooling manufacturers or to use the single product database as supplied. For those end users who obtain WinTool directly from Datos, tooling catalogues from a number of manufacturers will be pre-installed. Each tooling manufacturer's catalogue is included with the system subject to making a subscription payment to Datos.

During the analysis of WinTool two editions of the system were used by the author. The first version was a licensed Compact edition direct from Datos which had a significant number of catalogues pre-installed. This edition suffered from the drawback of being presented in German, and as a result served only served to illustrate the variety of tooling catalogues available, as shown in Figure 4.12. The alternative version was a Compact edition which was licensed via Seco Tools AB, Sweden. This latter copy featured solely the pre-loaded Seco product database, and it is this version that will serve to illustrate the features of WinTool in the remainder of this section. It should be noted that the functions made available in WinTool are common to all of the tooling manufacturers concerned.



Figure 4.12 : Tooling manufacturers supported by WinTool

Once a manufacturer has been selected the functions offered by the system will be displayed, as shown in Figure 4.13. A brief summary of each function follows.

- **New Catalogues** - For the uploading of new or additional product databases.
- **Tool Components** - Individual tooling items such as inserts, tool holders and arbors.
- **Assembled Tools** - Combinations of tool components which form complete tools - i.e. an assembly which consists of a chucking fixture (the device which allows a tool assembly to be mounted on a machine tool), a tool holder and an insert
- **Tool Lists** - Tool lists contain a number of assembled tools and, in general, correspond to a machining cycle in the production process.

- **Machines** - This is a selection of commonly used machine tools along with their general specifications in terms of machining ability.
- **Notepads** - Temporary component storage for use during tool assembly.
- **Experts** - Manufacturer specific modules which can be used to simplify searches for tool components and obtain proposals for suitable cutting parameters.

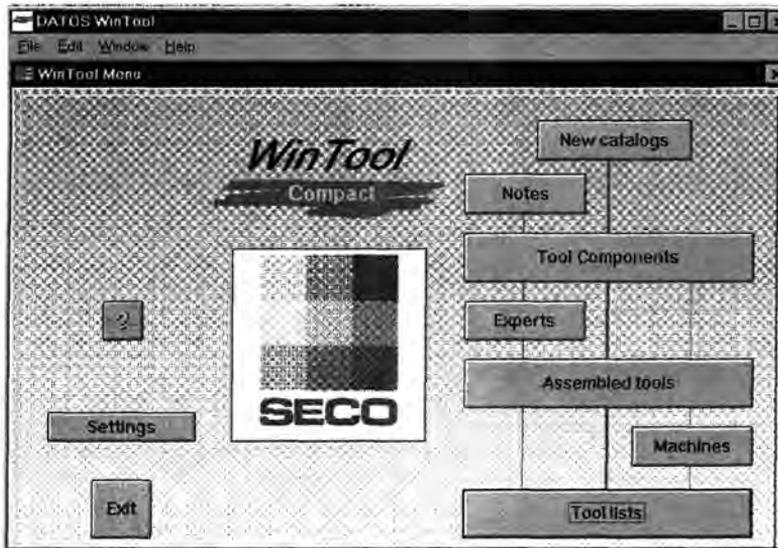


Figure 4.13 : Application choice in WinTool

From the range of functions only those relating directly to the subject matter will be considered in detail, namely;

- Tool Components
- Assembled Tools
- Tool Lists

To carry out the task of tool selection it is necessary to use the 'tool components' module, the graphical appearance of this being shown in Figure 4.14. The initial stage in generating a process plan for a component is the activity of assigning machining processes subsequent to interpretation of the product design. The general type of cutting tool which is needed to perform any given operation will be known and so the selection of the relevant machining category is routine. At this point the general category of tooling will be divided into sub-groups, each sub group being a distinct variety of the general category from which it derives.

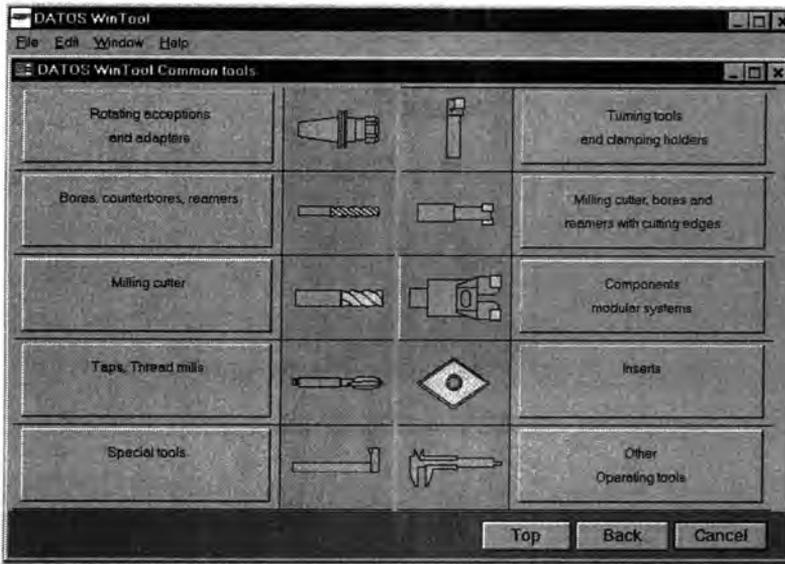


Figure 4.14 : WinTool depiction of tool categories

Once a specific operation type has been selected a list of the tool holders within the selected category will be presented as shown in Figure 4.15. Selection of an individual tool holder results in a number of key parameters relating to that item being displayed. The user is then able to select the required tool holder based upon the requirements of the machining operation. Once the selection has been made, the most detailed level of information will have been reached. This final level of tool selection is shown in Figure 4.16, from which it can be seen that a detailed technical description of the tool is made along with a CAD representation of the component.

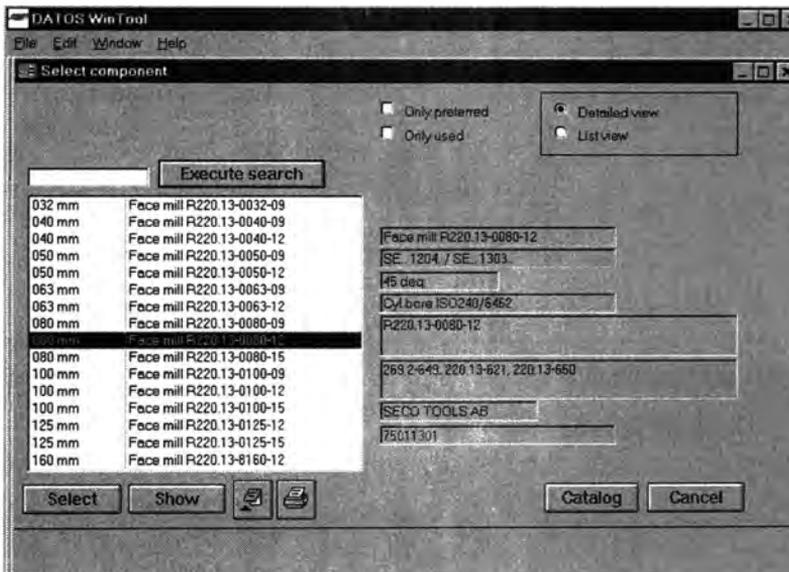


Figure 4.15 : WinTool listing of specific tool holders

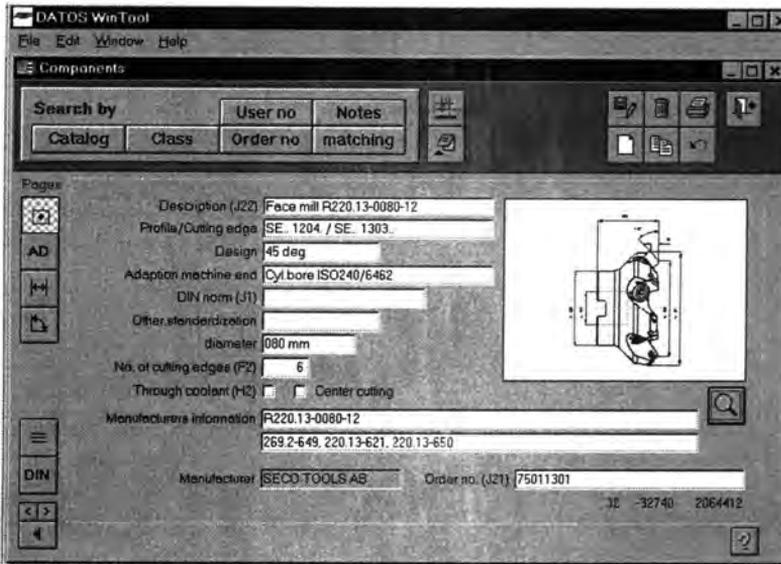


Figure 4.16 : WinTool presentation of detailed toolholder data

Having specified a tool holder it is possible to select an appropriate insert and chucking device. WinTool only provides support for the selection of compatible component parts in terms of their ability to physically match each other. An illustration of the insert data provided by WinTool is shown in Figure 4.17. The variety of materials which can be machined by any given insert are presented in a tabular format using the PMK classification standard.

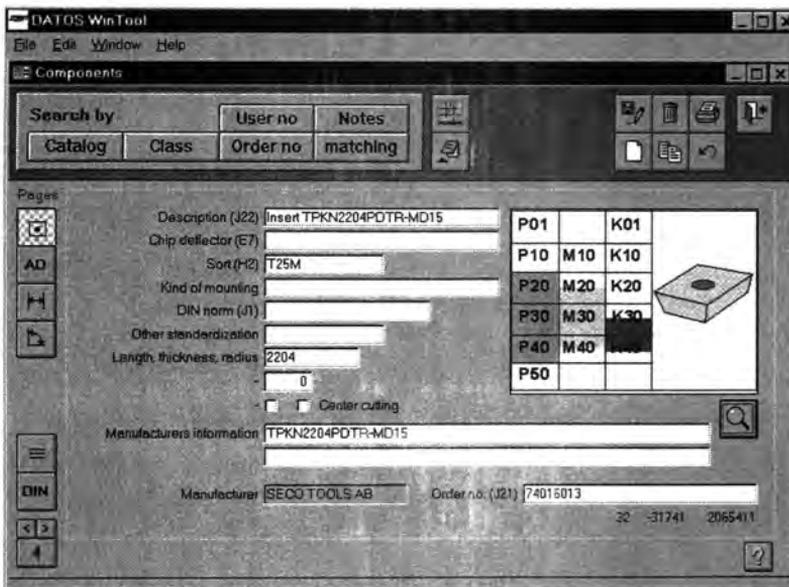


Figure 4.17 : Illustration of machining capabilities of an insert

Whilst WinTool has significant part libraries from which tool components can be chosen, and sufficient machine data to allow selection of adapters, the functionality offered in terms of insert selection is rather limited. The user is presented with a list of

inserts which would physically match the tool holder but WinTool offers no support in terms of considering inserts based upon material considerations and a-s chipbreaker specifications. Each insert is presented with a PMK material suitability chart, allowing visual assessment as to whether the chosen insert is suitable, but no provision is made for specifying the component material type and then searching the insert library based upon both physical compatibility as well as material suitability. An additional point to note is that no provision is made for the direct assessment of cutting parameters, the result of which is a need for the user to evaluate an insert in terms of its suitability for performing an operation in an efficient manner. Whilst an experienced process planner will have little difficulty in selecting initial cutting parameters it would be necessary to refine these parameters using a suitable support tool to ensure maximisation of manufacturing resources.

Further to the selection of cutting parameters for individual operations, it should be noted that any component is likely to need a variety of operations to be performed on it in order to produce the required dimensions and surface finishes. Because WinTool does not provide support for cutting parameter selection, it follows that there is no provision for carrying out tool set optimisation procedures.

In summary it can be seen that a progressive approach to tool selection is adopted by WinTool where the user is guided through a series of steps in order to transcend from an initial operation definition through to the specification of an assembled tool. Whilst the graphical nature of the WinTool approach to tool selection may aid the user in the course of selecting the tool, it should be noted that there is no support in bridging the gap from cutting operation specification in the initial process plans through to tool selection and specification. This fact is a further indication that WinTool, and similar breeds of software, are aimed at helping already technically able process planners in carrying out their task, rather than providing comprehensive support for users with little tooling experience. Despite these limitations, the power of WinTool should not be underestimated. It is the only generic system that collates tooling products from a significant variety of manufacturers, and allows both the selection and assembly of multiple tool components as well as a significant level of technical product data.

4.5 Discussion

The previous sections have briefly examined the key functions to be performed by a variety of systems designed to assist the process planner in the tasks of tool and cutting data selection. A brief summary of the conclusions which can be drawn from this review will be presented, followed by a statement of the precise aims of this research.

Consideration of the availability of technical tooling support systems suggests that there is a niche in the tooling market which requires the use of such systems to assist the industrial process planner. It has been demonstrated that there are a number of recurring themes across the range of such support systems, and in general terms, three of the most commonly occurring functions were found to be;

- Individual component selection and specification
- Component assembly to produce tool assemblies
- Cutting data selection

The graphical means by which these tasks are achieved varies considerably between manufacturers, but the overall goals of each individual software package generally fall within a number of key functions. The two components of most significance to this functionality are the database of tooling products and the algorithms that are used to calculate the cutting parameters. It was found that the product information presented in the software utilities was almost identical to the product data found in catalogues, and further to this the assessment of cutting data adhered to the tabular data presented in the technical guides.

These findings suggest that the functionality offered by the software is little different to the variety of information provided in catalogues, although this is not to say that the software does not demonstrate advantages in terms of assessing the catalogue data. Consideration of the tasks involved with tool and cutting data selection indicated that the numerical processing power of a personal computer can reduce the time taken for precise data to be found and assessed.

The computer based methods for tool selection are well developed and provide the user with a simple way of identifying a specific item of tooling. Further, ample provision is made for the identification of physically compatible tooling based upon consideration of the machine tool, the machining operation, the component geometry and material type.

The selection of specific machining parameters is an important task and consideration of the software has demonstrated that calculations used to provide these cutting data parameters are based upon the algorithms and tabular data presented in catalogues. Consideration of these algorithms shows them to be highly simplified and have been proved to result in values which are more conservative than those associated with optimal machining conditions.

Chapter 5 : JadeT - overview and context description

5.1 System aims

Whilst none of the systems detailed in the previous chapter claims to be a fully integrated CAPP utility capable of seamless integration with CAD and CAM functions, the software is valuable to industrial process planners as a tool which aids the task of finding detailed tooling product data. It was therefore important that any new development should be seen to support and enhance the functions already made available in CAPP support systems.

During the course of the industrial survey it was possible to discuss the techniques which are evident in commercial CAPP and CAPP support systems. There was general agreement amongst industrialists that the majority of systems use mathematical modelling techniques when performing cutting data selection and this tends to produce lackadaisical parameters significantly more conservative than optimal data. From consideration of previous research and the industrial input it was decided that the system to be developed as part of this research programme would address these issues. The aim was to develop a distributed support system which would aid both industrial process planners and engineers from the tooling manufacturers in carrying out their tooling related tasks.

Whilst the primary aim of this project was to carry out developmental work of relevance to the academic community, the practical nature of the industrial application for which it is intended meant that consideration of industrial needs in respect of the work were also important. From consideration of the needs of the tooling manufacturers and industrial machinists it was possible to define the goals of this research in terms of the industrialists whom it would concern. It was hence agreed that the primary aim of this research was to develop a networked software system capable of providing technical information and technical support on a real-time basis by embracing the distributed computing solutions made possible by the Internet, and in particular the World Wide Web.

Specifically the targets of the research were laid down as being to;

- Create a database of tool trials carried out by tooling engineers
- Facilitate direct database access to tooling engineers (from the tooling manufacturers) in order to assist the process of giving technical support to industrial machinists
- Enable direct database access from remote locations in order to support the work of tooling engineers 'in the field'
- Implement functions capable of analysing tool trials and distributing this information to remote industrial machinists in a structured and coherent manner

An opportunity has been identified to create a database of information and knowledge from the numerous tool trials which are carried out by tool manufacturers for individual industrial machinists. During such tests it is common for normal production to be reduced or even halted. The immediate consequence of this is that a reduction in machine utilisation will be experienced; a result which is increasingly unacceptable in such a competitive market. A system capable of storing the specific data obtained from individual tests thus providing a source of future reference can be seen to assist in reducing the need for industrial testing. It is commonplace for engineers from the tooling manufacturers to conduct their business in a remote environment which removes the convenience associated with centralised resources. It is therefore a key requirement that any technical information captured by a support system should be accessible in these remote locations.

It has been demonstrated that industrial machinists supplement mainstream process planning utilities with those provided by tooling manufacturers to assist in the process planning task. Whilst such systems are widely employed by industrial machinists it has been noted that the cutting parameters they yield tend to be conservative. The industrial applicability and suitability of the suggested cutting parameters could be improved by increasing the reliance on data sourced from actual industrial cutting tests.

The system developed during this research was entitled JadeT (Java Assisted Development for Engineering - Tooling), which served to address the issues highlighted. The next sections detail its architecture and development platform.

5.2 System structure

It has already been shown that WinTool uses standard product databases from a variety of tooling manufacturers in order to provide process planning utilities. Whilst these databases are provided by the manufacturers to the developer of WinTool, it was found to be the case that the information used to create these databases is often fragmented and stored in a variety of different systems. To avoid the need for a new product database to be designed and populated it was suggested that the WinTool product database could be used as the central database of mainstream product information.

It was decided that JadeT would make use of not only the standard databases of product information made available for use in packages such as WinTool, but a new database would be created in order to capture data from reserves of information which are currently unused. In particular a primary goal of this work was to create a database of the tool trial reports produced by tooling engineers. Whilst the detailed information in any given tool trial is confidential and could not be disclosed directly, the application of intelligent data processing techniques to the tool trials database would result in generic information being obtained which could then be applied in a wider context.

The overall structure of the JadeT system is shown in Figure 5.1. Both the product and tool trials databases would be stored in a central location, with access being made possible by the development of interactive utilities which could be used via World Wide Web browsers. This design would eliminate the problems associated with fragmented databases requiring regular updating yet would allow distributed access thus attending to the need for effective remote technical support.

The JadeT system would have an open-access area providing generic technical support in the form of tool and cutting data selection. These utilities would obtain technical data from the general WinTool database whilst enhancing cutting conditions by analysing trends within the database of tool trials. The trends identified from the tool trials database would be assessed to verify their integrity before being used to modify catalogue data. The restricted area would be for the use of tooling engineers who would be able to search and view individual tool trials.

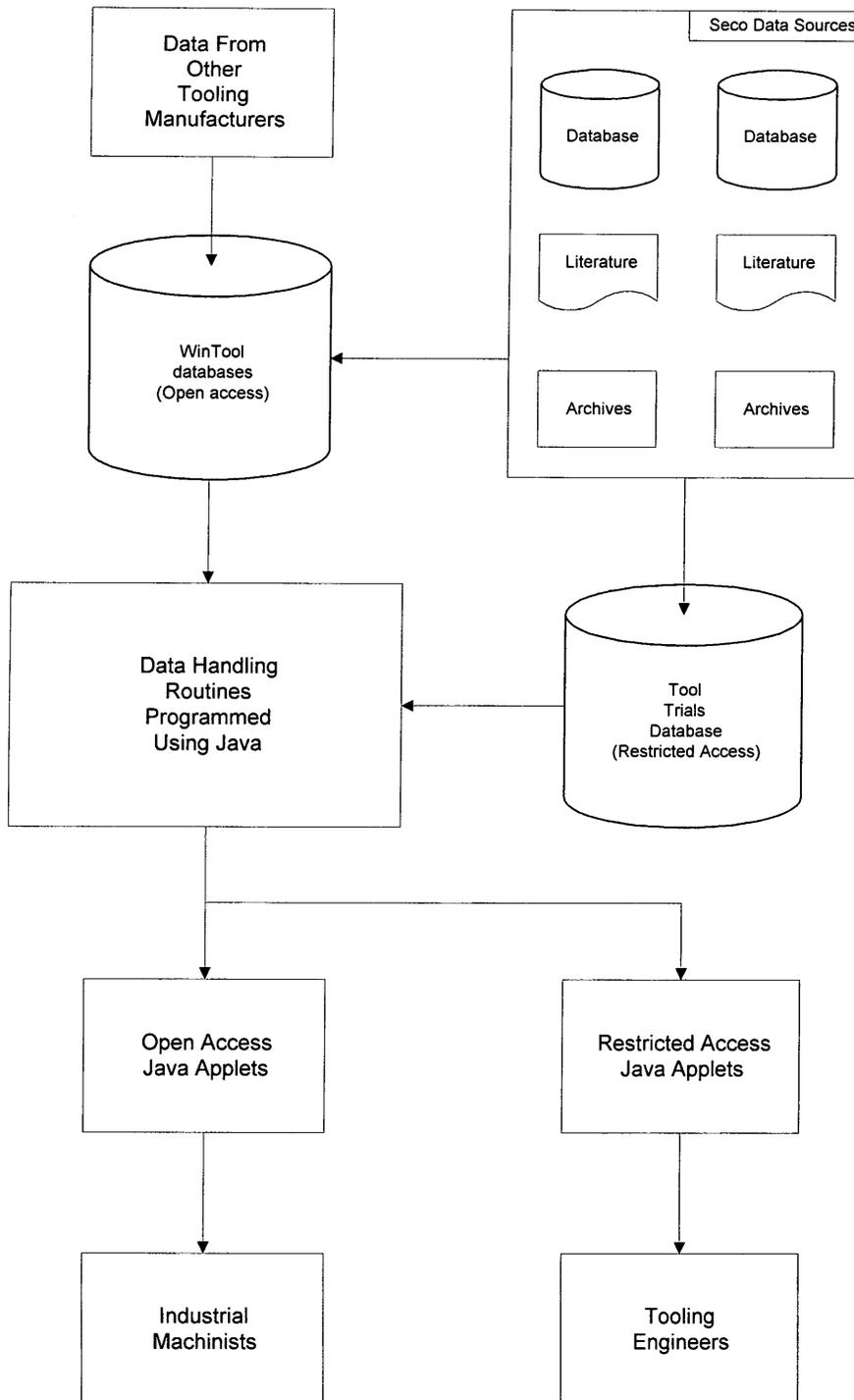


Figure 5.1 : Data source architecture of JadeT

The main stage in the development programme was to create the database of tool trials. The creation of such a database was attributed as being one of the most important modules of the overall system, as it would allow the globalisation and dissemination of highly technical information amongst tooling experts. Such a database would need to be able to efficiently store information relating to tool trials in order that the speed with which data could be obtained would be acceptable.

In terms of the tooling engineers, the aim of the tool trials database was to allow data retrieval from the database in an attempt to reduce the number of tool trials carried out. It was also necessary to provide a method for submitting results when a new tool trial is initiated so that the database would continually develop as the range of tooling products changes over time. Consideration of the implications of the successful creation of the tool trials database suggests that benefit will be given to both the tooling manufacturer as well as the industrial users of the open-access module of JadeT. The benefits for the tooling manufacturer are that the tooling engineers will be able to share a nation-wide database of knowledge created from their previous work, and that overall it should be possible to reduce the number of tool trials being carried out which are duplicate trials having been previously carried out by another tooling engineer.

In terms of the general industrial users of JadeT, the benefits obtained from the creation of the tool trials database are that the knowledge amassed from information provided by the tooling engineers will be used in providing technical support directly to the industrialists. Knowing that the level of technical tooling knowledge within industry appears to be decreasing and that the tool trials database will create a dynamic database of information based upon data obtained from highly qualified engineers the value in capturing this knowledge to solve industrial problems should be of merit.

5.3 Development platform

One of the key goals of this work was to unleash the ability of distributed technical data processing for experienced engineers. In order to achieve this it would be necessary to use a programming language which is compatible with commonly used Web-browsers. The literature review presented the variety of options for this, and it was decided that Java would be used to carry out the development of JadeT.

During the developmental phases of JadeT, the Java programming language was still in its early stages, and there were two distinct versions of Java, namely versions 1.02 and 1.1. Version 1.02 was the first version of Java and was widely supported by the main browsers (Internet Explorer from Microsoft and Netscape Navigator from the Netscape Corporation). However, rapid development of Java took place and version 1.02 was

quickly followed by 1.1, which offered significantly more functionality than the previous version. During the development phase, all major browser manufacturers stated that current browsers would provide full support for versions 1.02 and 1.1 of Java. However, they made it clear that future editions of browsers would only support version 1.1.

Initial programming of an illustrative package was carried out on a standard IBM PC running the Windows95 operating system, in particular the programming being carried out using J++ from Microsoft. This development suite offered no visual utilities for 'drag and drop' programming, and required the user to write and compile all the Java source code manually. This caused the initial development to be slow, and J++ was solely used to produce an illustration of how the JadeT system was intended to look and function. Once the illustrative version of JadeT had been produced, development using MS J++ was substituted for a package called PowerJ produced by Sybase and marketed by Powersoft. This development environment offered a number of crucial advantages over the Microsoft development environment, such as;

- Drag and drop creation of GUI¹'s
- Generation of both 1.02 and 1.1 Java bytecode
- Full database connectivity
- Complete DBMS provided with PowerJ

The PowerJ package not only allowed rapid development care of its drag and drop GUI creation, but was also provided with a fully functional DBMS (SQL-Anywhere). All of the databases used by JadeT were produced using Sybase's SQL-Anywhere package. This DBMS allowed full SQL interrogation procedures, and so PowerJ was used to issue SQL commands capable of both data retrieval and submission. During the initial stages of the development, a PC based applet viewer was used to test and monitor the performance of JadeT. As the development progressed it was possible to use a dedicated WWW server based within the research group to fully evaluate the functionality of JadeT in a real-life Web environment.

¹GUI is a commonly found acronym in the development of software systems, and refers to the Graphical User Interface - i.e. the interface which is presented to the user of the system.

Chapter 6 : The tool trials database

6.1 Introduction

The development of a tool trials database was carried out to address a clear industrial need. Not only did the industrial survey highlight the fact that there is pressure on process planners to improve the cycle times of machining operations, but further to this it was noted that to achieve this target it was necessary to have a quick and efficient method for solving technical queries.

Whilst tool trials have so far been defined solely as a means of solving specific industrial tooling problems, it should be noted that tool trials address another important area. The area in question is that associated with the introduction of a new tooling product or product range. Tooling manufacturers strive to test all new tooling products in as rigorous a fashion as possible, but it is not always possible to recreate the conditions in a real life manufacturing environment within the confines of a testing laboratory. To remedy this situation tests are carried out in a collaboration between the tooling manufacturers and a selection of industrial machinists. The aim of this type of trial is to subject the new products to the very conditions that they would be expected to handle as a part of their normal use. The conclusion to be drawn from this is that tool trials are a valuable source of information in two of the key areas associated with tooling products;

- Finding data to solve technical problems.
- Testing new tooling to find acceptable cutting parameters.

In the absence of a tool trials database, there was little feasibility of the data and knowledge acquired by individual tooling engineers becoming a shared resource. The tool trials database unites and standardises the information pertaining to tool trials in a manner that supports the business aims of tooling manufacturers and industrial machinists alike. Figure 6.1 summarises the way in which the tool trials database can be implemented into existing technical support procedures.

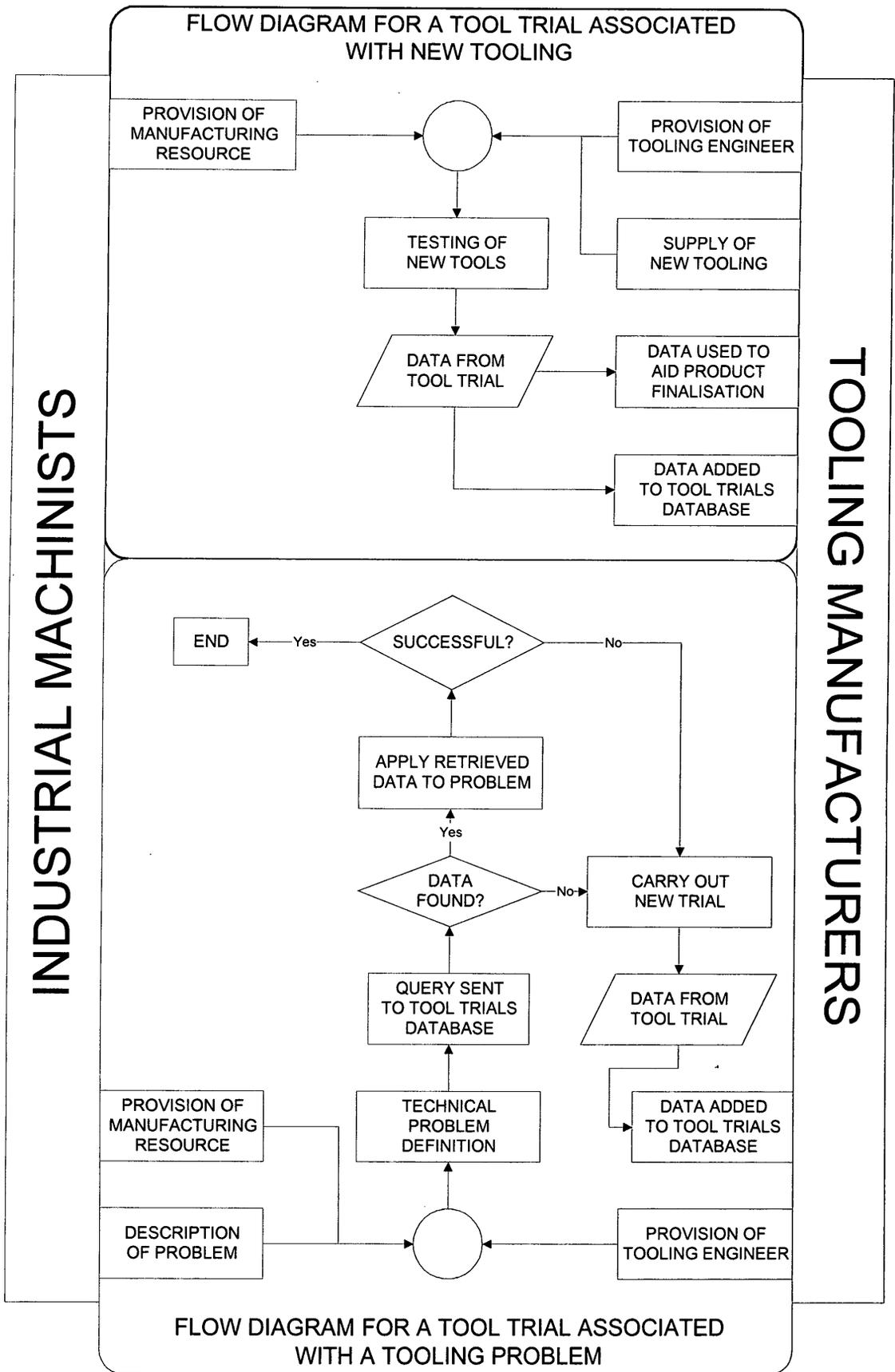


Figure 6.1 : Collection and application of data in the tool trials database

6.2 Review of fundamental DBMS concepts

Any DBMS is said to consist of two ends, namely a back-end and a front-end, and when applied in the context of a DBMS these terms have specific meanings. The back-end of the DBMS is formed by those parts of the DBMS which remain on the server side of the client/server architecture. In most cases the back-end items of a DBMS are the databases themselves and the files which contain them, as well as the main data handling features and any DBMS security systems.

Whilst the back-end is the most critical part of the DBMS as it performs the low level data storage, data processing and data security functions, this would be of little use without a means of accessing and invoking these functions. In order to achieve this a user interface is needed, and this is referred to as the front-end of the DBMS. The front-end is the interface that remote (client) users will see when performing tasks upon the database which resides on the server.

It should be noted that the back-end of the DBMS is not incapable of performing those tasks carried out by the front-end interface. In fact, quite the reverse is true as the back-end not only administers the data handling and security procedures, but will usually have powerful tools for inputting and manipulating data in the database. Because these tools are part of the back-end components they are of little consequence in terms of providing remote users with a means of accessing the database. The back-end data submission utilities are intended primarily for the use of the DBA (DataBase Administrator) in performing overall system regulation and management tasks.

No tour of the fundamental concepts relating to databases would be complete without the introduction of SQL. SQL is an acronym for *Structured Query Language*; a language that allows users to access data stored in relational database management systems. The way data in the database is accessed is by users describing the data they wish to see - this description being represented by an SQL command. SQL has been noted as having many qualities which begin to explain why it is such a popular tool when interrogating databases for specific information. One of the first and most important points to be realised about SQL is that it is able to produce result sets from the database in a quick and efficient manner. Further to this, SQL is a simple and yet

elegant language, with a single SQL command being able to replace scores of lines of programming code. Despite the simplicity in executing SQL commands it is a very powerful tool, as in addition to retrieving data, it has the ability to remove data from a database, to submit data to a database, or even to modify the structure of the database.

6.3 Specification of data

The first stage involved in the creation of the tool trials database was the assessment of data which should be stored in the database. From initial observations it may have been thought that the task would be to simply gather a selection of tool trials completed by tooling engineers and to transpose these data terms into the various tables that would ultimately produce the tool trials database. Whilst to a limited extent this was the case, it should be remembered that the tool trials database is not intended to be a simple database allowing the submission and retrieval of data terms for a specific manufacturer. Although any particular instance of the tool trials database is only likely to be associated with a single manufacturer, the concepts and methods employed within the database have to be sufficiently generic to allow the transportation and implementation of the database into the structure of any tooling manufacturer.

In order to be aware of the practical considerations which are faced during a tool trial the author was able to speak with a number of tooling engineers, each having had several years experience 'in the field'. Consideration of information gleaned from these discussions was then used in collaboration with a random selection of completed tool trial forms in order to identify the variety of data terms that would need to be present in the tool trials database.

Consider Figure 6.1, and in particular the section corresponding to the flow diagram associated with the execution of a tool trial due to a technical problem. It can be seen that there are three general categories of input into a tool trial when caused by the existence of a technical problem. Two of these inputs are from the industrial machinist; the manufacturing resource (i.e. the machine tool concerned) and the technical description of the problem. The other category of input is the tooling engineer from the tooling manufacturer. Each of these three groups was further subdivided into a number of discrete, exclusive categories. In addition to this, the general categories of outputs

from the tool trials process were considered. The overall summary of inputs and outputs with regard to the tool trials process is shown in Figure 6.2.

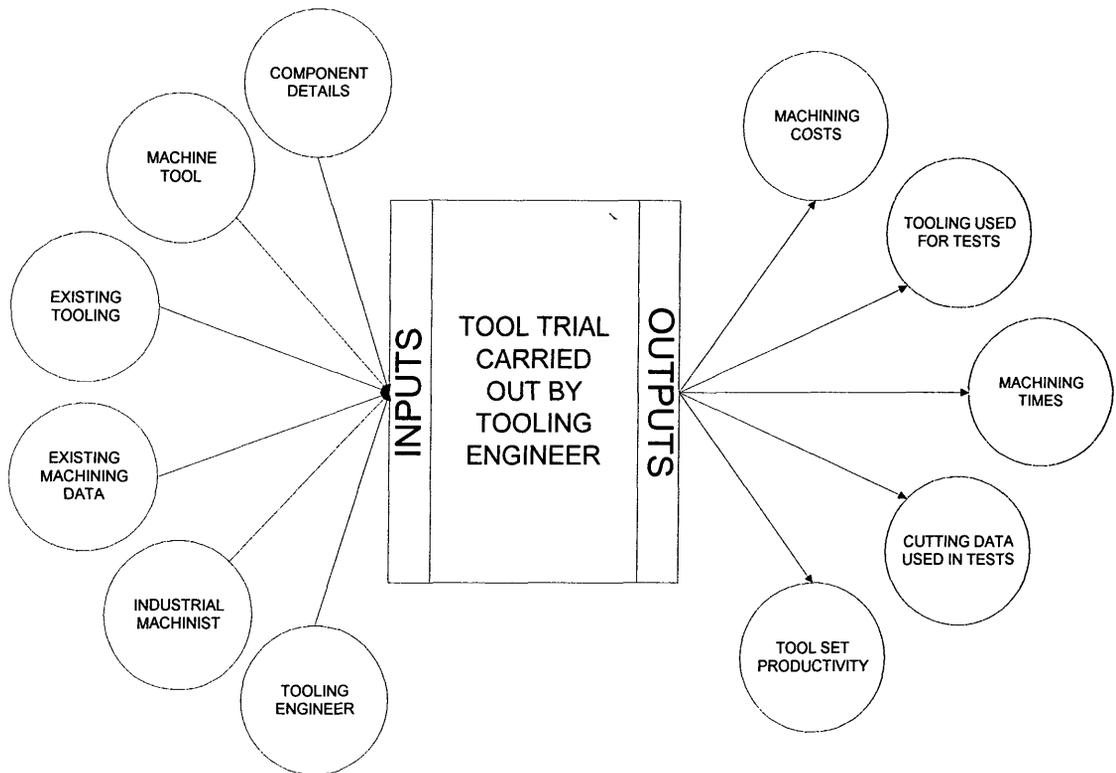


Figure 6.2 : Inputs and outputs of the tool trial process

Brief consideration of Figure 6.2, and in particular the fact that each category within this figure would contain a number of data terms, should make it clear that there is likely to be a significant number of data terms associated with just a single tool trial. Knowing that there are thousands of companies within the UK manufacturing sector who have a need to carry out metal cutting operations, it becomes immediately apparent that the scale of the database is significant.

During the period leading up to the specification of the Java development platform and the DBMS, the scale of a fully implemented tool trial storage and retrieval system was never underestimated. The chosen DBMS was a system called 'SQL-Anywhere' produced by Sybase. Full consideration of the technical specifications of SQL-Anywhere asserted the DBMS as being robust and suitable for Web-based industrial applications. Although the technical specification of the DBMS, in terms of capacity, was more than suitable for the intended application area, this is not to say that the

structure of the database was of little consequence. The time taken to interrogate a database using an SQL query is highly dependent upon the structure of that database, and so careful planning can yield significant benefits in terms of operating efficiency.

With the categories of system inputs and outputs having been determined, there were two further steps that needed to be completed. The first of these tasks was to specify the individual data terms within each of the categories depicted in Figure 6.2. Each of these data terms would then become a single field within the tool trials database. The second task was to define whether each of the input and output categories would only occur once in a single tool trial or whether they could occur several times in a single tool trial. Knowing whether each category would exist in either single or multiple instances allowed the table structure of the database to be defined. In order to summarise the results from these tasks, Table 6.1 lists whether each category has single or multiple instances, and Tables 6.2 and 6.3 list the data fields contained within the input and output categories respectively.

Input Categories	S/M	Output Categories	S/M
Component details	Single	Machining costs	Multiple
Machine tool	Single	Tooling used for tests	Multiple
Existing tooling	Single	Machining times	Multiple
Existing machining data	Single	Cutting data for tests	Multiple
Tooling customer	Single	Tool set productivity	Multiple
Tooling engineer	Single		

Table 6.1 : Analysis of tool trials data sub-groups

It should be noted that the tool trials database will deal solely with milling and turning operations. Whilst the principles presented here could be extended to deal with threading and drilling operations, the relatively low volume of these types of trials did not justify their inclusion. It should be assumed that each of the data terms presented in Tables 6.2 and 6.3 are common to both turning and milling operations. If this is not the case, the type of operation to which the data type relates will appear in parentheses - (M) corresponding to milling operations, and similarly (T) for turning.



It can be seen from consideration of Table 6.1 that all of the input categories exist as single instances within a tool trial and conversely, all of the output categories can exist as multiple instances. This symmetry in the properties of the two categories can be attributed to the fact that a tool trial may contain several tests based upon different tooling parameters, and hence several instances of the outputs are possible. Similarly, there is only likely to be one instance of the existing tooling parameters, and items such as the industrial machinist, tooling engineer and machine tool will, of course, only be specified once per tool trial report.

Component Details	Machine Tool	Existing Tooling	Machining Data	Tooling Customer	Other
Component Name	Name	Cutter	RPM	Contact	Test Objectives
Part Number	Condition	Insert	Cutting Speed	Department	Machining Type (T/M)
Material Description	Maximum Power	Insert Quantity	Feed	Company	Operation Type
Material Hardness	Coolant	Wiper	Feed Per Tooth		Brand of Existing Tooling
Material Group	Limitations		Axial Depth Of Cut		Date
Batch Quantity			Radial Depth Of Cut		Report Number
			Length Of Cut		Tooling Engineer
			Pieces Per Index		
			Time Per Piece		
			Remarks		

Table 6.2 : Data terms in each input category

Machining Costs	Tooling in Tests	Machining Times	Test Cutting Data	Tool Productivity	Other
Cost Per Insert	Cutter	Total Time	RPM	Comps Per Index	Reason Test Ended
Cost Per Set	Insert	Time Per Component	Cutting Speed	Tool Life in Test	Test versus Existing
Cost Per Index	Insert Quantity		Feed	Productivity Gain	
Cost Per Component	Wiper		Feed Per Tooth		
Tool Cost Savings			Axial Depth Of Cut		
Cost Red'n Per Comp			Radial Depth Of Cut		
			Length Of Cut		
			Pieces Per Index		
			Time Per Piece		
			Remarks		

Table 6.3 : Data terms in each output category

The data categories have now been identified and defined as to whether they would exist as single or multiple instances per report. As well as this the data terms within each category have also been specified and so it was possible to begin the procedure of constructing the database. It was decided that the database would contain two tables. One of these tables would be a general table containing all those parameters which would only exist once for a single tool trial. Each report within this table would be indexed via a report number. The report number field was defined as being a primary key of the table (i.e. no duplicate report numbers are permitted) with its data type being an integer that would be automatically assigned by the DBMS upon data submission.

The second table within the database would be a table for containing all those categories and data terms that could have multiple instances for a single tool trial report. The categories and data terms within this table were all the ones documented in Table 6.3, as well as the existing cutting parameters data terms shown in Table 6.2. In order to identify each record in the test data table a foreign key was defined. In addition to the data terms already specified, two additional fields were implemented in the test data table, namely a report number field and a test number field, both of these being defined as integer data types. This is to say that the combination of report number and test number for any single record would be unique. The report number in the general table would link directly with the report number in the test data table, whilst the test number field would be an integer representing the number of the test being added.

The SQL-Anywhere DBMS was used in order to create a database specifically for the tool trials information. Once the database had been created, each of the tables was defined and incorporated into the database. The full listing of the field names, data types and a description of the parameter associated with each field name can be found in Tables 6.4 and 6.5. Table 6.4 relates to the fields incorporated in the general table, with those field names appearing in bold type being parameters automatically assigned by the database rather than the tooling engineer completing the tool trial. The field name followed with a (*) indicates the primary key of the general table, which in fact is the report number - an automatically incremented integer. If a '(T)' or '(M)' is appended to the field description it indicates that the parameter pertains to only turning or only milling operations respectively.

Field	Field Name	Type	Description
1	ReportNumber (*)	Integer	Primary key of main table
2	IssuedBy	Text	Sales engineer performing tests
3	DateOfTest	Text	Date tool trial carried out
4	OldReportNumber	Text	Report no. assigned by engineer
5	Company	Text	Company in report
6	Department	Text	Dept. where tests took place
7	City	Text	City where company is based
8	Contact	Text	Company contact
9	ExistingSupplier	Text	Existing tooling supplier
10	OperationCode	Integer	Code defining machining op'n
11	TestObjectives	Text	Test objectives
12	MachineName	Text	Name of machine tool

/ continued

Field	Field Name	Type	Description
13	MachineID	Text	ID of machine tool
14	PowerMax	Text	Max. power available
15	PowerRequired	Text	Sufficient for all tests?
16	Year	Text	Machine age / year
17	ConditionCode	Integer	Machine tool condition code
18	Limitations	Text	Machine tool limitations
19	ComponentName	Text	Name of component to machine
20	PartNumber	Text	Part number of component
21	Material	Text	Component material description
22	SecoGpNo	Text	Seco material group number
23	Hardness	Text	Material hardness (BHN)
24	IntCutCode	Integer	Intermittent cutting code (T)
25	ClampingCode	Integer	Toolholding method code (T)
26	HeatTreatmentCode	Integer	Heat treatment code
27	SurfaceConditionCode	Integer	Surface condition code
28	DateOfSubmission	Date	Date submitted to database
29	TypeOfOperationCode	Integer	Code to identify turning / milling
30	CoolantCode	Integer	Code for coolant use

Table 6.4 : Data terms in general table

It can be seen from consideration of the parameters defined in Table 6.4 that a number of fields are coded and represented by integer values. From the view point of data storage and parameter matching for data retrieval methods, it is more efficient to use integer values rather than sometimes unwieldy text expressions. As a result of this, a number of fields which only have a discrete number of options are assigned an integer value which represents a certain definition rather than the text definition itself. For example, field number 29 is the TypeOfOperationCode. In this case, the digit '0' is used to represent turning operations, and '1' is used to represent milling operations. The definition of all coded fields in Tables 6.4 and 6.5 can be found in Appendix E.

Field	Field Name	Type	Description
1	ReportNumber	Integer	Foreign key (1)
2	TestNumber	Integer	Foreign key (2)
3	Manufacturer	Text	Manufacturer of tooling
4	Toolholder	Text	Toolholder type
5	XSection	Text	Toolholder cross section (T)
6	InsertType	Text	Type of insert
7	InsertSize	Text	Size of insert
8	Chipbreaker	Text	Insert chipbreaker
9	Grade	Text	Insert grade

/ continued

Field	Field Name	Type	Description
10	Diameter	Float	Diameter of workpiece (T)
11	RPM	Integer	Machine speed
12	CuttingSpeed	Float	Speed of cutting operation
13	FeedPerRev	Float	Feed rate per rev. (T)
14	FeedPerMin	Float	Feed rate per minute
15	DepthOfCut	Float	Depth of cut (T)
16	LengthOfCut	Float	Length of cut (T)
17	PartsPerEdge	Integer	Number of parts per edge / index
18	WearCode	Integer	Code for insert wear type
19	IndexingCode	Integer	Code for insert indexing reason
20	ChipFormCode	Integer	Code for chip form
21	CuttingTime	Float	Time of cutting operation
22	ToolLifePerEdge	Float	Tool life per edge / index
23	FlankWear	Float	Insert flank wear measurement
24	Comments	Text	Comments about the operation
25	NetPrice	Float	Net prices of insert / set
26	EdgesPerInsert	Integer	Number of edges per insert / set
27	MCCostPerHour	Float	Cost of the machine tool per hour
28	BatchSize	Integer	Component batch size
29	IndexingTime	Float	Insert indexing time
30	InsertQuantity	Integer	Insert quantity (M)
31	WiperInsertType	Text	Wiper insert type (M)
32	WiperInsertSize	Text	Wiper insert size (M)
33	WiperChipbreaker	Text	Wiper chipbreaker (M)
34	WiperGrade	Text	Wiper grade (M)
35	WiperQuantity	Integer	Wiper quantity (M)
36	FeedPerTooth	Float	Feed per tooth (M)
37	AxialDOC	Float	Axial depth of cut (M)
38	RadialDOC	Float	Radial depth of cut (M)

Table 6.5 : Data terms in test data table

Table 6.5 relates to the fields incorporated in the test data table, and, as in the case of the general table, field names appearing in bold type are parameters automatically assigned by the database. It can be seen from the test data table shown in Table 6.5 that the first two terms are defined as being the foreign keys of the table. A single tool trial will usually comprise of a number of tests, and so the *ReportNumber* field in the test data table is used to link every tool test with a specific report number. Further to this, the combination of *ReportNumber* and *TestNumber* form the primary key of the test data table, as each combination of these two fields will be unique. Finally, in the same way as Table 6.4, if a '(T)' or '(M)' is appended to the field description, it indicates that the parameter relates to only turning or only milling operations respectively.

6.4 Database communication

At this point the structure of the database has been defined, and the SQL-Anywhere DBMS has been used to create the tables that will store the tool trials data. Clearly the structure of the tool trials database is an important consideration which will effect the overall efficiency of submitting information to and retrieving information from the database. Besides the structure of the database and its tables, it is necessary to define the methods that will be used to either submit data to or retrieve data from the database, in particular;

- With the SQL-Anywhere DBMS, what is the structure of the front-end and can it be used to provide data access via the World Wide Web?
- Can the standard front-end of the DBMS be circumvented in order to allow the application of an alternative method for carrying out data submission and retrieval tasks? Of course, the back-end of the DBMS must be compatible with any alternative method being considered.

The SQL-Anywhere package is primarily designed to allow data sharing over a Local Area Network (LAN). It is possible to install the package as either a '*client-install*' or a '*server-install*'. As the names suggest, a server-install is the installation of the back-end components of the DBMS whilst the client-install relates to the front-end components. In a typical LAN application there will usually be a dedicated database server. The client version of the install process will then be undertaken on every machine that requires access to information stored on the centralised database.

In general corporate applications, most DBMS's are only ever required to operate as a centralised LAN service. It is only during recent years, with the explosion in popularity of the Internet as a medium for carrying out business tasks, that people have looked at expanding the capability of DBMS's in order that they can be accessed via the World Wide Web. It is commonplace that the front-end of a DBMS will only provide users with the possibility of carrying out database access via a LAN - this result is not borne out of a lack of knowledge in providing Web-based data access so much as the security considerations that need to be considered when exposing a database to global access. The answer to the question of providing Web-access via a client install of the SQL-

Anywhere package is that this would not be possible. Not only does the software not cater for direct Web-based data access, but it would require a client-install of the package for any user who wanted to gain access to the database. Whilst the front-end would be of no use in this particular application, analysis of the front-end revealed that database tasks were carried out by the execution of SQL commands. In general, whether there is a basic front-end requiring the user to manually generate the SQL commands, or a highly graphical front-end which automatically generates the SQL, it is the application of SQL that performs the tasks the user wants to execute.

Despite the lack of support within DBMS's in allowing Web-based data access, this is not to say that it is not possible to achieve this task. Many companies now provide Web-pages which interact with company databases to provide the user (via their browser) with the information they require. In general, these companies maintain their existing LAN structure and only provide access to important information for users within that LAN. However, there are two ways in which database access can be achieved using the World Wide Web, namely via the use of CGI or Java as discussed in the literature review.

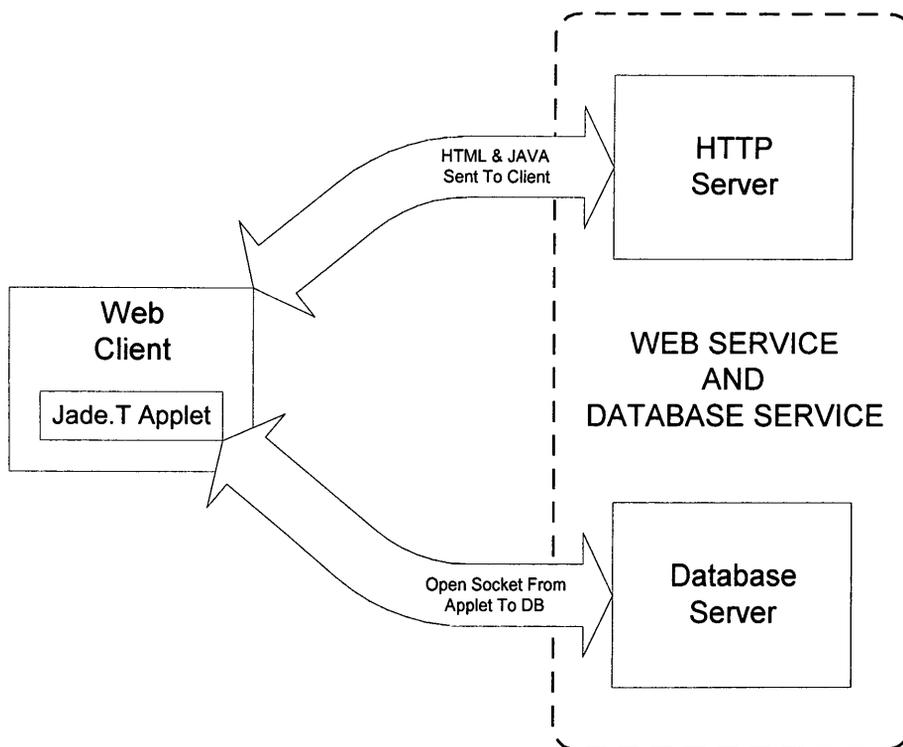


Figure 6.3 : JadeT network architecture

Once due consideration had been given to the implications of following either the CGI or Java paths it was decided that Java would be used to make a direct connection to the tool trials database server, with the SQL being generated by the Java GUI. Although the Java method suggests the database server and Web server are separate entities, it is possible to have both services being provided by a single machine. This was the option chosen during the developmental phase of this research and led to the architecture shown in Figure 6.3.

6.5 JadeT GUI development

The only part of the system so far not considered in detail is the development of a front-end that will provide client users with the tools they need to navigate their way through the tool trials database. The essence of the front-end of the system is to provide a graphical module capable of generating the SQL commands which are required to perform the variety of tasks upon the tool trials database. It was continually remembered that the tool trials database is designed to be operated by skilled engineers rather than computer software gurus and so significant emphasis was placed on the system being intuitive to use. Careful design of the front-end would result in a system that is simple to use and yet dynamic in terms of retrieving the engineering information being searched for by the user. In addition to this, methods would be developed which would try to minimise the amount of information the engineer would have to sift through before finding the data required.

The tool trials database has been developed as part of an overall suite of software aimed at providing a range of services to staff members from a tooling manufacturer. As a result of this, and the fact that confidential information was being stored, one of the first requirements of the tool trials database was that access to the data should be restricted. This was achieved by users being required to enter a valid user ID and password before being given access to the functions within the JadeT system. Whilst the whole JadeT system was contained within a single applet, this applet could contain a wide variety of different information screens. To understand how this was achieved, the JadeT applet could be considered as a pack of cards, each card having a different picture on it. By linking cards in a logical manner and displaying them when necessary, the user is presented with an entire software package on a single screen - a significant advance on

the days when exploratory hypertext ruled the Internet. It should be noted that the JadeT system offers a variety of different functions, and that these functions are, or are not, made available depending upon the identity of the user. An integral part of the system is a 'Super-user' area. This term was derived from the Super-user utilities made available to people with root permissions on UNIX systems. With JadeT the Super-user accounts are given access to a complete password management utility where user accounts could be created, modified or removed.

For the purpose of the tool trials database it is necessary for a user to choose whether to submit or retrieve data from the database. The result of this choice would then decide whether the screen for submitting a query to the database or alternatively the first screen in the process of submitting a new tool trial to the database is displayed. The precise details regarding the appearance of the tool trials database querying systems and their associated methods will be presented in the following chapter.

Assuming the user has chosen to submit a tool trial to the database it is then necessary to stipulate whether the tool trial relates to either a turning or a milling trial. A complete tool trial record requires the user to enter data on four different forms. In order to minimise the size of the JadeT applet (and hence the time taken to download it), only four general data submission screens were designed. Once the user has specified the operation to be performed each data submission screen is prepared according to the type of operation specified for the new tool trial. This preparation typically involved setting the text labels adjacent to data entry fields as well as minor changes to the geometrical arrangement of the items on the screen. In order to illustrate the principal of preparing the data submission panels according to the type of operation consider Figures 6.4 and 6.5. Figure 6.4 shows the panel where test data parameters are entered for turning operations, whilst Figure 6.5 illustrates the same panel for milling. From basic knowledge of turning tools it is evident that a tool holder carries a single insert, hence providing the tool with a single cutting edge at any particular time. Figure 6.4 depicts the way in which provision is made for both the submission of the general parameters for that holder and insert combination as well as the cutting data parameters associated with a general turning operation.

Tool Trial Page 3 - Test Number 1 Part A

Manufacturer		Diameter	
Toolholder		RFM	
XSection		Cut Speed (m/min)	
Insert Type		Feed (mm/rev)	
Insert Size		Feed (mm/min)	
Chipbreaker		Depth of cut (mm)	
Grade		Length of cut (mm)	
		Parts per edge	

Figure 6.4 : First test data page for turning operations

In a similar way, the field of milling is known as being the process of material removal from a workpiece with a tool that has multiple finite cutting edges. Whilst a number of milling cutter bodies will only utilise inserts of a single geometry, some of the more complex cutters will need to be fitted with two distinct type of insert. A typical example of these type of cutters is in the area of square shoulder milling (illustrated in Figure 6.6), where a cutter needs to machine both surfaces of a ninety degree feature in the form of a shoulder. The main inserts are those which machine the face normal to the axis of the cutter. Those inserts performing the secondary task of machining the face parallel to the axis of the cutter are referred to as the wiper inserts.

Tool Trial Page 3 - Test Number 1 Part A

Manufacturer			RFM	
Toolholder			Cut Speed (m/min)	
	insert	Wiper	Feed (mm/tooth)	
Insert Type			Feed (mm/min)	
Insert Size			Axial DOC (mm)	
Chipbreaker			Radial DOC (mm)	
Grade			Length of cut	
Quantity			Parts per edge	

Figure 6.5 : First test data page for milling operations

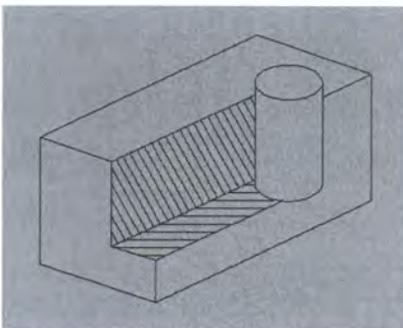


Figure 6.6 : Illustration of square shoulder milling

Knowing that there are four screens associated with any given tool trial, and that those screens vary according to the type of operation being performed, it follows that there are eight possible screens which may be encountered during the submission of data to the tool trials database. Figures 6.7 and 6.8 show the four screens associated with turning and milling operations respectively; for the sake of brevity these images display the screens in a collage-like arrangement.

<p>Tool Trial Page 1 - General Test Details</p> <p>Report No. (Old / New) <input type="text"/> / <input type="text"/> Automatic</p> <p>Company Name <input type="text"/></p> <p>Department <input type="text"/></p> <p>Co. Address / City <input type="text"/></p> <p>Contact Person <input type="text"/></p> <p>Issued By <input type="text"/></p> <p>Date of Test <input type="text"/></p> <p>Machine Tool / ID No. <input type="text"/> / <input type="text"/></p> <p>Power Needed / Max. <input type="text"/> / <input type="text"/></p> <p>Condition / Age <input type="text"/> 0 Not Sp. <input type="text"/></p> <p>Test objectives <input type="text"/></p> <p>Limitations <input type="text"/></p> <p style="text-align: right;"><input type="button" value="Forward >>"/></p> <p style="text-align: right;"><input type="button" value="Cancel"/></p>	<p>Tool Trial Page 2 : Component Test Details</p> <p>Comp. / Part No. <input type="text"/> / <input type="text"/></p> <p>Material / Group No. <input type="text"/> / <input type="text"/></p> <p>Hardness <input type="text"/></p> <p>Existing Tooling Supplier <input type="text"/></p> <p style="text-align: right;"><input type="button" value=" << Back"/></p> <p>Coolant Code <input type="text"/> 0 Not Specified <input type="button" value="v"/></p> <p>Int / Cont Cut Code <input type="text"/> 0 Not Specified <input type="button" value="v"/></p> <p>Clamping Code <input type="text"/> 0 Not Specified <input type="button" value="v"/></p> <p>Heat Treatment Code <input type="text"/> 0 Not Specified <input type="button" value="v"/></p> <p>Surface Finish Code <input type="text"/> 0 Not Specified <input type="button" value="v"/></p> <p>Operation Code <input type="text"/> 0 Not Specified <input type="button" value="v"/></p> <p style="text-align: right;"><input type="button" value="Forward >>"/></p> <p style="text-align: right;"><input type="button" value="Cancel"/></p>
<p>Tool Trial Page 3 - Test Number 1 Part A</p> <p>Manufacturer <input type="text"/></p> <p>Toolholder <input type="text"/></p> <p>XSection <input type="text"/></p> <p>Insert Type <input type="text"/></p> <p>Insert Size <input type="text"/></p> <p>Chipbreaker <input type="text"/></p> <p>Grade <input type="text"/></p> <p>Diometer <input type="text"/></p> <p>RPM <input type="text"/></p> <p>Cut. Speed (m/min) <input type="text"/></p> <p>Feed (mm/rev) <input type="text"/></p> <p>Feed (mm/min) <input type="text"/></p> <p>Depth of cut (mm) <input type="text"/></p> <p>Length of cut (mm) <input type="text"/></p> <p>Parts per edge <input type="text"/></p> <p style="text-align: right;"><input type="button" value=" << Back"/></p> <p style="text-align: right;"><input type="button" value="Forward >>"/></p> <p style="text-align: right;"><input type="button" value="Cancel"/></p>	<p>Tool Trial Page 4 - Test Number 1 Part B</p> <p>Wear code <input type="text"/> 0 Not Specified <input type="button" value="v"/></p> <p>Insert indexing code <input type="text"/> 0 Not Specified <input type="button" value="v"/></p> <p>Chip form code <input type="text"/> 0 Not Specified <input type="button" value="v"/></p> <p>Cutting time t_c-min <input type="text"/></p> <p>Tool life per edge t_l-min <input type="text"/></p> <p>Flank Wear Y_b-mm <input type="text"/></p> <p>Net Price <input type="text"/></p> <p>Edges per insert <input type="text"/></p> <p>MC Cost per hour <input type="text"/></p> <p>Batch Size <input type="text"/></p> <p>Indexing time <input type="text"/></p> <p>Comments <input type="text"/></p> <p>1. Add more test data?</p> <p style="text-align: right;"><input type="button" value="Yes"/></p> <p style="text-align: right;"><input type="button" value="No"/></p> <p>2. Submit test report?</p> <p style="text-align: right;"><input type="button" value="SUBMIT"/></p> <p style="text-align: right;"><input type="button" value="Cancel"/></p>

Figure 6.7 : Set of forms for submitting a turning trial

<p>Tool Trial Page 1 - General Test Details</p> <p>Report No. (Old / New) <input type="text"/> / <input type="text"/> Automatic</p> <p>Company Name <input type="text"/></p> <p>Department <input type="text"/></p> <p>Co. Address / City <input type="text"/></p> <p>Contact Person <input type="text"/></p> <p>Issued By <input type="text"/></p> <p>Date of Test <input type="text"/></p> <p>Machine Tool / ID No. <input type="text"/> / <input type="text"/></p> <p>Power Needed / Max. <input type="text"/> / <input type="text"/></p> <p>Condition / Age <input type="text"/> 1 Good <input type="text"/></p> <p>Test objectives <input type="text"/></p> <p>Limitations <input type="text"/></p> <p style="text-align: right;"><input type="button" value="Forward >>"/></p> <p style="text-align: right;"><input type="button" value="Cancel"/></p>	<p>Tool Trial Page 2 : Component Test Details</p> <p>Comp. / Part No. <input type="text"/> / <input type="text"/></p> <p>Material / Seco Gp. <input type="text"/> / <input type="text"/></p> <p>Hardness <input type="text"/></p> <p>Existing Tooling Supplier <input type="text"/></p> <p style="text-align: right;"><input type="button" value=" << Back"/></p> <p>Coolant Code <input type="text"/> 0 Not Specified <input type="button" value="v"/></p> <p>Int / Cont Cut Code <input type="text"/> 0 Not Specified <input type="button" value="v"/></p> <p>Clamping Code <input type="text"/> 0 Not Specified <input type="button" value="v"/></p> <p>Heat Treatment Code <input type="text"/> 0 Not Specified <input type="button" value="v"/></p> <p>Surface Finish Code <input type="text"/> 0 Not Specified <input type="button" value="v"/></p> <p>Operation Code <input type="text"/> 0 Not Specified <input type="button" value="v"/></p> <p style="text-align: right;"><input type="button" value="Forward >>"/></p> <p style="text-align: right;"><input type="button" value="Cancel"/></p>
<p>Tool Trial Page 3 - Test Number 1 Part A</p> <p>Manufacturer <input type="text"/></p> <p>Toolholder <input type="text"/></p> <p>Insert <input type="text"/> Wiper <input type="text"/></p> <p>Insert Type <input type="text"/></p> <p>Insert Size <input type="text"/></p> <p>Chipbreaker <input type="text"/></p> <p>Grade <input type="text"/></p> <p>Quantity <input type="text"/></p> <p>RPM <input type="text"/></p> <p>Cut. Speed (m/min) <input type="text"/></p> <p>Feed (mm/tooth) <input type="text"/></p> <p>Feed (mm/min) <input type="text"/></p> <p>Axial DOC (mm) <input type="text"/></p> <p>Radial DOC (mm) <input type="text"/></p> <p>Length of cut <input type="text"/></p> <p>Parts per edge <input type="text"/></p> <p style="text-align: right;"><input type="button" value=" << Back"/></p> <p style="text-align: right;"><input type="button" value="Forward >>"/></p> <p style="text-align: right;"><input type="button" value="Cancel"/></p>	<p>Tool Trial Page 4 - Test Number 1 Part B</p> <p>Wear code <input type="text"/> 0 Not Specified <input type="button" value="v"/></p> <p>Insert indexing code <input type="text"/> 0 Not Specified <input type="button" value="v"/></p> <p>Chip form code <input type="text"/> 0 Not Specified <input type="button" value="v"/></p> <p>Cutting time t_c-min <input type="text"/></p> <p>Tool life per edge t_l-min <input type="text"/></p> <p>Flank Wear Y_b-mm <input type="text"/></p> <p>Net Price per set <input type="text"/></p> <p>Edges per set <input type="text"/></p> <p>MC Cost per hour <input type="text"/></p> <p>Batch Size <input type="text"/></p> <p>Indexing time <input type="text"/></p> <p>Comments <input type="text"/></p> <p>1. Add more test data?</p> <p style="text-align: right;"><input type="button" value="Yes"/></p> <p style="text-align: right;"><input type="button" value="No"/></p> <p>2. Submit test report?</p> <p style="text-align: right;"><input type="button" value="SUBMIT"/></p> <p style="text-align: right;"><input type="button" value="Cancel"/></p>

Figure 6.8 : Set of forms for submitting a milling trial

Consideration of the screens shown in Figures 6.7 and 6.8 reveals that the first two screens allow the user to enter the data associated with the general table whilst the remaining two screens are for the submission of test data. During the submission process a number of procedures are in force which ensure all the necessary data has been entered and that the user is confronted with the screens in the correct order. The logic associated with the submission of data to the tool trials database is shown in Figure 6.9.

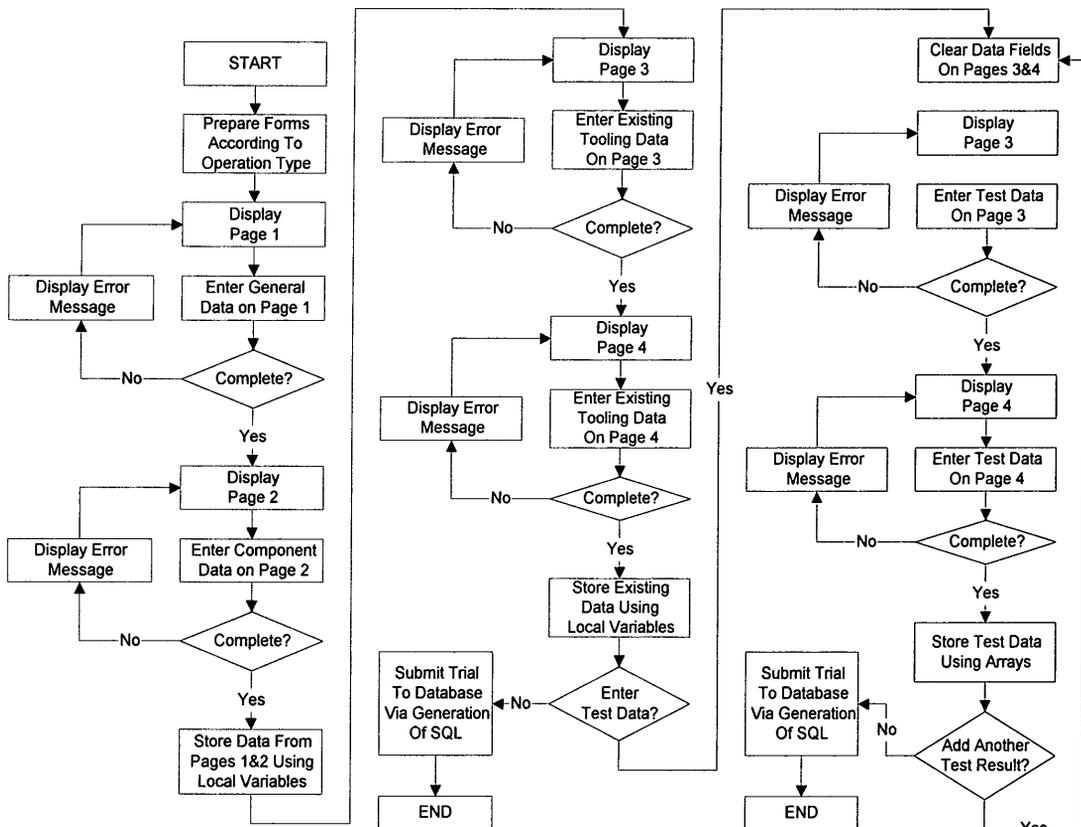


Figure 6.9 : Front-end data verification logic

The overall goal of the tool trials database was to create a global pool of information to be shared amongst experienced engineers in the face of technical problems. Whilst the creation of the tool trials database, and more importantly the application of computer technology, will lead to this goal being achievable, there are a number of beneficial side-effects. Returning to the previous situation where tool trial reports were committed to paper and then filed away, little effort was made to ensure that all of the data terms were entered by the engineer conducting the trial. A system which is computer based will be able to easily verify that all of the necessary data terms have been entered. The tooling manufacturers noted that this ability to regulate and enforce the way in which reports are completed would be of benefit.

From consideration of Figure 6.9, it should be apparent that the rules presented therein only deal with the stages that are involved in storing all the data terms associated with a tool trial on the client system. This is to say that when all of the data has been entered into the system, the values are actually being held by means of variables defined within the JadeT applet. At this point it is necessary for the data to be submitted for addition to the database. Invoking this procedure is achieved by the user clicking on a button labelled 'Submit' on the last page of the electronic tool trial forms. From the earlier discussion regarding the structure of the database and most significantly the existence of two tables within the database, it follows that it will not be possible to add a record to the database with a single SQL command. Despite the fact that the user of the JadeT system is never aware of the procedures which operate in the background of the application, the generation of the SQL commands necessary to add the tool trial to the database is by no means straightforward. The process of generating these SQL commands and the way in which they are transmitted to the database server can conveniently be summarised with the use of another flow diagram, as shown in Figure 6.10. Before inspecting this diagram it will be useful to define a number of terms associated with the task of getting a Java applet to communicate with a remote database server.

The first term to be introduced is a 'transaction object'. There is a transaction class defined within the PowerJ Java development environment, and the objects defined by instances of this class are the objects that actually link the Java applet with the database server. When a transaction object is created, there are a number of properties which can be set for that object. The most important ones are the specification of the database server URL, the port number which can be used for communicating with the server, and finally a user ID and password that will be used to validate the database query. Once the transaction object has been created the Java applet will use it to establish an open connection with the database. This communication line remains open until the applet is given a command to terminate it (for example, a 'Logoff' procedure from the applet would be a suitable candidate for effecting the disconnection of the transaction object). If the client's browser moves to another URL then the transaction object is automatically destroyed, terminating the communication with the database.

The second important term is a 'query object'. Query objects are created courtesy of the query class within the Java programming environment. The function of a query object is to send an SQL command as a data string to the database. Every query object has to be linked with a transaction object. This is achieved by specifying a string as one of the parameters used to instantiate the query object. This string identifies that transaction object with which that query is associated. A single query object therefore, can only perform tasks on those databases which are accessible with the specified transaction object. There are a number of properties for carrying out an SQL command on a database, and these properties can be set via the query object used to perform the updates. Not only does a query object carry out the transmission of the SQL strings to the database, but is also handles all of the information returned by the database which can be deciphered into establishing the exact result of submitting any given SQL string. It is via the monitoring of these messages sent from the database to the query object that the Java applet can evaluate the exact result of any given SQL submission and deal with it appropriately. For example, if an SQL string was submitted and it failed to append that data to the database, the query object would receive a code which would give the reason why it was not possible to add the data to the database.

The logic presented in Figure 6.10 illustrates the way in which JadeT monitors the submission of a tool trial to the database and ensures that the user is informed as to whether the submission procedure has been successful. The first stage in the data submission procedure is to verify that JadeT has successfully established a direct link to the database. If it is not possible to establish this link an error code will be generated and JadeT will analyse this code to determine whether the error is recoverable. In the event that a recoverable error is identified a further attempt will be made to connect to the database. If the error is unrecoverable JadeT will inform the user and suggest that the data is submitted at a later point in time. Once a direct link has been established the SQL commands generated by JadeT will be submitted to the database. The results of these SQL submissions will be monitored so as to ensure they are successful in updating the database in the required manner. If any SQL command is unsuccessful, an analysis of the error code will be made to determine whether the error is recoverable. As before, a recoverable error will produce a further attempt to submit the data whilst an unrecoverable error will result in the user being informed that the data submission has been unsuccessful. Upon the successful execution of the series of SQL commands the

user will be informed of the successful submission and the connection to the database will be terminated.

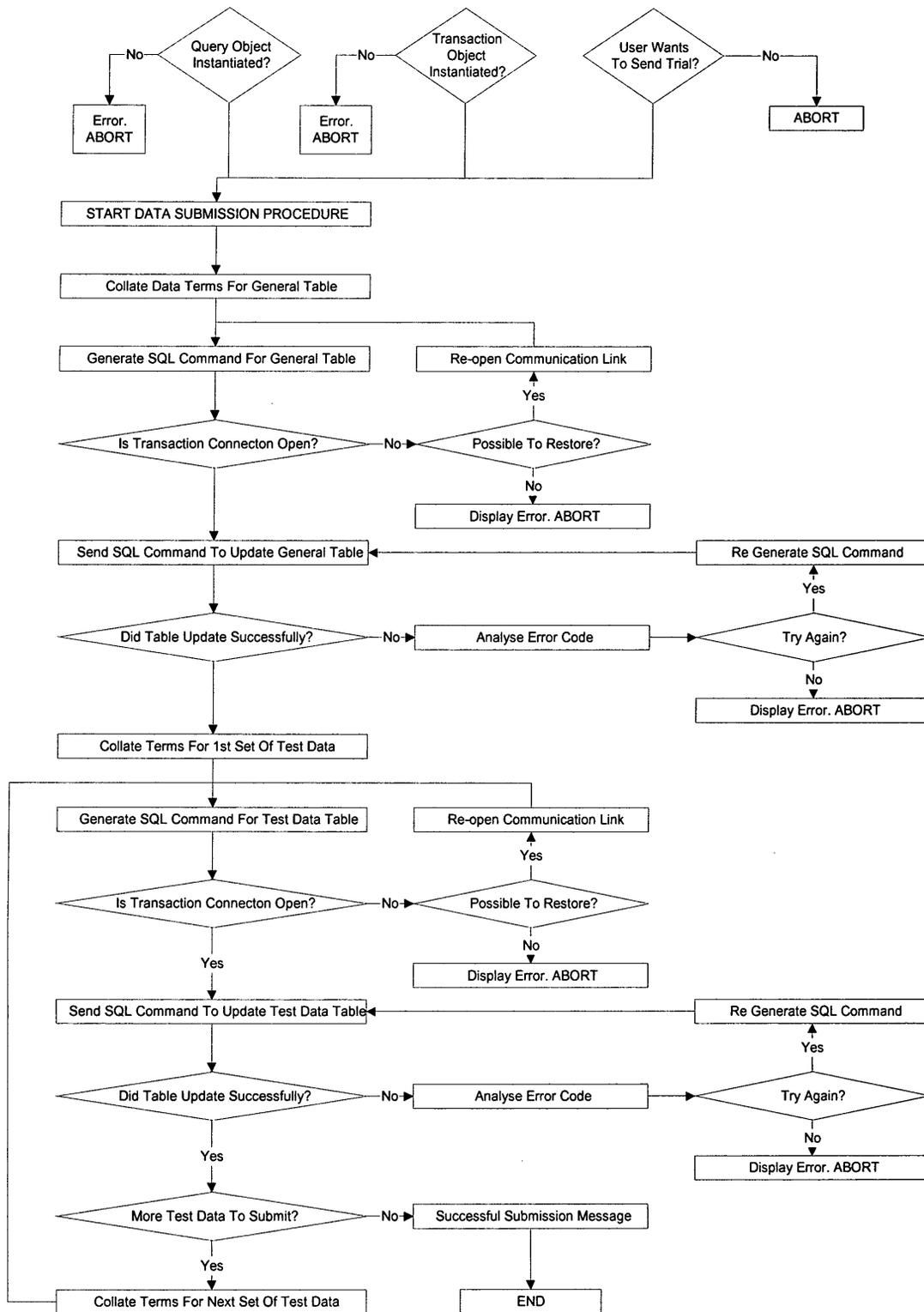


Figure 6.10 : Logic of applet communication with a remote database server

6.6 JadeT database population

At this point a fully functional GUI providing a link to the back-end of the DBMS has been created. The task of testing the GUI front-end was relatively straightforward. The first task was to launch the database service and verify that it was possible to access a database from a remote location. This was achieved with a simple applet which scans through records in a database table. Once the database service had been launched the same machine was then configured to provide a Web service; this single machine was acting as both the database server and the Web server. This is not an ideal arrangement in terms of operating speed, but for developmental purposes it was adequate.

The JadeT applet was then included within a basic HTML page, with a browser being used to check that the HTML page downloaded (verifying the operation of the Web service) and that the applet within the HTML document appeared as intended. This achieved, it had been verified that both services were operational and functioning as intended. The final stage of this preliminary testing phase was to create a number of fictional tool trial reports and submit them to the database via the JadeT applet. The front-end of the DBMS on the server was then used to examine the data in the various tables. This test was performed to ensure that the SQL commands generated by the JadeT applet were adding the data to the database in exactly the manner required.

In research of this nature it is important not only to design and implement the system, but clearly outlined methods for populating the database and performing a series of tests on the system must be in place. With regard to populating the database there were two options available.

- Launch the system and submit data as and when tool trials are carried out.
- Populate the database with previous tool trials allowing pre-launch testing.

It should be obvious that the first of these options is not ideal. The tasks of data submission and pure data retrieval are trivial in terms of testing their operability, but when data processing methods are incorporated into the system it is important to have real life data upon which to test and hone those methods.

This research has three key aims - to develop, test and finally evaluate a system capable of providing technical engineering information to remote users anywhere in the world via the World Wide Web. In order to carry out the testing and evaluation phases it was deemed necessary to have a representative database from real tool trials. Whilst a populated database would be excellent in terms of the testing opportunities it would provide, it also has to be remembered that the paper-based tool trials from which the data would be gleaned are unlikely to present the information in a manner suitable for direct implantation into the database described earlier. Whilst the JadeT concepts are generalised and suitable for integration within the foundation of any tooling manufacturer, the implementation of the JadeT software would be unique based upon particular considerations of that tooling manufacturer. The industrial collaborators were approached regarding the need to populate the tool trials database in order for the data processing methods to be developed and tested. Based on the understanding that the information within the tool trials was confidential, it was agreed that a sample of recently conducted tool trials would be provided for submission into the tool trials database.

It has been noted that every instance of the tool trials database will have a number of characteristics unique to the manufacturer for whom the system was developed. It was therefore decided that a new database would be created specifically to store the data from the tool trial forms which had been provided. The task of creating this new database was straightforward, as it simply involved the removal of a number of fields which were present in the original version. The fields to be removed were of course those which were not present on the tool trial forms. The style of the forms which contained the tool trials data can be found in Appendix F. The main difference between the paper based tool trials and the original database specification was that the results and cost parameters were only given for the most efficient tool rather than providing these details for all of the tests as suggested. The effect of this was that as only one set of parameters would be provided for the results and costs section, these data terms could be moved from the test data table to the general table. No other significant differences existed between the information contained within the tool trial forms and those data terms in the original database. Appendix G details the precise structure of these new database tables along with the explanation of any coded fields which were used. With the new database created, the JadeT data submission GUI was used to populate the tool trials database with a wide-ranging selection of tool trials.

Chapter 7 : Distributed technical support using the tool trials database

The previous chapter has described the design and creation of the tool trials database. The way in which data can be submitted to the database has been examined via the presentation of images from the user interface of JadeT as well as flow diagrams which have summarised the logic defining the way in which data submission occurs. With the database having been created and populated, it was necessary to define the way in which this data would be processed so as to provide distributed technical support for the benefit of industrial machinists. The aim of the support system is to provide tooling engineers with access to relevant technical data that is suggested to be of use in addressing a specific tooling problem. This chapter will investigate exactly this issue, beginning with a basic technical support utility through various stages of development to produce an advanced distributed technical support tool. This advanced support tool was multi-layered and incorporated not only confidence assessment but the application of data relaxation procedures. This combination of methods was able to provide a system capable of scoring any tool trial in terms of its closeness to the user's specification as well as data relaxation procedures being used to generate a scored result set even when no exact matches are found.

7.1 Introduction

The aim of the JadeT system was specified as being to utilise the Internet in providing a platform for distributed technical support to industrial machinists in the tasks associated with the process planning activity. To effect this goal the tool trials database has been designed and implemented with a user-friendly interface allowing the submission of data from remote locations by tooling engineers. For a given engineer this task only involves a single tool trial, at any given time, and the submission of the resulting data to the database is little different from the completion of a paper-based tool trials report. In effect the engineer is dealing with an isolated set of data with which complete familiarity is implied. Whilst this apparent self-sufficiency of the tool trials database is

an admirable characteristic for any database to achieve, care has to be taken when the task of data retrieval, and in particular data processing, is required. As soon as the focus of the database task alters there are a variety of factors which need to be addressed.

From a number of discussions the author held with tooling engineers from a variety of tooling manufacturers, it was ascertained that there are two primary tasks to be dealt with when retrieving technical data relating to tool trials, viz.;

- Searching for a tool trial when the engineer knows exactly which report(s) are required. This situation would allow a tool trial to be retrieved based upon the specification of a number of general parameters; the name of the industrial machinist, the name of the tooling engineer and the workpiece material would be typical examples.
- Searching for a tool trial based upon a specific technical difficulty which has been encountered. In contrast to the previous scenario, this type of query will result in the search being characterised by the specification of a number of technical parameters. A typical example would be a technical query encountered when performing a specific operation with a given combination of insert type and workpiece material.

To meet the needs of these fundamentally different types of technical query it was decided that two support utilities would be developed. The first support utility would be a basic interface where the engineer could complete a number of fields which related to general parameters featured in the required test reports. The second utility would be more advanced allowing technical parameters to be specified as well as the relative importance of each of those fields.

In the remaining sections the appearance and functionality of both the technical support utilities will be presented and discussed. The next section will look at the basic support utility. This will be followed by analysis of the major features which make up the advanced support utility based upon technical parameter specification and result processing. A brief summary of the entire technical support platform will be added to conclude this chapter.

7.2 Basic technical support utility

7.2.1 General specification

The remit of this utility was to provide the user with a way of accessing and retrieving specific tool trials based upon a knowledge of a number of the general parameters contained within those trials. Whilst one of the overall aims of the tool trials database was to effect the distribution of tool trials data, it is likely that any engineer may wish to firstly review reports completed by him or herself.

Any engineer with a history of ‘in-the-field’ tests is likely to remember poignant or significant tool trials. A combination of the specific knowledge of a single engineer applied to any given technical problem may result in the realisation that the problem could be solved directly with information from a previous trial carried out by that engineer. In such situations the information used to identify the required tool trial record(s) was considered to be sufficiently abstracted from technical terms to qualify as being referred to as general parameters. Whilst to a non-engineering person these terms may appear to be technical, when considered within the context of the system users the terms were predominantly of a general nature. After due consideration and discussion it was decided that the following parameters could be specified within the basic technical support utility;

- Type of operation (turning or milling) and / or
- Material group (any one or all of the 15 main material groups) or
- Material description and / or
- Tooling engineer and / or
- Test objectives

The appearance of the user interface for this utility can be seen in Figure 7.1, from which it can be seen that there is an additional parameter that the user can specify; this parameter is the archive to be searched, which appears as the first item to be specified in the utility. It is appropriate to mention the reason for the inclusion of this parameter as it may have been assumed that the support utilities were developed specifically for the

retrieval of information from the database of tool trials populated with information provided by the industrial collaborator. Whilst the utilities were tested upon this populated database, the methods within the querying utilities were sufficiently generic to allow abstraction to any instance of the tool trials database. Consequently it was possible for the user to query either the populated database or the general tool trials database as presented in Chapter 6. Whilst the general tool trials database was populated with some dummy reports in order to validate the data submission processes, it was necessary to ratify the more detailed searching methods with the database populated with real-life data. Following with the same theme it can be seen that the third parameter in Figure 7.1 is labelled as being for the selection of a material group as defined by Seco Tools. This refers to the database populated with real life data whereas if the general database were selected the material groupings would be specified via a generic material classification system.

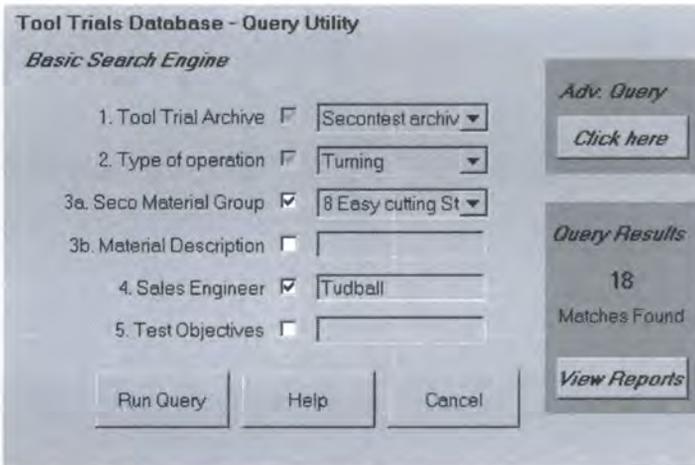


Figure 7.1 : User interface of the basic technical support utility

7.2.2 Technical system functionality

Now that the query utilities have been affirmed as being compatible with any instance of the tool trials database it is possible to look at the way in which the basic support module works. From consideration of Figure 7.1 the parameters which can be specified by the user are clear. It is not a requirement for the user to specify all of these parameters, and the inclusion of any single parameter within the query can be specified by simply checking or un-checking the checkbox adjacent to the relevant parameter.

The specification of the first three parameters relies on the user selecting from a finite number of choices for each. For example, when specifying the type of operation the user has to select the required operation type as being either a turning or milling operation. If the checkbox next to the choice menu is left unchecked, tool trials containing any operation type will be included in the search. In the latter choices it can be seen that the user is free to type in a text description of the value they wish any given parameter to assume.

Once the user has completed the required fields it is necessary to find out how many reports match the criteria defined by the parameters specified in the form. When the user performs this request, an SQL command is generated which is submitted to the database to evaluate how many reports match. For the first three parameters the choices are finite and so each of them was defined as having to match exactly. A little more freedom is allowed with those parameters identified by the user entering a text description. For example, suppose the name of the tooling engineer stored in the database for a given report is 'John Smith'. When the field in the database which holds the name of the tooling engineer is queried, it is not stipulated that the name specified by the user in the query module matches the field in the database verbatim. The user could enter a host of variations on John Smith, each of which would be accepted as a matching query, i.e.; 'Smith', 'John', 'Smith J', 'J Smith' would all be considered as matching queries. Whilst this freedom could be argued to risk incorporating a number of irrelevant reports in the result set, this is preferable to rejecting a number of reports simply because the field does not match according to a strict character-for-character comparison.

Once the database has been queried the user will be informed as to how many matching tool trials have been found. A matching query is defined as one which matches ALL of the parameters specified for inclusion in the query - i.e. all those which are checked. When the user has been informed of the number of results matching the query it is possible to modify the search criteria and for the database to be queried again to evaluate the number of matching reports based upon the new details. This option will be useful when too few criteria have been specified and a large number of trials have been found to match or conversely if the criteria were too precise and too few matching trials have been identified. Once an acceptable number of trials have been identified the user can elect to view those reports which match the criteria specified.

Having identified the reports which the user wants to view it is necessary to retrieve these trials from the database and present them to the user for consideration. The forms which are used to perform the data submission tasks are perfectly structured for the display of retrieved data. It was decided that once the data from the relevant reports had been retrieved, it would be displayed via those forms initially designed for data submission. The only modifications needing to be made were to alter each of the text fields on the form such that they would not allow the user to edit any of the data fields. The labels of the navigation icons were modified accordingly to represent the tasks associated with data retrieval. A collage of these screens is presented in Figure 7.2.

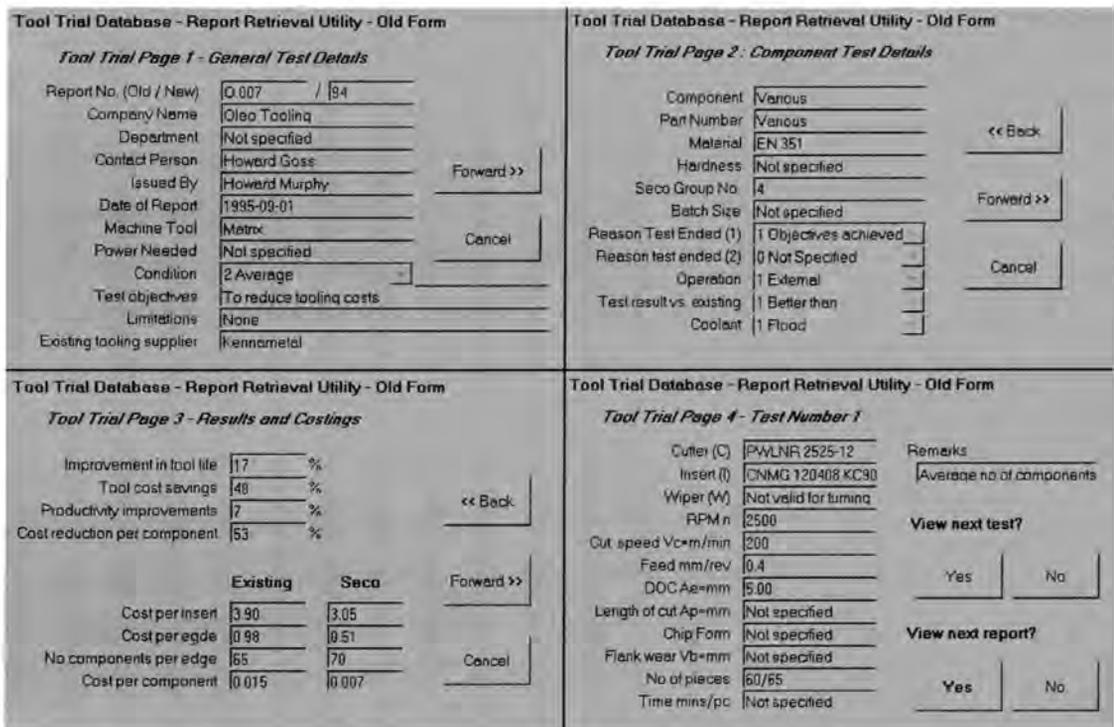


Figure 7.2 : Data retrieved using the basic query utility

The task of retrieving tool trial reports from the database for presentation to the user is not straightforward and relies on an appropriate logic structure to define the way in which the data retrieval process is managed. The need for such a process results from an appreciation that at several stages during the retrieval of tool trials data, the user is able to exercise different options in terms of the manner in which the data is displayed and ordered. In addition to this it is necessary to monitor the execution of the SQL commands generated by the retrieval process as well as the state of the communication channel established between the client system and the server database. The following section will look at the underlying logic support of the basic support facility.

7.2.3 Logic of primary system infrastructure

Consideration of Figure 7.3 illustrates that the actions which can be performed by the user are carefully controlled throughout the data retrieval process. The purpose of this control is to provide a robust utility which will be stable during general use. By limiting the available options to those which are valid at any given point in time, it not only benefits the system in terms of its stability, but the user will benefit as well. If it is only ever possible to select operations which are valid, the system will be intuitive to use, with the logic behind the functions guiding the user through the choices to be made during the operation of the system.

The logic structure detailed in Figure 7.3 commences with the preparation of the user interface so that it is possible to specify the search parameters. When the system is requested to perform the search a number of checks are made to ensure that the parameters have been specified appropriately. These checks test to ensure that at least one field has been completed, and in the case of those fields which allow a text string to be specified by the user, a test to ensure the integrity of each text string is made. Once the form has been confirmed to have been completed in an acceptable manner an SQL string is generated by JadeT and submitted to the database. In the event that the SQL string fails to be sent to the database the reason for the failure will be established. Assuming the error to be recoverable a further attempt to communicate with the database will be made but in the event of an unrecoverable fault an error message will be displayed to the user. If the submission is successful the user will be informed of the number of matching reports that were identified. At this point the user can modify the initial query and re submit it to the database. This feature will be used if the initial search identified too few or too many matching tool trials. Provided the number of reports is acceptable the user can elect to view those reports.

Consider the situation where JadeT has identified a number of reports which are believed to contain the information required for the technical query to be solved. Assuming each tool trial to have an equal chance of containing the necessary data, it is probable that the engineer will pinpoint the necessary information without the need to view all of the tool trial reports. The nature of remote database access results in a situation where the time taken for the data to be retrieved will increase as the amount of

data to be retrieved increases. This suggests that it may not be beneficial to download all of the reports prior to presenting the data to the user, as the time taken to achieve this task could be significant and yet not all of the data may be viewed by the user. It was decided that JadeT would adopt the practice of only retrieving data from the database when it is known with certainty that the user wants to view that data. This principle can be seen from consideration of the logic structure defined in Figure 7.3.

In summary it can be seen that a basic technical support system has been developed and implemented. The aim of this utility is to provide a method for engineers to view tool trial reports based upon the specification of a number of alternative parameters, and the methods used to achieve this goal have been presented. Detailed supervision of remote database communication parameters has produced a system which is stable during use and is intuitive to use from the graphical nature of the user interface.

7.3 Advanced technical support utility

7.3.1 General specification

With the basic support utility having been developed, the next utility to be considered was one which would allow technical support to be provided from the specification of technical tooling parameters. Typically this situation would be where the tooling engineer has no direct experience of the problem encountered and wishes to search for relevant information from trials carried out by other engineers. Despite the database containing reports from a variety of tooling engineers, any of which may be relevant in solving an individual query, a single engineer will have little knowledge of similar trials conducted by other engineers. This leads to the conclusion that in a situation where an engineer wants to consult the entire database with no perception of which specific reports will be relevant, that there will need to be some way of specifying the query in a purely technical manner.

One of the most fundamental ways in which data has been segregated within the tool trials database is according to whether the trial contains data relating to either a turning or a milling trial. The reason for this dichotomy is the rudimentary way in which turning and milling operations differ. Basic knowledge of turning and milling tools reveals that a turning tool will only have a single cutting edge whereas a milling cutter will have multiple cutting edges. It is not specifically this distinction which makes the two categories of cutters unique; it is the fact that milling always concerns an operation comprised of intermittent cutting movements whereas in most situations turning operations will involve a single continuous cutting action.

This fact is highlighted when the subject of insert coding is investigated. All inserts are assigned a code based upon geometry of the insert, the material from which the insert is made and the materials which the insert is capable of cutting. This coding system is an ISO standard, and allows a detailed analysis of any individual insert to be undertaken. Whilst the structure of an ISO insert code applies to all inserts irrespective of their operation designation, the individual elements of the code can vary according to whether the insert is designed to perform a milling or turning operation.

It should be apparent that during the execution of any cutting operation, one of the most important areas for consideration is the interface between the component being machined and the insert which performs the cutting task. In general terms the geometric features which need to be imparted to the component will define the geometry of the insert capable of carrying out the procedure. Equally, the material from which the component is made will to a large extent govern the composition properties of the insert which needs to be used. It was therefore decided that the specification of the technical problem with regard to which the engineer sought advice would be based upon the technical analysis of the insert / component interface.

7.3.2 ISO coding of inserts

The coding of carbide inserts associated with metal cutting operations is governed by ISO code 1832-1991. This coding system defines the international standard for the allocation of codes to any particular insert. In this system, the code can be broken down

into a finite number of constituent parts, each of which defines a property associated with either the function or geometry of the insert.

It should be noted that this ISO code can be applied to inserts associated with both turning and milling cutters, although the operation type has to be considered when a code is deciphered. Figure 7.4 illustrates the structure of the coding system for inserts, with the meaning of each parameter being defined in Table 7.1. Note that an ISO code element marked with a * indicates that the interpretation of the code is common to both turning and milling operations.

S	E	A	N	12	03	AF	T	N	-	M16
1	2	3	4	5	6	7	8	9		10

Figure 7.4 : Illustration of an ISO insert code

ISO code element	Definition for turning insert	Definition for milling insert
1*	Insert shape	Insert shape
2*	Clearance angle	Clearance angle
3*	Tolerances	Tolerances
4*	Type of insert	Type of insert
5*	Cutting edge length	Cutting edge length
6*	Insert thickness	Insert thickness
7	Nose radius	Wiper edge
8	-	Cutting edge condition
9	-	Intended direction of cutting
10	Chipbreaker	Designation

Table 7.1 : Elements of ISO insert code

The majority of the elements defined in Table 7.1 are fundamental properties of an insert and do not merit further description. Brief notes will be made in relation to the function of a wiper edge and the interpretation of the insert designation.

7.3.2.1 Function of wiper edge

In the case of milling operations the seventh ISO parameter refers to the presence of a wiper edge on the insert. Whilst the term wiper *insert* has already been used to describe a secondary insert on a milling cutter designed to machine the secondary face of the

operation, a wiper *edge* is simply a flattened edge on the primary insert which ‘cleans up’ the primary machining face in the wake of the main cutting action. The function performed by a wiper edge is illustrated in Figure 7.5.

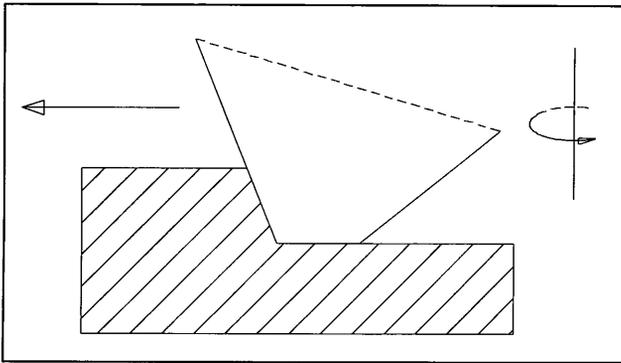


Figure 7.5 : Illustration of wiper edge function

7.3.2.2 Insert designation

Although the intermittent nature of milling operations removes the obvious need for a chipbreaking system, it is not the case that the upper face of milling inserts is planar in terms of its geometry. Whilst the contours on an insert are able to impart chipbreaking behavioural characteristics in the case of turning inserts, the geometry can also affect the smooth flow of material during the cutting operation. The way in which milling inserts are defined in terms of their metal cutting ability is via a designations system. In some respects the designation system of milling inserts has close links with the specification of chipbreakers for turning. The way in which a milling insert’s designation is evaluated is to assess the difficulty of the cutting operation and the chip thickness. These two parameters are scored on a graph, with each insert designation occupying a precise area in a similar manner to chipbreaker diagrams. The difficulty of the machining operation is plotted on the vertical axis and varies from light machining operation near the axis origin through to heavy machining conditions at the extreme of the range. An easy operation is one which involves soft workpiece materials, thin chips, pre-machined workpieces and other situations which result in good chip flow characteristics. Chip thickness is plotted on the horizontal axis and increases with distance from the origin. The chip thickness is synonymous with the feed rate, so an assessment of the feed rate and the difficulty of the operation will indicate the insert designation that is required to perform that task.

7.3.3 Insert grade and material suitability

Most inserts are made from a material called carbide, or cemented carbide to use its full name. Carbide is a mixture of tungsten carbide (WC), which is a very hard substance, and cobalt (Co), which serves as the binder. Tungsten carbide is responsible for the wear resistance of an insert whilst cobalt affects the toughness. By altering the relative proportions of tungsten carbide and cobalt within an insert, the wear resistance and toughness of the inserts varies. It is this variation which makes any particular insert adept at machining a given type of material. In addition to the variations in the chemical composition of the insert, there are a variety of different methods by which the inserts are produced. Again, these different methods of manufacture result in inserts which have different suitability for machining particular materials.

In terms of the guidance given for choosing an insert grade based upon the component material, the ISO PMK classification system is frequently employed. This standard splits insert grades into three broad categories, namely those for machining steels (P), stainless steels (M) and cast irons (K). Each of these categories is further sub-divided resulting in a scale which rises with the increasing hardness and machinability index of the materials which the inserts are designed to machine. For example, the P group for steels is divided into a range from P01 up to P50, where the first group contains inserts designed to machine very soft low-carbon steels and purely ferritic mild steels. The P50 group, at the opposite end of the scale, will contain inserts designed for use with high strength steels which are difficult to machine and have high hardness values. Figure 7.6 illustrates the way in which a region on each of the P, M and K scales can be shaded to represent which materials the insert grade is capable of machining. Knowing the material which needs to be machined it is possible to evaluate the most suitable insert grade.

Grade	P					M				K					
	P01	P10	P20	P30	P40	P50	M10	M20	M30	M40	K01	K10	K20	K30	K40
TP100		■	■				■	■			■	■	■	■	
TP200			■	■	■		■	■	■				■	■	
TP300				■	■			■	■						

Figure 7.6 : Specification of insert grade machining capability

7.3.4 Technical parameters for database searching and the GUI design

The previous sections have detailed the ISO coding system for inserts from which a highly specific set of parameters can be attributed to define the exact properties of any single insert. With the capability of the insert in terms of the materials it can machine also having been investigated, the use of a standard grade / material chart together with an inserts ISO code can allow the most essential elements of the cutting process to be specified.

Having decided that the advanced technical support system would be based on analysis of the insert / workpiece interface it was possible to define what parameters would be presented in the user interface. In addition to the user being presented with a choice as to which database would be queried, provision was made for specifying the criteria listed below. For those parameters where numbers are specified in parentheses after the brief description, it should be noted that these numbers refer to the constituent elements of the ISO code, as detailed in Figure 7.4.

- Operation category
- Material group
- Material description
- Insert type ⁽¹⁻⁴⁾
- Insert grade
- Insert geometry ⁽⁵⁻⁷⁾
- Chipbreaker / designation ⁽¹⁰⁾

With the choice having been made as to which parameters could be specified within the advanced technical support utility, it was necessary to consider the exact way in which those parameters could be defined. It was hoped that the ruggedness of the basic support utility could be enhanced to provide a more refined system allowing the user greater control over the way in which the technical support query could be specified.

The user interface of the advanced technical support system was developed so as to allow the user not only the ability to decide which parameters would or would not be specified, but to attribute the relative importance of each of those parameters. In this

manner, the engineer using the tool trials database would be able to impart their detailed tooling knowledge to specify a technical query based upon a thorough assessment of the tooling problem. The information contained within the request for technical support could then be used to pinpoint those tool trial reports which most closely matched the user's requirements. Figure 7.7 shows the user interface of the advanced query utility.

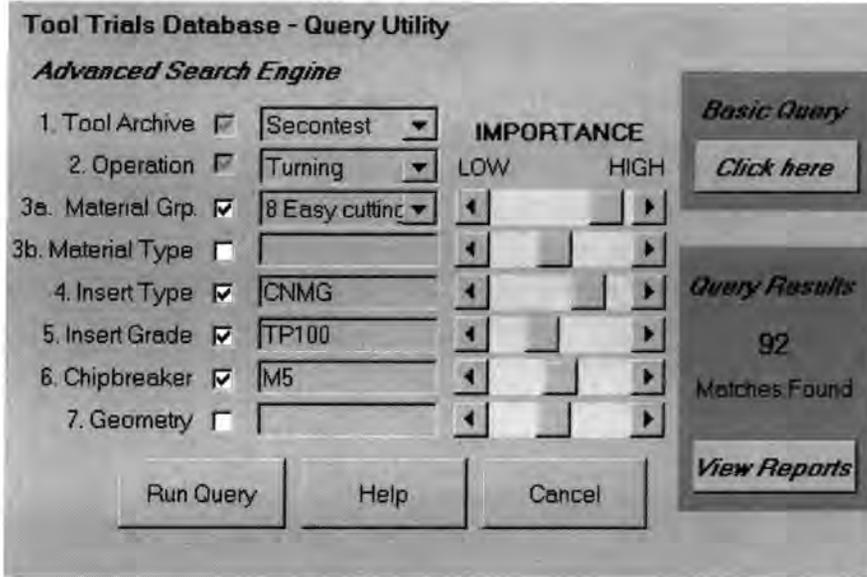


Figure 7.7 : User interface of the advanced technical support utility

7.3.5 Functionality of the advanced technical support utility

Although the structure of the user-interface has been defined and implemented, this is by no means the most important element of the utility. It is important that the tooling engineer is able to easily understand how to generate a technical query, but beyond this the overall performance of the system will hinge upon how efficiently the information provided by the user can be interpreted to identify the most relevant tool trials stored in the database.

From the viewpoint of the Java programmer, it is a trivial matter to generate an SQL query which searches for reports which exactly match the specifications laid down by the user. Consideration of the insert / workpiece interface has revealed a complex series of processes involving many variables, from which it can be concluded that there is a significant probability of not finding a tool trial that meets all of the user's specifications. This is not to say that the database does not contain tool trials which may

be of use to the tooling engineer, and it could be the case that the database contains trials which are similar to the specifications laid down by the user. In this situation it would seem appropriate for the data from these trials to be made available to the user for consideration in context of the given technical problem. Such functionality would also absolve the user of being requested to perform the frustrating task of making minor alterations to the initial request so as to find a perfectly matching tool trial.

From consideration of the user interface shown in Figure 7.7, it can be seen that provision has been made for the user to attribute a measure of relative importance between fields. The possibility of allocating parameter importance measure would utilise the tooling engineer's interpretation of the technical difficulty. The ability to score a tool trial in terms of its closeness to the user's specifications would be a significant aid in generating a set of results with which the user will be satisfied. If a single parameter was identified as being of greater importance than other parameters, any tool trial in which this parameter matched would be allocated a higher score than a trial in which that parameter did not match.

Further consideration of the task of searching the tool trials database for relevant information raises an additional important issue. The scroll bars incorporated in the user interface are obviously a graphical way of letting the user specify the importance of one parameter relative to another. However, imagine a situation where a parameter from the database does not match the specified value exactly, but is very close to it. Whilst it is not a simple task for a computer to identify 'nearly matching' values, thought needs to be given to the validity of discarding values which may in fact be very close to the values which are required. As a result of the points just discussed, it was decided that there would be three distinct levels of matching tool trial reports in the context of the advanced technical support system, namely;

- Reports where all of the criteria match exactly
- Reports where some of the criteria match exactly
- Reports where some of the criteria match either exactly or partially

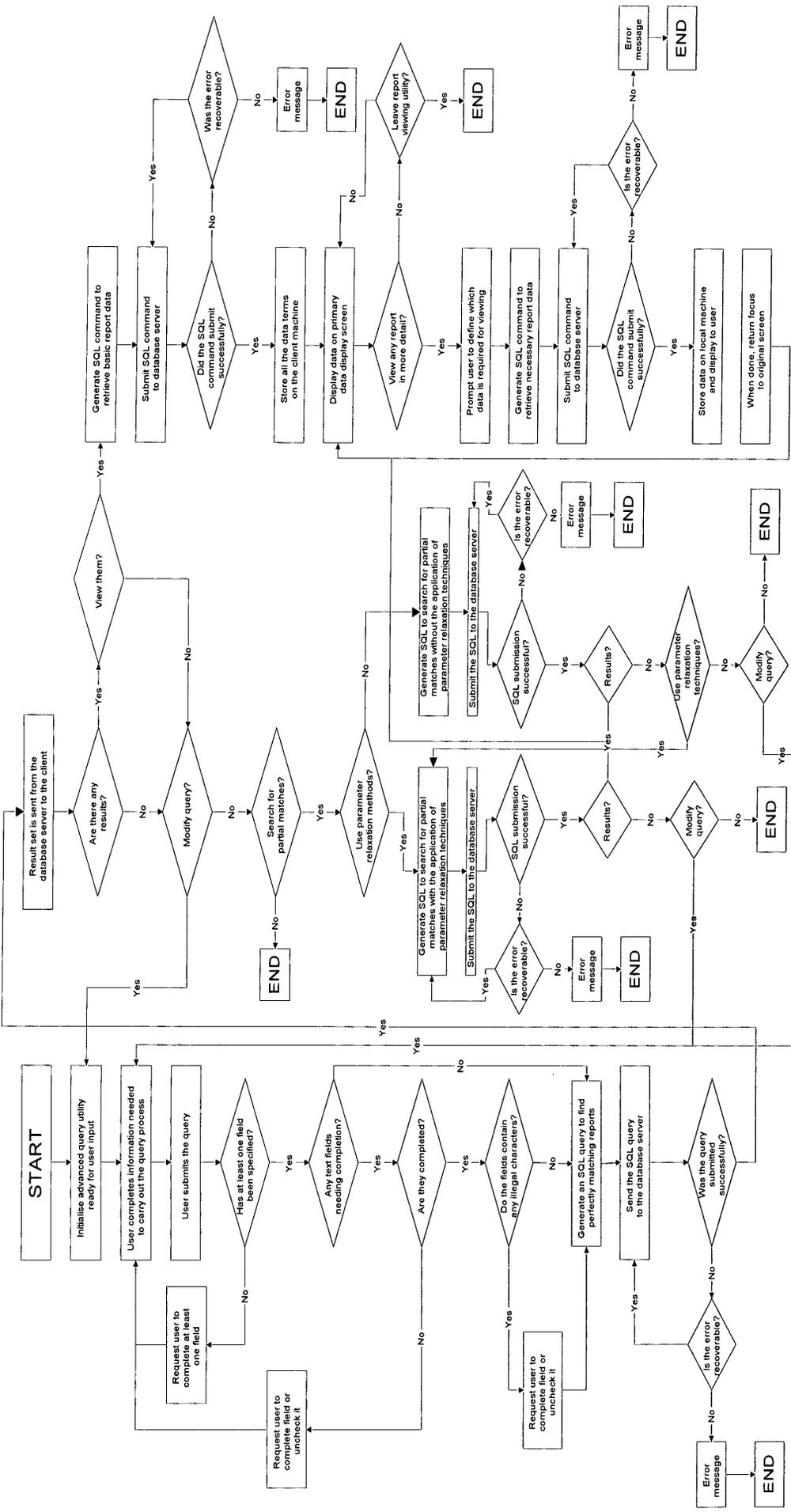


Figure 7.8 : Logic flow diagram summarising advanced query utility behaviour

A flow diagram summarising the logic which controls the main events during the process of carrying out an advanced technical support query is presented in Figure 7.8. As was the case for the basic support utility, the primary aims of the logic structure supporting the system's operation were to ensure the integrity of the communication between the server and the tool trials database as well as to guide the user through the various options for retrieving data from the database.

From consideration of Figure 7.8 it can be seen that the first function to be performed during the execution of an advanced database search is to verify that the technical parameters entered by the user are appropriate. Once this has been established a search will be carried out to identify the number of reports which match the user's specifications exactly. If a number of tool trials have been identified it will then be possible to view these reports. In the situation where no reports match exactly, the user will be able to make a choice between modifying the technical specification of the problem manually or allowing JadeT to perform a search for partially matching tool trials. Should the user decide to perform a search for partially matching tool trials then it will be necessary to decide whether parameter relaxation techniques will be applied. If the user does not opt to apply parameter relaxation techniques a search will be carried out for tool trials where a number of the fields, but not all the fields, match exactly. Each tool trial report will be scored¹ in terms of its closeness to the original specifications made by the user and it will then be possible to view the most closely matching reports. For those situations where parameter relaxation techniques are used, JadeT will perform a database search whereby each parameter will be assessed in terms of its closeness to the values specified by the user. Again, each tool trial report will be scored and it will then be possible to view the most closely matching tool trials.

In certain situations the database may have little relevant data in relation to a specific technical difficulty. If the user was to search for partially matching tool trials, the reports identified by JadeT may have a low confidence score indicating a poor match. Functionality was introduced whereby the user could specify the lower limit for the confidence scores and so remove the possibility of retrieving poorly matching reports.

¹The full analysis of the way in which reports were allocated a confidence score can be found later in this chapter. The confidence score is simply a numerical indication of how closely the report from the database matches the parameters specified by the user.

7.3.6 Presentation of tool trials data

Irrespective of the method used to generate a result set, it is important that the data should be displayed in a manner congenial to rapid evaluation by the user. Not only is there merit in adopting a cautious approach to the display of data, but a reduction in the number of parameters from any single report to be displayed will be beneficial in terms of the speed with which the system operates.

It was decided that a number of key parameters from each of the matching reports would be downloaded and displayed to the user. In the case of partially matching reports these would be displayed in descending order of confidence score. These initial parameters to be shown were intended to provide the user with sufficient information to decide whether or not there was value in viewing more data from that report. Whilst only details of three reports could be seen at any one time, it was possible for the user to scroll through the entire result set, should that be appropriate. Figure 7.9 shows the screen for the preliminary display of report data.

View Perfectly Matching Reports

Company	Albon Engineering		
Issued by	M K Myall		
Date of test	1993-02-23		
Objectives	Tool life		
Machine	Cinturn 12		
Component	Ford Zeta Flywheel		
Material	SG Iron		
Cutter	Not specified		
Insert	CNMA 120412 IC8		
Confidence	100%		

Figure 7.9 : Preliminary display of test data in advanced query utility

It can be seen from this figure that at any point it is possible to view a single report in more detail. It was decided that displaying all of the data terms associated with a single report en-masse would bombard the user with too much information and would reduce the speed with which the data could be retrieved. The test report data was therefore split into a number of distinct sections, viz.;

- General information
- Component specification
- Test data
- Results

If the user decided that it was necessary to look at the data for a single report in more detail, it would simply be a case of selecting which of the categories of data they wished to view. The data would then be downloaded from the database and displayed to the user. It is then the responsibility of the tooling engineer to make the final decision as to whether the data stored in an existing tool trial report could be adopted in order to solve an existing technical query.

The preliminary aim of the tool trial database was to create a pool of information which could be shared amongst tooling engineers, whilst also providing a way in which future tool trials could be stored in a standard format. The creation of the tool trials database and the functions which allow the submission of data to the database have realised this aim. The next logical step to take in light of this progress was to implement methods which would reduce the amount of time and effort needed in finding data of relevance to a particular technical query. Three levels of tool trial report identification have been stated, although it is clear that those reports which match all of the parameters specified by the user are going to be the most likely candidates for providing information suitable for dealing with the technical problem. It is those situations which identify no perfectly matching reports where consideration needs to be given as to how relevant results can be found and returned to the user. A system which can accurately assess the closeness of any report to a specified ideal and provide a clear way of viewing closely matching reports will keep the user in a dominant position for solving technical problems.

The next section will present the way in which reports are scored based upon the number of parameters which exactly match those specified by the user. This will be followed with a consideration of the way in which parameter relaxation techniques can be applied to assess the closeness of any single parameter to the required value, despite them not matching exactly.

7.4 Confidence scoring of tool trials

7.4.1 Preliminary considerations

It was decided that in addition to searching for perfectly matching reports, it would be made possible for the user to assign the relative importance of different search criteria. From Figure 7.7 it can be seen that this was achieved by providing the user with a graphical means of indicating parameter importance. With the user now having the capability of indicating the relative importance of parameters it was necessary for the system to be able to deal with that information in a way that would provide the user with the most closely matching data contained within the database.

One of the first issues to be considered was the scale that would be used for the weightings derived from the scroll bars. Each weighting assumes a value that can vary between an upper and a lower limit, and these limits can be set individually for each of the scroll bars. The two main issues to be addressed were whether each weighting would be set with the same limits, and secondly what those limits would be. In consideration of the weighting scales it should be remembered that the function of the weightings is to provide the *user* with a means of assigning parameter importance. If the scale of any one parameter was to be set higher or lower than that of the others, it would reduce the user's ability to assign importance indications and it was therefore decided that each parameter weighting would be based on the same scale.

Having defined all the parameters to be based on the same scale, it was necessary to decide what form the scale should take. The fixing of this scale would then indicate what the difference would be between the maximum value and the minimum value. If the limit was to be set to a minimum of 0 and a maximum of 100, any parameters set to the lowest value would be assumed to have no importance and it was thought that this could be misleading in terms of the graphical appearance of the user interface. Equally, a scale that varied between 100 and 110 would provide the user with little scope for assigning a parameter's importance as they could only vary within a 10% band of each other. Clearly, the weightings are sensitive to the scale adopted and based upon these considerations it was decided that the maximum value would indicate a ten fold greater

importance than the lower value, and so a scale of 1 to 10 was set for each parameter's weighting scale.

Consideration of Figure 7.7 also shows that it is not possible to assign an importance to either the database archive or the type of operation. This is logical, since the particular database which would be searched for information would not be expected to have any bearing on the validity of the data stored within the database. Knowing there to be a significant diversity between the underlying processes taking place in turning and milling operations it would be a brave, if not foolhardy, measure to attempt to compare them.

The material presented so far deals with the structure of the user interface and the justification for the way in which the items within the user interface are constructed. Having provided the user with the tools necessary to conduct a search where parameters can be assigned relative importances, it is necessary to consider the way in which the confidence scores are assigned. A confidence score is defined to be a numerical indication of the closeness of the parameters of a tool trial in the database to the technical parameters specified by the user. The confidence score for any single tool trial can assume any value between 0% and 100%. A confidence score of 100% indicates a tool trial report where all the parameters specified by the user have been matched exactly. Conversely, a confidence score of 0% indicates that none of the parameters match either exactly or partially.

In the case of confidence scoring without parameter relaxation techniques, the methods used to assign a confidence score are mathematically trivial. Once the user has generated the search criteria and instigated the search, the first step is to retrieve all the report numbers of those trials which match at least one of the search criterion. The number of reports returned can then be used to display the size of the result set to the user. If the number of reports generated by the search is small, it is possible for the user to modify the query manually and perform a further search. Alternatively the user can decide to either view the few reports which have been identified, or opt for parameter relaxation techniques to be applied, the details of which will be dealt with in the next section.

7.4.2 Retrieval of data and calculation of confidence scores

Assuming the number of reports in the result set to be acceptable, the confidence scoring task will begin. By scanning through the parameters which can be specified by the user it can be seen that the material group and material type will be stored in the general table, with the insert parameters coming from the test data table. Referring back to the structure of the database it should be remembered that there will only be one record in the general table for a single report whilst there can be multiple records in the test data table.

Dealing with the material group and material type terms in the general table was relatively straightforward. During the evaluation of the number of results in the result set, all of the report numbers where at least one of the search criteria matched were downloaded and stored. It was therefore possible to generate a further SQL command which would return the material group and the material description for all the reports identified by the initial database search. If the user had specified any insert properties to be matched with trials in the database it was necessary to download the insert ISO code for each test for every report identified in the initial search. With all of the necessary data downloaded and stored on the client machine it is possible to begin calculating the confidence scores for each report.

The first logical parameter to evaluate is the maximum score possible for any single report. The checkboxes are the most convenient way of determining those parameters which have been specified by the user, and for each marked checkbox, the corresponding value of the weighting will be taken and added to the running total. The result of this summation is the maximum score that any tool trial could receive if each of the parameters matched exactly.

It is known that the parameters from the general table will only occur once for each report. The material group and the material type are compared with those specified by the user, and if either or both of them match, the value of the parameter weighting will be added to the running total for that report.

In the case of the insert specifications, the first task is to evaluate how many tests were performed for the report being considered. Each parameter is then compared with all of the test records, and the number of times it matches as a proportion of the total number of tests will be multiplied by the parameter weighting. This task is performed for all of the insert characteristics separately.

Once all of the parameters have been compared and assessed, the confidence score can be found by expressing the tally for that particular report as a percentage of the maximum possible score. The same procedure is adopted for the next test, and so on until all of the reports are assigned a confidence score. Equation 7-1 shows the algebraic expression which is used in the calculation of a confidence score without the application of data relaxation procedures.

$$CS(\%) = \frac{\sum_{x=3a}^{3b} \alpha_x \beta_x \chi_x + \left(\frac{1}{n}\right) \sum_{y=1}^n \sum_{x=4}^7 \alpha_x \beta_x \chi_x}{\sum_{x=3a}^7 \alpha_x \chi_x} \times 100\% \quad (7-1)$$

where;

α_x = Boolean value for checkbox state of parameter x (1 \Rightarrow checked)

β_x = Boolean value for comparison of database and user values for parameter x (1 \Rightarrow matched)

χ_x = Weighting assigned by user for parameter x ($1 \leq \chi_x \leq 10$)

n = Number of tests in current report

x = Parameter identification as presented in Figure 7.7

y = Test number

In the numerator of equation 7-1, the first summation assesses the confidence tally obtained from the general table whilst the second summation averages the confidence score from the test data table assuming that there are n tests in the report. Finally, the denominator is the summation to produce the maximum possible tally from all those parameters which are included in the search. By expressing the confidence tally as a percentage of the maximum possible tally the confidence score is produced.

7.4.3 Presentation of data within JadeT

With each of the reports having been assessed, there is an array of report numbers and an array of the corresponding confidence scores. A simple sorting algorithm is applied to these arrays to arrange them in order of confidence score, leaving just the data to be prepared for display. The key terms which are needed to be able to complete the viewing utility are downloaded from the database and the data is then displayed to the user along with the confidence scores of the reports, as shown in Figure 7.10

View Partially Matching Reports

Company	Pacson Engineerin	Land Rover	NV Tools Ltd
Issued by	A MacDonald	Peter Birley	Martin Myall
Date of test	1992-11-27	1992-05-01	1993-07-01
Objectives	To achieve optimi	To find a suitable r	Increase life
Machine	Mori-seki SL3	Wyvermatic (20/4t	Mazak Quickturn 1
Component	Cartridge housing	UJ Coupling Flang	Case
Material	316 Stainless	BS970 080M 40Q	EN24 / AISI 4140
Cutter	PCLNR 2525-12	MCLNR 12CA-12	PCLNR 2525-M12
Insert	CNMG 120408 MA	CNMG 120404 550	CNMG 120408 N-N
Confidence	63%	60%	60%

Figure 7.10 : Preliminary display of scored test reports

The nature of confidence scoring inevitably means that at the bottom end of the scale reports will have been assigned confidence scores of only a few per cent. A report with a confidence score of five per cent, say, is unlikely to yield data of relevance to the initial technical specification. Whilst it is an important part of the searching functionality to initially select all reports matching any of the specified criteria, this is not to say that all of those reports will prove to be worthy of detailed consideration. In order to maximise the speed with which the system operates and reduce the amount of irrelevant data being stored and handled, functionality has been introduced which allows the user to specify a lower limit for the confidence scores. Once each report has been assigned a confidence score, those reports which fall below the threshold are deleted from memory.

7.5 Data relaxation functions

In many situations the technical parameters specified by the user for performing an advanced technical support database search will not match the values stored in the database exactly. The technological functions presented so far have only identified exact parameter matches and null parameter matches. Data relaxation is the task of assessing the 'closeness' of two parameter values when they do not match exactly. The situations in which the user will be provided with the option of applying parameter relaxation techniques have already been examined. This section will look in detail at each of the parameters within the advanced tool trial utility, and the ways in which parameter relaxation techniques have been applied to them.

Equation 7-1 was presented in the previous section in the context of calculating the confidence score for a tool trial which did not apply any form of parameter relaxation techniques. This equation remains valid for the calculation of a confidence score when parameter relaxation techniques are applied, although the β_x parameter requires a minor alteration to its definition. In the situations where data relaxation techniques are applied, the β_x values are no longer a simple Boolean value which assume the value one for a matching parameter and zero otherwise. This Boolean value is replaced with a decimal value which can vary continuously within the limits of zero and one, i.e. $0 \leq \beta_x \leq 1$. The exact value taken by any single β_x value is assessed via the application of the parameter relaxation techniques. A β_x value close to unity would indicate a parameter has been found which closely matches the required value whilst a value close to zero would indicate a parameter which is a poor match for the value specified by the user. The parameter relaxation techniques applied to each of the user-specified parameters will now be presented.

7.5.1 Material group

The general term which has been adopted to describe the properties of a material in respect of its machining characteristics is *machinability*. In a general text associated with engineering materials, Bolton (1989) states that 'There is no accepted standard test for machinability and so it is based on empirical test data and is hence subjective.' This

view can be substantiated by considering the research which has been, and is being, conducted into machinability assessment [Choudhury and El-Baradie (1996), Fang and Jawahir (1994)]. This reveals a number of widely differing views upon the constituents of a machinability assessment method or indeed a machinability index which can be used to directly compare the machining characteristics of different workpiece materials.

In general, every tooling manufacturer will define a number of material groupings. Materials within these groups are expected to exhibit similar machining qualities, and further to this the groupings are used by the tooling manufacturers to define generic cutting data values which should be suitable for machining any material within a particular group. Based upon this information it was decided that an analysis would be undertaken whereby a number of key mechanical properties would be examined for those materials within the same material group. If this was to find that those materials within any single group did display correlation in terms of their mechanical properties, then it would be possible to look at the relationships *between* material groups.

Yeo *et al.* (1989), El-Baradie (1993), Choudhury and El-Baradie (1996) all identify the analysis of the mechanical properties of materials to be a valid and useful way in which the machinability of materials can be, and has been, assessed. Based upon the information presented by these and other researchers it was decided that a number of widely used mechanical properties would form the basis of a material machinability assessment. The properties which were chosen are;

- Tensile strength
- Yield stress
- Impact strength
- Hardness

Before continuing with the analysis of these mechanical properties it was necessary to give due consideration to the way in which materials were grouped by tooling manufacturers. In most cases tooling manufacturers categorise materials into the three broad groups, namely steels, stainless steels and cast irons. These groups are then further subdivided so as to identify 15 specific material groups, as illustrated in Table 7.2.

Gp. No.	Generic material description
1	Very soft, low-carbon steels. Low-carbon and purely ferritic mild steels.
2	Free-cutting steels, excluding stainless steels.
3	Structural steels and carbon steels. Plain carbon steels with low to medium-high carbon contents.
4	High-carbon and ordinary low-alloy steels. Medium-hard hardening and tempering steels. High-carbon steels.
5	Normal tool steels. Harder hardening and tempering steels.
6	Difficult tool steels. High-alloy steels with high hardness.
7	Difficult high-strength steels with high hardness.
8	Easy-machining stainless steels. Free cutting stainless steels.
9	Medium-difficult stainless steels. Austenitic and duplex stainless steels.
10	Stainless steels that are difficult to machine. Austenitic and duplex stainless steels.
11	Cast iron with high hardness. Grey iron.
12	Cast iron with medium-high hardness. Grey iron.
13	Low-alloy cast iron. Malleable cast iron. SG Iron.
14	Medium-difficult cast iron. Medium-difficult malleable cast iron. SG Iron.
15	High-alloy cast iron which is difficult to machine. Difficult malleable cast iron. SG Iron.

Table 7.2 : General classification of material groups

A selection of materials within each group was then referenced via a number of detailed material analysis manuals [Bolton (1989), British Steel (1989)] in order to find their tensile strength, yield stress, impact strength and hardness. For each material group it was possible to find an average value for each of the mechanical properties, and the standard deviation (SD)² associated with that property in order to assess the variability within the material group. The absolute standard deviation values vary according to the mean of the sample and so the values were also expressed as a percentage of the mean in order that different properties could be compared in a valid manner.

Whilst the content of this section will consider the analysis of the steel material groups, the methods presented here were also applied to the stainless steel and cast iron material groups. The results that were obtained from the initial analysis of steel material groups have been summarised in Table 7.3. It can be seen from consideration of the standard deviation expressed as a percentage of the mean that the mechanical properties of the materials within a specific material group did not vary by a significant amount. In light of this fact it was decided that direct comparisons between the material groups would be used as a way of contrasting machinability indexes between standard material groups.

² Standard deviation is a measure of how widely values are dispersed from the average value (the mean).

	Tensile Strength (MPa)	Yield Strength (MPa)	Izod Impact Strength (J)	Hardness (HB)
Material Group 1	Very soft, low-carbon steels. Low-carbon and purely ferritic mild steels			
Property Values	452	280	23	142
Standard Deviation	29.8	4.76	0.67	13.78
% Standard Deviation	6.59	1.70	2.91	9.70
Material Group 2	Free-cutting steels, excluding stainless steels.			
Property Values	519	325	22	162
Standard Deviation	38.4	26.7	2.85	12.3
% Standard Deviation	7.40	8.22	13.0	7.59
Material Group 3	Structural steels and carbon steels. Plain carbon steels with low to medium-high carbon contents.			
Property Values	631	349	30	183
Standard Deviation	37.2	30.1	2.84	13.2
% Standard Deviation	5.90	8.62	9.47	7.21
Material Group 4	High-carbon and ordinary low-alloy steels. Medium-hard hardening and tempering steels. High-carbon steels.			
Property Values	646	403	31	209
Standard Deviation	49.7	38.2	4.28	18.9
% Standard Deviation	7.69	9.48	13.8	9.04
Material Group 5	Normal tool steels. Harder hardening and tempering steels.			
Property Values	732	428	30	237
Standard Deviation	62.1	39.0	3.88	22.9
% Standard Deviation	8.48	9.11	12.9	9.66
Material Group 6	Difficult tool steels. High-alloy steels with high hardness.			
Property Values	898	496	35	242
Standard Deviation	81.8	47.0	3.51	21.5
% Standard Deviation	9.11	9.48	10.0	8.88
Material Group 7	Difficult high-strength steels with high hardness.			
Property Values	928	545	38	272
Standard Deviation	82.2	53.7	3.26	25.1
% Standard Deviation	8.86	9.85	8.58	9.23

Table 7.3 : Properties for material groups containing steels.

From consideration of Table 7.3 it can be seen that, in numerical terms, the impact strengths are an order of magnitude away from the tensile strengths. In order for each of the mechanical properties to be given an equal weighting in the machinability index calculations it was necessary to normalise these values. From the four mechanical properties the tensile strength values were set as the benchmark, and so the normalisation procedure was carried out on the other parameters relative to this group. The relationship that was used to carry out this normalisation procedure is presented in Equation 7-2.

$$\omega'_a = \omega_a \left(\frac{\sum_{n=1}^7 \sigma_n}{\sum_{n=1}^7 \omega_n} \right) \quad (7-2)$$

In equation 7-2, ω_n is the value of the parameter being normalised, whilst σ_n is the value of the tensile strength value, the 'n' subscript being used to identify the material group with which each parameter is associated. ω_a is the original value of the parameter being normalised whilst ω'_a is the normalised value, the 'a' subscript representing the material group from which the parameters originate. The normalised mechanical property scores are shown in Table 7.4.

Material Group Number	Tensile Strength (MPa)	Normalised Yield Strength	Normalised Impact Strength	Normalised Hardness
1	452	477	532	471
2	519	553	514	539
3	631	593	679	609
4	646	685	719	693
5	732	728	689	788
6	898	843	798	803
7	928	927	875	902

Table 7.4 : Normalised mechanical property values for steel material groups

With this task completed it was then possible to make direct comparisons between the material groups. The initial segregation which was made split materials into the broad steel, stainless steel and cast iron groups. Within each of these three categories there would be a series of normalised material properties. For each individual material group the sum of the normalised material properties was taken, as shown in Table 7.5.

Material Group Number	Sum of Material Properties
1	1932
2	2125
3	2512
4	2743
5	2937
6	3342
7	3632

Table 7.5 : Total of machinability index parameters

It was the values shown in Table 7.5 that were to be used to make the comparisons between the different material groups. It was decided that each material group would be normalised in turn. This is to say that the first material group would be normalised to have a total machinability score of unity. The values of the other groups relative to this value would then be calculated. This normalisation procedure was carried out for each of the material groups, and produced the results shown in Table 7.6.

	Index 1	Index 2	Index 3	Index 4	Index 5	Index 6	Index 7
1	100	91	77	70	66	58	53
2	110	100	85	77	72	64	59
3	130	118	100	92	86	75	69
4	142	129	109	100	93	82	76
5	152	138	117	107	100	88	81
6	173	157	133	122	114	100	92
7	188	171	145	132	124	109	100

Table 7.6 : Individual normalisation of material groups (percentage)

The data presented in Table 7.6 represents the results that were obtained when each of the steel material groups was normalised and then expressed relative to the other materials within the steel categorisation. The reason for the normalisation of all the groups is based upon the operating methods of the tool trials database. The user of the system could specify any of the material groups, and it will hence be necessary for that group to have been normalised in order to assess the proximity of the records from the database to that value. The overall aim of the algorithms being applied to the material properties data is to allow two different steel material groups to be compared in terms of their relative machinability indexes. In order to achieve this the table was adjusted so as to centralise each of the normalised values. In addition to this it was necessary to note those values in the table which took values above unity. For example, in the first normalisation procedure, group 1 was assigned the value of 100% whilst group 2 was 110% relative to this. Although this is true in terms of the material property values, the overriding piece of information to be gleaned from this data is that group 2 is ten percent away from unity and so in the final phase of the operation this would be assigned a value of 90%. The results from the application of this adjustment are summarised in Table 7.7.

Material Group Reference	Index 1	Index 2	Index 3	Index 4	Index 5	Index 6	Index 7
-6							53
-5						58	59
-4					66	64	69
-3				70	72	75	76
-2			77	77	86	82	81
-1		91	85	92	93	88	92
0	100	100	100	100	100	100	100
1	90	82	91	93	86	91	
2	70	71	83	78	76		
3	58	62	67	68			
4	48	43	55				
5	27	29					
6	12						

Table 7.7 : Linearisation of the machinability index scores for regression analysis

Table 7.7 contains sufficient data to allow the machinability of a specified group to be compared directly with that of another material group. The series defined in Table 7.7 were plotted and produced the graph shown in Figure 7.11.

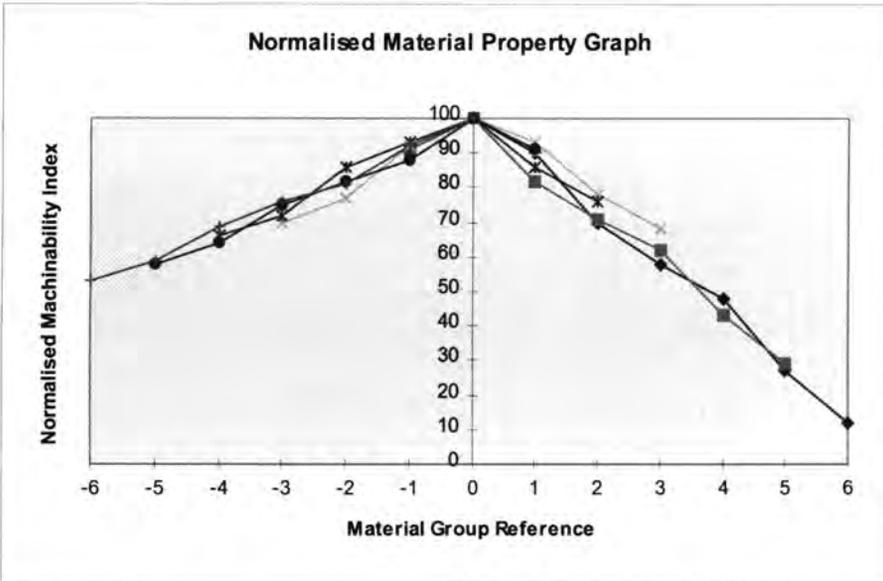


Figure 7.11 : Graph of normalised material property series

Consideration of Figure 7.11 shows that there is a good level of conformance between the normalised machinability index series. Rather than using a number of mini-series to assess the machinability index confidence score it was decided that a single line would be plotted, the values for the vertical axis being obtained by finding the mathematical average of those scores in each row from Table 7.7. A second order regression

calculation was performed to estimate the equation of the line formed by these points, the result being displayed in Figure 7.12.

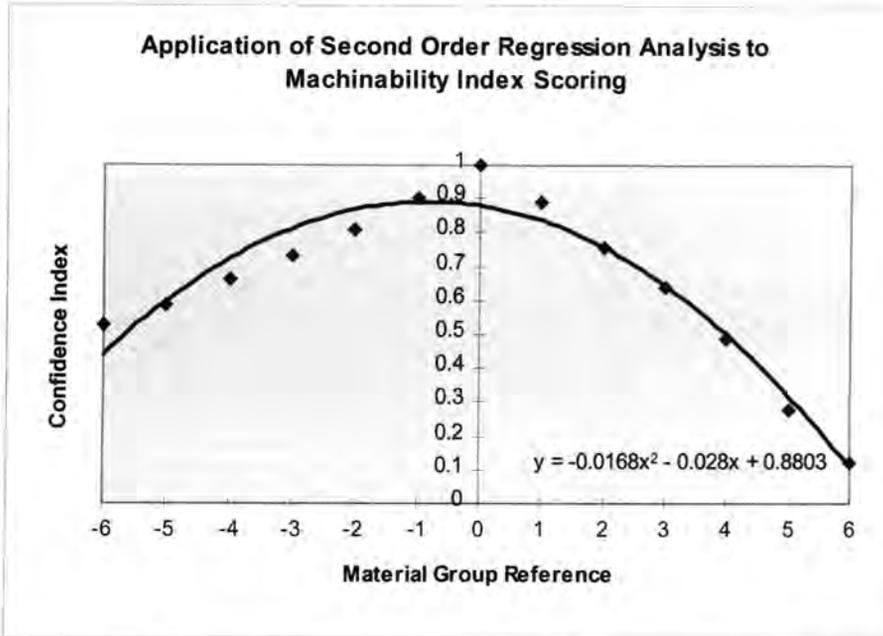


Figure 7.12 : Regression analysis of machinability index scoring for steels

Consideration of Figure 7.12 shows that the vertical axis contains data relating to the machinability index of any particular material group. The horizontal axis is defined by assessing the required material group (specified by the user) and the actual material group (from the database record). The x value can be found by using equation 7-3.

$$x = (\text{group from database}) - (\text{group specified by user}) \quad (7-3)$$

Once the x value is known, it can be used in the quadratic equation to obtain a value for the closeness of the actual value to the required value. This is to say that the output value from the quadratic equation is the value of β to be used in assessing the material confidence score in equation 7-1.

The aforementioned procedures were also applied in exactly the same manner to stainless steel and cast iron material groupings. The final regression curves which were evaluated for the stainless steel and cast iron groups are presented in Figures 7.13 and 7.14 respectively.

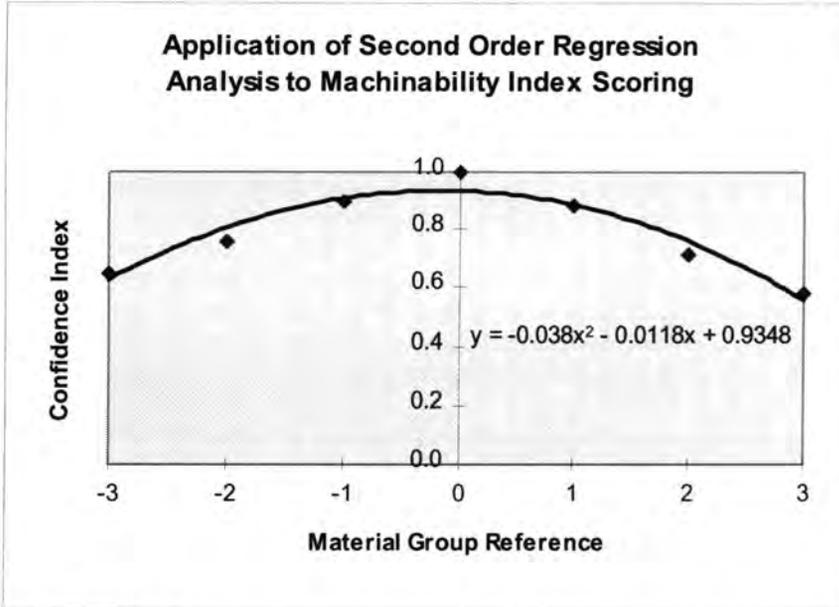


Figure 7.13 : Regression analysis of machinability index scoring for stainless steels

With the complete analysis having been completed for the three major material classifications, the rules for calculating the material confidence score were transferred to the JadeT system.

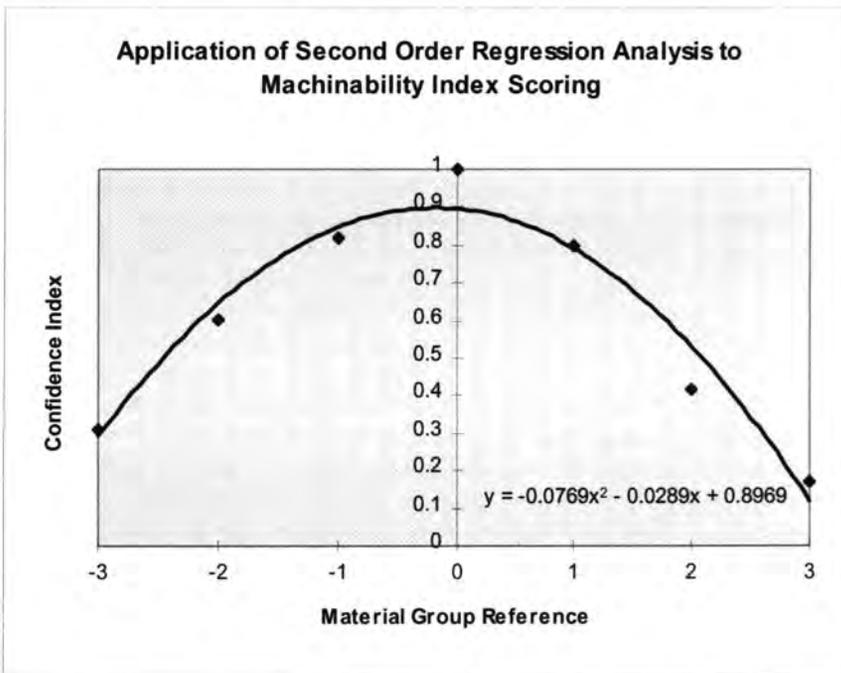


Figure 7.14 : Regression analysis of machinability index scoring for cast irons

The logic associated with assessing the material confidence score within JadeT is summarised in the flow diagram shown in Figure 7.15.

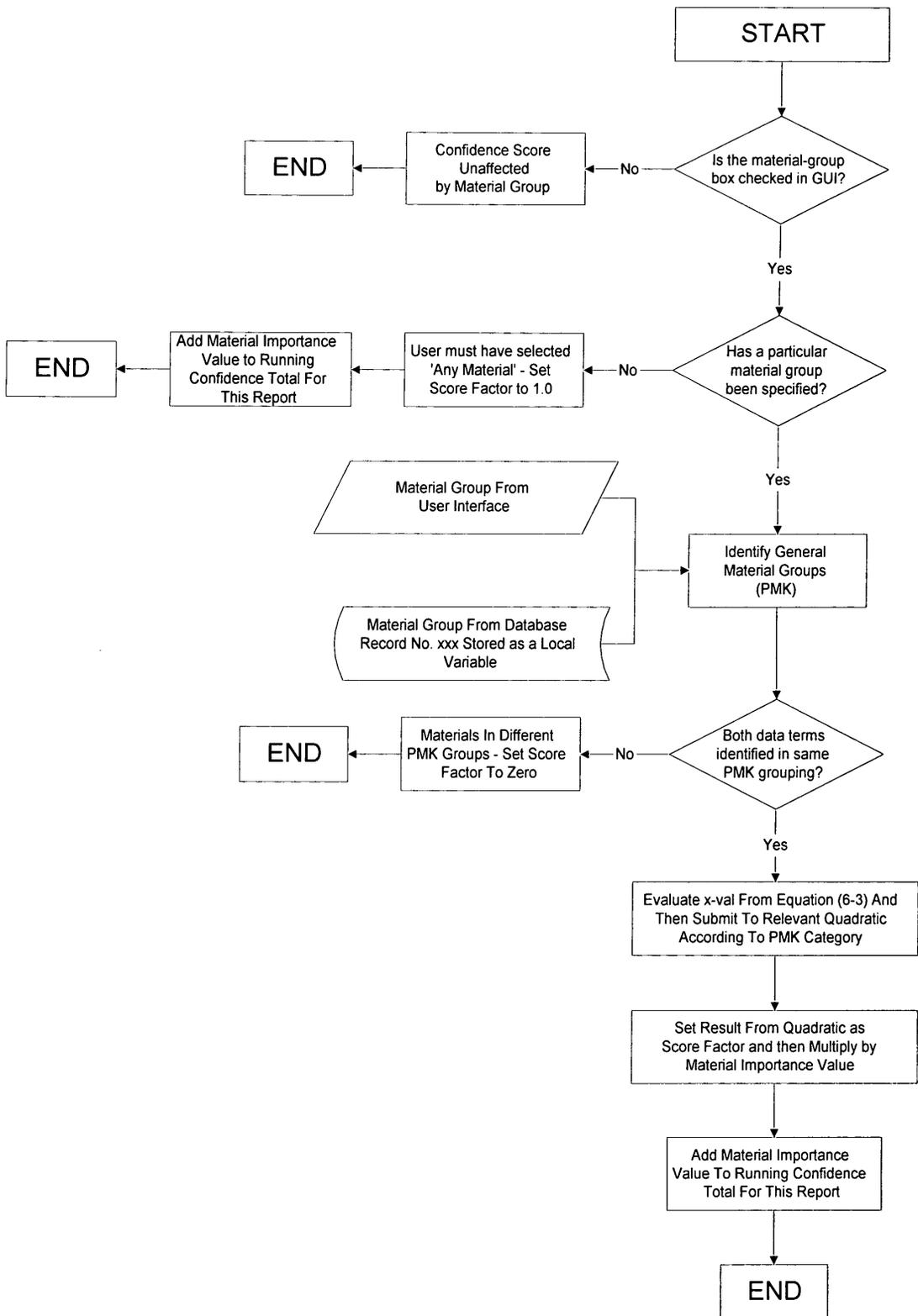


Figure 7.15 : Processing logic for material confidence scoring

From consideration of Figure 7.15 it can be seen that the first check to be made is whether or not the user has specified that the material group is to be included in the technical specification of the database search. Only if this test is positive will the analysis continue. Having established that the material group is to be included in the

specification, the value specified by the user will be identified. If the user has selected 'Any material' within the GUI, then the confidence factor is set to unity, as all materials would match this specification. If a specific material group has been chosen by the user then the process of assessing the β value will begin.

Firstly a check is made to see whether the two material groups are within the same general category; steels, stainless steels or cast irons. If the categories are not the same, the value for β is defined to be zero. The justification for this is that the cutting data pertaining to a stainless steel, say, is of little use when considered in the context of machining a cast iron for example. Should the groups fall within the same category, then the value of x as defined by equation 7-3 will be evaluated. This value will then be submitted to the relevant quadratic equation according to whether the materials are steels, stainless steels or cast irons. The value returned from this quadratic equation is the value of β for the material assessment, and this will be multiplied by the importance weighting of the material group and then added to the running total of the confidence score for the tool trial report being analysed.

In summary it has been shown that the machinability properties of any material can be assessed from the way in which that material is grouped relative to other materials. Knowledge of this, and the application of regression techniques' has allowed any material within the fifteen material classifications presented in Table 7.2. to be scored against another in terms of the closeness of their machinability characteristics.

7.5.2 Material description

Consideration of the JadeT GUI presented in Figure 7.7 reveals that the user is provided with the possibility of typing the name of a material which is to be found in the reports contained within the tool trials database. There are a number of reasons as to why this provision has been made. This section will explore those reasons and then go on to explain the functionality which allows an assessment of the material description parameter to be made.

One of the most significant flaws of the material group comparison methods is that they are unable to cater with materials which were not within the fifteen standard groups - for example, aluminiums and various alloys such as nickel based alloys, titanium alloys and cobalt alloys. These alloys are experiencing growth in terms of the frequency with which they are encountered in machining environments, although no formal designations have been produced for placing such alloys within material groups. This lack of organisation and standardisation of material groups for alloys can partly be attributed to the scenario being faced, where machining data relating to such alloys is fragmented and undisciplined.

Because no formal material groups exist for these metals, it was decided that it would be necessary to search the database for individual alloys. In such cases the user would not specify a particular material group but would simply enter the name of the alloy for which machining data was required. When the user performs the query the specified material will then be searched for within the database records. If the material matches one of the records then the material description factor used to assess the material description confidence score will be set to unity. If the material is not found then the material description factor will be set to zero. The only manner in which parameter relaxation techniques could be applied in this situation was to evaluate the number of words in the material description that were matched with the database record as a proportion of the total number of words specified; this proportion is the value of β .

In addition to providing functionality for searching the database for tool trials carried out with workpieces made from alloys, the material description facility was also useful in another situation. If the user was unsure as to what material group a component belonged to then it would be possible to type the standard name of the material in the material description to see if it could automatically be identified as a material belonging to a particular material group. The two material description standards used to perform this task were the BS and AISI classification systems. If the BS or AISI material code entered by the user was found within the database of material standards then the group to which it belonged would be identified. Having assessed the group number of the required material, the confidence score assessment would be based upon those methods presented in the previous section.

The logic that is used when performing the analysis of the material description fields has been summarised in the flow diagram presented in Figure 7.16.

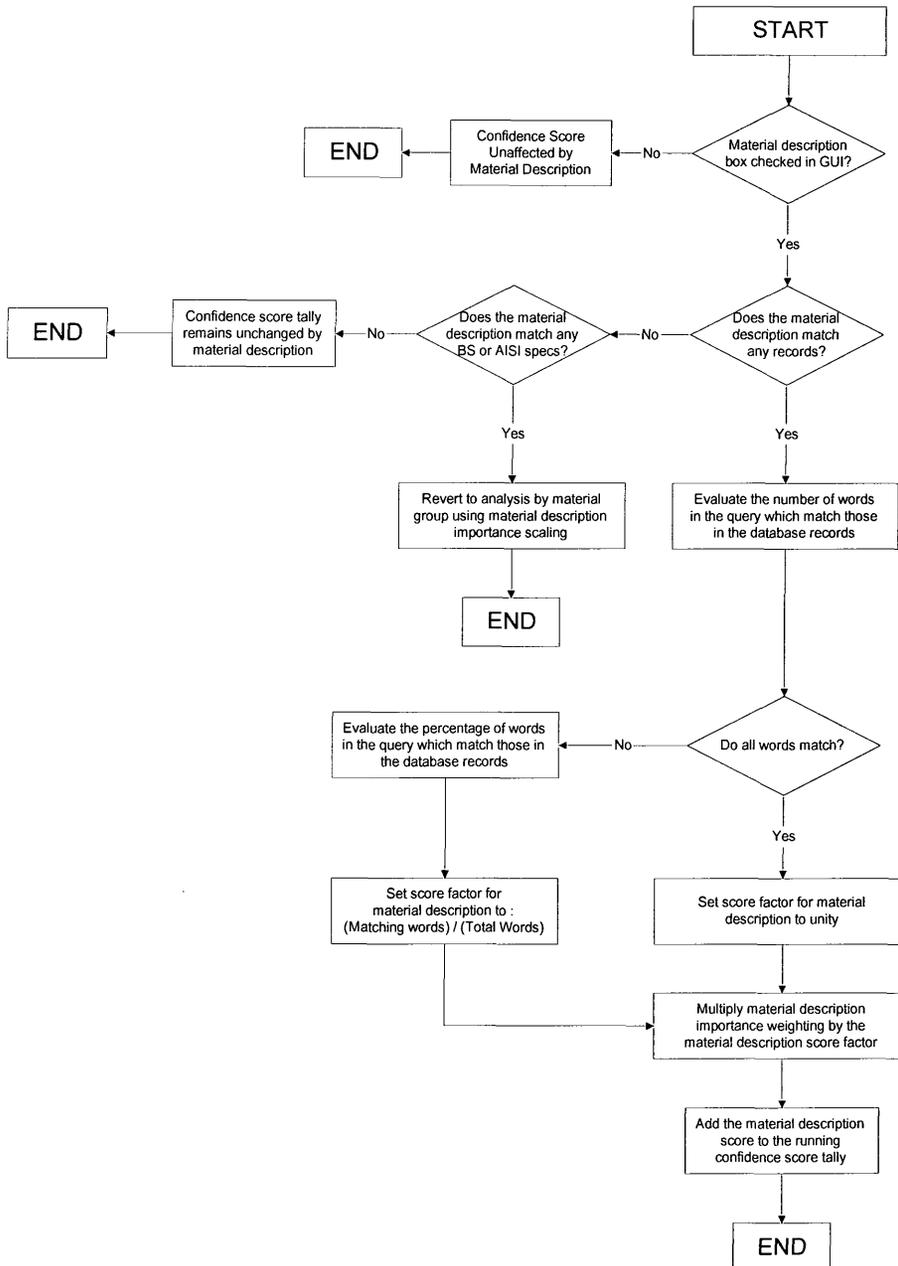


Figure 7.16 : Processing logic for material description confidence scoring

The main task of the material description facility has been to provide the user with a method of dealing with those situations when it is necessary to find data relating to tests performed on alloys. In addition to this, functionality has also been put in place which will attempt to identify the group to which a material belongs based upon the BS and AISI material specification standards. In this latter situation the material group scoring methods presented in the previous section will be invoked.

7.5.3 Insert type

In the context of toolholders which are fitted with an indexable carbide insert, the term 'insert type' has been taken to mean the part of the insert ISO code which refers to particular geometrical features of that insert. Referring back to the explanation of the insert ISO coding system it will be seen that the general insert geometry can be evaluated from the first four letters of the ISO code.

Although no capability has been provided for specifying the toolholder within the advanced query utility, this does not mean to say that it is impossible to search the tool trial records based upon a specific toolholder. Imagine a situation where a manufacturing organisation has been using a particular toolholder and insert combination for performing an operation on a component. If the workpiece material was to change for whatever reason, it is possible that the existing insert may not be capable of performing the operation on the new workpiece material. It will be undesirable to purchase new toolholders and inserts and so inserts which are capable of being accommodated in the existing toolholder will be considered. Each and every toolholder will be assigned a code which defines the inserts which are geometrically suitable for the toolholder. For example, a PCLNR type toolholder can accept inserts with an ISO code beginning CN**. If a search was then carried out for tests using a CN** type insert with the specified material type, this would result in reports containing data for inserts which are suitable for both the PCLNR toolholder and the component material. It can hence be seen that the bilateral nature of information contained within insert and toolholder codes allows a highly specific query to be formulated based upon both insert and toolholder specifications.

If the user decides that the insert type will be specified in an advanced technical support query it is expected that the code entered by the user will be four characters in length. If more than four letters are specified then the user will be informed of the precise aims of the insert type specification method and then be prompted to change the selection previously entered. If less than four letters are entered, the user will be asked to confirm that the selection is correct. For example, if the user was looking for *NMG inserts and only entered NMG in the parameters specification box then the query would not operate as intended by the user because the system will automatically search for NMG* in this

situation. The user will be informed of this and can add the wildcard character appropriately.

Once the character format of the search parameter has been verified a final check will be made which assesses each of the characters in the search string specified by the user. With the sole exception of wildcard characters, each parameter character will be taken individually and then checked against the ISO code definition to confirm that each character is a valid letter in the ISO specification system. If any character fails this test then the user will be informed accordingly and can either modify the search parameter or ignore the warning and continue.

The reason for the user being required to enter a four character string to indicate the type of insert that is sought within the database is not based purely on technical grounds. It could be argued that in most cases the dimensional tolerances associated with an insert, as indicated by the third parameter of the ISO code, are not of critical importance to the machining task. This assertion is substantiated by tooling manufacturer's tending to produce inserts of a given type with only a single tolerance standard available. Despite the relatively minor importance attributed to insert tolerance it was decided that to request the user to enter only isolated elements of the ISO code could be confusing. For this reason users of the system are required to enter all of the first four characters of the ISO code.

Although it would be a trivial task for the confidence scoring algorithms to assign equal weightings to each of the four parameters in the insert type specification it was decided that this would perhaps overstate the importance of certain parameters, namely the dimensional tolerance (element 3 of the ISO code) and type of insert (element 4 of the ISO code). Both the insert shape and clearance angle are important aspects of the interface between an insert and the component being machined. These elements of an insert's geometry affect the cutting conditions of the machining operation as well as the ability to form specific geometrical features on the workpiece.

In order to reflect the relative importance of different elements of the ISO code it was decided that the first two parameters would be attributed as being of major influence to the confidence score whilst the third and fourth parameters would only be considered to

be of minor importance. Further to this it was decided that if the first two parameters of the code failed to match during the confidence scoring calculation that the third and fourth parameters would be ignored. It is evident that if the only common feature between two inserts is the tolerance specification that this does not merit an assertion that there is similarity between the two inserts.

The maximum value that can be assumed by the insert type confidence factor, β_4 , is one, with the minimum being zero. The algorithm that is used to calculate the insert type confidence factor is shown in equation (7-4).

$$\beta_4 = \frac{4\delta_1 + 4\delta_2 + [\delta_1 \times \delta_2 \times (\delta_3 + \delta_4)]}{10} \quad (7-4)$$

δ_i = Boolean value. 1 if ISO parameter i matches, 0 otherwise

The value of β_4 is subsequently multiplied by the importance weighting of the insert type and then added to the running confidence score tally for the tool trial report being considered.

7.5.4 Insert grade

The grade of an insert is an important consideration when assessing the insert's capability of machining any given material. From Figure 7.6 it can be seen that the application range of materials of any given insert grade can be specified by shading the relevant areas on a PMK classification chart.

The number of grades produced by any given tooling manufacturer is usually significant, and it is common for two or more grades to be capable of machining the same material. In order to assess the similarity of one insert grade when compared with another it was decided that an analysis of the application range as defined by the PMK classification chart would be undertaken. If it was found that the insert's application ranges overlapped, then this would be the basis of assigning a value to the confidence score factor, β . Consider the PMK capability specifications for two imaginary insert grades, A123 and B234, as shown in Figure 7.17.

Material ↓ Grade →	ISO-P					ISO-M				ISO-K					
	P01	P10	P20	P30	P40	P50	M10	M20	M30	M40	K01	K10	K20	K30	K40
A123		/					/				/				
B234	/							/			/				

Figure 7.17 : Insert grade capability assessment in PMK classification chart

In order to formalise the specification of the variety of materials which can be machined by any given insert it was decided that the maximum and minimum values of each of the PMK ranges would be specified. The variable names assigned to these parameters and the values associated with the imaginary grades depicted in Figure 7.17 are shown in Table 7.8.

Variable Name	A123 Grade	B234 Grade
pMin	13	1
pMax	46	23
mMin	14	25
mMax	33	45
kMin	15	5
kMax	32	24

Table 7.8 : Illustration of insert grade material capability

From consideration of Table 7.8 it can be seen that the application range of any given insert can be summarised by six variables representing the maximum and minimum values in each of the three PMK classifications.

Whilst it is important to be able to choose an insert based upon the materials which need to be machined, the aim of the insert grade specification analysis in the advanced technical support utility is to calculate a confidence score factor which assesses the proximity of the insert grade from any given tool trial record with the insert grade specified by the user.

It was decided that a suitable way in which this confidence score factor, β , could be evaluated would be to directly compare the application range as defined by the PMK classification of the insert grade from the database record with that specified by the user.

In order to assess this overlap it was necessary to evaluate all those situations which could be encountered when determining the extent of the overlap. A pictorial representation of these conditions is presented in Figure 7.18.

If the entire application range of the insert grade defined by the user could be machined with the grade associated with a particular tool trial record, then the confidence score factor would be set to unity. This situation is represented by scenario 1 in Figure 7.18. Conversely, if the application range from the user-specified grade has no overlap with the grade from a tool trial record then the confidence score factor is zero. Consideration of Figure 7.18 shows that there are two scenarios in this case, the first one being where the user capability falls above the capability of the database grade (scenario 4), and the second case being the exact opposite of this (scenario 5).

Whilst these two extremes are relatively easy to test with the application of a suitable logic structure, it is necessary to define a way in which those confidence score factors between the limits of zero and one would be calculated. This is to say that a mathematical algorithm needs to be in place to assess the confidence score factors associated with scenarios two and three as depicted in Figure 7.18. It was decided that for those scenarios where the overlap in terms of material machinability capability was not complete, the overlap would be expressed as a percentage of the user defined insert grade. The algorithms which were used to calculate the insert grade confidence score factors for scenarios 2 and 3 as depicted in Figure 7.18 are presented in equations 7-5 and 7-6 respectively.

With the development of rules to cater for any condition of overlap between two linear parameters it was necessary to define the way in which they would be applied. Whilst the specification of the insert grade can be made independently of any other parameters within the advanced tool trial query utility, it was necessary to consider the implications of those situations where a material has been specified and also those situations where a material has not been specified.

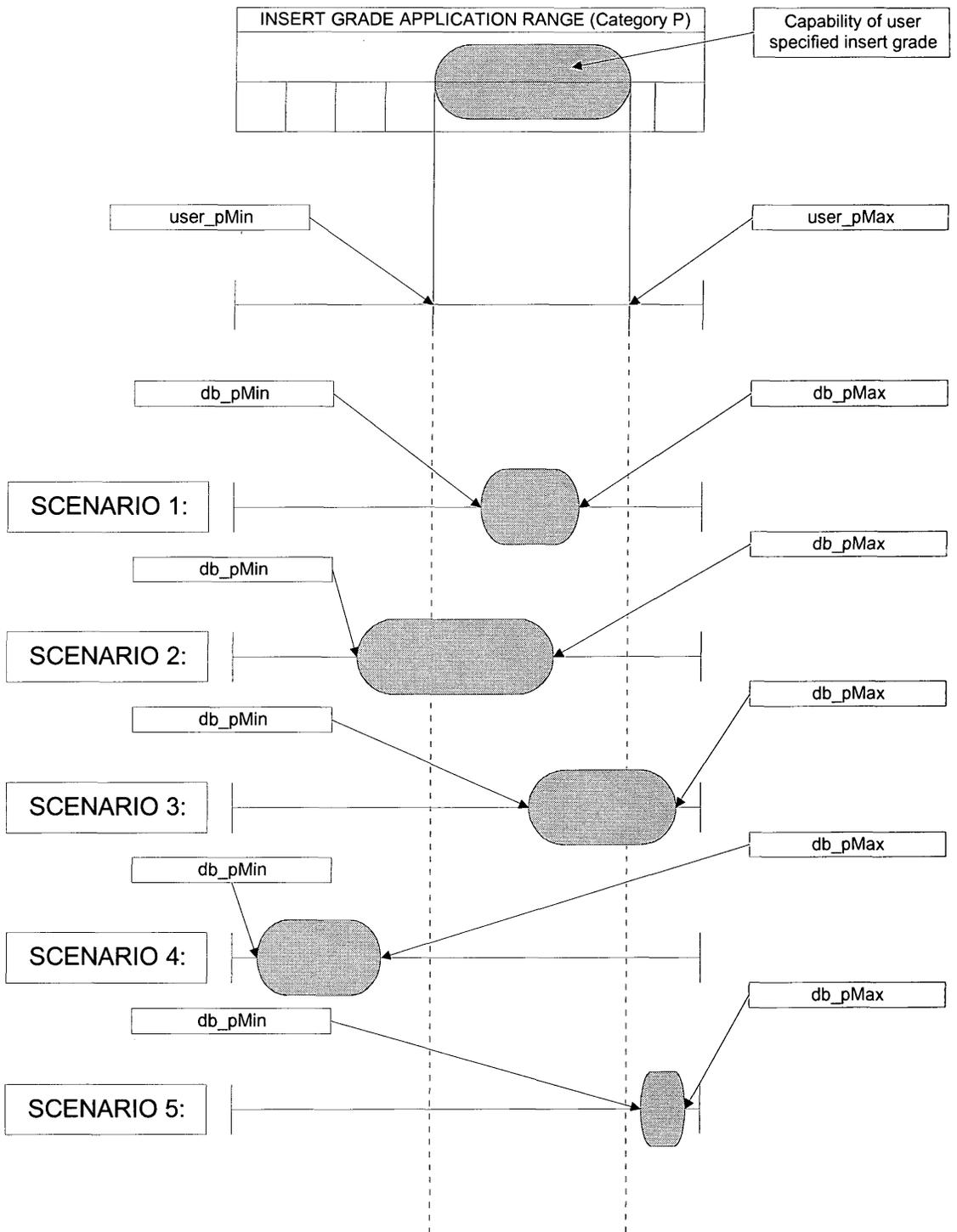


Figure 7.18 : Summary of linear overlap permutations

$$Confidence_Factor_2 = \frac{[(db_pMax) - (user_pMin)]}{[(user_pMax) - (user_pMin)]} \times 100\% \quad (7-5)$$

$$Confidence_Factor_3 = \frac{[(user_pMax) - (db_pMin)]}{[(user_pMax) - (user_pMin)]} \times 100\% \quad (7-6)$$

Consider those situations where both an insert grade and a material group have been specified. In this situation it is possible to immediately work out which of the three PMK insert application range is of relevance to the specified material group. With the relevant PMK classification having been identified and the insert grade having been validated it is possible to perform the calculation of the machinability overlap percentage factor based upon the relevant values. For example, if the component material was in material group 5, this is known to be a steel and so the confidence score factor would be calculated specifically on the application range of that grade within the 'P' classification.

In a situation where the user has not specified the material group to which the component material belongs, then the calculation of the confidence factor cannot be based upon a particular PMK cluster. In these situations, a confidence factor is calculated for each of the three PMK groups and the average of these three values becomes the confidence factor for the specified grade.

7.5.5 Insert chipbreaker / designation

7.5.5.1 Insert chipbreaker

The aim of a chipbreaker is to discretise a continuous length of swarf into a number of chips to avoid any entanglement of the swarf within the machining area. The physical appearance of a chipbreaker is simply a groove which is present around the periphery of the top face of an insert. Different chipbreaker geometries are developed to accommodate different material types and variations in machining conditions. With the variety of materials and machining conditions which can be encountered, it is predictable that there are a significant number of chipbreakers from which to choose.

The specification of a chipbreaker is usually in the form of a diagram which defines the range of depth of cut and feed combinations over which the chipbreaker is effective and a brief description of the material types intended for its application. It was decided that in order to have a method of assessing the similarity between two different chipbreakers it would be necessary to consider both the material specifications and machining condition ranges.

The way in which material suitability is indicated with reference to chipbreakers is not particularly detailed. In general, a chipbreaker will be described only in terms of its ability to perform suitable chip forming actions on the three general categories of material; steels, stainless steels and cast irons. It was hence decided that any single chipbreaker would be assigned three Boolean values which could be set to indicate the ability of that chipbreaker to be used with these three categories of material.

The only capability of the chipbreaker remaining to be defined is the range of cutting conditions over which it is designed to be used. Whilst the precise shape of any chipbreaker when plotted on a graph of depth of cut versus feed rate can be quite complex, it is generally the case that a simple rectangle can be used which will define the range of feeds and depths of cut over which the performance of the chipbreaker is acceptable. Each chipbreaker was additionally assigned four more variables which were used to identify the upper and lower limits for the feed rates and depths of cut. With all these parameters having been assigned it was possible to evaluate the capability of one chipbreaker in terms of another.

The way in which the chipbreaker confidence score factor was calculated depended upon whether a particular material group had been specified by the user. If a material group has been defined then a brief assessment will be made to eliminate those chipbreakers not designed for machining that particular category of material. In the event that a material group has not been defined then all of the chipbreakers will be forwarded to the next stage of analysis.

To analyse the capabilities of two chipbreakers in the area of machining conditions a graphical approach will be adopted. Figure 7.19 shows the machining parameter ranges of two different chipbreakers; firstly in isolation and then together.

From consideration of Figure 7.19 it can be seen that when considering the machining capabilities of two chipbreakers, it is possible to identify ranges of cutting parameters which will be common to both. It is therefore suggested that by identifying the percentage of the total chipbreaking area which is common to both chipbreakers it will be possible to assign a confidence score factor giving an indication of the similarities between the chipbreakers. Having decided to pursue the evaluation of chipbreaking

overlap potential subsequent to a material evaluation it was necessary to identify the different ways in which two areas can overlap each other.

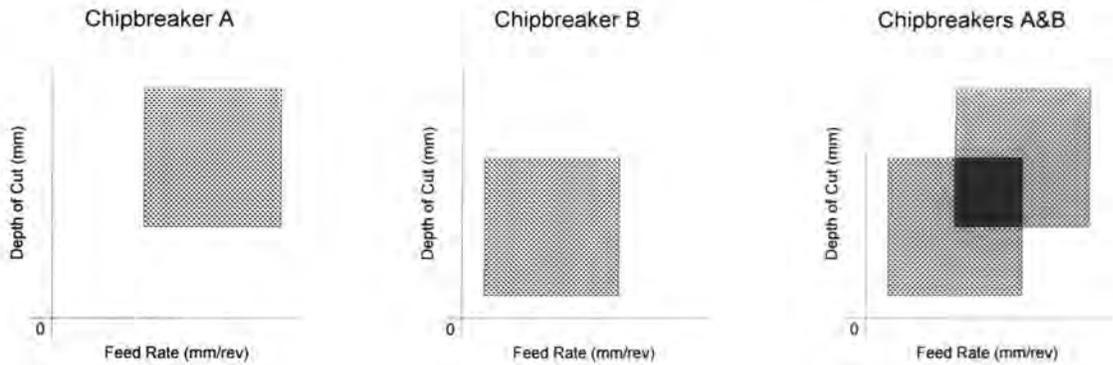


Figure 7.19 : Illustration of chipbreaker capability overlap

Each chipbreaker has four parameters associated with it which can be combined to define the range of acceptable machining parameters. By considering the four parameters associated with each of two chipbreaker diagrams it was found that there were sixteen unique ways in which there would be a capability overlap. Figure 7.20 shows the parameters associated with two chipbreakers, the first one being specified via the user interface and the second being the one retrieved from the database for a particular test.

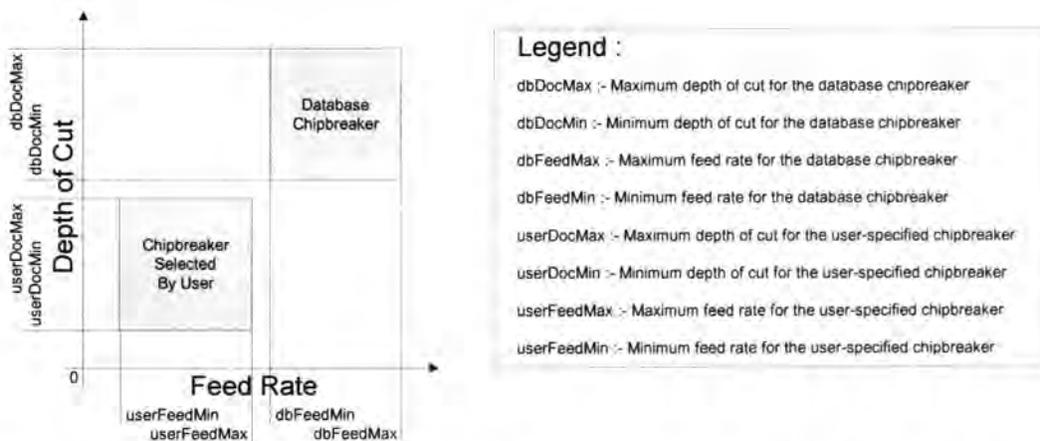


Figure 7.20 : Specification of parameters associated with chipbreaker overlap

It is not possible to assume that any two chipbreakers will overlap in terms of their machining capability. As a result it was necessary to analyse the relationships which needed to exist between the eight parameters outlined in Figure 7.20 in order to assess the situations where there would or would not be an overlap of capability. Figure 7.21

illustrates those situations where there would be no overlap of capability and hence the chipbreaker confidence score factor would be set to zero.

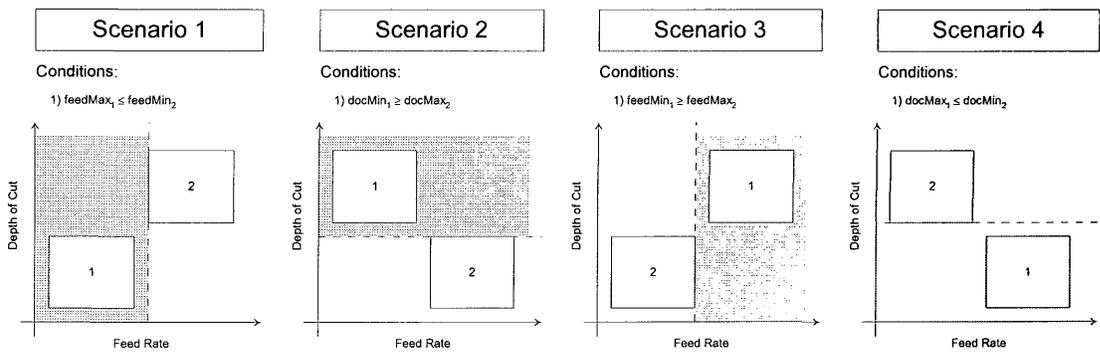


Figure 7.21 : Conditions for no overlap of chipbreaker capability

Figure 7.22 presents the conditions necessary for there to be an overlap of machining capability, and from this it can be seen that there are sixteen discrete ways in which the two regions, when plotted together on a single graph, could overlap. The nomenclature used in Figure 7.22 makes no indication as to the chipbreaker represented by either area on the charts, and as there are two ways in which the chipbreakers can be assigned on any single chart there are sixteen combinations in total.

Whilst each of the charts in Figure 7.22 identifies a unique combination of logic conditions, it is the overlap area which is of key importance. Not only do the logic conditions define a unique overlap solution, but they also define a unique equation for calculating the area of overlap. With the various overlap scenarios having been identified it is a relatively simple task to calculate the area of overlap as a percentage of the total machining capability. The overlap percentage can be found from equation 7-7.

$$\%Overlap = \frac{Overlap_Area}{(Chipbreaker1_Area + Chipbreaker2_Area - Overlap_Area)} \times 100\% \quad (7-7)$$

In order to calculate the percentage overlap from equation 7-7 it is necessary to firstly evaluate which of the overlap scenarios is appropriate in the existing case. This is achieved by using the maximum and minimum values of feed and depth of cut for the two chipbreakers to establish which set of logic conditions are true. It should be noted that the conditions for each case specified in Figure 7.22 are mutually exclusive, indicating that no two sets of the logic conditions can be true for a single set of data.

Once the overlap scenario has been identified it is possible to work out the relevant equation which will yield a value for the area of overlap. With this parameter known equation 7-7 can be completed to produce a value for the overlap percentage. It is this value from equation 7-7 that is used as the chipbreaker confidence score factor, β . In the same manner as the previous parameters the confidence score factor is multiplied by the importance weighting and then added to the running confidence total for the report being examined.

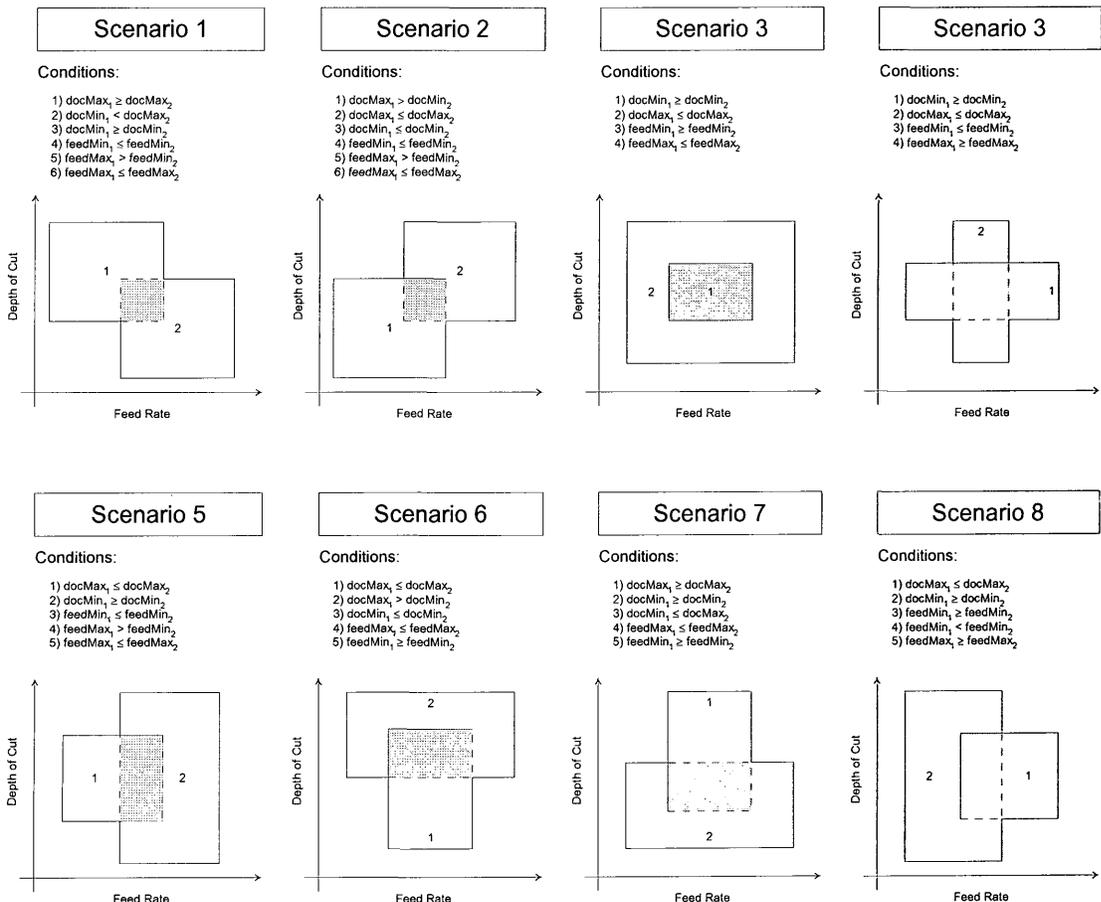


Figure 7.22 : Specification of overlap scenarios

7.5.5.2 Insert designation

The need for milling to be considered in a slightly different way to turning is due to the change from continuous to intermittent cutting actions in respect of the inserts. Whilst the intermittent nature of a milling operation may appear to devolve all necessity for a chipbreaker, or similar geometric feature, this is not always the case. Although in the case of turning operations the upper geometry of an insert is developed primarily to perform the chipbreaking action, this is not to say that the chipbreaking geometry does

not perform other important tasks. The geometry which is incorporated into carbide inserts designed for turning has evolved from the consideration of a number of factors, most of these factors having a direct link with the actual mechanical principles adhered to by the metal cutting process. Variations in the geometry of the insert have been shown to affect a number of important cutting parameters such as the force distribution in the workpiece / tool interface, the wear and failure pattern of the tool, and the type of chips produced. It is by a combination of laboratory testing and mathematical modelling that the geometry of an insert can be assessed in terms of its suitability for performing a certain operation.

In the case of milling operations, a number of parameters have been identified as playing an important role in the cutting process. In general, an assessment of the machining difficulty will be made based upon the hardness of the workpiece material and the difficulty in performing a cutting operation on the pre-machined surface of the component. The assessment of the machining difficulty will then be used in combination with the feed rate and chip thickness values to define the optimum insert geometry.

The difficulty of the operation is not a parameter which obeys hard and fast rules of analysis. The appraisal of the difficulty of an operation takes into account a number of cutting parameters, each of which has an effect on the overall difficulty of the operation. The most commonly used parameters which are used in the allocation of a machining difficulty index are the hardness of the workpiece material, the roughness of the machining surface (i.e. the pre-machining state of the workpiece surface), and the thickness of the chips which are generated (which is proportional to the feed rate for the same workpiece material and insert combination).

The result of the operation difficulty appraisal is an alphanumeric series of characters. The letters in the code indicate the level of difficulty of the operation, whilst the numeric part results from the assessment of the chip thickness based upon the feed rate. An easy operation will result in the selection of an insert with sharp cutting edges, whilst more difficult operations will have strong, protected cutting edges. In general an easy operation will have the lower chip thickness whilst a more difficult operation results in the generation of thicker chips. In terms of the ISO coding associated with

inserts, the way in which an assessment of the insert designation is made does not follow strictly imposed rules. This results in insert designation systems which vary between tooling manufacturers.

From a selection of catalogues, sourced from the industrial collaborator, it was possible to identify the range of insert designations which were appropriate for the populated database. There were found to be five levels of operation difficulty, which are presented in Table 7.9, where for each level of difficulty there were a range of values associated with the feed rate and chip thickness' which would be most suitable for the normal application of the insert.

Code	Meaning
E	Easy
ME	Medium - easy
M	Medium
MD	Medium - difficult
D	Difficult

Table 7.9 : Insert designation difficulty codes

Because of the lack of a precise structure for the insert designation associated with milling, an approach was adopted which seemed appropriate from both the practical viewpoint of engineers and the algorithmic content of the mathematics. The first stage of the confidence score factor assessment was to see whether the insert designation from the user matched that from the chosen database record. If the match was perfect then the confidence factor assumed a value of unity. In the cases where the match was not perfect it was necessary to see if the group from the database was adjacent to the group from the user. If the groups were adjacent the preliminary confidence score factor was set to 0.5 whilst all other combinations resulted in a confidence score factor of zero.

Subsequent to the preliminary assessment, an analysis of the numeric part of the codes was undertaken. The numeric part of the code gave an indication of the chip thickness which would be appropriate for normal use. For example, a code of 14 would indicate a chip thickness of 1.4mm. From an analysis of the range of the numeric content within any one difficulty groups it was decided that an inverse law of confidence would be implemented. Equation 7-8 shows the formula used for adjacent difficulty groups,

where $numeric_{database}$ is the integer represented by the numeric part of the designation code from the database, and similarly $numeric_{user}$ is for the user-specified value. The multiplication factor μ is set to 1.0 for matching difficulty groups and 0.5 if the groups are adjacent.

$$Designation_Confidence_Factor = \mu \times \left(\frac{1}{(numeric_{database} - numeric_{user}) + 1} \right) \quad (7-8)$$

As an example, consider a situation where the insert designation from a certain database record is 'ME16' and the designation specified by the user is 'M14'. In this case μ would be set to 0.5 as the difficulty groups are adjacent, and the numeric terms would have a difference of 2. This would result in a confidence score factor of 0.167, which would then be multiplied by the insert designation importance weighting and added to the running confidence score tally for the tool trial being analysed.

It can be seen that procedures have now been defined for assessing the closeness of chipbreakers which are found in turning inserts, and the designation associated with milling inserts. Whilst the insert designation analysis may appear to be less rigorous than the chipbreaker analysis due to the rather more limited structure of the ISO coding, it has none the less put functionality in place for assigning a confidence score based upon the closeness of the parameters.

7.5.6 Insert geometry

In all the parameters that have been considered so far it has been possible for the values of those parameters to be specified entirely independently of each other, i.e. any combination of the various parameters can be selected. In some situations however, a link can be made between the parameters specified by the user in assessing a confidence score. An example of this is when the insert grade analysis is being undertaken. If a material group has been specified then the insert grade analysis will be based upon that material group, although the analysis can be undertaken independently of the material group in situations where a material group has not been specified.

From the ISO coding system for inserts, it was noted that the first four characters of the code allow a specification of the geometric features of the insert. Having assigned these four parameters, there are only a certain number of toolholders which would be able to accommodate the inserts defined by the ISO code. This is to say that the geometrical *shape* of the insert defines the geometrical shape of the holder which is necessary to hold them. It is those parameters which specify the physical *size* of the insert that in turn define the necessary size of the holder to contain them. In short, if the geometrical shapes of two inserts are not the same then it is not appropriate to assign a confidence score associated with the physical size of the insert. This leads to a situation where it is necessary to restrict the specification of the physical size of an insert.

In the JadeT system it is possible for a user to enter an insert type, which defines the geometrical shape of the insert, and the insert geometry, which defines the specific size of the insert. The restriction imposed on the user was that it is not possible to specify an insert geometry requirement without having first specified an insert type. To justify this measure, imagine a situation where two inserts have the same ISO geometry code and yet are different insert types. If there was to be no dependence of the insert geometry confidence score factor on the insert type, then the geometry score confidence factor would be set to unity as the match is perfect.

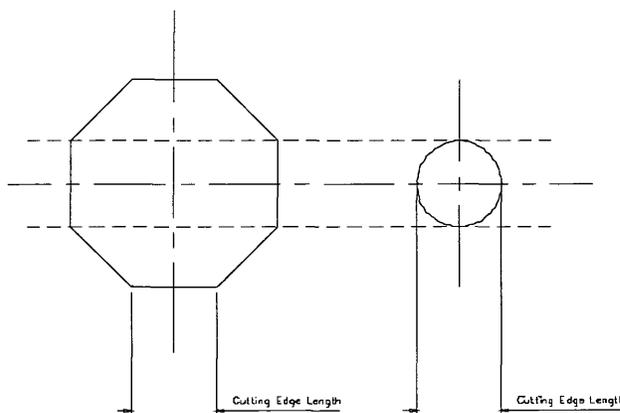


Figure 7.23 : Cutting edge length and insert shape

Figure 7.23 shows two inserts which are different insert types and yet have the same cutting edge length. Consideration of this figure shows that assessing just the geometric properties of the insert can result in a confidence score factor that is not representative of the similarity of the inserts, and it was for precisely this reason that the insert geometry would only become valid when comparing two inserts of the same type.

If the insert types are identified as being the same, each of the individual components of the insert geometry are compared. Those parameters of interest are;

- Cutting Edge Length
- Insert Thickness
- Nose Radius (for turning inserts)
- Wiper Edge (for milling inserts)

The physical form of the inserts has already been verified by the analysis of the insert type parameters, and so the comparison of the insert geometry parameters can be considered as a fine tuning exercise for the confidence assessment. As the confidence score of the matching insert type will have already been included in the tally it was decided that the insert geometry assessment would be based upon a go / no go approach. Each of the insert geometry parameters was isolated from the parent ISO code and then compared directly with its required value as defined through the user interface. For any geometry comparison there would be three matches to consider and each of these would receive an equal weighting. For each matching parameter the confidence score factor would be incremented by 0.33 so that a perfectly matching set of the three geometry parameters would result in a geometry confidence score factor of unity.

7.6 Summary

This chapter has described the situations which may give rise to an engineer needing to retrieve tooling data from the tool trials database. Consideration of these situations has led to the development of two technical support utilities, with the advanced utility adopting a multi-layered approach to assessing tool trial report confidence scores.

In the case of the basic technical support utility the user has been provided with a simple form which can be used to search the tool trials database for specific tool trial reports. A full logic structure has been developed to supervise the data communication between the database and the client system to maximise system reliability. In addition to this the

logic structure ensures the user is guided through the specification of technical support queries in an intuitive and graphical manner. Once the relevant tool trials have been identified, the user is able to download and view each report, with steps having been taken to minimise the time taken for data to be transferred to the client system.

The aim of the advanced query utility was to provide the user with a GUI allowing a detailed technical support query to be generated and used to search the tool trials database. This GUI has been shown to allow the specification of a number of detailed parameters relating to the tool / workpiece interface as well as providing a way in which the user can indicate the relative importance of each parameter. Based upon analysis of these parameters a multi-layer confidence assessor has been designed and implemented. At the most basic level the confidence assessor would simply search for reports which contained exactly the same data as specified by the user. At the more detailed levels of analysis, confidence scores were assigned to reports based upon mathematical and engineering considerations and allowed the full integration of parameter relaxation techniques into the system. Additional flexibility was implemented in the advanced technical support utility in terms of the manner in which data was presented to the user. The initial level of data presentation displayed a number of key parameters to the user to facilitate a decision as to whether it was necessary to see the tool trial data in more detail. Four categories of tool trial data were defined and the data for each category could be downloaded independently of the other data categories, so minimising the likelihood of redundant data being downloaded and presented to the user.

Chapter 8 : Tool and cutting data selection utility incorporating data from the tool trials database

The previous chapters in this thesis have examined the design and implementation of a Web-based database suitable for the submission and retrieval of data pertaining to tool trials. Whilst JadeT provides a complete system insofar as tooling manufacturer's engineers are concerned, it is the remit of this research to examine the tool trials database in other fields. In particular this chapter will examine the design of a rudimentary Web-based tool and cutting data selection utility which applies classical process planning algorithms. This will be followed by consideration of using the cutting data from the tool trials database to enhance and improve the applicability and confidence of the parameters obtained by the application of the standard cutting data algorithms. The cutting data parameters obtained from the standard equations will be compared with those obtained when incorporating data from the tool trials database.

8.1 Introduction

The design and specification of the tool trials database has resulted in the JadeT utility, which is capable of allowing remote users to submit and retrieve data from a central database. The confidence scoring and parameter relaxation techniques which were applied to the tool trials database are designed to prioritise the tool trial reports based upon firm engineering principles. However, it is still necessary for the engineer to assess whether the data retrieved from the database is important in terms of its potential for solving an existing problem. In these situations the specific data from the database is being combined with the knowledge of an experienced engineer in a manner which aims to solve the tooling problem which has been encountered.

It should be evident that such a system, which is accessible only by specific highly skilled tooling engineers, has produced a reserve of approved data which could be applied in other contexts not exploited within the JadeT system. Rather than providing a tool for the solution of tooling problems, it is suggested that the information contained within

the tool trials database could also be used in the tool and cutting data selection processes within process planning. This concept is summarised in Figure 8.1.

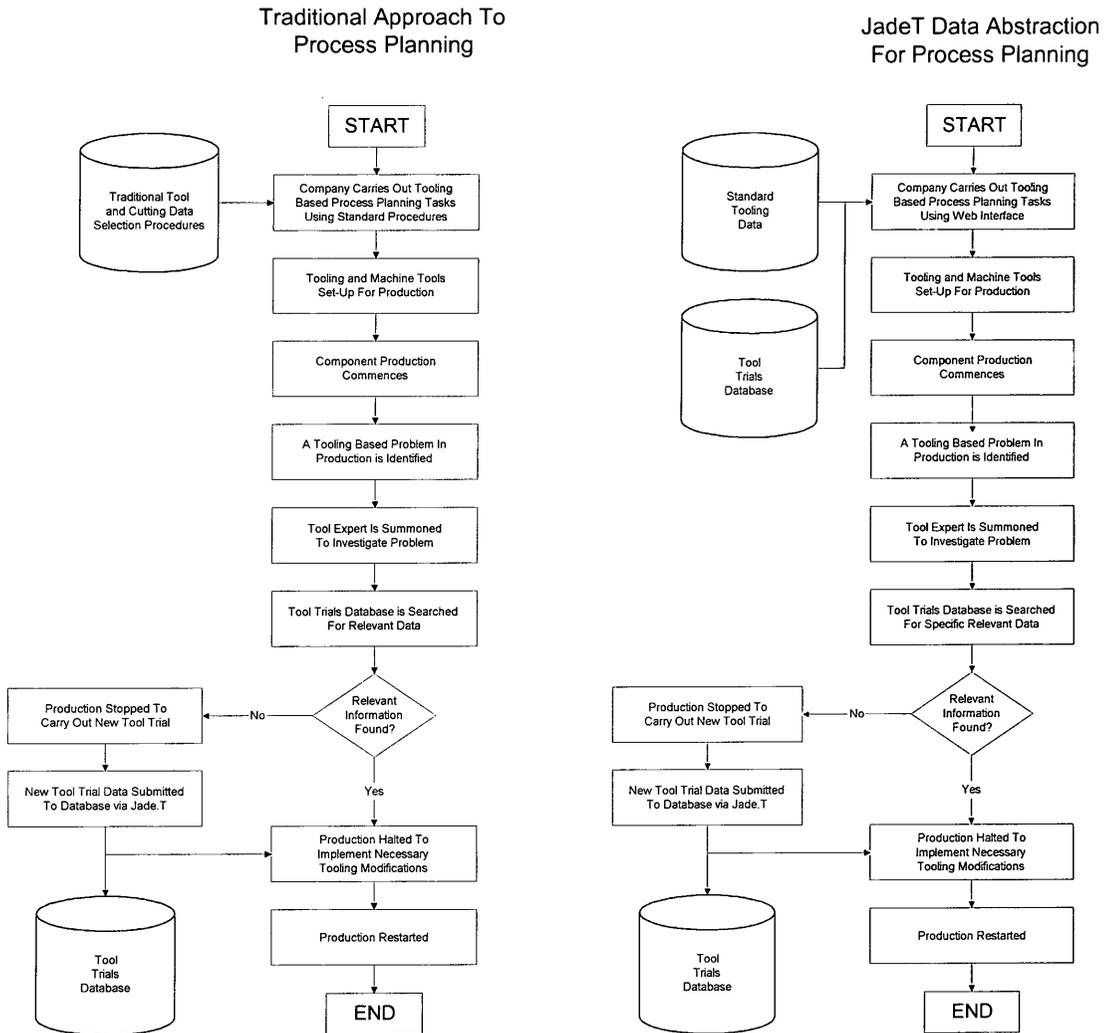


Figure 8.1 : Process planning incorporating tool trials data

From Figure 8.1 it can be seen that the traditional approach to manufacturing results in a situation where possible tooling problems are only identified once the production stage has been reached. Whilst this approach to process planning is likely to have produced a plausible set of machining operations based upon the specific requirements needed to produce the component, no analysis has been undertaken with regard to assessing the success of previous similar operations.

This situation can now be contrasted with the new methodology which presents the concept of using information contained within the tool trials database prior to production commencing. The database of approved information could be analysed as an

integral part of the overall process planning task in order to assess whether any problems with a particular set up can be foreseen. In addition to this it is possible to evaluate whether standard process parameters can be confidently enhanced by tool trials data.

8.2 Tool and cutting data selection for turning

Turning operations are classified as those operations in which a single cutting edge is used to effect the task of material removal. A number of specific turning operation categories can be identified, viz;

- Orthogonal turning
- Threading
- Grooving
- Parting-off

The first three turning operations in the above list can be carried out as either external or internal cutting actions whilst parting-off is only ever considered as an external operation. In a general turning operation the feed rate and depth of cut can be varied within a range of values defined by the chipbreaker of the insert being used. By varying these parameters it is possible to alter a number of important values such as the machining time, power required and surface finish.

Brief consideration of threading and grooving operations reveals that in each of these operations it is not possible to vary both the depth of cut and feed rate. In the case of threading operations, both the feed rate and depth of cut are fixed in order to generate a specific thread using the recommended cutting speed. Grooving operations involve no longitudinal motion of the tool, and for a given cutting speed the range of radial feeds are specified. Parting-off operations are a unique form of grooving operations, where the groove is sufficiently deep to cause a separation of the workpiece along the line of the cutting plane.

Whilst there is limited scope for the analysis of grooving and threading operations it was decided that these operations would not be the focal point of the tool and cutting data selection functions for turning. The orthogonal turning operations allow the full chipbreaking area to be explored and to hence present the effects which are caused by the variation of the primary cutting data values. Appendix H presents a brief review of the fundamental relationships that exist between the various parameters encountered when performing a turning operation.

One of the most important aspects of a machining operation is the relationships that exist between the cutting speed, depth of cut, feed rate and tool life. The area of tool life has been the centre of many research initiatives ever since the seminal work completed by F.W. Taylor at the turn of the twentieth century. Taylor used empirical techniques to derive equations capable of predicting the useful life of a tool based upon the cutting parameters for a given insert and material combination. Equation 8-1 shows one of Taylor's most notable derivations.

$$T = \frac{C}{\left(v^{1/\alpha}\right) \left(s^{1/\beta}\right) \left(a^{1/\chi}\right)} \quad \left(\frac{1}{\alpha} > \frac{1}{\beta} > \frac{1}{\chi}\right) \quad (8-1)$$

In equation 8-1, v , s , and a are the cutting velocity, feed rate and depth of cut respectively. The indices of these parameters and the numerator in the equation are all determined empirically, these constants varying for any given workpiece material and insert grade combination. Whilst the application of equation 8-1 yields results which exhibit good accuracy, it is not practical for a modern day tooling manufacturer to provide the Taylor coefficients for every combination of workpiece material, insert grade and cutting parameters.

The nature of the Taylor coefficients is such that variations in the depth of cut have only a small effect on the tool life. In order to simplify Taylor's tool life equation, tooling manufacturers absorb the cutting depth and its index into the constant numerator. It is extensively the case that catalogues present cutting data for turning operations assuming a fixed tool life of twenty minutes. By imposing this assumption it is possible to specify the cutting velocities that should be used with specific feed rates. An extract from a

catalogue provided by the industrial collaborator, shown in Table 8.1, illustrates this concept.

Cutting speed, V_c (m/min) based upon a tool life of 20 minutes.											
Grade(→)			TP100			TP200			TP300		
Mat. Gp.	Material (↓)	Feed(→) (mm/rev)	0.2	0.4	0.6	0.2	0.4	0.6	0.2	0.4	0.6
1	Soft low carbon steels		500	385	320	445	340	285	365	275	230
2	Free cutting steels		425	325	270	380	290	240	305	235	195
3	Structural steels		365	275	230	325	245	205	260	200	165
4	High carbon steels		300	230	190	265	205	170	215	165	140
5	Normal tool steels		255	195	160	225	170	145	185	140	115
6	Difficult tool steels		230	175	145	205	155	130	165	125	105

Table 8.1 : Cutting velocities for turning based upon Taylor's tool life equation

From Table 8.1 it can be seen that for a given material and insert grade combination, the cutting velocities associated with feed rates of 0.2, 0.4, and 0.6 mm/rev are presented. In general the feed rate of a turning operation will lie between 0.2 and 0.6 mm/rev and linear interpolation can be used for any feed rate within this prescribed range. For the limited number of cases where the feed rate falls outside the specified range, linear extrapolation can be used to assess the necessary cutting velocity.

In order to cater for machinists who wish to adopt a tool life other than that specified, it is possible to use a constant factor which can be multiplied by the cutting velocity associated with a tool life of twenty minutes. To achieve a longer tool life a reduced machining velocity is needed, and acceptance of a shorter tool life allows the cutting velocity to be increased.

Once the cutting velocity for an operation has been defined it is then possible to calculate the required spindle speed of the machine tool, as shown by equation 8-2.

$$n = \frac{1000 \times v_c}{\pi \times D} \quad \begin{array}{l} n = \text{Spindle speed (rev/min)} \\ v_c = \text{Cutting velocity (m/min)} \\ D = \text{Workpiece diameter (mm)} \end{array} \quad (8-2)$$

8.3 Tool and cutting data selection for milling

In contrast to turning, which emphasises the application of single point continuous cutting actions, milling deals with the use of multi-edged cutters performing intermittent cutting operations. Modelling a process which involves a significant number of variables, as in the case of milling, produces a series of equations which involve additional complexities when compared with the mathematical analysis of turning operations. Despite this fact there are a number of similarities between turning and milling, and these similarities will be used as the foundation for the analysis of milling operations.

Appendix I presents a brief review of the fundamental relationships that exist between the various parameters encountered when performing a milling operation. As in the case of turning, basic geometric principles and engineering knowledge will be used to assess the type of cutting operations which are required to generate the required features on the workpiece. Once the initial tool selection has taken place the process planner will be keen to assess the most appropriate cutting conditions which will be used during the machining process.

In a similar fashion to the chipbreaker diagram for turning inserts, milling cutters are constrained by means of imposing limits between which the depth of cut and feed per tooth values must lie. It is the physical characteristics of the inserts which define the ranges for the depth of cut and feed per tooth, whilst the cutter geometry needs to be considered when converting the feed per tooth into either feed per revolution or absolute feed speed.

The way in which cutting velocities for milling operations are defined is little different from the area of turning, although the opinion of industrial machinists is that tool life in milling operations exhibits significantly greater variance. For a given combination of insert grade and workpiece material group, a number of convenient feed per tooth intervals will be used for specifying the necessary cutting velocity. Assessment of feed per tooth values falling in between the marker values is achieved with linear interpolation. A brief extract from a catalogue provided by the industrial collaborator is shown in Table 8.2 to illustrate the way in which cutting data is presented.

Material Group	Insert Grade (→)		T25M			
	Material Type (↓)	Feed Per Tooth (mm) (→)	0.15	0.30	0.45	0.60
1	Soft low carbon steels		270	215	185	160
2	Free cutting steels		245	190	165	145
3	Structural steels		200	160	135	120
4	High carbon steels		185	145	125	110
5	Normal tool steels		155	125	105	100

Table 8.2 : Illustrative cutting velocity table for milling

With the range of cutting parameters having been defined it is then possible to vary their values to see the effect upon the dependent variables such as material removal rate, power requirement, chip thickness and spindle speed.

8.4 Tool and cutting data selection utility on the web

Having established a suitable platform of knowledge it is now possible to examine the design and deployment of a Web-based utility which would allow the selection of tools and the analysis of cutting data for both turning and milling operations. Earlier analysis highlighted the sources of data which would be available for incorporation into the JadeT system. The initial goal of the system was to provide a standardised method of storing and retrieving data relating to tool trials. The resulting database of tool trials information was used to provide appointed people with verbatim access to the records stored in the database.

In addition to the closed-loop functions offered by JadeT, opportunities for the development of open-loop functions have already been noted. The standardised database structures used in commercial tooling related software packages, such as WinTool, provided an opening to investigate the deployment of a distributed tool and cutting data selection system. If the tool trials database is considered in a more abstract manner it reveals an opportunity to examine a utility based upon the collaboration of data sources. The aim of this new utility would be to analyse data contained within the tool trials database. The results from this analysis could then be used to assess whether it is possible to modify the more conservative cutting data sourced from tooling catalogues to yield data which is closer to optimum machining conditions.

8.4.1. Standard tool and cutting data selection

The wide range of computer-based tool and cutting data selection utilities made available to the industrial machinist illustrates that the data pertaining to these tasks can be consolidated in a manner suitable for storage in a database. The tooling information stored within the database can then be processed algorithmically to evaluate suitable cutting parameters for any specific item of tooling. The existence of commercial tooling databases may offer initial encouragement in terms of developing and establishing a Web-based tooling related application. Whilst such software developments utilise databases which store sufficient information so as to allow a wide variety of analyses to take place, the limiting features of Internet based computing applications need to be considered.

The time taken to locate or download information from the Internet is an area of continual debate amongst researchers and significant criticism from end users. It is unfortunate that the rate at which Web users increase is higher than the rate at which technological advances are made in the area of bandwidth utilisation and transfer protocols' efficiency. The situation which arises from these considerations is one where the developers of Web-based applications strive to minimise download times and maximise the efficiency of distributed database access.

As for the technical support facilities, the differences between the CGI and Java based approaches to distributed data access are important factors in assessing overall application performance. In addition to this, the volume of information which is generated by a particular request must be considered when evaluating system performance. Despite Internet users having local machines with significant data processing capability, this is of little use in a situation where the pre-processing time taken to retrieve that data is high. As a result of these considerations, developers of Web software are careful to ensure that SQL is used neatly, in a manner which allows bulk processing tasks to be carried on the server side of the client-server set-up. The tidy and efficient manner in which SQL carries out database interrogation can result in highly specific result sets which can be quickly transferred to the client device. The development of a Web based tooling utility needed to provide client side users with a tool capable of quickly and efficiently allowing the tool and cutting data selection tasks to be carried out, and so a combination of Java and SQL were used.

8.4.1.1 Tool and cutting data selection for turning

One of the primary stages in the process planning task is to assess the general type of operations that will be required based upon visual examination of the component geometry. As an example, consider the component illustrated in Figure 8.2.

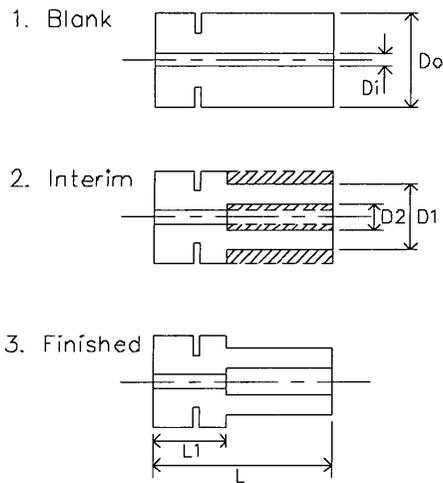


Figure 8.2 : A general component

From consideration of Figure 8.2 it is apparent that it will be necessary to use turning operations in order to generate the cylindrical profile that is required.

Consideration of the areas which need to be machined show that both external and internal operations will be required. The depth of cut values can also be estimated at this time.

At this point an initial assessment of the machine tool which will be used can be made. This will be based upon the overall size of the component, the power which will be required given the workpiece material and estimates of the cutting depths which will be used. Aside from the task of fixture definition and datum surface specification, it is possible to list the sequence of operations which will be used to machine the component. Once the operation sequence has been defined it is necessary to analyse specific cutting data, based upon the individual operations to be performed, the tolerances which are imposed on the workpiece and the power constraints of the machine tool being used.

The above analysis is a simplistic example of the tooling related issues which are encountered when carrying out process planning tasks. Based upon this information, a general structure can be assigned to the Web-based tool and cutting data selection utility. Included in this structure will be the identification of data provided by the user, and data which will be sourced from the tooling database, as illustrated in Figure 8.3.

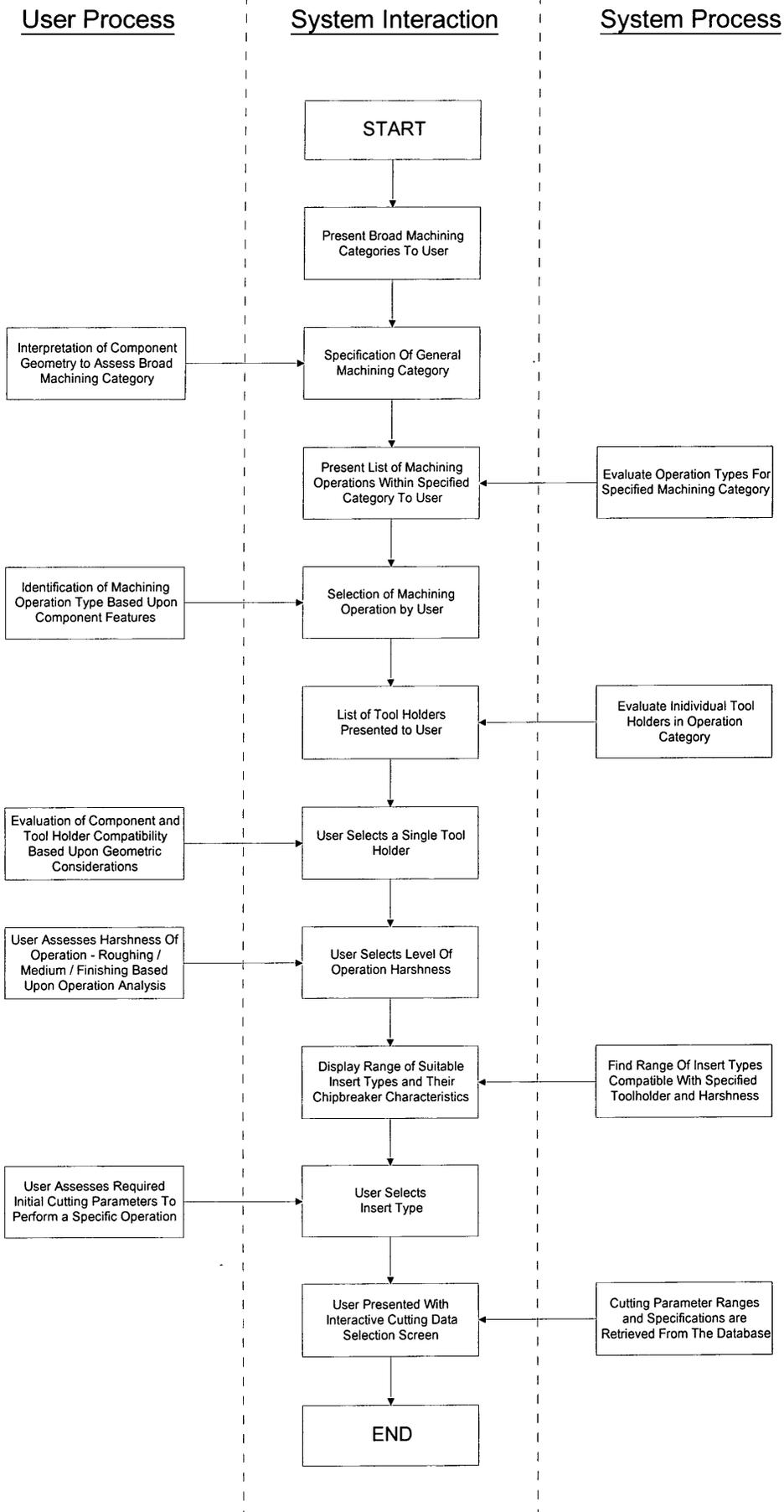


Figure 8.3 : Interaction of user with JadeT tool selection system

Consideration of Figure 8.3 shows a structure which defines a smooth progression from abstract specification in the initial stages of the selection process through to the presentation of highly specific cutting data parameters for an individual insert and toolholder combination. The structure of the database which was created to store the necessary elements of turning tool information is presented in Table 8.3.

Field Name	Data Type	Description
OpCode	Integer	Code for the operation type. e.g. 1 = Internal turning
HoldCode	Integer	Code for the toolholder type. e.g. 1 = PWLNR
InsOpCode	Integer	Code for insert operation. e.g. 0 = Roughing
InsType	Text	Insert family. e.g. WNMG-MF2
MinDepth	Float	Minimum depth of cut for the insert.
MaxDepth	Float	Maximum depth of cut for the insert.
MinFeed	Float	Minimum feed rate for the insert.
MaxFeed	Float	Maximum feed rate for the insert.
InsNo	Integer	Tally of inserts within an insert family.
PartNo	Text	ISO code for insert.
NoseRad	Float	Nose radius of the insert.
Grade	Text	Grade of the insert.

Table 8.3 : Database structure for turning tool selection

During the selection process, the user would be presented with graphical choices which allowed the specification of the type of operation being considered. The first level of the user interface provided the user with a choice between the category of machining to be considered, namely turning or milling. Once this selection has been made the main tool selection user interface will be displayed to the user as shown in Figure 8.4.

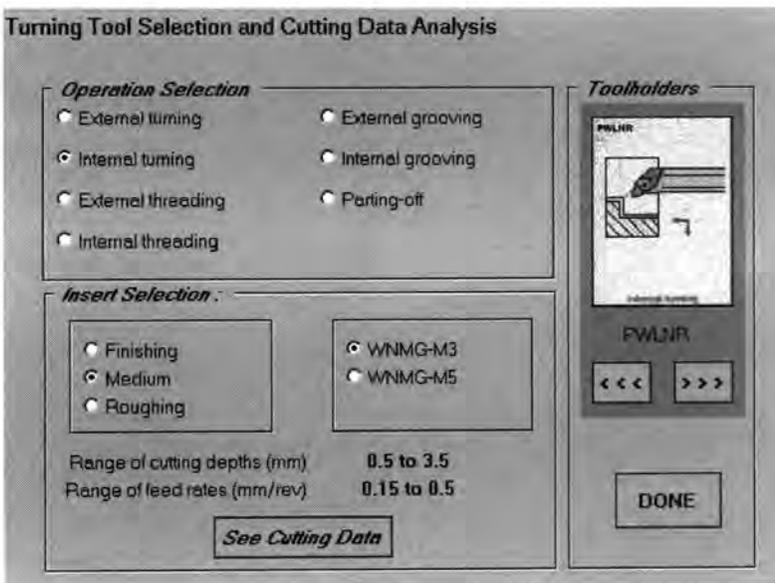


Figure 8.4 : User selection of turning operation specification

At the initial presentation of the screen shown in Figure 8.4 the 'Insert selection' window would initially be blank. The area situated directly above this element allows the user to choose any one of seven categories of turning operation from external turning through to parting-off. When a particular category is selected, it is possible for the user to scroll through the available toolholders. A picture of each toolholder is displayed along with important geometric values such as the approach and trailing angles. When the user has decided upon the tool holder required it is necessary to simply click on the picture of the tool holder presented in the right hand corner of the screen. This results in the 'Insert selection' window becoming visible, and the user is initially presented with the range of insert families available to perform finishing operations. If a different type of operation (finishing, medium or roughing) is chosen by the user then the list of insert families will be updated. The user is able to choose any available insert family from the list presented, and for the insert family highlighted the range of depths of cut and feed rates are displayed. Once a suitable holder and insert selection have been made it is possible for the user to view the interactive cutting data analysis screen, as shown in Figure 8.5.

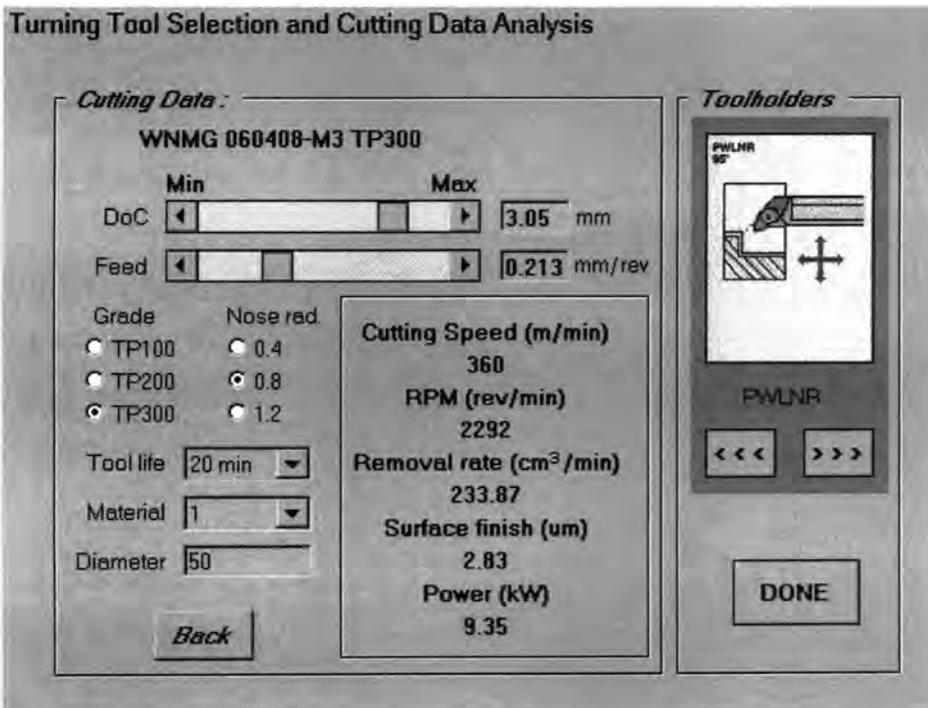


Figure 8.5 : Interactive cutting data analysis for turning

From consideration of Figure 8.5, it can be seen that for the specified combination of insert and toolholder, the user is able to independently vary the following parameters;

- The depth of cut between the maximum and minimum values.
- The feed rate between the maximum and minimum values.
- The grade of the insert from a list of those grades in which the insert is available.
- The nose radius of the insert from a list of those nose radii in which the insert is available.
- The tool life from a menu containing four tool life values - 10, 20, 40 and 60 minutes.
- The material group to which the component belongs.
- The diameter of the workpiece for the operation being considered.

For any single combination of the above parameters it can be seen that the user is provided with a variety of information pertaining to more general aspects of the operation, such as the required spindle speed of the machine tool, the surface finish generated by the operation, and the power required to perform the operation.

The equations presented in Appendix H are the same as those which have been implemented into the JadeT tool and cutting data selection utility. Consideration of Figure 8.5 reveals that it is necessary for the system to calculate the cutting velocity in order for the subsequent parameters to be evaluated. To provide a means for JadeT to calculate cutting velocities it was necessary to create a simple database from which the cutting velocity could be calculated. For any combination of insert grade and material, the cutting velocities for three specific feed rates would be stored. A process of linear interpolation was used to provide an approximation of the cutting velocity which would give the required tool life as specified by the user. With a cutting velocity specified, the remaining parameters can be calculated and displayed in the cutting data screen.

8.4.1.2 Tool and cutting data selection for milling

A number of the tasks involved with tool and cutting data selection for milling operations are similar to the equivalent task for turning. At the outset, the geometry of a given component can be used to assess the requirement for milling operations to be performed. From this, a general outline of machining operations and estimates of the harshest cutting conditions can be used in collaboration with component geometry to indicate the machine tool which is most suited to perform the machining tasks.

The logic presented in Figure 8.3 in respect of the JadeT turning module applies equally well to milling. There is much similarity in not only the operating logic but also the visual manner in which milling data is presented to the user in order to create the feeling of a standardised tool and cutting data selection environment. The greater complexity associated with milling operations, both practically and mathematically, lead to the milling database being larger, in terms of the number of fields, than the database dedicated to turning. This is due partly to the additional information needed to perform the analysis of a milling cutter / insert combination and also that the cutting velocity data needed to be included within the primary milling database. The structure of the milling database is presented in Table 8.4.

Field Name	Data Type	Description
OperationCode	Integer	Code for operation type. e.g. 1 = Face milling.
HolderCode	Integer	Code for cutter type. e.g. R220.13.
HolderPart	Text	Part number of the cutter body.
PrimaryInsertCapacity	Integer	Number of primary inserts on cutter body.
SecondaryInsertCapacity	Integer	Number of secondary inserts on cutter body.
PrimaryInsertType	Text	Insert family to which primary insert belongs.
SecondaryInsertType	Text	Insert family to which secondary insert belongs.
PrimaryInsertPartNo	Text	ISO code of primary insert.
SecondaryInsertPartNo	Text	ISO code of secondary insert.
SteelFM	Boolean	True if suitable for finishing - medium operations on steel workpieces.
SteelMR	Boolean	True if suitable for medium - roughing operations on steel workpieces.
StainlessFM	Boolean	True if suitable for finishing - medium operations on stainless steel workpieces.
StainlessMR	Boolean	True if suitable for medium - roughing operations on stainless steel workpieces.
CastIronFM	Boolean	True if suitable for finishing - medium operations on cast iron workpieces.
CastIronMR	Boolean	True if suitable for medium - roughing operations on cast iron workpieces.
Aluminium	Boolean	True if suitable for machining aluminium components.
Alloys	Boolean	True if suitable for machining super alloys.
CutterDiameter	Float	Diameter of the cutter body (mm).
MinDoC	Float	Minimum depth of cut value (mm).
MaxDoC	Float	Maximum depth of cut value (mm).
MinFeed	Float	Minimum feed rate value (mm/min).
MaxFeed	Float	Maximum feed rate value (mm/min).
CuttingEdgeAngle	Integer	Angle of the cutting edge in degrees.
EffectiveRakeAngle	Integer	Effective rake angle in degrees.
EffectiveNoOfTeeth	Integer	Effective number of teeth for the cutter body.
FpT1	Float	Feed per tooth - lower index.
FpT2	Float	Feed per tooth - middle index.
FpT3	Float	Feed per tooth - higher index.
SteelFM1	Float	Cutting velocity for F-M operations on steel - lower index.
SteelFM2	Float	Cutting velocity for F-M operations on steel - middle index.
SteelFM3	Float	Cutting velocity for F-M operations on steel - higher index.
SteelMR1	Float	Cutting velocity for M-R operations on steel - lower index.
SteelMR2	Float	Cutting velocity for M-R operations on steel - middle index.
SteelMR3	Float	Cutting velocity for M-R operations on steel - higher index.
StainlessSteelFM1	Float	Cutting velocity for F-M operations on stainless steel - lower index.
StainlessSteelFM2	Float	Cutting velocity for F-M operations on stainless steel - middle index.
StainlessSteelFM3	Float	Cutting velocity for F-M operations on stainless steel - higher index.
StainlessSteelMR1	Float	Cutting velocity for M-R operations on stainless steel - lower index.
StainlessSteelMR2	Float	Cutting velocity for M-R operations on stainless steel - middle index.
StainlessSteelMR3	Float	Cutting velocity for M-R operations on stainless steel - higher index.
CastIronFM1	Float	Cutting velocity for F-M operations on cast iron - lower index.

/ continued

Field Name	Data Type	Description
CastIronFM2	Float	Cutting velocity for F-M operations on cast iron - middle index.
CastIronFM3	Float	Cutting velocity for F-M operations on cast iron - higher index.
CastIronMR1	Float	Cutting velocity for M-R operations on cast iron - lower index.
CastIronMR2	Float	Cutting velocity for M-R operations on cast iron - middle index.
CastIronMR3	Float	Cutting velocity for M-R operations on cast iron - higher index.
Aluminium1	Float	Cutting velocity for aluminium - lower index.
Aluminium2	Float	Cutting velocity for aluminium - middle index.
Aluminium3	Float	Cutting velocity for aluminium - higher index.
SuperAlloy1	Float	Cutting velocity for aluminium - lower index.
SuperAlloy2	Float	Cutting velocity for aluminium - middle index.
SuperAlloy3	Float	Cutting velocity for aluminium - higher index.

Table 8.4 : Database structure for milling tool and cutting data selection

The manner in which the initial levels of milling cutter selection were approached is little different from the analysis presented earlier in conjunction with turning. The first level within the milling utility allows the user to specify the particular category of operation to be performed. Having selected an operation, the relevant cutter bodies within that category are then displayed graphically along with their most important specifications. With a suitable cutter body having been identified the user is then presented with the screen shown in Figure 8.6.

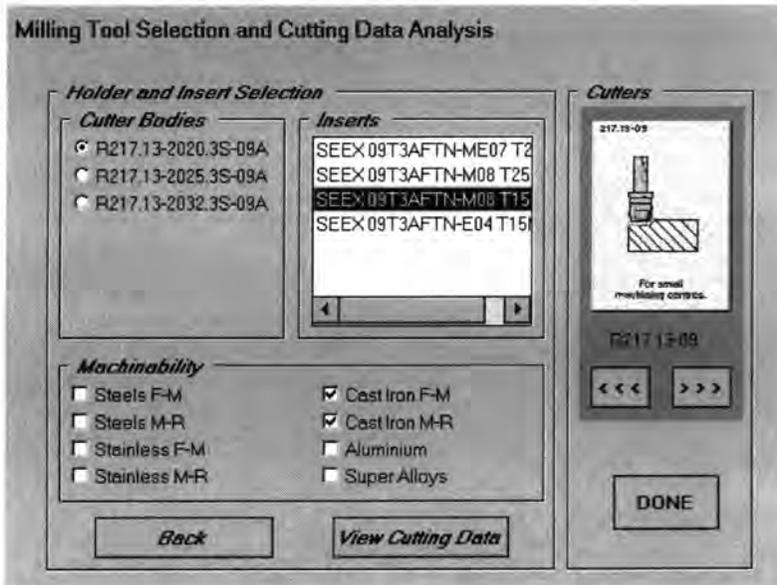


Figure 8.6 : Holder and insert selection for milling

It can be seen from Figure 8.6 that the user is presented with a listing of the available cutter bodies and, for the selected holder, the range of compatible inserts is displayed. To assist in the selection of inserts a machinability indication of each insert is presented. Included in this assessment is the ability of the insert to machine aluminium and super alloy workpiece materials.

Once the user has identified the cutter body which is required and the inserts to be used with that cutter body based upon a machinability assessment it is possible to move forward and look at the cutting data for that cutter body / insert combination. The general layout of the milling cutting data analysis interface is similar in appearance to that for turning, although from consideration of Figure 8.7 it can be seen that the user has the ability to vary a selection of different parameters, namely;

- The axial depth of cut between the maximum and minimum values.
- The feed per tooth between the maximum and minimum values.
- The radial width of cut up to and including the cutter diameter.
- The category of cutter / workpiece engagement (full, central and off-centre).
- The material and hardness combination based upon the machinability specification.

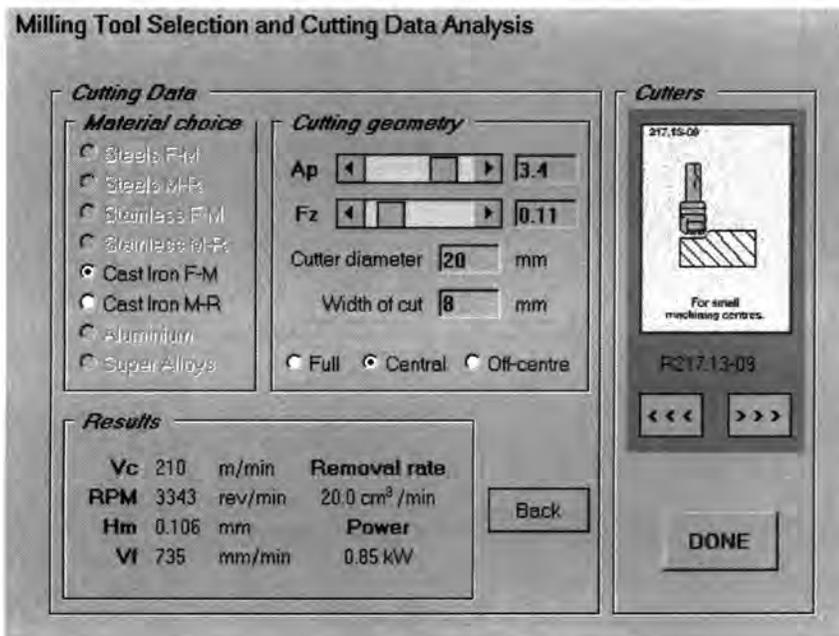


Figure 8.7 : Analysis of cutting data for milling

Based upon any single combination of these parameters the user is supplied with information regarding some overall process characteristics such as the cutting velocity, spindle speed, material removal rate and power requirement. As in the case of turning, an initial cutting velocity is estimated by applying linear interpolation techniques to the velocity / feed combinations stated within rudimentary product literature. This initial value of cutting velocity is then used in combination with the user specified values to evaluate the resulting operation conditions.

8.4.1.3 Review of tool and cutting data selection utility

The previous sections have looked at the way in which JadeT has been developed to provide a tool and cutting data selection utility designed specifically for use on the World Wide Web. The Internet is perhaps one of the best mediums for providing a distributed computing resource whilst allowing system control and maintenance to be carried out from a central administrative site. With efficient management practices being utilised in respect of the product databases, the end-users can be assured of receiving the most up to date information that is available.

The turning and milling utilities have provided an effective way for machinists to carry out the tasks of tool and cutting data selection on the Internet. The tool selection is based upon geometric constraints and overall operation specifications, whilst the cutting data selection tool provides the user with a flexible interface for varying a number of the more important operation parameters. This flexible interface allows the user to easily assess the impact of cutting data variations on overall process parameters such as spindle speeds, the material removal rate and the power requirement necessary to perform an operation.

8.4.2. Cutting data enhancement using the tool trials database

8.4.2.1 Preliminary considerations

The thesis thus far has shown how the Internet has been used as a central core for the collection and dissemination of information relating to tool trials amongst experienced engineers. In addition to this the JadeT development has provided general tool and cutting data selection utilities aimed at the industrial machinist. These utilities offer a visual environment which is supported by proven engineering algorithms applied to an up-to-date database of product information. In essence, these utilities form an interactive product catalogue where user navigation is effected with points and clicks rather than the turning of pages and jotting of notes.

Whilst the JadeT development in the area of tool trials data may be a useful tool for the tooling engineer, referring back to Figure 8.1 it can be seen that this approach is one initiated subsequent to the discovery of a tooling problem. From the perspective of the manufacturing industry it would be beneficial if tool related problems could be highlighted at design time rather than at the production stage which inevitably leads to far greater financial inconvenience. It is therefore suggested that the information contained within the tool trials database could be analysed and applied to the utilities which have been designed to perform the tool and cutting data selection functions. In this situation not only would machinists have access to the most up to date product database, but the cutting data recommendations would be based upon those proven within production environments. Rather than the JadeT tool selection utility being classified as an 'electronic catalogue', the technology incorporated into JadeT would provide machinists with a framework incorporating new reserves of previously unused data. Although such a reserve of previously unaccessed material may indeed contain valuable information in performing tooling related tasks, it is necessary to give thought to the validity of the ways in which the data is handled and processed.

From the presentation of the JadeT tool and cutting data selection activities it has been shown that the end user is able to vary a number of the parameters associated with performing process planning tasks. Based upon the information specified by the user an estimate of the cutting velocity is ascertained, which when combined with the data stipulated by the user allows the evaluation of a series of overall operation parameters. The subject of cutting velocity selection for metal cutting operations has attracted a number of research initiatives. Not only are tooling manufacturers sometimes vague when specifying suitable cutting velocities for a given material and insert combination, but it is commonplace for the way in which these cutting velocities are obtained to be omitted. Carpenter (1996) identifies this trend and comments that it is particularly prevalent in milling data specifications. Colding (1992) explores the area of parameter optimisation and concludes that cutting data provided by sources which do not include shop floor feedback are leading to the application of conservative and sub-optimal cutting parameters. Whilst the possibility of machine shops employing significantly sub-optimal data has been highlighted, much comment has been made regarding the ease of achieving optimal cutting conditions. It is frequently the case that equations

dedicated to the evaluation of optimal cutting conditions require practically determined values which are not commonly available.

It was decided that an analysis of the tool trials database would be made, and its suitability for enhancing cutting data calculations would be considered. The basis of this cutting data enhancement would be to analyse the cutting velocities used in previous similar operations as a basis for specifying a cutting velocity which could be confidently applied in a new cutting operation.

Up to this point, cutting velocities have been estimated based upon the cutting data selection tables sourced from tooling manufacturers catalogues. It was decided that the first stage in improving the assessment of cutting velocity would be to employ a technique rather more encompassing than linear interpolation. Instead of assuming a linear relationship to exist between specific data points a method which generated a second order polynomial equation, based upon a least squares approximation, relating cutting velocity to feed rate was applied. The analysis that was performed to justify this step, along with the fundamental principles of curve fitting, can be found in Appendix J.

8.4.2.2 Calculation of cutting velocity from catalogue data and tool trials data

With the successful identification of sufficient cutting velocity / feed rate data pairs from both tooling catalogues and the tool trials database, each data source will have generated a quadratic equation modelling the relationship between the cutting velocity and feed rate. It is now that due consideration needs to be given to the way in which, for any given feed rate, a cutting velocity will be evaluated. The use of the least squares polynomial approximation has already been examined, with particular reference being made to its characteristic ability to minimise the root mean square error of the data being considered. It is the value of this error that will form the basis of a cutting velocity assessment.

The curve fitting analysis detailed in Appendix J has demonstrated that the error associated with the quadratic polynomial approximation of the data from catalogues is very low. When the same insert grade and material combination was examined with data sourced from the tool trials database, the error in the approximation was invariably

found to be at least two orders of magnitude greater than the error achieved with the catalogue data. Because of the minimal error in the quadratic approximation based upon the catalogue data, it was decided that only the error in the tool trials database approximation would be used when assigning a cutting velocity for a specific feed rate. This is a logical step to take, as in situations where the tool trials data is found to exhibit a root mean square error which is too high to justify its use as a predictive assessor, the default values as specified within the catalogues would be applied.

The root mean square error adopts a single value for any given polynomial approximation based on the data set from which the approximation is derived. Whilst this value is meaningful in assessing the overall conformance of the data set to the polynomial approximation, it is of little use *per se* in attributing a local error for a specific value of either variable. However, if the root mean square error is expressed as a percentage of the value yielded by the polynomial approximation a good indication of the local error can be obtained. It is by assessing this local error that it will be possible to decide upon the weighting given to the tool trials database cutting velocity approximation. The mathematical derivation of this assessment will now be presented.

Consider the two quadratic polynomials obtained from the application of the least squares approximation technique, as presented in equation 8-3, where $f_{cat}(x)$ is the polynomial approximation of the catalogue data and similarly, $f_{udb}(x)$ is the polynomial approximation of the data from the tool trials database.

$$\begin{aligned} f_{cat}(x) &= a_1 + a_2x + a_3x^2 \\ f_{udb}(x) &= b_1 + b_2x + b_3x^2 \end{aligned} \quad (8-3)$$

The tool trials database quadratic approximation was obtained from the data set shown in equation 8-4.

$$\{(x_1, y_1), (x_2, y_2), \dots (x_n, y_n)\} \quad (8-4)$$

The two cutting velocities obtained from equations 8-3 for a specific feed rate of x_{feed} , (units either mm/rev or mm/tooth), are as shown in equation 8-5.

$$\begin{aligned} c_{cat} &= f_{cat}(x_{feed}) = a_1 + a_2 x_{feed} + a_3 x_{feed}^2 \\ c_{udb} &= f_{udb}(x_{feed}) = b_1 + b_2 x_{feed} + b_3 x_{feed}^2 \end{aligned} \quad (8-5)$$

The root mean square error for the tool trials database polynomial is given by equation 8-6.

$$E_{udb} = \sqrt{\frac{1}{n} \sum_{i=1}^n [f_{udb}(x_i) - y_i]^2} \quad (8-6)$$

The error presented in equation 8-6 can then be expressed as a fraction of the local value of the cutting velocity obtained from the tool trials database polynomial. The value for the local error is shown in equation 8-7.

$$\varepsilon_{udb_{local}} = \frac{E_{udb}}{f_{udb}(x_{feed})} \quad \text{where; } 0 < \varepsilon_{udb_{local}} < \quad (8-7)$$

Finally, the cutting velocity which will be presented as the final cutting velocity can be evaluated from equation 8-8.

$$c = (1 - \varepsilon_{udb_{local}}) V_{c_{udb}} + \varepsilon_{udb_{local}} \cdot V_{c_{cat}} \quad (8-8)$$

From consideration of the final cutting velocity equation presented in equation 8-8, it can be seen that the local error in the tool trials database polynomial is used to directly attribute a weighting to each of the quadratic polynomial approximations. If the error in the tool trials data is high then a low weighting is given to the tool trials database approximation. If there is good conformance of the tool trials data, a higher weighting is attributed to it when calculating the final cutting velocity. For situations where the local error is above one, zero weighting is given to the tool trials database data.

8.5 Analysis and testing of the data enhancement procedures

The previous chapters in this thesis have presented the development of the tool trials database and the way in which it facilitates the submission and retrieval of technical tooling information. In addition to this the development of a tool and cutting data selection utility for turning and milling operations has been described.

The examination of related literature highlighted the potential benefits associated with tooling support systems being able to use a combination of theoretically derived and empirically obtained data. The industrial survey demonstrated the interest of industrialists in such tooling support systems being made available.

To address these issues a framework has been developed which allows data from the tool trials database to be analysed and used within a tool and cutting data selection utility in an attempt to enhance standard catalogue data. Having developed and described this framework in the previous section, consideration will now be given to the analysis and testing which was carried out in order to evaluate the performance of these methods.

As a pre-cursor to the testing details, a review of the methods used to obtain cutting data from the tool trials database will be presented. Consideration will be given to a number of important aspects, viz.;

- What checks are made to ensure that the volume of data is satisfactory?
- What controls are in place to identify and deal with “rogue” data?
- Could the data retrieval and analysis be improved?

This review will be followed by a description of the tests to be performed, the limitations inherent in the testing framework and the differences which would exist between the testing environment and the intended application area. In light of the methods used to perform the tests and their limitations, the results from the tests will be presented and analysed. This section will conclude with a summary of whether the tests have been shown to endorse the original aims of the system and whether they suggest that modifications should be made to the core functionality.

8.5.1 Data retrieval from the tool trials database

In order for the tool and cutting data selection system to analyse the cutting velocity / feed rate relationship it is necessary to obtain a series of data points, as defined in equation 8-4, for the given combination of insert grade and workpiece material. The data set for the polynomial approximation relating to the catalogue data is implicitly defined within the system and therefore does not require database consultation. The main element of data retrieval is in association with identifying and processing the data set sourced from the tool trials database.

Given a set of data points from the tool trials database, basic statistical theory suggests that the quantity of data obtained for analysis has a direct effect on the confidence with which moments such as the mean and variance can be established. More specifically, the central limit theorem indicates that the standard deviation of the sampled data will have an inverse relationship with the square root of the number of data points. If each data point is assumed to come from a distribution with mean μ and variance σ^2 , then given a set of n data points, the data set as a whole will have the same mean μ , but a reduced variance σ^2/n . It is therefore advantageous to collate as much data as possible in terms of assessing the quality of conformance of the data although the processing times associated with the manipulation of significant volumes of data has to be considered as a limiting factor.

For the purpose of testing the functionality of the system it was decided that a suitable lower bound for the number of data points from the tool trials database would be set equal to ten. This figure was obtained from dual consideration of the statistical implications of the volume of data being considered against the actual volume of data which was available within the test version of the tool trials database. This lower bound for the volume of data required to perform the tool trials database analysis could be increased accordingly as the volume of data available within the database increases, as would be the case in its intended operating environment.

In terms of the data submitted to the tool trials database it is known that associated with each tool trial report are a significant number of data terms. Whilst basic procedures have been implemented to ensure that all data fields are completed by the user it was

decided that to analyse the “reasonableness” of each data term within the context of the tool trial being entered would result in the process of submitting data being excessively regimented and time consuming. As the precise numerical values of the cutting parameters are not examined in detail at the data submission stage it is necessary for the system to be able to minimise the impact of rogue data terms on the cutting velocities suggested by the system in respect of the data from the tool trials database.

Having considered the algorithms used to analyse cutting data from the tool trials database it was evident that there is an inherent capability for the system to deal with both rogue data and data that exhibits poor conformance. A rogue data term may be defined as being a data term which is clearly incorrect; situations in which such data may be present include typing errors and confusion of measurement units. When the analysis of the data set is performed a rogue data term will make a marked contribution to the overall RMS error of the data set. In doing so, the rogue data term will have the effect of reducing the weighting given to data from the tool trials database and a heavier weighting will be given to the approved catalogue data. This mechanism will be illustrated during the description of the tests which were performed.

One of the limiting factors associated with data retrieval from the mock tool trials database is the quantity of records that are stored within the database. Because of relatively low volumes of data available for testing it is the case that a number of simplifications have been made. One such simplification is that the retrieval of data from the tool trials database is based upon any given combination of insert grade and workpiece material. It is evident that the objective function of the reports matching this combination may vary. For example, some of the tests may relate to optimisation of tool life whilst others may have been performed to maximise the rate of production. To differentiate between these objective functions would result in insufficient data being available to carry out the testing of the data processing algorithms. It is suggested however that with a database containing more records, differentiation between objective functions would be possible and could enhance the capability of the cutting data utility.

8.5.2 Methods adopted for testing the cutting data utility

Consideration will now be given to the tests which were performed in order to provide results that would allow conclusions to be drawn on the efficiency with which the cutting data selection utility operated. The results will also be used to suggest modifications that could be made in order to make good any shortfalls in the system's behaviour.

The nature of the testing was to pick a selection of insert grade and material combinations and to consider how the cutting parameters obtained from the integration of cutting data from the tool trials database compared with the parameters that would be obtained based solely on approved data from technical tooling guides. As suggested in the previous section, the main factor limiting the scope of the testing is that the volume of data was low in comparison with a fully operative tool trials database with several thousand tool trials. In light of this it is suggested that the test results presented within this section deal with aggregate measures of effectiveness, whilst fine-tuning of the system would be possible only with an expanded data set.

8.5.3 Test 1 : Turning - TP100 insert grade machining group 3 steel

The insert grade to be considered is TP100 in the context of performing turning operations on group three steels. The cutting velocity / feed rate characteristics as specified in the relevant catalogue are shown in Table 8.5.

Feed Rate (mm/rev)	Cutting Velocity (m/min)
0.2	365
0.4	275
0.6	230

Table 8.5 : Cutting velocity / feed rate data for TP100 machining group 3 steel

In the case of a turning operation on a group three material using the TP100 insert grade, the database query generated the data presented in Table 8.6.

Pair number	1	2	3	4	5	6	7	8	9	10
Feed rate (mm/rev)	0.13	0.15	0.18	0.2	0.22	0.25	0.3	0.33	0.35	0.4
Cutting velocity (m/min)	380	352	366	321	365	344	322	321	308	291

Pair number	11	12	13	14	15	16	17	18	19
Feed rate (mm/rev)	0.44	0.45	0.5	0.55	0.55	0.6	0.62	0.66	0.68
Cutting velocity (m/min)	266	302	225	284	245	288	280	255	253

Table 8.6 : Cutting velocity and feed rate pairs from tool trials database

At this point there is sufficient data to allow the least squares polynomial approximation to be carried out on both the catalogue data and the data sourced from the tool trials database. The resulting quadratic equations and their respective data points are displayed graphically in Figure 8.8. With the quadratic approximation for the tool trials database data pairs having been obtained it is possible to evaluate the root mean square error of the approximation. When the data presented in Table 8.6 is examined in the context of the tool trials database approximating polynomial, the root mean square error is found to be 19.09. This value can then be used to assess the local error hence allowing the cutting velocity to be calculated in accordance with equation 8-8.

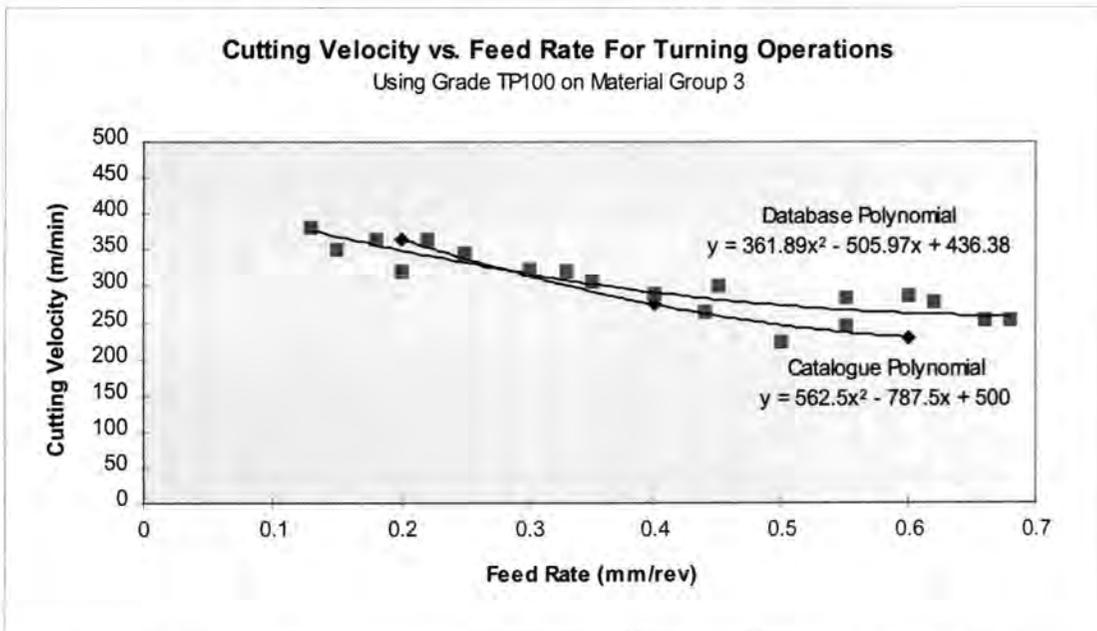


Figure 8.8 : Quadratic equations for TP100 insert grade with group 3 materials

To summarise the method for evaluating the cutting velocity once the least squares approximation technique has been used to obtain the two quadratics;

1. For the given feed rate evaluate the cutting velocity from the catalogue quadratic.
2. For the given feed rate evaluate the cutting velocity from the tool trials database quadratic.
3. Establish the RMS error of the tool trials database data, using equation 8-6.
4. Evaluate the local error for the specified feed rate.
5. Calculate the cutting velocity using equation 8-8.

Table 8.7 shows the logical progression of the cutting velocity calculation for a series of different feed rate values.

x_i	y_{cat}	y_{ttdb}	E_{ttdb}	e_{local}	New Vc
0.20	365.00	349.66	19.09	0.055	350.50
0.25	338.28	332.51	19.09	0.057	332.84
0.30	314.38	317.16	19.09	0.060	316.99
0.35	293.28	303.62	19.09	0.063	302.97
0.40	275.00	291.89	19.09	0.065	290.79
0.45	259.53	281.98	19.09	0.068	280.46
0.50	246.88	273.87	19.09	0.070	271.99
0.55	237.03	267.57	19.09	0.071	265.39
0.60	230.00	263.08	19.09	0.073	260.68

Table 8.7 : Cutting velocities resulting from data enhancement

From consideration of Table 8.7 it can be seen that for the particular insert grade and material group chosen there is close agreement between the catalogue and tool trials database. This agreement is seen not only in the proximity of the trendlines to each other, but also in the low value for the root mean square error of the tool trials database data. In this situation, whilst a significant degree of confidence can be attributed to the tool trials database trendline, the initial proximity of the two trendlines leads to only a small change being observed in the cutting velocity assessment. In order to visualise the enhanced cutting data relative to the catalogue data consider Figure 8.9. In this illustration, the cutting velocity from the cutting data enhancement process is expressed as a ratio in respect of the cutting velocity from the catalogue.

From consideration of Figure 8.9 it can be seen that for those operations with a feed rate above 0.3 mm/rev the cutting data enhancement procedures suggest the use of a cutting velocity which exceeds the value presented in the catalogue. For the lower values of

feed per revolution the cutting data enhancement procedures can be seen to indicate the use of a cutting velocity more conservative than suggested within the catalogue.

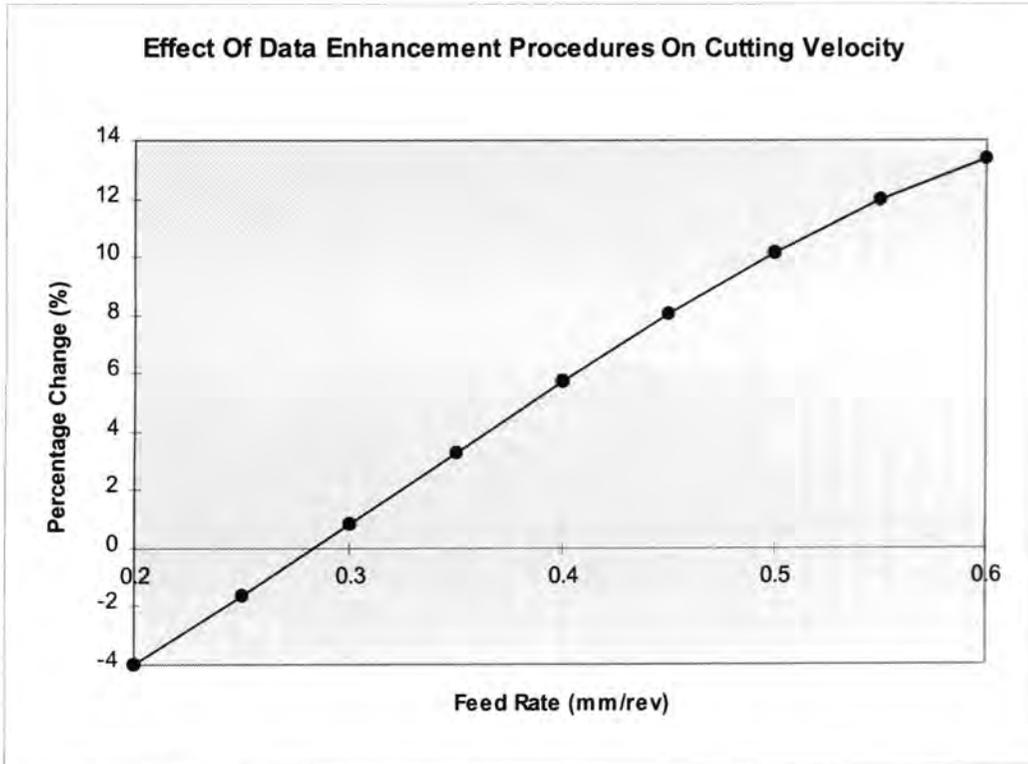


Figure 8.9 : Graphical representation of cutting data enhancement significance

8.5.4 Test 2 : Milling - T25M machining stainless steel

The previous illustration for a specific insert grade and material combination was chosen due to the pleasing level of conformance demonstrated by the data sampled from the tool trials database. It may not always be the case that data sampled from the database does exhibit such conformance. In these situations it is necessary for the algorithmic analysis of the cutting velocity / feed rate dependency to regulate the weighting given to information from the tool trials database. This example considers an insert grade and material combination where the tool trials database furnishes a data set which exhibits erratic behaviour, as shown by the data terms in Table 8.8.

Pair number	1	2	3	4	5	6	7	8	9	10
Feed rate (mm)	0.09	0.10	0.10	0.14	0.17	0.18	0.20	0.28	0.30	0.32
Cutting velocity (m/min)	420	318	145	200	205	100	192	178	62	40

Table 8.8 : Cutting velocity and feed rate pairs from tool trials database (2)

In exactly the same manner as before, the least squares polynomial approximation was carried out on both the catalogue data and the data sourced from the tool trials database. The quadratic equations which were generated as a result of this analysis and their respective data points are shown in Figure 8.10.

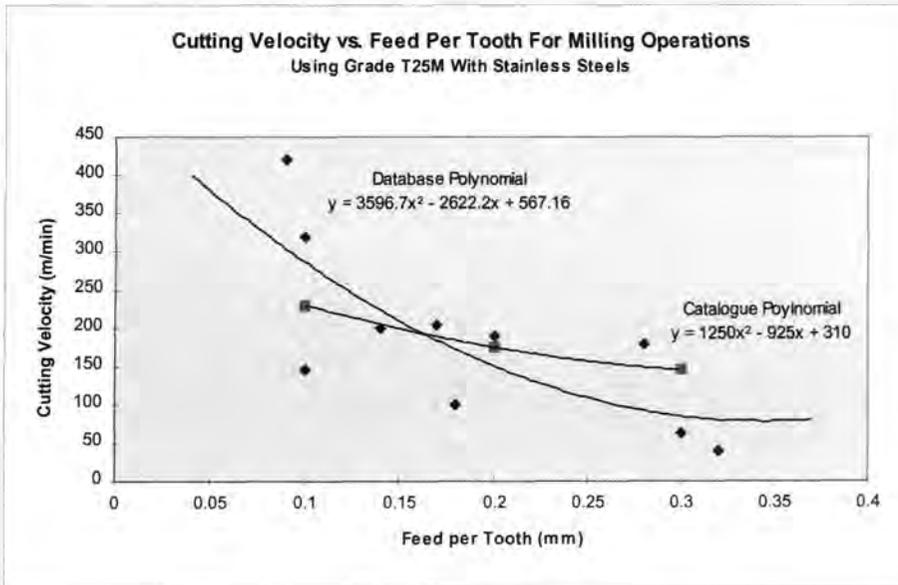


Figure 8.10 : Quadratic equations for T25M insert grade machining stainless steels

From consideration of the quadratic approximations shown in Figure 8.10 it can be seen that there is significant disparity between the two quadratic approximations. Having seen the graphical illustration of the two polynomials, now consider the cutting velocity values that the JadeT system would provide based upon this data. Table 8.9 shows the progression of the cutting velocity calculations for a series of feed per tooth values.

x_i	y_{cat}	y_{ttdb}	E_{ttdb}	e_{local}	New Vc
0.10	230.00	285.50	221.18	0.77	242.50
0.14	205.00	223.09	221.18	0.99	205.15
0.18	184.00	171.82	221.18	1.00	184.00
0.22	167.00	131.69	221.18	1.00	167.00
0.26	154.00	102.70	221.18	1.00	154.00
0.30	145.00	84.86	221.18	1.00	145.00

Table 8.9 : Cutting velocities resulting from data enhancement (2)

In contrast to the previous illustration it is evident that the root mean square error of the tool trials database polynomial approximation is indicating poor data conformance. It can be seen from Table 8.9 that as the feed per tooth value increases, the local error rises sharply to its limiting value of unity, where no weighting is given to the cutting velocity

predicted from the tool trials database data. Comparing the polynomial approximations with the JadeT cutting velocity values it can be seen that the erratic data handling procedures have effectively identified and dealt with data offering limited conformance. Figure 8.11 expresses the JadeT cutting velocities as a percentage of the catalogue predictions. From this figure it can be concluded that the JadeT system is capable of analysing and subsequently ignoring data which offers limited conformance. It is suggested that as more data becomes available it would be possible to consider poorly structured data in greater detail which would allow a smoothing process to be considered. Such a smoothing process would focus on the local error value and work to eliminate the risk of attributing any importance to the data from the tool trials database when the data behaves erratically. In terms of Figure 8.11, the smoothing function would serve to eliminate the small weighting given to the tool trials database data for the feed rates between 0.10 and 0.15 mm.

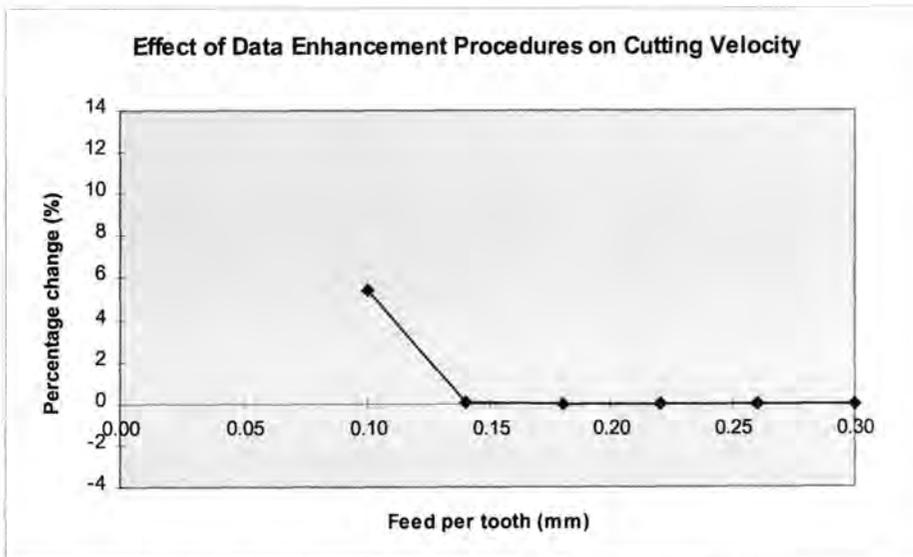


Figure 8.11 : Graphical representation of cutting data enhancement significance

8.5.5 Summary of test results

The mathematical foundation for the cutting velocity assessment has been presented and examined for particular material group / insert combinations. By first verifying that sufficient valid data exists within the tool trials database and then examining the data for numerical conformance it has been possible to model the dependency of the cutting velocity upon feed rate. For a specific insert grade and material combination it is then

possible to evaluate the cutting velocity for any particular feed within the limits defined by the insert's chipbreaker statistics.

The advantage of adopting such modelling techniques is that the data within the tool trials database is not constrained in the manner associated with many algorithmic-based cutting data evaluation systems. By sampling data obtained from actual machining operations carried out in a cross section of industrial scenarios, it is possible to provide the industrial machinist with indirect access to approved cutting data. In those situations where the tool trials database sampling procedure results in limited data sets it is possible for the JadeT system to automatically revert to the data originally presented in tooling catalogues. Additionally, JadeT has demonstrated the ability to deal with data that behaves erratically by attributing a significant weighting to the data from tooling catalogues with little emphasis attributed to the cutting velocity suggested by the tool trials database.

In a situation where the JadeT tool trials data submission utility was launched on a commercial scale the volume of data contained within the database would be significantly larger than the database upon which the initial JadeT testing was carried out. It is therefore likely that the information contained within the database would cover a wider range of tooling products. As the reserve of approved information grows with time, the likelihood of the JadeT system being unable to identify insufficient data for a particular machining condition to be examined would lessen. In addition to this, an expanded data source would permit a more in-depth analysis of specific technical functions such as the objective function of the process.

8.5.6 Links between confidence scores and cutting parameter selection

It has been seen that the cutting data selection utility considers data from the tool trials database where the insert grade and material combination match exactly. If sufficient data is not available the JadeT system reverts to the use of cutting parameters as defined in technical tooling guides.

In Chapter 7 the concept of confidence scoring was introduced and its underlying methods described. The purpose of this section is to investigate whether the dependency between confidence score and cutting parameters can be established in a manner that would allow cutting parameters to be estimated based upon tool trial reports which do not exactly match the insert grade and material combination chosen by the user. If such a dependency can be modelled in a satisfactory manner, the amount of data available for looking at any single combination of insert grade and workpiece material would be increased, thereby serving to reduce the variance of the cutting parameter predictions. To investigate this hypothesis the case studies presented in sections 8.5.3 and 8.5.4 will be extended to make allowance for the inclusion of data ranked by confidence score.

More formally, given a certain confidence score associated with a cutting velocity / feed rate data pair for an alternative combination of insert grade and workpiece material $\{v_i, s_i\}$, the estimated cutting velocity and feed rate associated with the chosen combination of insert grade and workpiece material, $\{v_i', s_i'\}$, can be calculated according to equations 8-9. Note that these equations assume a univariate dependency between the confidence score and the cutting velocity, the result of which is that only the cutting velocity is modified.

$$s_i' = s_i, \quad v_i' = \begin{cases} v_i + \{[0.01 \times (100 - CS)] \times v_{cat}\} & \text{if } m_i \leq m_{ref} \\ v_i - \{[0.01 \times (100 - CS)] \times v_{cat}\} & \text{if } m_i > m_{ref} \end{cases} \quad (8-9)$$

CS = Confidence score (%)

v_{cat} = Cutting velocity from catalogue

v_i' = New cutting velocity

s_i' = New feed rate

m_i = Material group to which test belongs

m_{ref} = Reference material group

In words, equation 8-9 is saying that if the material group upon which the test data pair is based is not equal to the material group specified within the cutting data selection utility, an adjustment is necessary which is proportional to the the shortfall in the confidence score from 100. In the first case, this adjustment is necessary to allow for the fact that the original data pair comes from a lower material group than the material group specified by the user in the cutting data selection utility. Similarly, if the original data pair is based on a higher material group the cutting velocity will need to be increased. The increase is again proportional to the shortfall of the confidence score from 100.

It should also be noted that the confidence score referred to in equations 8-9 is based upon the results that would be obtained if only the material group and insert grade were specified in the advanced query utility, with equal weightings being given to each parameter. This simplification is necessary to limit the distorting effect that would result from a confidence score based upon additional parameters. In the event where additional parameters are incorporated it is suggested that the equations necessary to attempt to establish a link between confidence score and cutting parameters would be more complex than that presented in equations 8-9.

8.5.6.1 Confidence scoring test 1 : TP100 insert grade machining group 3 steel

Based upon the need to look at the possible relationship between confidence scores and cutting parameters there are additional data terms from those presented previously in Table 8.6. The full data set is detailed in Table 8.10.

Pair number	1	2	3	4	5	6	7	8	9	10
Feed rate (mm/rev)	0.13	0.15	0.18	0.2	0.22	0.25	0.3	0.33	0.35	0.4
Cutting velocity (m/min)	380	352	366	321	365	344	322	321	308	291
Confidence score (%)	100	100	100	100	100	100	100	100	100	100

Pair number	11	12	13	14	15	16	17	18	19	20
Feed rate (mm/rev)	0.44	0.45	0.5	0.55	0.55	0.6	0.62	0.66	0.68	0.12
Cutting velocity (m/min)	266	302	225	284	245	288	280	255	253	420
Confidence score (%)	100	100	100	100	100	100	100	100	100	88

Pair number	21	22	23	24	25	26	27	28	29	30
Feed rate (mm/rev)	0.13	0.13	0.17	0.18	0.21	0.22	0.27	0.28	0.30	0.32
Cutting velocity (m/min)	352	368	382	257	415	388	327	336	287	265
Confidence score (%)	89	92	98	68	77	83	94	92	83	89

Pair number	31	32	33	34	35	36	37	38	39	40
Feed rate (mm/rev)	0.37	0.41	0.41	0.47	0.49	0.52	0.52	0.53	0.55	0.59
Cutting velocity (m/min)	308	228	212	273	209	226	198	257	166	186
Confidence score (%)	88	71	77	97	80	89	80	98	66	74

Pair number	41	42	43
Feed rate (mm/rev)	0.61	0.62	0.62
Cutting velocity (m/min)	217	153	197
Confidence score (%)	75	61	64

Table : 8.10 : Extended data set for TP100 insert grade machining group 3 steel

The data presented in Table 8.10 was used in combination with equations 8-6 and 8-9 in order to derive the confidence score adjusted data set, $\{v_i', s_i'\}$. The derivation of this data set is shown in Table 8.11.

Data Pair	Feed Rate	Cutting Velocity	Yttdb	Squared Error		Data Pair	Feed Rate	Cutting Velocity	Ycat	Yttdb	Conf. Score	Adj. Velocity	Squared Error
	s_i	v_i					s_i	v_i				v_i'	
1	0.13	380	376.7	10.8		20	0.12	420	413.6	380.9	88	370.4	110.4
2	0.15	352	368.6	276.5		21	0.13	352	407.1	376.7	89	396.8	402.6
3	0.18	366	357.0	80.4		22	0.13	368	407.1	376.7	92	400.6	568.9
4	0.2	321	349.7	821.5		23	0.17	382	382.4	360.8	98	389.6	830.8
5	0.22	365	342.6	502.6		24	0.18	257	376.5	357.0	68	377.5	417.8
6	0.25	344	332.5	132.1		25	0.21	415	359.4	346.1	77	332.3	189.2
7	0.3	322	317.2	23.4		26	0.22	388	354.0	342.6	83	327.8	217.8
8	0.33	321	308.8	148.4		27	0.27	327	328.4	326.1	94	346.7	422.4
9	0.35	308	303.6	19.2		28	0.28	336	323.6	323.1	92	310.1	168.2
10	0.4	291	291.9	0.8		29	0.3	287	314.4	317.2	83	340.4	542.2
11	0.44	266	283.8	317.4		30	0.32	265	305.6	311.5	89	298.6	166.7
12	0.45	302	282.0	401.0		31	0.37	308	285.6	298.7	88	273.7	624.5
13	0.5	225	273.9	2388.0		32	0.41	228	271.7	289.8	71	306.8	289.7
14	0.55	284	267.6	270.0		33	0.41	212	271.7	289.8	77	274.5	233.5
15	0.55	245	267.6	509.3		34	0.47	273	254.1	278.5	97	265.4	172.6
16	0.6	288	263.1	621.1		35	0.49	209	249.2	275.3	80	258.8	272.5
17	0.62	280	261.8	331.6		36	0.52	226	242.6	271.1	89	252.7	340.2
18	0.66	255	260.1	25.8		37	0.52	198	242.6	271.1	80	246.5	605.7
19	0.68	253	259.7	44.3		38	0.53	257	240.6	269.9	98	252.2	312.7
			TOTAL	6924.14		39	0.55	166	237.0	267.6	66	246.6	440.1
			AVE	364.43		40	0.59	186	231.2	263.8	74	246.1	314.2
			RMS ERROR	19.09		41	0.61	217	228.9	262.4	75	274.2	140.1
						42	0.62	153	228.0	261.8	61	241.9	395.2
						43	0.62	197	228.0	261.8	64	279.1	298.7
			OVERALL TOTAL	15400.67								TOTAL	8476.5
			OVERALL AVERAGE	358.1551								AVE	353.189
			OVERALL RMS ERROR	18.92499								RMS ERROR	18.7933

Table 8.11 : Determination of RMS error from extended data set

From consideration of Table 8.11 it can be seen that the original data presented in Table 8.6 is located on the left hand side of the table. At the foot of this data set the RMS error is displayed as 19.09, as noted previously. The additional data terms generated by relaxing the constraints on selecting data from the tool trials database is shown on the right hand side of Table 8.11. It can be seen that the RMS error associated with the additional data terms is 18.79, with the overall RMS error being 18.92.

The implications of the data displayed in Table 8.11 are that the RMS error of the additional data terms is only slightly different to the RMS error in the absence of the additional data. Although this result does not appear to help in suggesting whether the initial hypothesis was correct, it does suggest that by incorporating allowance for the data associated with a confidence score of less than 100% the aggregate error has not

worsened. This result indicates that the linear assumption in equations 8-9 between confidence score and cutting velocity is reasonable in this case.

The purpose of performing this extended analysis was to provide an indication of whether the additional data terms, in isolation from the initial data set, could be used as a predictive tool for cutting velocity estimation. The results detailed in Table 8.11 calculate a value for y_{ttdb} based upon the initial polynomial approximation for the tool trials database data set, as shown in Figure 8.8. In order to see whether the additional data does provide reasonable conformance to the aggregate results, a new second order polynomial was fitted to just the additional data terms, as illustrated in Figure 8.12.

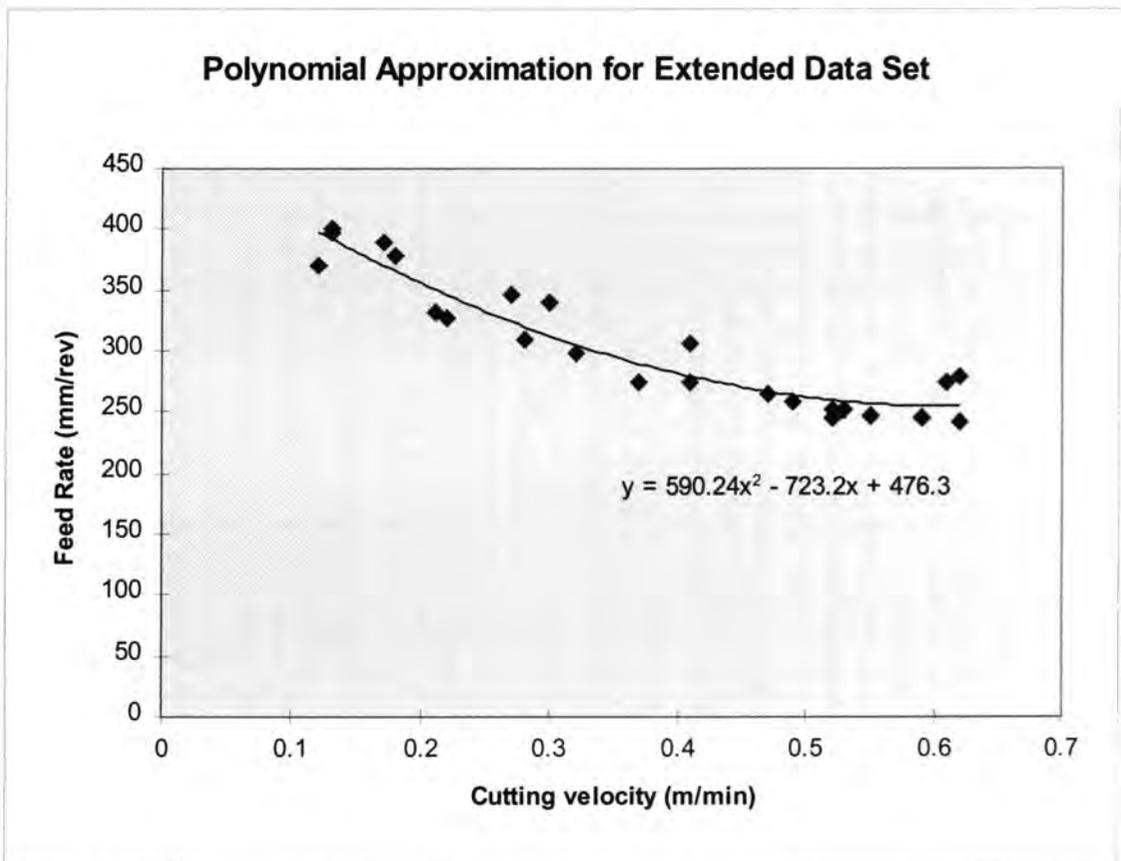


Figure 8.12 : Polynomial approximation for extended data set

Figure 8.13 shows the polynomials linking cutting velocity and feed rate for both the catalogue polynomial and the initial tool trials database polynomial shown in Figure 8.8 and the alternative polynomial given in Figure 8.12.

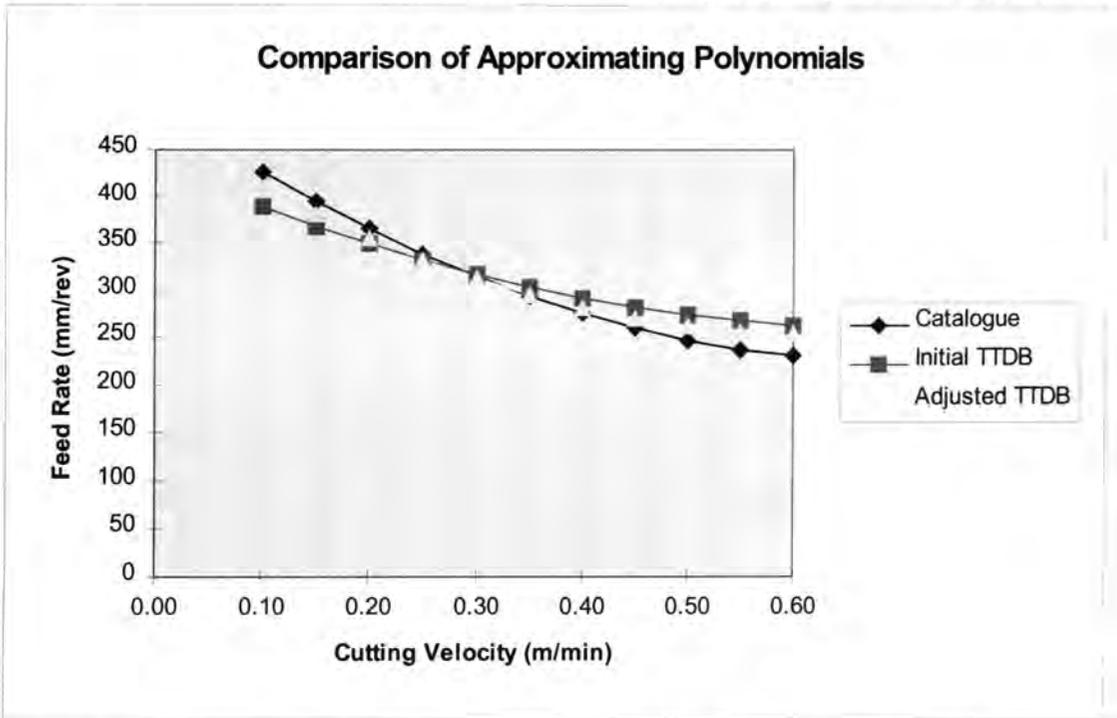


Figure 8.13 : Comparison of cutting velocity / feed rate dependency polynomials

From consideration of Figures 8.12 and 8.13 it can be seen that there is a good level of conformance with the information obtained from the extended data set. Because the extended data set itself has a variance broadly equivalent to that of the original data set it is suggested that the polynomial given in Figure 8.12 could support a cutting velocity assessment without reference being made to the initial data set. This result has the implication that for combinations of insert grade and workpiece material where precisely similar tests are low in number that a confidence-scored data set processed in line with equations 8-9 could be used to calculate cutting velocities for any feed rate within the bounds of the chipbreaker's capabilities.

8.5.6.2 Confidence scoring test 2 : T25M machining stainless steel

The extended data set for the given combination of insert grade and workpiece material are given in Table 8.12.

Pair number	1	2	3	4	5	6	7	8	9	10
Feed rate (mm/rev)	0.09	0.10	0.10	0.14	0.17	0.18	0.20	0.28	0.30	0.32
Cutting velocity (m/min)	420	318	145	200	205	100	192	178	62	40
Confidence score (%)	100	100	100	100	100	100	100	100	100	100

/cont.

Pair number	11	12	13	14	15	16	17	18	19	20
Feed rate (mm/rev)	0.12	0.13	0.21	0.23	0.23	0.25	0.26	0.26	0.29	0.30
Cutting velocity (m/min)	218	253	168	221	157	163	210	137	166	92
Confidence score (%)	97	68	72	93	84	91	89	88	71	67

Pair number	21	22	23	24	25	26
Feed rate (mm/rev)	0.31	0.32	0.32	0.33	0.35	0.36
Cutting velocity (m/min)	121	174	118	132	98	104
Confidence score (%)	64	70	71	67	82	75

Table : 8.12 : Extended data set for T25M insert grade machining stainless steels

In a similar manner to the previous test, the additional data terms were adjusted in line with equations 8-9 and the resulting points were plotted to see whether any enhancement to the correlation of the data was noticeable. The graph displaying this series of data terms is given in Figure 8.14. From consideration of Figure 8.14 it is evident that the additional data terms display erratic distribution with poor correlation. In light of this result it is suggested that the additional data terms made available through the use of confidence score based cutting data have not improved the consistency of the aggregate data set.

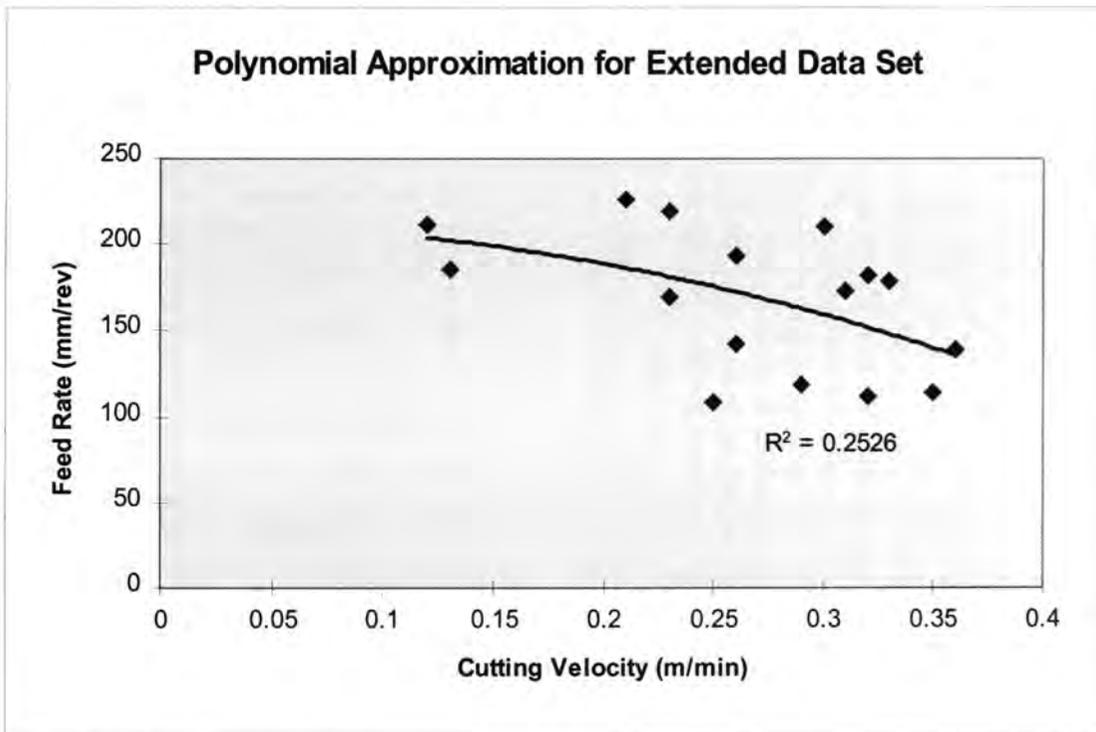


Figure 8.14 : Polynomial approximation for extended data set (2)

8.5.6.3 Summary of test results

The tests described in the previous sections have shown that it is possible to make a link between confidence scores and cutting parameter estimation. This means that if cutting parameters are required for an insert grade and material combination that do not exactly match a sufficient number of database records, it is possible to use cutting data from tool trials based on similar tests. A simple case of this method, as defined by equations 8-9, where only a two parameter search is carried out, has been shown to yield cutting data with a similar standard deviation to the initial data set based only on perfectly matching tool trial records.

Based upon these results it is suggested that the extended data set obtained from the consideration of confidence scores could be used in isolation from perfectly matching data. This would cause the likelihood of sufficient data not being available for any given combination of insert grade and workpiece material to be reduced. The extended data set would be subject to the same analysis as for the original data set as suggested by equations 8-5 through to 8-8, with the data now forming the set denoted $\{v_i', s_i'\}$, as defined by equations 8-9. It should be noted that in cases where the extended data set gives rise to poorly correlated relationships between cutting velocity and feed rate that the RMS error would result in a low weighting being given to the data from the tool trials database, in exactly the same manner as described previously.

In summary it can be seen that the extension of the data set to incorporate allowance for confidence scores generates additional data which has broadly similar variance to the original data set and can be processed using the same methodology. This has reduced the likelihood of the database being unable to identify sufficient records with which to perform the cutting data analysis. It may be possible to extend this result to those cases where the confidence scores are generated by a search with more than two parameters being specified. Such analysis would be likely to result in a more complex link between confidence score and cutting parameters than that suggested by equations 8-9. It would also be necessary for a larger database record set to be available for the testing of such relationships.

Chapter 9 : Conclusions and recommendations for further work

9.1 Discussion

A system which is capable of collating and disseminating information relating to tool trials amongst a variety of user groups has been developed. Further to this the system has demonstrated how cutting data enhancement techniques in reference to process planning activities can be effected by stringent assessment of trends within the database of tool trials. This system is called JadeT and has been successfully created using PowerJ 2.0 (for Windows). PowerJ is a Rapid Application Development (RAD) tool for the creation of Java based objects. The use of such a RAD tool has minimised the time taken to create the user interface courtesy of the 'drag-and-drop' component editor. The programmer is hence provided with additional time in which to carry out the more important matter of implementing the technical features by utilising RAD support for in-depth interaction with the source code. The final JadeT package has been wrapped in HTML code allowing distributed world-wide access through suitable Internet browsers.

In the context of tooling engineers the JadeT system has provided a platform from which it is possible to submit and retrieve highly specific technical tooling data. A combination of a sleekly designed user interface and behind-the-scenes data processing techniques based upon firm engineering principles has provided tooling engineers with a method for rapidly finding data of relevance to a given tooling problem.

The implication of a central database of tooling information having been created from approved sources led to research being carried out into the possibility of devising cutting data enhancement procedures. This particular avenue of the research led to the extension of JadeT and the development of a tool and cutting data selection system for both milling and turning operations. This work demonstrated not only the suitability of the Internet as a distributed computing resource, but more importantly it was possible to look at the ways in which approved data could be analysed and then applied to cutting data selection within the process planning arena.

A thorough review of published literature has been carried out which focuses on four main areas; process planning, tool selection, cutting data optimisation, and a brief review of relevant issues associated with the Internet. It has been seen that process planning has commanded the attention of significant research, although unfortunately much of this research is based upon the identification of solutions to isolated aspects of process planning tasks. This has resulted in the fragmentation of novel process planning ideas and a low uptake of the systems by the industrialists for whom they were designed.

The traditional role of the process planner saw tool and cutting data selection being carried out manually using a combination of the knowledge of the planner concerned with cutting parameters being sourced from tables of machinability data. In today's manufacturing environment the need is to ensure high utilisation of machining resources and cutting tool capability. When this need is assessed in light of the prolific range of tooling products and the dynamic machine tools that use them, the task of tool and cutting data selection is found to be critical and yet highly complex.

The subject of cutting data analysis and optimisation has been examined, and the systems dedicated to performing these tasks have been found to exhibit common weaknesses, viz.;

- The model is too complex and relies on data not readily available in a practical manufacturing environment.
- The model is too simple and considers few or no constraints leading to the risk of catastrophic failure during a machining operation.
- The model is too rigid and applies unimportant constraints to different classes of operations.

It has been shown that the majority of process planning systems which incorporate cutting data selection and optimisation procedures tend to congregate at either end of the parameter constraint spectrum. To compound this situation there is also the issue of whether a system bases its data evaluation on the application of algorithmic equations or alternatively using data retrieval methods. A balance needs to be struck between not only the complexity of the modelling process but the basis of the data sources which will be used as well.

The problem of declining industrial knowledge in the sphere of tooling has been identified and examined in detail in Chapter 3. With the tooling area becoming ever more complex with the passage of time, the ease with which industrial machinists can effectively utilise tooling products is decreasing. In recent years it has become the responsibility of the tooling manufacturers to provide technical support services to their customers. The role of specialist tooling engineers working for tooling manufacturers has been considered, and the concept of tool trials has been revealed. With the increasing demands for technical support, a tool which can aid the tooling engineer in performing this task would be of interest. The JadeT system was borne from this need, and it has been shown how a database was designed and implemented allowing the sharing of information at a national (and international) level. The centralised database was made accessible in a distributed manner courtesy of the Internet and tooling engineers were presented with an effective way to obtain data relating to similar previously conducted tests.

The JadeT interface for submitting a query to the tool trials database provides users with a multi-layered approach to database searches. The basic interface is intended for use in situations where the engineer concerned is familiar with the report to be retrieved. The advanced search engine provides the user with an interface for the specification of a highly technical query as well as the opportunity to indicate parameter importance when executing the search.

The advanced search engine incorporates a fully fledged confidence scoring system which allows individual reports to be assessed in terms of their closeness to the user's specifications. This confidence scoring ability is provided on two levels; namely with and without the application of parameter relaxation techniques. When parameter relaxation is not permitted, the records in the database have to exactly match the specification laid down by the user. Based upon the number of matching parameters and their importance values a confidence score can be assigned. In the case of parameter relaxation techniques being permitted, each data term specified by the user is examined in terms of its closeness to the required value based upon engineering considerations. Again, this assessment is used in conjunction with the importance indications to assign an overall confidence score and allow reports to be sorted in preparation for viewing by the user.

The earlier analysis relating to cutting data selection and optimisation is particularly relevant when considered in the context of the JadeT tool trials database. It has been shown how systems tend to be entirely algorithmic in terms of data processing or alternatively probabilistic for data retrieval systems. The reserve of approved data created during the first stage of the JadeT development gave rise to several opportunities for extended research.

Within the remit of this research it was decided that a publicly accessible area to the JadeT system would be designed. The aim of this system is to provide efficient tool selection techniques from a central product database whilst cutting data selection incorporates an assessment of cutting data within the tool trials database. If the tool trials database is found to contain well-behaved and relevant data, it is used to enhance the data obtained directly from the purely algorithmic approach to cutting data selection.

This cutting data analysis is based upon the application of multiple regression techniques to cutting velocity and feed rate dependencies for a particular combination of insert grade and workpiece material. Multiple regression adopting the least squares approximation is used to generate a second order polynomial for the relationship exhibited by the data from the tool trials database. In the event of a low Pearson product moment correlation coefficient, indicating good data conformance, the cutting velocity predicted algorithmically is modified to incorporate the trends indicated within the tool trials database data.

This approach is fully integrated into a tool and cutting data selection system for turning and milling products, and an analysis of the results achieved with this system has been given. This analysis demonstrates that there is a pleasing level of conformance within the tool trials data, resulting in the confident prediction of slightly more aggressive cutting parameters. In addition to the incorporation of tool trials data, the JadeT system demonstrates the effectiveness of adopting a centralised product database to provide industrial machinists with the most up to date product data. It is suggested that should the JadeT system be launched at a commercial level allowing a significant increase in database population, the true extent to which tool trials data can be used to enhance the more conservative data presented in catalogues could be evaluated.

9.2 Conclusions

Whilst the demand for product manufacture has seen no signs of abatement, the same cannot be said for the level of machining expertise found within British manufacturing organisations. This is not entirely reflective of those industrialists who are responsible for tooling matters so much as an indication that it is becoming more and more difficult to exhibit expertise among such a wide portfolio of tooling products and workpiece materials.

The area of tool and cutting data selection within the process planning field is becoming ever more important in affecting the overall utilisation of highly versatile machining centres. The scenario commonly found within engineering departments is that a high percentage of time is being dedicated to the process planning element of a product's manufacture. The importance for an industrial machinist to have up to date tooling information, including assistance for cutting data selection, has been identified.

It has been found that in a variety of situations there is a need for tooling manufacturers to provide industrial machinists with direct assistance in carrying out the tool and cutting data selection tasks. This is particularly true in situations where tooling has not been used successfully, and it is common for this type of support to be regarded by industrial machinists as an automatic entitlement upon initial purchase of the tooling products. The provision of such support, commonly referred to as *tool trials*, has resulted in a significant volume of technical information which is stored in a manner devoid of the possibility for dissemination or analysis.

The Internet has been identified as a medium which benefits from boasting the ability of allowing the world-wide distribution of information whilst permitting administration from a central location. Further to this the World Wide Web has been discussed with industrial machinists who have confirmed a definite interest in being able to receive technical support by utilising the distributed and yet technically precise methods supported by the Web. To date, the Web hosts little or no documents, based upon the principles of constructive hypertext, for the transmission of data pertaining to metal cutting tooling products. There is no support for performing tool selection and cutting data selection tasks directly on the Web.

In order to address these issues;

- A system has been developed allowing authorised users to submit and retrieve information relating to tool trials in a standardised format. The system incorporates security features suitable for it being made accessible on the World Wide Web.
- The electronic tool trial submission forms have created a standardised format for tool trial completion and the possibility of ensuring data integrity by analysing individual fields has been utilised.
- The tool trial retrieval utility is a multi-layered search engine developed specifically for the analysis and display of tool trial reports. Many aspects of the workpiece / insert interface can be specified for inclusion in the search, and parameters can be assigned an importance weighting directly by the user.
- The advanced query utility incorporates a technical assessment of confidence scores in order that reports can be organised into a folder in order of their closeness to the user's specifications. In addition to this a summary report can be seen for any individual search providing the user with details of the overall statistics identified within the results generated by the search.
- The confidence scoring system includes a facility for the application of parameter relaxation techniques. Rather than an individual search parameter being assessed on a 'go / no-go' basis, the parameter relaxation techniques allowed the closeness of the retrieved fields to be assessed in terms of their level of conformance with the fields as specified by the user in the search utility.
- A tool and cutting data selection system for turning and milling operations has been developed and deployed for use on the Internet. An intuitive visual interface allows sleek progress to be made in performing the intended tasks. The system provides a distributed process planning tool which operates from a centralised product database, ensuring the system administrators of simple database maintenance procedures.
- The process of data abstraction in relation to tool trials has been analysed in detail. Multiple regression techniques and data confidence assessment via consideration of the Pearson product moment correlation coefficient has been used in assessing the cutting data within the tool trials database. The application of these techniques has led to the successful integration of cutting data from the tool trials data into the JadeT cutting data selection utility which had originally presented only catalogue data.

The tasks which have been carried out during the course of this research have demonstrated novelty in the following areas;

- A multi-level confidence scoring system for tool trials has been developed which allows the assessment of confidence scores incorporating parameter relaxation techniques. These relaxation techniques are based upon engineering principles which allow the most relevant tool trial reports to be identified with ease.
- A tool and cutting data selection system has been developed, deployed and evaluated. The system is for turning and milling operations and allows the tool selection to take place based upon a central product database stored on the server. In addition to this, an interactive cutting data module has been developed allowing changes in cutting parameters to be evaluated in terms of the effect on overall process parameters. Such a system, which operates strictly from a server-side database, has not been encountered in the duration of this research.
- The mathematical principles of multiple regression techniques and evaluation of local errors based upon application and interpretation of the Pearson product moment correlation coefficient have allowed cutting data from the tool trials database to be integrated into the cutting data selection module within the tool selection utility. This part of JadeT presents a system capable of performing 'live' numerical analysis calculations and combining approved data with catalogue data to present the user with the most up to date assessment of the cutting velocity to be used for the specific operation.

9.3 Recommendations for further work

Seco Tools (UK) Ltd. have already been identified as the industrial collaborators associated with this research. With bilateral considerations in the areas of industry and academia the recommendations for further work will be duly carried out in two distinct sections.

9.3.1 Recommendations for further industrial evaluation

All the software described herein has been developed and deployed in the manner indicated within the thesis. Whilst the functionality of the system has been a relatively simple task in terms of testing, the application of JadeT in providing a full business solution would be a matter requiring further attention. In assessing the likely number of users of the different areas of the system it would be possible to specify the network and data processing resources needed to support its operation.

It has been shown that the product database used for the tool and cutting data selection system has been obtained from analysis of the tooling database of a third party organisation, namely Datos. In this situation an SQL file is used to create a new smaller version of the database suitable for operation in a Web environment. Instead of adopting this configuration it is suggested that JadeT could eventually be used in parallel with a central product database operated by Seco Tools. This would provide industrial machinists not only with the current tooling product range but would open up the possibilities of monitoring product availability information as well.

The tool trials database search engines and processing algorithms are the thin end of the wedge of the technologies referred to as data warehousing and datamining techniques. These methodologies are designed to allow the identification of knowledge from extensive databases of information in an attempt to discover previously unseen relationships within the data. The enhancement and furtherance of the JadeT search engines to incorporate such methods could provide information allowing the specification of cutting data with a greater degree of confidence.

The turning tool and cutting data selection utility provides users with no support for the evaluation of cutting parameters associated with aluminium alloys or relatively new materials referred to as super-alloys. With the recent expansion in the volume of manufacturing industries having a need for machining such materials it is suggested that the range of materials offered within the system should be expanded. The milling utility provides limited coverage of these materials with the identification of aluminium and super-alloy groups, although no sub-groups have been included. The application of

datamining techniques on this particular area would be beneficial in establishing whether the relationships seen in the standard PMK range extends to these new material groups.

9.3.2 Recommendations for further research

It is likely that a number of the points raised in the previous section could be appropriate for inclusion in this section as well. A point of particular note concerns the assessment of aluminium alloys and the super alloys. In traditional manufacturing environments such materials were limited to the aerospace and medical industries. This situation is rapidly changing and such materials are now commonplace in food processing industries, automotive industries as well as other general mechanical engineering areas. It is suggested that these materials merit further investigation in terms of the way in which they can be assessed relative to the traditional ranges of materials. It is not necessarily the case that such materials will obey the machinability and mechanical property trends discussed during the course of this thesis.

Other research [Maropoulos (1995)] has given precise indications of the way in which a database of approved data can be used in assisting the specification of operations which are due to be performed. It is suggested that further investigation of these similarity assessment procedures could be used in conjunction with an analysis of the data fields within the tool trials database to add a further level to the assessment of tool trials confidence scoring. The existing system makes little attempt to identify geometric similarity and this was attributable to the lack of real data with which to populate such a database. Despite this, it is an area suitable for investigation and may lead to the evolution of a confidence assessor based upon both the tool and workpiece interface as well as the geometric similarity between tests.

The JadeT system has a database with a population far less than would be expected in a situation where it was operating on an industrial level. However, the database population has been sufficient to allow the testing and evaluation of the ideas presented in this thesis. To perform a more thorough analysis of JadeT's confidence assessor and data submission constraints it is suggested that a diagnostic trial period should be

entered. This would allow both active submission constraints to be evaluated and the efficiency which is being achieved by the confidence assessor.

This research has shown the development and deployment of a system which can collate technical tooling data and use it in a verbatim manner such as tool trials. It has also been shown how the data can be analysed and used to enhance cutting parameters obtained from catalogue recommendations. More work is required in analysing such reserves of technical information, and perhaps when more precise trends can be found the industrial machinist will once again be able to select cutting data with confidence and ease.

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Appendix A

SIC codes

Table A.1 lists all those SIC groups which were sampled during the survey of manufacturing industry.

SIC80 Code	Description of Industrial Classification
3137	Bolts, nuts, washers, rivets, springs and non-precision chains
3161	Hand tools and implements
3205	Boilers and process plant fabricators
3211	Agricultural machinery
3212	Wheeled tractors
3221	Metal-working machine tools
3222	Engineers' small tools
3244	Food drink and tobacco processing machinery; packaging and bottling machinery
3245	Chemical industry machinery; furnaces and kilns; gas, water and waste treatment plant
3251	Mining machinery
3254	Construction and earth moving equipment
3255	Mechanical lifting and handling equipment
3261	Precision chains and other mechanical power transmission equipment
3262	Ball, needle and roller bearings
3275	Machinery for working wood, rubber, plastics, leather and making paper, glass, bricks and similar materials; laundry and dry cleaning machinery
3276	Printing, bookbinding and paper good machinery
3281	Internal combustion engines (except for road vehicles, wheeled tractors and aircraft) and other prime movers
3283	Compressors and fluid power equipment
3285	Scales, weighing machinery and portable power tools
3287	Pumps
3288	Industrial valves
3290	Ordnance, small arms and ammunition
3510	Motor vehicles and their engines
3521	Motor vehicle bodies
3522	Trailers and semi-trailers
3523	Caravans
3530	Motor vehicle parts
3610	Shipbuilding and repairing
3620	Railway and tramway vehicles
3633	Motor cycles and parts
3634	Pedal cycles and parts
3640	Aerospace equipment manufacturing and repairing
3710	Measuring, checking and precision instruments and apparatus
3720	Medical and surgical equipment and orthopaedic appliances

Table A.1 : SIC groupings in manufacturing industry survey

Appendix B

Industrial questionnaire

This Appendix contains a copy of the questionnaire that was used to survey manufacturing industry via the mail shot and industrial visits.

1. General Company Details:

Name of company	
Address of company	
Telephone number	
Fax number	
Name of contact	
Position of contact	
Tel. No. / ext. of contact	
Interview date and time	
SIC code of company	

Main business activity	
Total number of employees	
Workforce -	
Machine operators	
Part programmers	
Stores personnel	
Tool presetters	
Tool purchasers	
Process planners	
Equipment on shop floor -	
Lathes	
Milling machines	
Drilling machines	
Other	
Factory layout	Large projects / Jobbing / Batch / FMS / GT / Transfer
Variety of products	Low Medium High
Volume of products	Low Medium High

2. Tooling Performance Requirements:

1. What is the typical length of your planning period?

--

2. How variable is the **content** of your machining work per period?

Totally unpred.	1	2	3	4	5	Highly predic.
Totally unpred.	1	2	3	4	5	Highly predic.
Very short	1	2	3	4	5	Very long

3. How variable is the **volume** of your machining work per period?

4. How long is the planning horizon for machining jobs?

5. What variety of materials do you have to machine?

Very low	1	2	3	4	5	Very high
None	1	2	3	4	5	Very many

6. Do you have any material machinability problems?

7. How much time do you spend on selecting tools?

Very short	1	2	3	4	5	Very long
None	1	2	3	4	5	Very many

8. Do you have any problems when selecting tools?

9. How much time do you spend on calculating cutting conditions?

Very short	1	2	3	4	5	Very long
None	1	2	3	4	5	Very many

10. Do you have any problems when selecting cutting conditions?

11. How important is tool life?

Unimportant	1	2	3	4	5	Very imp.
No, never	1	2	3	4	5	Yes, always

12. Can you predict tool life accurately?

13. How important is the material removal rate?

Unimportant	1	2	3	4	5	Very imp.
Unimportant	1	2	3	4	5	Very imp.
Unimportant	1	2	3	4	5	Very imp.

14. How important is set-up time reduction?

15. How important is tool variety reduction?

16. Are there opportunities for tool-holder rationalisation?

No, none	1	2	3	4	5	Yes, many
No, none	1	2	3	4	5	Yes, many

17. Are there opportunities for insert rationalisation?

18. To what extent can one tool manufacturer satisfy your tooling performance needs?

Not at all	1	2	3	4	5	Yes, 100%
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19. For each of the following categories of machining please indicate the performance of the major tooling suppliers (1 = Best, 4 = Worst)

	Seco	Sandvik	Iscar	Kenna
Turning				
Milling				
Drilling				
Threading				
Spindle Tooling				

3. Technical Support Requirements:

1. How frequently do you have technical queries?

Very freq.	1	2	3	4	5	Very infreq.
Highly variable	1	2	3	4	5	Not at all variable

2. How variable are your technical queries?

3. Please indicate the **importance (X)** of each of the following in tool selection.

(1 = No importance, 5 = Very important)

Tool catalogues & technical guides	1	2	3	4	5
Sales engineers	1	2	3	4	5
Telephone technical support	1	2	3	4	5
Software systems (CAD/CAM)	1	2	3	4	5
Employee experience	1	2	3	4	5

4. Please indicate the **effectiveness (O)** of each of the following in tool selection.

(1 = Very ineffective, 5 = Very effective)

5. Please indicate the **importance (X)** of each of the following in selecting cutting conditions.

(1 = No importance, 5 = Very important)

Tool catalogues & technical guides	1	2	3	4	5
Sales engineers	1	2	3	4	5
Telephone technical support	1	2	3	4	5
Software systems (CAD/CAM)	1	2	3	4	5
Employee experience	1	2	3	4	5

6. Please indicate the **effectiveness (O)** of each of the following in selecting cutting conditions.

(1 = Very ineffective, 5 = Very effective)

7. Please indicate the **importance (X)** of each of the following in predicting tool life.

(1 = No importance, 5 = Very important)

Tool catalogues & technical guides	1	2	3	4	5
Sales engineers	1	2	3	4	5
Telephone technical support	1	2	3	4	5
Software systems (CAD/CAM)	1	2	3	4	5
Employee experience	1	2	3	4	5

8. Please indicate the **effectiveness (O)** of each of the following in predicting tool life.

(1 = Very ineffective, 5 = Very effective)

9. Please indicate the **importance (X)** of each of the following when introducing new materials.

(1 = No importance, 5 = Very important)

Tool catalogues & technical guides	1	2	3	4	5
Sales engineers	1	2	3	4	5
Telephone technical support	1	2	3	4	5
Software systems (CAD/CAM)	1	2	3	4	5
Employee experience	1	2	3	4	5

10. Please indicate the **effectiveness (O)** of each of the following when introducing new materials.

(1 = Very ineffective, 5 = Very effective)

11. Please indicate the **importance (X)** of each of the following when tooling up a new machine tool.

(1 = No importance, 5 = Very important)

Reputation of tooling supplier	1	2	3	4	5
Experience with tooling supplier	1	2	3	4	5
Recommendation of MC supplier	1	2	3	4	5
Cost of tooling	1	2	3	4	5
Sales engineers	1	2	3	4	5

12. When tooling up a new machine tool, what is the preferred method for specifying the tooling?

MC builder spec. turnkey package	
Company specified turnkey package	
MC supplied without tooling - i.e. 'tooled-up' post delivery	

13. Would you like tool suppliers / manufacturers to take full responsibility for tooling up your machines?

No	1	2	3	4	5	Yes
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14. Please indicate the **importance (X)** of each of the following when tools are made obsolete.

(1 = No importance, 5 = Very important)

Tool catalogues & technical guides	1	2	3	4	5
Sales engineers	1	2	3	4	5
Telephone technical support	1	2	3	4	5
Software systems (CAD/CAM)	1	2	3	4	5
Employee experience	1	2	3	4	5

15. Please indicate the **effectiveness (O)** of each of the following when tools are made obsolete.

(1 = Very ineffective, 5 = Very effective)

16. In the future it may be possible to attend a variety of training courses organised by tooling suppliers. A list of the topics which could be covered is given - please indicate the interest that your company may have in attending each of these courses.

(1 = No interest, 5 = Significant interest)

Tool coding systems	1	2	3	4	5
Selection of cutting tools	1	2	3	4	5
Machinability assessment	1	2	3	4	5
Selection of cutting conditions	1	2	3	4	5
Operations planning	1	2	3	4	5
Tool life control	1	2	3	4	5
Advanced machining methods	1	2	3	4	5
New tool materials	1	2	3	4	5
Improving tool set-up times	1	2	3	4	5
NC programming	1	2	3	4	5

4. Logistics Requirements:

1. How important is tooling delivery?

Unimportant	1	2	3	4	5	Very imp.
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2. What variety of tooling do you use?

Very low	1	2	3	4	5	Very high
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3. How difficult is it for you to keep control of your overall inventory of tools?

Highly complex	1	2	3	4	5	Very simple
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4. How important is tool requirement planning?

Unimportant	1	2	3	4	5	Very imp.
-------------	---	---	---	---	---	-----------

5. Can you predict accurately your tooling requirements?

No, never	1	2	3	4	5	Yes, always
-----------	---	---	---	---	---	-------------

6. Do you have a need for a tool management system?

No, never	1	2	3	4	5	Yes, always
-----------	---	---	---	---	---	-------------

7. How many problems do you have when trying to monitor the location of tools in the following situations?
(1 = None, 5 = Very many)

On the shop floor	1	2	3	4	5
In the tool stores	1	2	3	4	5

8. Please rate the importance of each of the methods for ordering tools?
(1 = No importance, 5 = Very important)

Telephone	1	2	3	4	5
Fax	1	2	3	4	5
Mail	1	2	3	4	5
Electronic mail	1	2	3	4	5

9. How much interest would you have in giving tool suppliers the responsibility for tool ordering?

Very low	1	2	3	4	5	Very high
----------	---	---	---	---	---	-----------

10. There are a number of ways in which obsolescence may affect your company. A list of them is given - please rate the importance of each of the possible effects.
(1 = No importance, 5 = Very important)

Difficult to find alternative	1	2	3	4	5
Need to work out new cutting cond.	1	2	3	4	5
Have to change NC programs	1	2	3	4	5
Unclear benefits	1	2	3	4	5
Data handling / ordering systems	1	2	3	4	5
Additional cost of tooling	1	2	3	4	5
Additional tooling inventory	1	2	3	4	5
Need to trust tool supplier	1	2	3	4	5

11. How many tooling vendors do you use to satisfy your tooling requirements?

1	2	3	4	5	6	7
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12. There are a number of reasons why you may choose to use multiple vendors. A list of these is given below - please indicate the importance of each of them.

(1 = No importance, 5 = Very important)

Variety unavailable from only one supplier	1	2	3	4	5
To minimise the cost of tooling	1	2	3	4	5
Inadvertent - poor internal comms	1	2	3	4	5
To use best tooling in each machining category (turn, mill etc)	1	2	3	4	5

13. How important is it for you to be able to obtain special tooling from tool suppliers?

Unimportant	1	2	3	4	5	Very imp.
-------------	---	---	---	---	---	-----------

14. What is an acceptable delivery time for special tooling?

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15. How important is it for tooling suppliers to keep this delivery time?

Unimportant	1	2	3	4	5	Very imp.
-------------	---	---	---	---	---	-----------

16. With what frequency do tooling suppliers supply special tooling that functions as required and on time?

Never	1	2	3	4	5	Always
-------	---	---	---	---	---	--------

17. During the course of time, tooling suppliers are introducing improved products into their product range -

a) How well informed are you of these new products?

Not at all	1	2	3	4	5	Well informed
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b) How much time do you spend on considering these new tools?

None	1	2	3	4	5	A lot
------	---	---	---	---	---	-------

c) How difficult would it be for you to change to these new tools?

Very simple	1	2	3	4	5	Very complex
-------------	---	---	---	---	---	--------------

d) How important are tool trials when considering new tools?

Unimportant	1	2	3	4	5	Very imp.
-------------	---	---	---	---	---	-----------

18. How easy is it for you to identify obsolete tools?

Very complex	1	2	3	4	5	Very simple
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Appendix C

Summary of response to industrial questionnaire

Table C.1 summarises the volume of companies that were surveyed as part of the review of manufacturing industry.

Mail-shot 1 : Tooling Performance Requirements				Total number of questionnaires sent :	208
				Number returned by Royal Mail :	13
				Number of questionnaires received by companies :	195
				Number of questionnaires returned completed:	26
				Percentage return rate :	13.33
Mail-shot 2 : Technical Support Requirements				Total number of questionnaires sent :	209
				Number returned by Royal Mail :	18
				Number of questionnaires received by companies :	191
				Number of questionnaires returned completed:	24
				Percentage return rate :	12.57
Mail-shot 3 : Logistics Requirements				Total number of questionnaires sent :	203
				Number returned by Royal Mail :	16
				Number of questionnaires received by companies :	187
				Number of questionnaires returned completed:	30
				Percentage return rate :	16.04
Overall Mail-shot Results				Total number of questionnaires sent :	620
				Number returned by Royal Mail :	47
				Number of questionnaires received by companies :	573
				Number of questionnaires returned completed:	81
				Percentage return rate :	14.14
INDUSTRIAL VISITS :					
North East Region				Visits Completed	9
Midlands Region				Visits Completed	23
Overall				Visits Completed	32
OVERALL RESULTS OF SURVEY :				Tooling performance requirements	58
				Technical support requirements	56
				Logistical requirements	62

Table C.1 : Summary of response volumes from industrial survey

Appendix D

Tables of results from industrial survey

This Appendix presents the aggregate results which were obtained in respect of the three sections of the survey of manufacturing industry. The questions numbers referred to in Tables D.1, D.2 and D.3 correspond directly with those presented in Appendix B.

Question No.	Sample Size	Total	Average	Rating
2	49	157	3.2	-
3	49	157	3.2	-
4	48	122	2.54	-
5	50	161	3.22	-
6	50	124	2.48	-
7	49	116	2.37	-
8	49	97	1.98	-
9	50	97	1.94	-
10	50	101	2.02	-
11	49	201	4.1	-
12	49	141	2.88	-
13	50	192	3.84	-
14	50	215	4.3	-
15	50	192	3.84	-
16	50	134	2.68	-
17	50	142	2.84	-
18	48	121	2.52	-
Turning(Se,Sa,I,K)	24,33,19,21	42,46,45,41	1.75,1.39,2.37,1.95	Sa,Se,K,I
Milling(Se,Sa,I,K)	21,28,21,20	42,43,40,47	2.00,1.54,1.90,2.35	Sa,I,Se,K
Drilling(Se,Sa,I,K)	18,21,12,22	34,34,23,39	1.89,1.62,1.92,1.77	Sa,K,Se,I
Threading(Se,Sa,I,K)	20,23,11,15	35,33,23,29	1.75,1.43,2.09,1.93	Sa,Se,K,I
Spindle Tooling(Se,Sa,I,K)	11,16,10,22	25,22,30,32	2.27,1.38,3.00,1.45	Sa,K,Se,I

Table D.1 : Results for tooling performance requirements

Question nineteen was used to establish the rankings of the four major carbide tooling manufacturers, namely, Kennametal Hertel (K), Iscar (I), Sandvik Coromant (Sa) and Seco (Se). These companies were rated for the five major areas of tooling; turning, milling, drilling, threading and spindle tooling. The additional column labelled 'Rating' applies to question nineteen only and ranks the tooling manufacturers for each of these categories of machining, with the best manufacturer appearing first in the list.

Question Number / Details	No.	Tot.	Ave.	Question Number / Details	No.	Tot.	Ave.
1 Query Frequency	47	147	3.13	9 Software Systems	36	77	2.14
2 Query Variability	47	123	2.62	9 Employee Experience	37	134	3.62
3 Tool Catalogues	47	178	3.79	10 Tool Catalogues	37	112	3.03
3 Sales Engineers	47	161	3.43	10 Sales Engineers	37	136	3.68
3 Telephone Tech. Support	47	144	3.06	10 Telephone Support	37	104	2.81
3 Software Systems	45	105	2.33	10 Software Systems	36	72	2.00
3 Employee Experience	47	201	4.28	10 Employee Experience	37	133	3.59
4 Tool Catalogues	47	172	3.66	11 Reputation	45	186	4.13
4 Sales Engineers	47	170	3.62	11 Experience	45	200	4.44
4 Telephone Tech. Support	47	144	3.06	11 Recommendation	44	125	2.84
4 Software Systems	45	106	2.36	11 Cost	45	160	3.56
4 Employee Experience	47	201	4.28	11 Sales Engineers	45	134	2.98
5 Tool Catalogues	46	151	3.28	12 (1/2/3)	46	8/25/18	
5 Sales Engineers	46	158	3.43	13 Resp. for 'Tooling-up'	43	91	2.12
5 Telephone Tech. Support	46	116	2.52	14 Tool Catalogues	43	141	3.28
5 Software Systems	44	94	2.14	14 Sales Engineers	44	168	3.82
5 Employee Experience	45	192	4.27	14 Telephone Support	43	116	2.70
6 Tool Catalogues	46	151	3.28	14 Software Systems	42	78	1.86
6 Sales Engineers	46	159	3.46	14 Employee Experience	42	132	3.14
6 Telephone Tech. Support	46	116	2.52	15 Tool Catalogues	43	130	3.02
6 Software Systems	44	93	2.11	15 Sales Engineers	44	165	3.75
6 Employee Experience	45	190	4.22	15 Telephone Support	43	115	2.67
7 Tool Catalogues	44	114	2.59	15 Software Systems	42	74	1.76
7 Sales Engineers	44	123	2.80	15 Employee Experience	42	132	3.14
7 Telephone Tech. Support	44	95	2.16	16 Tool Coding Systems	43	117	2.72
7 Software Systems	43	90	2.09	16 Tool Selection	44	149	3.39
7 Employee Experience	45	180	4.00	16 Machinability Ass.	45	148	3.29
8 Tool Catalogues	44	111	2.52	16 Cutting Cond. Sel'n	45	152	3.38
8 Sales Engineers	44	126	2.86	16 Operations Planning	44	126	2.86
8 Telephone Tech. Support	44	94	2.14	16 Tool Life Control	43	142	3.30
8 Software Systems	43	91	2.12	16 Adv. Machining Meth.	46	172	3.74
8 Employee Experience	44	177	4.02	16 New Tool Materials	44	158	3.59
9 Tool Catalogues	37	117	3.16	16 Improving Setup Times	46	166	3.61
9 Sales Engineers	37	137	3.70	16 NC Programming	45	126	2.80
9 Telephone Tech. Support	37	104	2.81				

Table D.2 : Results for technical support requirements

Question No.	Sample	Total	Average	Question No.	Sample	Total	Average
1	53	239	4.51	10 Cost	49	162	3.31
2	53	189	3.57	10 Inventory	49	144	2.94
3	53	160	3.02	10 Trust	49	180	3.67
4	53	191	3.60	11	53	249	4.70
5	53	184	3.47	12 Variety Unavailable	51	196	3.84
6	53	186	3.51	12 Minimise Cost	51	185	3.63
7(i)	53	147	2.77	12 Inadvertent	50	76	1.52
7(ii)	49	89	1.82	12 To Use Best Tooling	51	212	4.16
8(i)	53	224	4.23	13	53	218	4.11
8(ii)	53	208	3.92	14	44	163 Wks.	3.70 Wks.
8(iii)	53	142	2.68	15	49	239	4.88
8(iv)	51	65	1.27	16	48	156	3.25
9	52	122	2.35	17a	52	208	4.00
10 Alternative	49	122	2.49	17b	52	152	2.92
10 Cutting Conditions	49	110	2.24	17c	52	142	2.73
10 NC Programs	49	105	2.14	17d	52	221	4.25
10 Unclear Benefits	48	130	2.71	18	48	156	3.25
10 Data Handling	49	100	2.04				

Table D.3 : Results for logistics requirements

Appendix E

Coded fields in the tool trials database

A number of fields in the tool trials database have been referred to as coded fields. This term means that a numerical code has been used to represent a specific choice made by the user from a list of options. For example, during the tool trial submission process the user is requested to define whether the tool trial is for a milling operation or a turning operation. This decision has been stored using a coded field named *TypeOfOperationCode* - if the user selects turning this field will be assigned a value of '0', and if milling is specified the value for this field will be '1'.

This Appendix contains a listing of the fields which are coded fields. For each coded field a table will be provided listing the range of integer values and their associated definition. Further to this concept it should be noted that some of the coded fields have different meaning for the same integer value according to whether the operation defined by that record is a turning or milling operation. This will be made clear in the tables concerned.

Field Name	OperationCode
Operation	Turning
Table	General
0	Not specified
1	Finishing
2	Roughing
3	External
4	Internal
5	Facing
6	External copying
7	Internal copying
8	External threading
9	Internal threading
10	External grooving
11	Internal grooving
12	External MDT
13	Internal MDT
14	Axial MDT

Table E.1 : OperationCode for turning

Field Name	OperationCode
Operation	Milling
Table	General
0	Not specified
1	Face milling
2	Square shoulder milling
3	Slot milling
4	Drilling end milling
5	End milling
6	Helical milling
7	Copy milling
8	Chamfer milling
9	Minimaster

Table E.2 : OperationCode for milling

Field Name	ConditionCode
Operation	Turning & Milling
Table	General
0	Not specified
1	Good
2	Average
3	Poor

Table E.3 : ConditionCode explanation

Field Name	IntCutCode
Operation	Turning Only
Table	General
0	Not specified
1	Interrupted
2	Continuous

Table E.4 : IntCutCode explanation

Field Name	Clamping Code
Operation	Turning Only
Table	General
0	Not specified
1	Chuck
2	Fixture

Table E.5 : ClampingCode explanation

Field Name	CoolantCode
Operation	Turning & Milling
Table	General
0	Not specified
1	Flood
2	Dry

Table E.6 : CoolantCode explanation

Field Name	HeatTreatmentCode
Operation	Turning & Milling
Table	General
0	Not specified
1	None
2	Stress relieved
3	Through hardened
4	Hardened & tempered
5	Surface hardened

Table E.7 : HeatTreatmentCode explanation

Field Name	SurfaceConditionCode
Operation	Turning & Milling
Table	General
0	Not specified
1	Pre-machined
2	Forge skin / hot rolled
3	Cold rolled or drawn
4	Mill scale
5	Casting skin
6	Difficult casting skin
7	Casting skin with sand inclusions

Table E.8 : SurfaceConditionCode explanation

Field Name	TypeOfOperationCode
Operation	N.A.
Table	General
0	Turning
1	Milling

Table E.9 : TypeOfOperationCode explanation

Field Name	ChipFormCode
Operation	Turning & Milling
Table	Test Data
0	Not specified
1	Short
2	Medium
3	Long

Table E.10 : ChipFormCode explanation

Field Name	WearCode
Operation	Turning & Milling
Table	Test Data
0	Not specified
1	Flank wear
2	Notching
3	Crater wear
4	Cratering
5	Deformation
6	Built up edge
7	Fracture
8	Chipping

Field Name	WearCode (continued)
Operation	Turning & Milling
Table	Test Data
9	Thermal cracking
10	Chiphammering
11	Breakdown of insert
12	Edge of insert breaks down
13	Breakdown due to chiphammering
14	Adhesive wear
15	Coating comes off the insert
16	Cracks right angled to cutting edge
17	Cracks parallel to cutting edge

Table E.11 : WearCode explanation

Field Name	IndexingCode
Operation	Turning & Milling
Table	Test Data
0	Not specified
1	Poor surface finish
2	Out of tolerance
3	Increased workpiece temperature
4	Edge breakdown
5	Edge chipping
6	Built up edge
7	Deformation
8	Flank wear
9	Crater wear
10	Vibrations

Table E.12 : IndexingCode explanation

Appendix F

Secontest tool trial forms

This Appendix contains blank versions of the Secontest tool trial forms from which the tool trials database was populated.

SECONTEST

TURNING

OPERATION	External	<input type="text"/>	Internal	<input type="text"/>
	Facing	<input type="text"/>	Copying	<input type="text"/>
		<input type="text"/>		<input type="text"/>
Existing Tooling Supplier				
Test Objectives				

Company	<input type="text"/>	Report No	<input type="text"/>
Dept	<input type="text"/>	Date	<input type="text"/>
Contact	<input type="text"/>	Issued by	<input type="text"/>
Machine	<input type="text"/>	Component	<input type="text"/>
Power	<input type="text"/>	Part No	<input type="text"/>
Condition	Good / Av / Poor	Material	<input type="text"/>
Coolant	Yes / No	Hardness	<input type="text"/>
Limitations	<input type="text"/>	Seco Grp No	<input type="text"/>
	<input type="text"/>	Batch/Annual Qty	<input type="text"/>

Test No	Tool No	RPM n	Cutting Speed V_c m/min	Feed f mm	Depth of Cut a_p mm	Length of Cut a_p mm	Chip Form	Flank Wear V_b	No of Pieces	Time Total/ min/pc	Remarks	Reason for ending test:
	Insert											
Exstg Data	T											Objectives achieved
	I											Poor surface finish
1	T											Out of tolerance
	I											Edge breakdown
2	T											Edge chipping
	I											Built up edge
												Deformation
												Flank wear
												Crater Wear
												End of Batch

Costings and Customer Benefits		Test result versus existing tooling		Improvement in tool life	
	Existing	Seco		_____ %	
Cost per insert			Better than	_____ %	Tool cost savings
Cost per edge			Equal to	_____ %	Productivity improvements
No compts/edge			Worse than	_____ %	Cost reduction per component
Cost per compt				_____ %	

SECONTEST

MILLING

OPERATION

Copy Milling Face Milling
 Chamfering Sq Shoulder
 Profiling

Slot End

Disc Mill

Existing Tooling Supplier:

Test Objectives:

Company		Report No	
Dept		Date	
Contact		Issued by	
Machine		Component	
Power		Part No	
Condition	Good / Av / Poor	Material	
Coolant	Flood / Dry	Hardness	
Limitations		Seco Grp No	
		Batch Quantity	

Test No	Cutter No		RPM n	Cutting Speed V _c m/min	Feed			Depth of Cut			Length of cut mm	No of Passes	Total Time/ mins/pc	Remarks	Reason for ending test:
	Inserts	/qty			Speed	Per Tooth	Axial	Radial							
	Wiper/s	/qty			mm/min	f _z mm	a _p mm	a _r mm							
Exstg Data	C														
	I	/													
	W	/													
1	C														
	I	/													
	W	/													
2	C														
	I	/													
	W	/													

Costings and Customer Benefits

	Existing	Seco				
Cost per insert			Test result versus existing tooling	Better than <input type="checkbox"/>	_____ %	Improvement in tool life
Cost per set					_____ %	Tool cost savings
Cost per index (1 set)					_____ %	Productivity improvements
No of compts per index (1 set)					_____ %	Cost reduction per component
Cost per component						

Test result versus existing tooling

Better than

Equal to

Worse than

_____ %

Improvement in tool life

_____ %

Tool cost savings

_____ %

Productivity improvements

_____ %

Cost reduction per component

Appendix G

Structure of the Seco tool trials database

As noted in the main body of this thesis, in order to create a populated tool trials database it was necessary to design an instance of the database based upon the Secontest tool trial forms made available by Seco Tools.

This Appendix contains details of the general and test data tables within the database and in particular the fields that were used within those tables. All of the coded fields will be defined directly after the details of the table structure have been presented.

Field No	Field Name	Type	Description
1	ReportNumber	Integer	Primary Key
2	OldReportNumber	Text	Paper based report number
3	CompanyName	Text	Company featured in report
4	Department	Text	Department within the company
5	Contact	Text	Contact within the company
6	IssuedBy	Text	Engineer who did the tool trial
7	DateOfTest	Text	Date when test was carried out
8	DateOfSubmission	Date	Date of submission to database
9	MachineTool	Text	Name of machine tool
10	Power	Text	Power of the machine tool
11	ConditionCode	Integer	Code to represent M/C condition
12	TestObjectives	Text	Objectives of the tool trial
13	Limitations	Text	Limitations of the M/C tool
14	ExistingSupplier	Text	Existing tooling supplier
15	Component	Text	Name of the component
16	PartNumber	Text	Part number of the component
17	Material	Text	Component material
18	Hardness	Integer	Component hardness (BHN)
19	SecoGpNo	Integer	Seco material group number
20	TestEndOneCode	Integer	Primary test end reason code
21	TestEndTwoCode	Integer	Secondary test end reason code
22	OperationCode	Integer	Operation type
23	ResultCode	Integer	Code for test result
24	ToolLifeImprovement	Float	% tool life improvement (max)
25	ToolCostSavings	Float	% tool cost savings (max)
26	ProductivityImprovement	Float	% productivity improvement (max)
27	CostReduction	Float	% cost reduction (max)
28	ExistingCostOne	Float	Existing cost per insert
29	SecoCostOne	Float	Seco cost per insert
30	ExistingCostTwo	Float	Existing cost per edge (T) or per set (M)

continued/..

Field No	Field Name	Type	Description
31	SecoCostTwo	Float	Seco cost per edge (T) or per set (M)
32	ExistingCostThree	Float	Existing comps per edge (T) or cost per index (M)
33	SecoCostThree	Float	Seco comps per edge (T) or cost per index (M)
34	ExistingCostFour	Float	Existing cost / comp (T) or comps per index (M)
35	SecoCostFour	Float	Seco cost / comp (T) or comps per index (M)
36	ExistingCostFive	Float	Existing cost per component (M) Null for (T)
37	SecoCostFive	Float	Seco cost per component (M) Null for (T)
38	TypeOfOperationCode	Integer	Code to define operation type
39	CoolantCode	Integer	Code to specify presence or absence of coolant
40	BatchSize	Integer	Batch size for the component

Table G.1 : Structure of general table for Secontest forms

Field No	Field Name	Type	Description
1	ReportNumber	Integer	Foreign Key (1)
2	TestNumber	Integer	Foreign Key (2)
3	Cutter	Text	Cutter used in the test
4	InsertNo	Text	Insert used in the test
5	Wiper	Text	Wiper insert (automatically null for turning)
6	DataMemberOne	Float	RPM (T&M)
7	DataMemberTwo	Float	Cutting speed (T&M)
8	DataMemberThree	Float	Feed per rev (T&M)
9	DataMemberFour	Float	Depth of cut (T) Feed per tooth (M)
10	DataMemberFive	Float	Length of cut (T) Axial depth of cut (M)
11	DataMemberSix	Float	Chip form (T) Radial depth of cut (M)
12	DataMemberSeven	Float	Flank wear (T) Length of cut (M)
13	DataMemberEight	Float	No of pieces (T&M)
14	DataMemberNine	Float	Total time (T&M)
15	Remarks	Text	Remarks on the test

Table G.2 : Structure of test data table for Secontest forms

Field Name	ConditionCode
Operation	Turning & Milling
Table	General
0	Not specified
1	Good
2	Average
3	Poor

Table G.3 : ConditionCode explanation

Field Name	CoolantCode
Operation	Turning & Milling
Table	General
0	Not specified
1	Flood
2	Dry

Table G.4 : CoolantCode explanation

Field Name	ResultCode
Operation	Turning & Milling
Table	General
0	Not specified
1	Better than
2	Equal to
3	Worse than

Table G.5 : ResultCode explanation

Field Name	TypeOfOperationCode
Operation	Turning & Milling
Table	General
0	Turning
1	Milling

Table G.6 : TypeOfOperationCode explanation

Field Name	TestEndOneCode
Operation	Turning
Table	General
0	Not specified
1	Objectives achieved
2	Poor surface finish
3	Out of tolerance
4	Edge breakdown
5	Edge chipping
6	Built up edge
7	Deformation
8	Flank wear
9	Crater wear
10	End of batch

Table G.7 : TestEndOneCode for turning

Field Name	TestEndOneCode
Operation	Milling
Table	General
0	Not specified
1	Objectives achieved
2	Poor surface finish
3	Out of tolerance
4	Chipping
5	Chip welding
6	Flank wear
7	Insufficient power
8	Unstable set-up
9	End of batch

Table G.8 : TestEndOneCode for milling

Field Name	TestEndTwoCode
Operation	Turning
Table	General
0	Not specified
1	Objectives achieved
2	Poor surface finish
3	Out of tolerance
4	Edge breakdown
5	Edge chipping
6	Built up edge
7	Deformation
8	Flank wear
9	Crater wear
10	End of batch

Table G.9 : TestEndTwoCode for turning

Field Name	TestEndTwoCode
Operation	Milling
Table	General
0	Not specified
1	Objectives achieved
2	Poor surface finish
3	Out of tolerance
4	Chipping
5	Chip welding
6	Flank wear
7	Insufficient power
8	Unstable set-up
9	End of batch

Table G.10 : TestEndTwoCode for milling

Field Name	OperationCode
Operation	Milling
Table	General
0	Not specified
1	Face milling
2	Copy milling
3	Square shoulder
4	Profiling
5	Chamfering
6	Slot end
7	Disc mill

Table G.11 : OperationCode for milling

Field Name	OperationCode
Operation	Turning
Table	General
0	Not specified
1	External
2	Internal
3	Facing
4	Copying

Table G.12 : OperationCode for turning

Appendix H

Fundamentals of turning operations

This Appendix presents a brief review of the fundamental cutting parameters associated with turning and the relationships that exist between them.

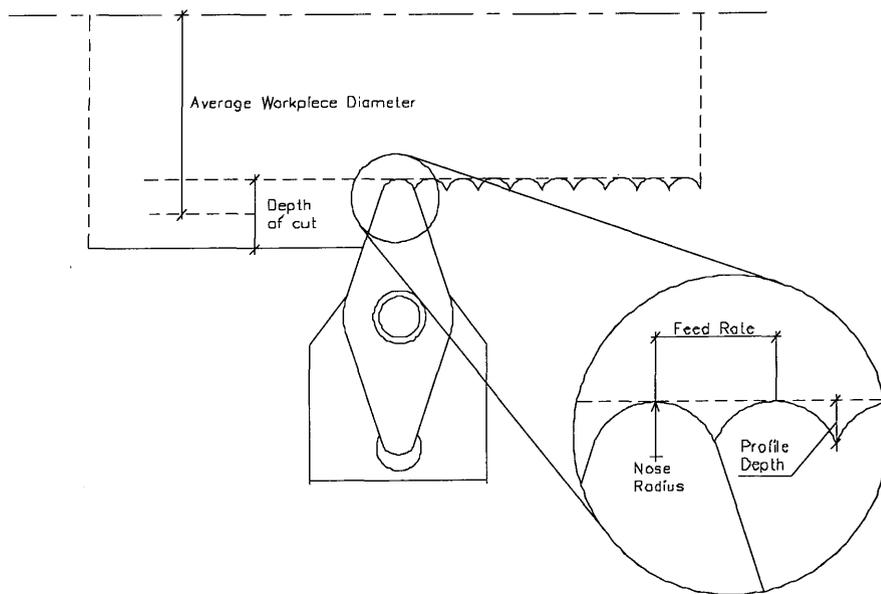


Figure H.1 : An orthogonal turning operation

Figure H.1 presents an illustration of some of the most important physical parameters associated with the analysis of machining operations. The reader has already been presented with the concept of a chipbreaking diagram being used to define the acceptable values for feed rate and depth of cut. This knowledge will now be extended to see how the depth of cut, feed rate and cutting velocity affect other cutting parameters and the physical outcome of those parameters on the workpiece.

It may appear that the maximum material removal rate will be achieved when the values for the depth of cut and feed rate are set to their maximum values as defined by the chipbreaker diagram. However, consideration needs to be paid to both the capabilities of the machine tool and the physical characteristics of the workpiece. Equations H-1a, b & c provide a way of assessing the power required to perform a turning operation.

$$P_c = \frac{v_c \times f \times a_p \times k_c}{60000 \times \eta} \quad (\text{H-1a})$$

$$k_c = \frac{1 - (0.01 \times \gamma_0)}{h^{mc}} \times k_{c1} \quad (\text{H-1b})$$

$$h = f \times \sin \kappa \quad (\text{H-1c})$$

P_c = Power required (kW)
 v_c = Cutting velocity (m/min)
 f = Feed rate (mm/rev)
 a_p = Depth of cut (mm)
 k_c = Specific cutting force (N/mm²)
 η = Efficiency
 γ_0 = Cutting rake (deg)
 h = chip thickness (mm)
 k_{c1} = cutting force constant (N/mm²)
 κ = approach angle (deg)

Whilst these equations present a mathematically accurate way of assessing the power required to perform the machining operation, an approximate indication of power requirement can be obtained by using equation H-2. This equation has been produced by assuming a machine tool efficiency of 75% and an average cutting force constant of 1800 N/mm².

$$P_c \approx \frac{v_c \times f \times a_p}{25} \quad (\text{kW}) \quad (\text{H-2})$$

P_c = Power required (kW)
 v_c = Cutting velocity (m/min)
 f = Feed rate (mm/rev)
 a_p = Depth of cut (mm)

From equation H-2 we can clearly see that those factors which are of the most importance when assessing the power requirement of a turning operation are the cutting velocity, depth of cut and feed rate. If values for these three parameters are known then it is possible to make an assessment as to whether the operation is within the power capacity of the machine tool being used.

Referring back to Figure H.1 it can be seen that the feed rate is the major determining factor in the profile that is generated on the workpiece as a result of the operation being performed. A combination of the feed rate and insert nose radius can be used to directly evaluate the surface finish, as shown in equation H-3

$$R_a \approx \frac{f^2 \times 50}{r_\epsilon} \quad (\text{H-3})$$

f = Feed rate (mm/rev)
 r_ϵ = Nose radius (mm)
 R_a = Surface finish (μm)

From equation H-3 it can be seen that for any chosen insert an increase in the feed rate of the operation will result in a higher value for the surface finish - i.e. a rougher surface. A further parameter which is of importance when analysing a turning operation is the material removal rate, Q , which can be found from equation H-4.

$$Q = v_c \times f \times a_p$$

Q = Metal removal rate (cm^3/min)
 v_c = Cutting velocity (m/min)
 f = Feed rate (mm/rev)
 a_p = Depth of cut (mm)

(H-4)

Appendix I

Fundamentals of milling operations

Definition of the geometric properties of milling cutters and milling operations should prove a suitable starting point for the analysis. Consider the general milling cutter presented in Figure I.1.

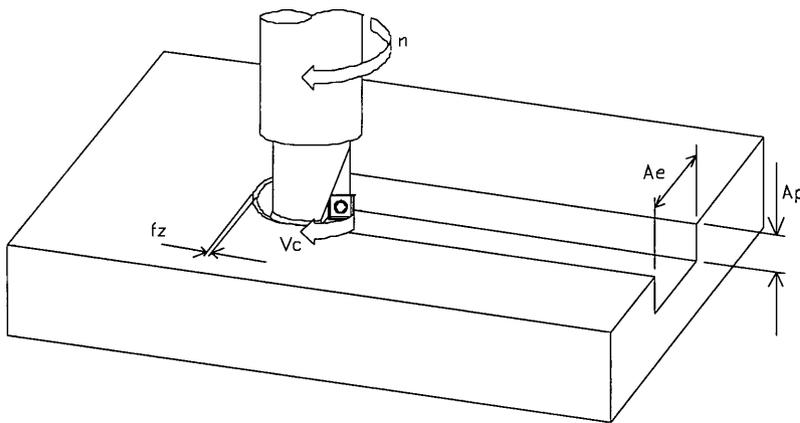


Figure I.1 : Elementary parameter definition for milling

As in the case of turning, it is standard for the cutting velocity to be specified based upon consideration of the feed rate and depth of cut values, and from this cutting velocity the spindle speed can be calculated. Equation I-1 presents the relationship between these parameters, and it can be seen that the equation is identical to that presented earlier for turning.

$$n = \frac{v_c \times 1000}{\pi \times D} \quad \begin{array}{l} n = \text{Spindle speed (rev/min)} \\ v_c = \text{Cutting velocity (m/min)} \\ D = \text{Milling cutter diameter (mm)} \end{array} \quad (\text{I-1})$$

The geometry of the generic milling operation in Figure I.1 illustrates that there are two depth of cut values; namely the axial depth of cut and the radial width of cut. The assessment of the depth of cut values can be dependent upon the particular category of operation which is being considered, as illustrated in Figure I.2.

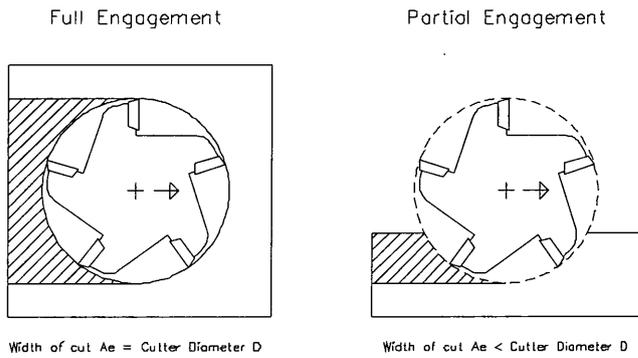


Figure I.2 : Full and partial engagement

In general operations such as slotting, copying, end milling and contouring will involve the cutter exhibiting full engagement; this is to say that the width of the material being removed is equal to the diameter of the cutter. In the areas of face and square shoulder milling however the width of cut will be less than the width of the cutter, and such operations are said to exhibit partial engagement. The differences in cutting data analysis between full and partial cutter engagement will be examined in due course.

The occupation of milling cutter bodies with multiple inserts leads to the assessment of feed rates being less simple than the analysis for single point cutting operations. When evaluating the feed rates for milling operations it is necessary to look at the number of inserts and their arrangement on the cutter body.

Milling cutters are designed to perform a high variety of different machining operations and hence a wide variety of milling cutter body shapes and sizes are encountered. In terms of cutting data selection for milling, each milling insert will be designated as having a range of feed per tooth values, these values being entirely independent of the cutter body in which they are housed. Knowing the feed per tooth range it is then possible to analyse the milling cutter body to assess the feed rate per revolution and the absolute feed rate relative to the workpiece which can be obtained.

In a high proportion of milling cutters, there is a simple relationship between the feed per tooth, feed per revolution and absolute feed speed, as shown in equations I-2a & b. It is valid to use these equations when each insert on the cutter body is performing the same operation.

$$v_f = n \times z \times f_z \quad \begin{array}{l} f_z = \text{Feed per tooth (mm)} \\ f = \text{Feed per revolution (mm/rev)} \end{array} \quad (\text{I-2a})$$

$$f = z \times f_z \quad \begin{array}{l} z = \text{Number of teeth} \\ n = \text{Spindle speed (rev/min)} \\ v_f = \text{Feed speed (mm/min)} \end{array} \quad (\text{I-2b})$$

In some milling cutters however, the inserts do not all perform the same task and the equations just presented are modified as shown in equations I-3a & b.

$$v_f = n \times K \times f_z \quad \begin{array}{l} f_z = \text{Feed per tooth (mm)} \\ f = \text{Feed per revolution (mm/rev)} \\ K = \text{Effective number of teeth} \end{array} \quad (\text{I-3a})$$

$$f = K \times f_z \quad \begin{array}{l} n = \text{Spindle speed (rev/min)} \\ v_f = \text{Feed speed (mm/min)} \end{array} \quad (\text{I-3b})$$

Consider cutter shown in Figure I.3. This cutter is suitable for performing plunging operations (cutting in the axial plane) or for milling operations (plane normal to the cutter axis). When used for milling operations, despite there being two inserts, the rhombic shaped insert performs the bulk material removal process with the secondary insert simply finishing the surface of the plane being milled. In this case the effective number of teeth is one, and this is the value which would be used in equations I-3a & b.

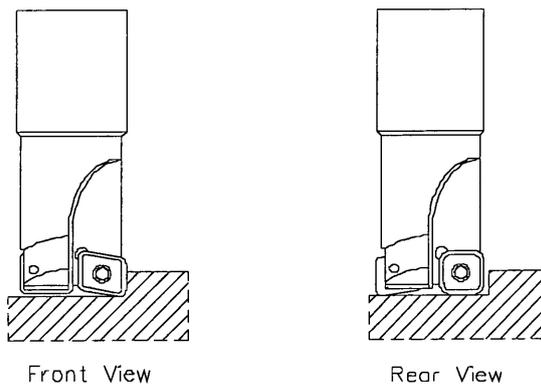


Figure I.3 : Obverse and reverse elevations of a drilling end mill

A final situation where the number of inserts is not equal to the number of teeth is where the inserts are staggered not only in the radial plane, but also in the axial plane. A typical helical mill used for achieving significant material removal rates consists of a series of flutes around the circumference of the cutter. Each of these flutes will hold a series of inserts mounted along the length of the flute. The inserts mounted along the flutes are designed to mill the vertical plane along which the cutter transverses.

If each flute holds the inserts in exactly the same positions, then the effective number of teeth is equal to the number of flutes. However, in some helical mills, two consecutive flutes may contain staggered inserts which are needed to generate the vertical face, and in these cases the effective number of teeth of the cutter is equal to half the number of flutes.

With the axial and radial depths of cut and the feed speed having been defined, the metal removal rate can be evaluated as shown in equation I-4.

$$Q = \frac{a_e \times a_p \times v_f}{1000} \quad \begin{array}{l} Q = \text{Metal removal rate (cm}^3/\text{min)} \\ a_e = \text{Width of cut (mm)} \\ a_p = \text{Depth of cut (mm)} \\ v_f = \text{Feed speed (mm/min)} \end{array} \quad (\text{I-4})$$

The calculation of the power requirement for a milling operation is founded on the same principles as that for turning, and the similarity can be seen when considering the power demand algorithm for milling presented in equation I-5.

$$P_c = \frac{a_p \times a_e \times v_f}{(60 \times 10^6) \times \eta} \times k_c \quad \begin{array}{l} P_c = \text{Power demand (kW)} \\ a_e = \text{Width of cut (mm)} \\ a_p = \text{Depth of cut (mm)} \\ v_f = \text{Feed speed (mm/min)} \\ \eta = \text{Efficiency} \\ k_c = \text{Cutting force per mm}^2 \text{ (N/mm}^2\text{)} \end{array} \quad (\text{I-5})$$

Whilst the cutting force per square millimetre, k_c , is identical to the expression presented in equation H-1b, the average chip thickness value is more complex to calculate, as shown in equation I-6.

$$h_m = \frac{360 \times f_z \times a_e}{\pi \times D \times \omega_e} \times \sin \kappa \quad \begin{array}{l} h_m = \text{Average chip thickness (mm)} \\ f_z = \text{Feed per tooth (mm)} \\ a_e = \text{Width of cut (mm)} \\ D = \text{Cutter diameter (mm)} \\ \omega_e = \text{Engagement angle (}^\circ\text{)} \end{array} \quad (\text{I-6})$$

It is due to the added complexity and inherently greater diversity of values that the power demand in milling is unable to be simplified in the same manner which was appropriate for turning. Earlier in this section reference was made to the definition of an operation exhibiting either full or partial engagement. It is in the calculation of the engagement angle where the importance of the operation's type of engagement becomes clear.

When the engagement type is encountered with reference to engagement angle, there are in fact three types of engagement. Full engagement maintains the same definition as given earlier whilst partial engagement is split into two sub-categories; central cutter engagement and off-centre cutter engagement. Figure I.4 illustrates these categories.

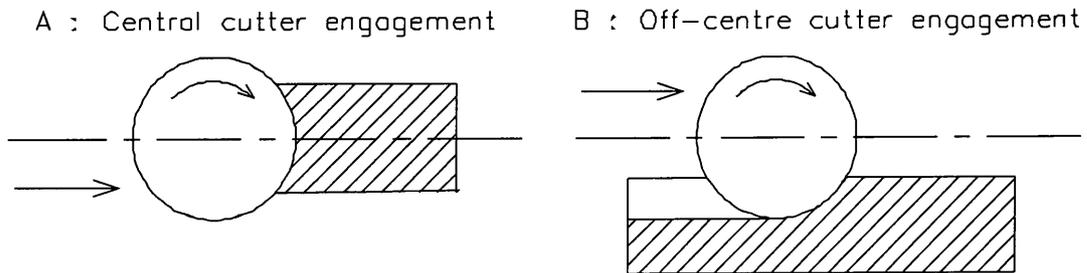


Figure I.4 : Types of partial cutter engagement

A simple geometric analysis of the two partial engagement types yields expressions which can be used to evaluate the engagement angle based upon the diameter of the cutter and the engagement width. Consider Figure I.5 which presents the geometric analysis necessary to evaluate the engagement angle for the case of central cutter engagement. The resulting algorithm for calculating the engagement angle is shown in equation I-7.

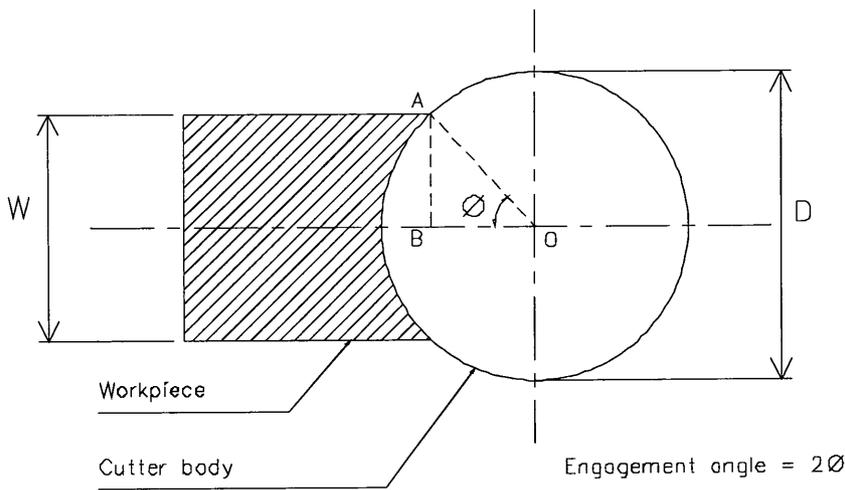


Figure I.5 : Central cutter engagement geometry

$$\omega_e = 2 \left(\sin^{-1} \left(\frac{W}{D} \right) \right)$$

ω_e = Engagement angle (°)
 W = Width of cut (mm)
 D = Cutter diameter (mm)

(I-7)

Figure I.6 presents the geometrical analysis which is used to produce the engagement angle equation for off-centre cutter engagement.

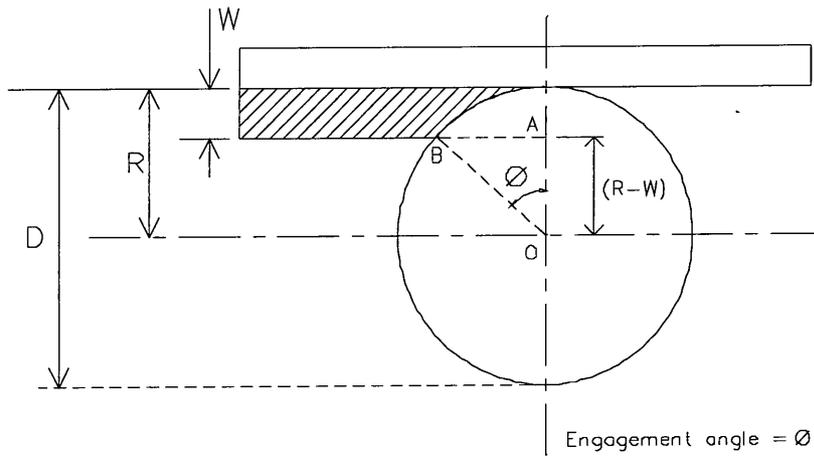


Figure I.6 : Off-centre cutter engagement geometry

The algorithm derived from the geometry-based examination of the off-centre cutter engagement is shown in equation I-8.

$$\omega_e = \cos^{-1} \left(1 - \frac{2W}{D} \right) \quad \begin{array}{l} \omega_e = \text{Engagement angle } (^\circ) \\ W = \text{Width of cut (mm)} \\ D = \text{Cutter diameter (mm)} \end{array} \quad (\text{I-8})$$

Appendix J

Numerical analysis and curve fitting

J.1 The theory of numerical analysis applied to curve fitting

Elementary numerical analysis texts present a variety of methods which are suited to generating polynomial equations from a series of data points. There are two broad categories into which these interpolating methods can be assigned;

- Polynomial interpolation - A polynomial of degree n is evaluated which passes through $(n+1)$ data points.
- Least squares approximation - A polynomial of degree less than or equal to n is evaluated to produce the 'best-fit' line / curve through the data points.

In layman's terms, polynomial interpolation forces a polynomial to pass through a series of data points, whilst the least squares approximation method simply evaluates a polynomial which is deemed to be the best fit curve through the data points. This best fit approximation is defined as the polynomial which minimises the *root mean square* distance of the data points from the curve given by the polynomial approximation. Whilst the differences between the two polynomial approximation techniques may not be immediately apparent, the decision as to the most appropriate technique to adopt for any given set of data points is an important one.

Consider the example of a scientific experiment where the measurement of physical quantities will inherently contain inaccuracies in the data, be it due to human error, equipment limitations or any other source of error. If such an experiment involves the measurement of two related variables x and y , it may be proposed that an unknown relationship exists between the variables, as shown in equation J-1.

$$y = f(x) \tag{J-1}$$

During the course of the experiment a series of values of x , say $x_1, x_2, x_3 \dots x_n$, are chosen and the corresponding values for y are measured, denoted by $y_1, y_2, y_3 \dots y_n$. Recognition of the presence of data sampling errors allows us to define error values, $\varepsilon_1, \varepsilon_2, \varepsilon_3 \dots \varepsilon_n$, given by equation J-2.

$$\varepsilon_i = f(x_i) - y_i \quad (\text{J-2})$$

The aim of the experiment may be to try and predict the relationship between x and y as accurately as possible. By applying any form of interpolating assessment (Lagrangian interpolation, Newton's interpolating polynomial, spline functions) an analytic relation can always be found. However, such interpolation techniques makes no provision for the inclusion of errors when processing the (x_i, y_i) data points, and this can often lead to a poor estimate of the true function $f(x)$.

However, by assuming each error, ε_i , is a random variable chosen from a *normal probability distribution* it is possible to incorporate the acceptance of the error into the algorithm used to evaluate a polynomial approximation. The name given to this technique is least squares data fitting, and the polynomial approximation produced by the application of this method minimises the *root mean square* in the approximation of the data $\{y_i\}$ by $f(x)$. The expression for the RMS error, E , is shown in equation J-3.

$$E = \sqrt{\frac{1}{n} \sum_{i=1}^n [f(x_i) - y_i]^2} \quad (\text{J-3})$$

The least squares polynomial approximation technique can be applied to any suitable data set so long as the order of polynomial required is less than the number of data points which have been defined.

Not only does the least squares approximation technique incorporate the acceptance of errors, but it also provides a method by which, for example, a second order polynomial can be calculated from a set of perhaps one hundred data points. This is of course particularly useful when dealing with experimentally or practically determined values. When the same situation is approached with interpolation techniques, only three points

from the entire data set can be used to generate a second order polynomial approximation. It can be seen that polynomials generated by interpolation techniques are of limited value in a practical situation. Having examined different polynomial approximation techniques, it is necessary to consider the mathematical information which has been presented in order to assess a suitable manner for performing the analysis of cutting data sourced from tooling catalogues and the tool trials database.

J.2 Analysis of catalogue data

The starting point for any cutting data analysis is likely to broach the equations which brought Taylor his fame at the beginning of the century. Indeed, with the passing of almost one hundred years since Taylor's seminal work, the knowledge he ascertained and disseminated is still prevalent in the cutting data we see presented in modern tooling catalogues. Although cutting data is generally obtained from a series of practical tests, the industrial machinist is not privy to the individual results that are obtained from these tests. Whilst tooling catalogues may contain only limited assistance in assessing cutting velocity, there is a reassuring level of agreement between the early work carried out by Taylor and the data presented in these catalogues. As a starting point, the cutting velocity / feed rate data was analysed in terms of its ability to be examined using polynomial approximation techniques.

It is now common for spreadsheet and similar data presentation utilities to provide a means of graphically displaying and mathematically analysing data provided by the user. Four types of two dimensional curves were compared in terms of their ability to model the cutting velocity and feed rate dependency, hence allowing the use of polynomial interpolation to be adopted or rejected. The four chosen line types were;

- Second order polynomial $y = a.x^2 + b.x + c$
- Power $y = a.x^b$
- Logarithmic $y = a.Ln(x) + b$
- Exponential $y = a.e^{b.x}$

In order to assess the conformance of cutting speed and feed value data samples to any given curve type the Pearson product moment correlation coefficient was examined. This coefficient is more commonly referred to as the R-squared value of a trendline and gives both an indication of the conformance of the trendline to the specified data points, and the validity of using that trendline for approximating x-values which are a specific distance outside of the data set range.

Figure J.1 shows the results of fitting the four curve types to the cutting velocity / feed rate values for the case where a T25M grade insert is used to machine a group 1 steel. The data points used to obtain these curve approximations is shown in Table J.1.

Feed Rate (mm/tooth)	Cutting Velocity (m/min)
0.15	230
0.3	180
0.45	155
0.6	135

Table J.1 : Cutting velocity and feed rate data

From analysis of the cutting data presented in technical guides it was found that in the majority of situations the feed rate range for a specific insert / material combination falls within the range of feed rates for which cutting velocities are specified. To cater for those rare situations where this is not the case the trendlines were set to indicate the R-squared value based upon a ten percent extrapolation at each end of the feed range.

From consideration of Figure J.1 it can be seen that in the region populated with the sample data there is close agreement between each of the four curves and the data points. It is only when the extrapolation of the curves outside of the data source range is considered that any significant differences between the curves are observed.

It can be seen that at the lower feed rate bound the curves based upon power and logarithmic modelling deviate quite markedly. The exponential curve model can be seen to be almost linear both throughout and beyond the feed rate bounds, and it is for this reason that it assumes the lowest Pearson product moment correlation coefficient. At the values above the higher feed rate bound it can be seen that ill-behaves curves at the

lower bound are seen to exhibit significantly improved adherence to the data points. Whilst this improves their R-squared values above that shown for the exponential model, the second order polynomial is found to have exhibit the closest agreement with the data points and the extrapolation criteria. A second order polynomial is unlikely to exhibit good correlation with a significantly higher upper feed bound due to the reaching of it's minimum and subsequent ascent of the y-values. However, the approximate minima location of the second order polynomial coincides nicely with the upper feed rate bound, and the deterioration of the model is not encountered.

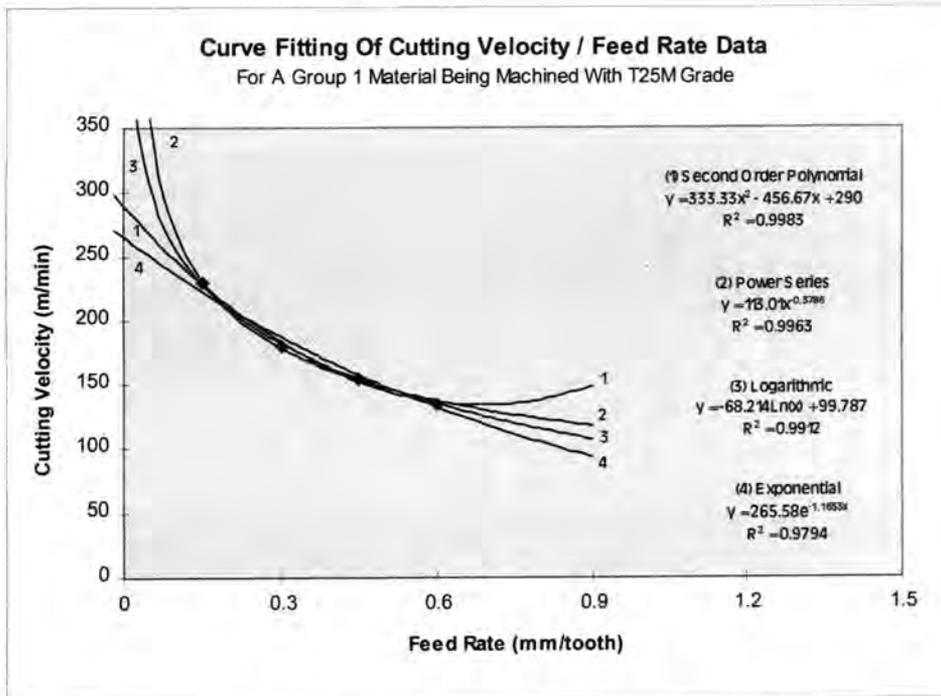


Figure J.1 : Illustration of curve fitting for cutting velocity / feed rate data

Upon the evaluation of further insert grade and material combinations it was consistently found that a second order polynomial gave the greatest level of conformance. Examples of second order polynomial curve fitting for both turning and milling inserts grades are presented in Figures J.2 and J.3. As a result of this the second order polynomial was adopted as the method for evaluating a continuous equation, based upon catalogue data, relating the feed rate and cutting velocity for a given combination of insert grade and material choice. Once this step had been taken, it was possible to create a database from which the relationships between cutting velocity and feed rate, as presented in tooling catalogues, could be evaluated for any valid combination of insert grade and material group.

The way in which Taylor suggested cutting speed and velocity were related and the consistent way in which catalogue based cutting velocity has been modelled against feed rate has allowed the use of a second order polynomial to be justified as a method for establishing a continuous function relating feed rate to cutting velocity.

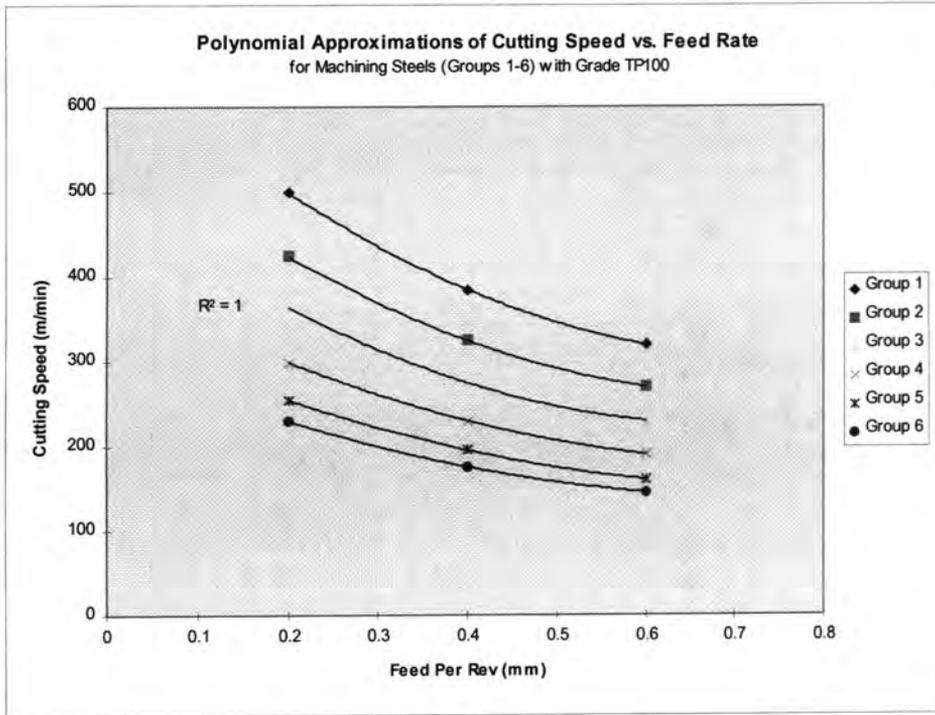


Figure J.2 : Polynomial approximation of machining steels in groups 1-6

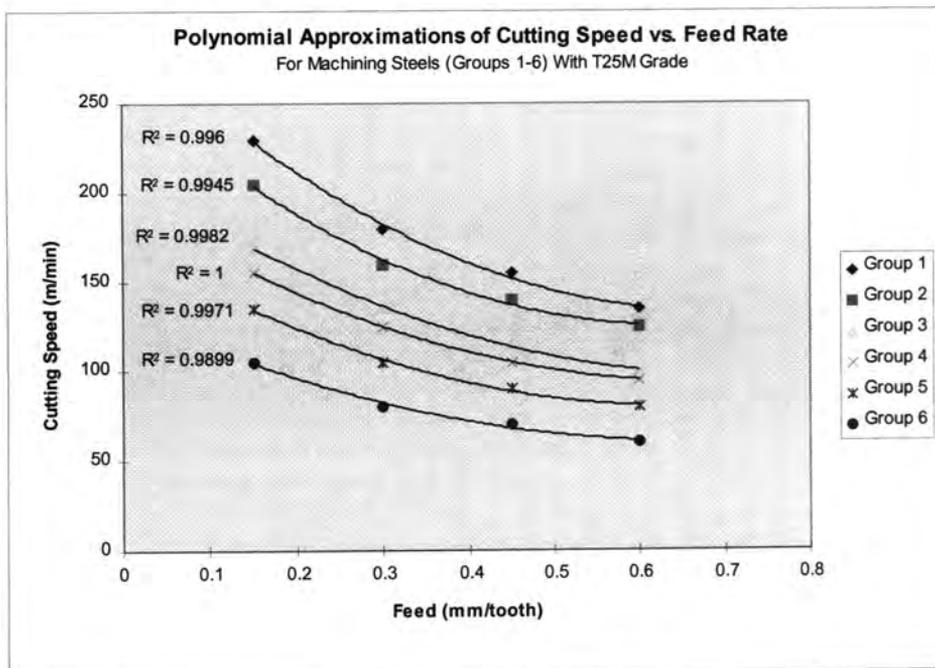


Figure J.3 : Polynomial approximation of machining steels in groups 1-6 (2)

J.3 Analysis of tool trials data

With an assessment of catalogue based data having been made and a convincing evaluation of modelling based upon second order polynomial approximation being carried out it was necessary to consider a way in which the cutting data found in tool trials could be interpreted and incorporated into the tool and cutting data selection utilities within JadeT.

The differences between polynomial interpolation methods and least squares data fitting techniques have already been discussed. When this knowledge is considered alongside the information gleaned from the examination of catalogue data it was decided that a polynomial of order two would be fitted to tool trials data points using the least squares approximation technique. Thus, for any combination of insert grade and material group specified by the user within the cutting data selection utility, a search would be carried out upon the tool trials database. This search would retrieve approved points containing a cutting velocity value and a feed rate value for those tests which were carried out on the same workpiece material and insert grade combination.

Let us now consider the manner in which the polynomial least squares approximation technique will be applied. In the general case, the data $\{x_i, y_i\}$ will be used to approximate the functions $\hat{f}(x)$ as given by equation J-4.

$$\hat{f}(x) = a_1\varphi_1(x) + a_2\varphi_2(x) + \dots + a_m\varphi_m(x) \quad (\text{J-4})$$

To simplify equation J-4, let's examine the particular case where $m = 3$. In this situation equation J-4 is converted to the form shown in equation J-5.

$$\hat{f}(x) = a_1\varphi_1(x) + a_2\varphi_2(x) + a_3\varphi_3(x) \quad (\text{J-5})$$

Under the normal error assumption, the function $\hat{f}(x)$ is chosen to minimise the RMS error presented in equation J-3. Solving the equations generated by the need to minimise the function $\hat{f}(x)$ yields the three linear equations presented in equation J-6.

$$\left[\sum_{j=1}^n \varphi_1(x_j) \varphi_i(x_j) \right] a_1 + \left[\sum_{j=1}^n \varphi_2(x_j) \varphi_i(x_j) \right] a_2 + \left[\sum_{j=1}^n \varphi_3(x_j) \varphi_i(x_j) \right] a_3 = \sum_{j=1}^n y_j \varphi_i(x_j), \quad i=1,2,3 \quad (\text{J-6})$$

In the case of a quadratic polynomial, equation J-5 becomes;

$$\hat{f}(x) = a_1 + a_2 x + a_3 x^2 \quad (\text{J-7})$$

where, $\varphi_1(x) \equiv 1$, $\varphi_2(x) = x$ $\varphi_3(x) = x^2$

By applying the three linear equations presented in J-6 to the quadratic polynomial in J-7, three equations with three unknowns are obtained, as shown in J-8.

$$\begin{aligned} [n]a_1 + \left[\sum_{j=1}^n x_j \right] a_2 + \left[\sum_{j=1}^n x_j^2 \right] a_3 &= \sum_{j=1}^n y_j \\ \left[\sum_{j=1}^n x_j \right] a_1 + \left[\sum_{j=1}^n x_j^2 \right] a_2 + \left[\sum_{j=1}^n x_j^3 \right] a_3 &= \sum_{j=1}^n x_j y_j \\ \left[\sum_{j=1}^n x_j^2 \right] a_1 + \left[\sum_{j=1}^n x_j^3 \right] a_2 + \left[\sum_{j=1}^n x_j^4 \right] a_3 &= \sum_{j=1}^n y_j x_j^2 \end{aligned} \quad (\text{J-8})$$

By applying the rudimentary principles of Gaussian elimination, equations J-8 can be solved for a_n , viz.;

$$\begin{aligned} a_3 &= \frac{(bn - a^2)(vn - bt) - (cn - ab)(un - at)}{(bn - a^2)(db - b^2) - (cn - ab)^2} \\ a_2 &= \frac{(un - at) - (cn - ab)a_3}{(bn - a^2)} \\ a_1 &= \frac{(t - a(a_2) - b(a_3))}{n} \end{aligned} \quad (\text{J-9})$$

$$\text{where; } a = \sum_{j=1}^n x_j, \quad b = \sum_{j=1}^n x_j^2, \quad c = \sum_{j=1}^n x_j^3, \quad d = \sum_{j=1}^n x_j^4,$$

$$\text{and; } t = \sum_{j=1}^n y_j, \quad u = \sum_{j=1}^n x_j y_j, \quad v = \sum_{j=1}^n x_j^2 y_j,$$

$n = \text{number of points.}$

