Internet-based solutions to support distributed manufacturing

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INTERNET-BASED SOLUTIONS TO SUPPORT DISTRIBUTED MANUFACTURING

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ABSTRACT

With the globalisation and constant changes in the marketplace, enterprises are adapting themselves to face new challenges. Therefore, strategic corporate alliances to share knowledge, expertise and resources represent an advantage in an increasing competitive world. This has led the integration of companies, customers, suppliers and partners using networked environments.

This thesis presents three novel solutions in the tooling area, developed for Seco tools Ltd, UK. These approaches implement a proposed distributed computing architecture using Internet technologies to assist geographically dispersed tooling engineers in process planning tasks. The systems are summarised as follows.

TTS is a Web-based system to support engineers and technical staff in the task of providing technical advice to clients. Seco sales engineers access the system from remote machining sites and submit/retrieve/update the required tooling data located in databases at the company headquarters. The communication platform used for this system provides an effective mechanism to share information nationwide. This system implements efficient methods, such as data relaxation techniques, confidence score and importance levels of attributes, to help the user in finding the closest solutions when specific requirements are not fully matched in the database.

Cluster-F has been developed to assist engineers and clients in the assessment of cutting parameters for the tooling process. In this approach the Internet acts as a vehicle to transport the data between users and the database. ***Cluster-F*** is a KD approach that makes use of clustering and fuzzy set techniques. The novel proposal in this system is the implementation of fuzzy set concepts to obtain the proximity matrix that will lead the classification of the data. Then hierarchical clustering methods are applied on these data to link the closest objects.

A general KD methodology applying rough set concepts is proposed in this research. This covers aspects of data redundancy, identification of relevant attributes, detection of data inconsistency, and generation of knowledge rules. ***R-sets***, the third proposed solution, has been developed using this KD methodology. This system evaluates the variables of the tooling database to analyse known and unknown relationships in the data generated after the execution of technical trials. The aim is to discover cause-effect patterns from selected attributes contained in the database.

A fourth system was also developed. It is called ***DBManager*** and was conceived to administrate the systems users accounts, sales engineers' accounts and tool trial monitoring process of the data. This supports the implementation of the proposed distributed architecture and the maintenance of the users' accounts for the access restrictions to the system running under this architecture.

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DECLARATION

I hereby declare that this thesis is the result of work undertaken by myself. It has not been submitted for any other degree in this or any other University. All sources of referenced information have been duly acknowledged.

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ABBREVIATIONS.

AI	Artificial Intelligence
API	Application Programming Interface
AQ	Advanced Query
BOM	Bill Of Materials
BQ	Basic Query
BTL	British Telecommunications Laboratories
CA	Cluster Analysis
CAD	Computer-Aided Design
CAM	Computer-Aided Manufacturing
CAPP	Computer-Aided Process Planning
CD	Compact Disc
CE	Concurrent Engineering
CGI	Common Gateway Interface
CIM	Computer-Integrated Manufacturing
CIM	Computer Integrated Manufacturing
CLI	Call Level Interface
CNC	Computer Numerically Controlled
COM	Component Object Model
CORBA	Common Object Request Broker Architecture
CPU	Central Process Unit
CVEs	Collaborative Virtual Environments
DB	DataBase
DBManager	Database Manager System
DBMS	DataBase Management Systems
DCOM	Distributed Component Object Model
DM	Data Mining
DNC	Direct Numerical Control
DNS	Domain Name Service
DR	Data Replication
DS	Distributed System
DSS	Decision Support Systems
DW	Data Warehousing
EI	Enterprise Integration
FK	Foreign Key
FMS	Flexible Manufacturing Systems
FS	Fuzzy Sets

FTP	File Transfer Protocol
GUI	Graphical User Interface
HTML	Hyper Text Mark-up Language
IAB	Internet Architecture Board
IBL	Instance-Based Learning
ICM	In-Cycle Measuring
IDL	Interface Definition Language
IETF	Internet Engineering Task Force
IMS	Intelligent Manufacturing Systems
IP	Internetworking Protocol
IRTF	Internet Research Task Force
IT	Information Technology
JANET	Joint Academic Network
JDBC	Java Database Connectivity
JIT	Just-In-Time
KD	Knowledge Discovery
KDD	Knowledge Discovery in Databases
KMD	Knowledge Mining from Databases
LAN	Local Area Network
MAS	Manufacturing Analysis Service
MIT	Massachusetts Institute of Technology
MPC	Manufacturing Planning and Control
MRP	Material Requirement Planning
NN	Neural Networks
ODBC	Open DataBase Connectivity
OLE	Object Linking and Embedding
OMG	Object Management Group
OOP	Object Oriented Programming
ORB	Object Request Broker
PDF	Portable Document Format
PK	Primary Key
PLC	Programmable Logic Controllers
PP	Process Planning
PPC	Production Planning and Control
RDBMS	Relational Database Management Systems
RS	Rough Sets
SMG	Seco Material Group
SMTP	Simple Mail Transfer Protocol
SQL	Structured Query Language
SQLA	Structured Query Language Anywhere (Sybase)

STEP	Standard for the Exchange of Product
TCP	Transmission Control Protocol
TCP/IP	Transmission Control Protocol/Internet Protocol
TLC	Tool Life Control and management system
TPO	Technical Planning of the cutting Operation
TTS	Tool Trial System
UDP	User Datagram Protocol
URL	Uniform Resource Locator
VM	Virtual Machine
VR	Virtual Reality
VRML	Virtual Reality Modelling Language
W3C	World Wide Web Consortium
WT	WinTool
WWW	World Wide Web

CHAPTER 1: INTRODUCTION

Traditional business paradigms assume that companies are 'islands', independent and self-operating entities, when in fact they are part of a business system composed of customers, suppliers, products and dynamic information schemes. With the globalisation and constant changes in the market, corporations are adapting themselves to face new challenges. They are moving from traditional internal vertical structures to a more flexible, external and horizontal integration. This supposes not only functional but also geographical integration (Azevedo and Sousa, 1999). This notion of an integrated enterprise has become increasingly important for maintaining a competitive advantage.

To benefit from this global and integrated business vision, manufacturing companies need to develop their ability to respond efficiently to customers' requirements. As part of these new challenges, enterprises have embraced continuous improvement strategies to modernise their manufacturing environments. This is, in part, supported by the implementation of distributed computing methods for product design and manufacturing planning. Furthermore, introduction of new technologies plays an important role in supporting these operations. It has been widely accepted that the future of manufacturing organisations will be information-oriented, knowledge driven and much of the daily operations will be automated around a global information network that connects everyone together (Leung *et al.*, 1995). This situation gives rise to two main challenges: ***a)*** the efficient processing and analysis of large amounts of data stored in corporate databases and, ***b)*** the establishment of a communication infrastructure to support the integration and sharing of the information.

To respond to the first issue, a new technology to extract implicit, unknown and potentially useful knowledge from the data is emerging. It is called Knowledge Discovery (KD) and uses intelligent learning techniques to 'mine' the data. The use of this technology maximises business opportunities and represents a competitive advantage allowing the companies to migrate from data-rich to knowledge management scenarios.

The second challenge requires a global networked environment to exchange information. Recent years have seen how the Internet has become the most widely used communicational platform. It is obvious that the Internet can be used as a vehicle to integrate work groups and help with decision taking in geographically dispersed places. However, these advantages have yet to be fully exploited. In the area of manufacturing, some solutions have been proposed to provide remote manufacturing services and information (Küssel *et al.*, 1999) and (Zhao *et al.*, 1999), but there is still a lack of general information infrastructures to support interactions with external entities.

Manufacturing tooling industry is one of the areas requiring substantial contributions in relation to distributed computing technology (Casavant and Singhal, 1994). Technical support is an important sector where communications exerts a big impact. Machining operations are still highly dependent on decisions made by skilled engineers. Current tooling aids only provide support for the most common tools and processes. These aids are not widely available and cannot be updated easily. Moreover, huge amounts of data, the result of tooling trials, are constantly generated in geographically dispersed machining sites. The way in which these are stored makes the sharing of the information difficult. There are currently no automated mechanisms to take advantage of these data, and able to provide valuable information to underpin tooling and research tasks.

To help in these situations, some solutions are proposed in this research. These focus on two main areas: ***1)*** web-based distributed infrastructures and; ***2)*** Internet-based and knowledge discovery approaches.

1.1 AIMS AND OBJECTIVES OF PRESENT WORK

Two general aims have been addressed in this research:

- The proposal and implementation of a web-based infrastructure to support integration, information exchange, and collaborative work, and;

- The development of novel Internet-based solutions using KD approaches to provide support in tooling tasks, underpinning decision-making processes.

To accomplish the mentioned aims six specific objectives are proposed:

i. To analyse the suitability of applying web-based distributed solutions in companies having geographically dispersed branches.

ii. To propose an infrastructure able to support the sharing and integration of information sources remotely located, applied on the manufacturing tooling industry.

iii. To develop and implement a web-based system able to assist engineers in sharing a nation-wide database of tooling knowledge and facing new technical problems.

iv. To develop and implement mechanisms to guaranty the confidentiality of the data as well as the efficiency in the maintenance of the tooling database.

v. To provide Internet-based knowledge discovery methods able to assist engineers and technical staff in the assessment of tooling parameters, specifically in relation to cutting data.

vi. To propose a consistent knowledge discovery methodology able to support the application of rough sets concepts for analysing hidden patterns in a database containing experimental tooling data.

The solutions proposed in this research will be implemented by the industrial collaborator, Seco Tools (UK) Ltd, and later be adopted by the other Seco branches world-wide located.

1.2 STRUCTURE OF THIS THESIS

The main body of this thesis comprises of seven chapters. Chapter 2 gives a broad review of manufacturing systems and important aspects in process planning and metal cutting sector, the application area of this research. In Chapter 3, the role of internet-based platforms and their impact on manufacturing is examined. A Web-based architecture is proposed, which supports the developments in this thesis. The needs of manufacturing industries in the area of tooling and a Web-based system developed to support machinists in the tooling industry are presented in Chapter 4. Chapter 5 provides a theoretical foundation of KD and proposes a formal methodology to assist in the development of KD-oriented systems. A novel KD approach to assess cutting parameters for turning operations is described in Chapter 6. ***Cluster-F***, a system that uses a combination of cluster and fuzzy set techniques to undertake datamining operations is presented. Chapter 7 proposes a formal attribute-oriented methodology to support the development of KD systems using rough set concepts. This methodology is then applied to the development of ***R-sets***, a KD system to eliminate data redundancy, identify relevant attributes, detect data inconsistency and generate knowledge rules in the area of tooling. The results of the tests are presented in Chapter 8. Finally, Chapter 9 presents a summary of this thesis and areas for further work are identified.

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CHAPTER 2: REVIEW OF MANUFACTURING SYSTEMS AND THE TOOLING INDUSTRY

2.1 INTRODUCTION

This chapter presents an overview of key concepts in the area of manufacturing systems. The second section provides basic definitions, a historical review, and addresses issues related to manufacturing strategies, Manufacturing Planning and Control (MPC) and Computer-Integrated Manufacturing (CIM). Important concepts in relation to Computer-Aided Process Planning (CAPP) are examined. Then, in the third section the role of process planning and relevant aspects of metal cutting processes are discussed. Finally, in the fourth section the motivation and growing interest for implementing global manufacturing systems are introduced.

2.2 MANUFACTURING SYSTEMS

A manufacturing system usually employs a series of value-adding manufacturing processes to convert raw materials into finished products. Simultaneously, a manufacturing system encompasses a variety of functions including management, design, engineering, simulation, purchasing, production and quality control, inventories, marketing and sales. In general terms, it can be considered as an input-output process, having controllable as well as uncontrollable variables. Variables that can be controlled include materials, machines, personnel management, technological updates and investments. Examples of variables difficult to control include customer demand, influence of global markets, currency changes and environmental regulations. The importance of manufacturing must be appreciated when taking into consideration its economic and social significance. The prosperity and a nation's position (international spheres) depend to a great extent upon the success of its manufacturing industries. Quality of life, continued employment and the creation and preservation of skills constitute significant social factors (Wu, 1992).

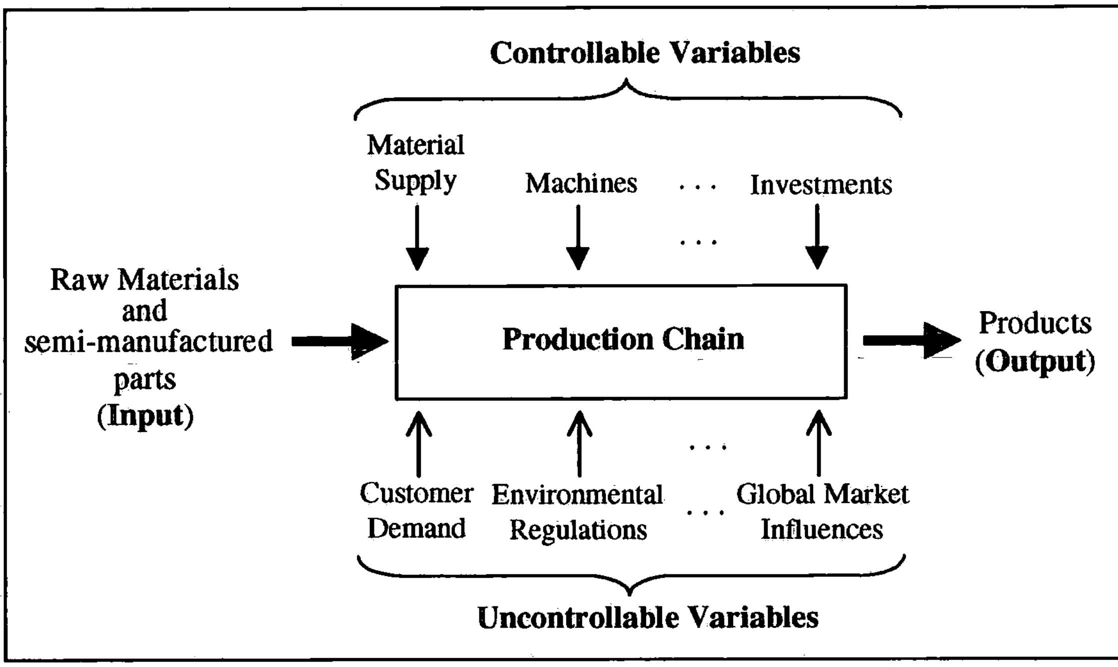

Figure 2.1 A General Input-Output Manufacturing System Model.

Figure 2.1 shows a general model of a manufacturing system as an input-output process. The production chain is mainly dependent on customer demand. Fluctuations in production orders determine changes to the desired output of the production process. This is known as the "push-principle", a concept that will be detailed later in section 2.2.2. Other parameters, such as the availability of raw materials, personnel and machinery, as well as the incorporation of new technology, also influence the adjustment of production plans.

While some variables have been categorised as "uncontrollable", recent technological advances are closing the gap between the controlled and uncontrolled nature of these variables. The establishment of more precise demand forecasts and a better knowledge of changes in global markets are examples of variables that are now easier to control. Likewise, there are variables not mentioned in the model, which, although they can occur sporadically, can significantly affect production process decisions. Meteorological changes and drastic political laws/regulations are typical examples. Improvement of working conditions is another factor that also affects the investment levels.

To achieve efficiency in manufacturing is not an easy task, mainly because this does not depend on technical manufacturing issues alone. The concept of efficient manufacturing goes beyond the volume of products it is possible to manufacture in a given time. It is also a matter of how to increase the value of the products to the customers. In modern marketing, there is not only the question of meeting the needs of customers. It is desirable that the quality of products elicits unequivocal acceptance of the product from final customers. The value-added properties of the product are also a function of the services provided before, during and after the sale process. According to Alting (1992) ten product value qualities can be identified, namely: *product price, product reliability, manufacturing quality, product design, product lifetime, maintenance cost, product customisation, speed of delivery, delivery reliability and volume flexibility.*

2.2.1 Background to Manufacturing Systems

The complexity and required accuracy in manufacturing processes during the 1950s, motivated the development of better machinery to solve problems, which conventional manual machine tools could not address. The introduction of Computer Numerically Controlled (CNC) machines during the 1960s significantly impacted on the automation levels in manufacturing industry. The emergence of Direct Numerical Control (DNC) technology followed, facilitating a communication link between interconnected computers and controller machines. The emergence of micro-computers and Programmable Logic Controllers (PLC), working together with CNC machines, made possible the implementation of semi-autonomous cells for manufacturing a selected range of components. Efforts to minimise costs and, in general, optimise the product manufacturing cycle, made possible the implementation of Production Planning and Control (PPC) systems. Within these systems, Material Requirement Planning (MRP) and Just-In-Time (JIT) have become very popular and have been widely used.

Frequent changes of production plans to respond to market fluctuations, motivated the incorporation of a major flexibility in manufacturing processes. Highly automated computer-controlled manufacturing facilities were implemented, which allowed the production of small batches while keeping the efficiency of mass-production. All the components in such a production system are integrated through a technology known as Flexible Manufacturing Systems (FMS). The significant evolution in the capabilities of micro-computers and the need for integrating design and manufacturing favoured the technology of Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM). CAD systems allow computer-based modelling of complex views of the product. CAM systems are able to generate the programs for CNC machines, on the basis of a CAD model of the part to be manufactured.

The next logical step was the integration and extension of the concepts provided by FMS technology, Production Planning and CAD/CAM systems. Computer Integrated Manufacturing (CIM) is a combination of systems and technologies, seen as a global set of strategies oriented to integrate data from a company. The target stretches beyond manufacturing operations, extending to engineering, management and a variety of different business functions. The CIM approach promises to extend existing schemes of automation, involving for example, the information generated, implementing MRP, JIT, CAD/CAM, FMS, marketing and sales. In parallel with these technological advances, improvements in the capabilities of industrial robots has revolutionised the way manufacturing tasks are executed. Welding, material handling, painting, assembly and inspection are some important industrial activities currently performed by robots. An extended explanation of these important topics now follows.

2.2.2 Manufacturing Planning and Control

An MPC system supports managers to efficiently conduct operations and make decisions in relation to the manufacturing activities. The information generated by MPC systems allows the control and planning of materials, personnel, machinery, processes, marketing and sales activities. Vollmann *et al.* (1997)

have identified ten key management activities supported by a MPC system. These are:

- Plan capacity requirements and availability to meet marketplace needs.
- Plan for materials to arrive on time in the right quantities needed for product production.
- Ensure utilisation of capital equipment and other facilities.
- Maintain appropriate inventories of raw materials, work in process and finished goods, in the correct locations.
- Schedule production activities so people and equipment are working on the correct processes.
- Track material, people, customers' orders, equipment and other resources in the factory.
- Communicate with customers and suppliers on specific issues and long-term relationships.
- Meet customer requirements in a dynamic environment that may be difficult to anticipate.
- Respond when things go wrong and unexpected problems arise.
- Provide information to other functions on the physical and financial implications of the manufacturing activities.

Regarding production planning and control, two techniques known as Materials Requirement Planning and Just-In-Time have been widely used. Alting (1992) performed a comparative analysis of both of these techniques, which is presented below.

Production Planning by MRP

In large-scale production processes, the planning of purchase and production becomes a huge and complex task, which no human can handle without assistance from appropriate techniques. MRP has been one of these techniques used since the early 1970s. The MRP technique is built around a bill of materials (BOM). The principle is based on the decomposition of a product and ending at its fundamental components, which are raw materials and/or purchased parts. A BOM includes the quantities needed of the fundamental as well as the intermediate components to produce one end product. Then, the MRP calculation takes the master production schedule giving the requirements for finished products in a given period of time, and calculates the gross requirements for subassemblies and components in the BOM. When this calculation is performed on all products manufactured, the gross requirements are added up, providing the total gross requirements for all subassemblies and components for each period of time. Taking into account the amount of materials in stock and the scheduled deliveries of materials from suppliers, the chain production requirements then can be calculated. These requirements give the amount of materials and components to purchase as well as the production orders to be produced in-house.

The MRP technique follows the "push-principle". The incoming orders and/or demand forecasts determine the need for finished products. These requirements for finished products are then broken down, by the MRP calculation, to production orders and purchase needs, which are "pushed" down to the departments and suppliers handling the various production phases. The co-ordination of shop-floor activities is centralised in the production planning department and the periodic MRP calculation. This is in direct contrast to the principle often applied in JIT.

Production Planning in JIT

It may be argued that customer-focused manufacturing is borrowed from the JIT philosophy of having customers create a demand (a pull) on manufacturing, which extends through each operation right back to the suppliers. The use of JIT to eliminate waste is focused on both company operation and customer quality. JIT is just one example of the Japanese concentration on improving a process of manufacture rather than the individual operations (Hannam, 1997).

Figure 2.2 (Alting, 1992) shows the difference between a "pull" system and the "push" system. In a pull system no detailed scheduling is done at any of the intermediate manufacturing stages. The assembly line receives a production schedule that corresponds to actual customer demands. The final assembly line then pulls parts and subassemblies from the intermediate manufacturing stages based on actual needs. The pull system first developed at the Toyota Motor Corporation was a two-card Kanban system (Kanban is the Japanese word for card).

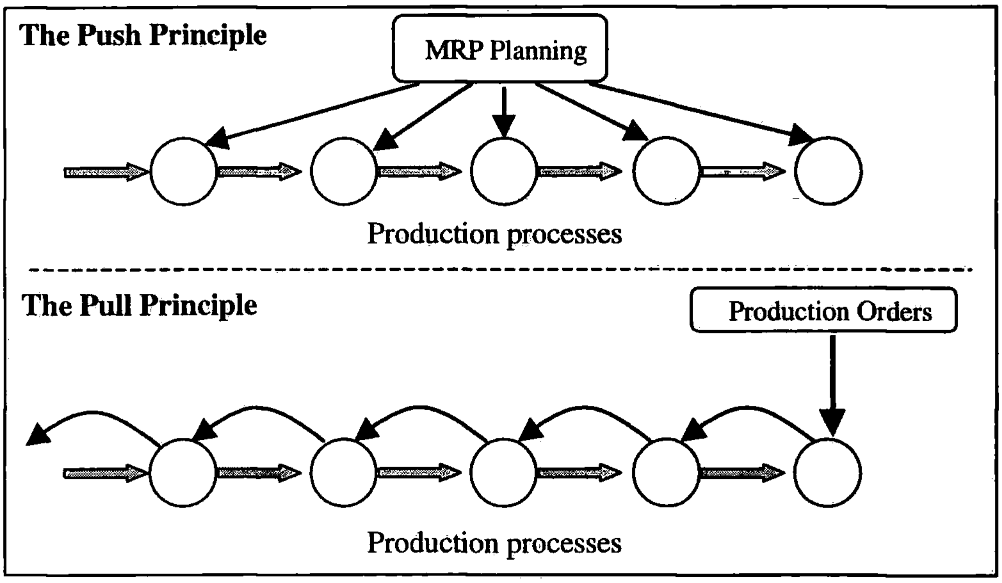

Figure 2.2 Push and Pull Production Planning Techniques.

The basic principle of Kanban is that each manufacturing stage at the assembly line has a minor buffer storage of the components used in the assembly process. These are divided into batches, typically represented by a container, and each batch of components is attached to a Kanban. When components are consumed at the assembly line, the Kanban is sent back to the manufacturing cell or the supplier producing the components. The employees in the manufacturing cell or the supplier must then produce and deliver the quantity of components represented by the incoming Kanbans. When this principle is applied at all manufacturing stages, no detailed centralised planning, such as MRP, is needed. The manufacturing system controls itself through the flow of Kanbans. Figure 2.3 (Alting, 1992) illustrates the basic configuration of an assembly line pulling components from manufacturing cells dedicated to the production of specific part families.

The Kanban system is very much related to the concept of manufacturing cells but can just as well be used for controlling the supply of components and materials from suppliers. The major advantages of this system are its autonomy, because very little centralised planning is needed and it is easy to control the inventories.

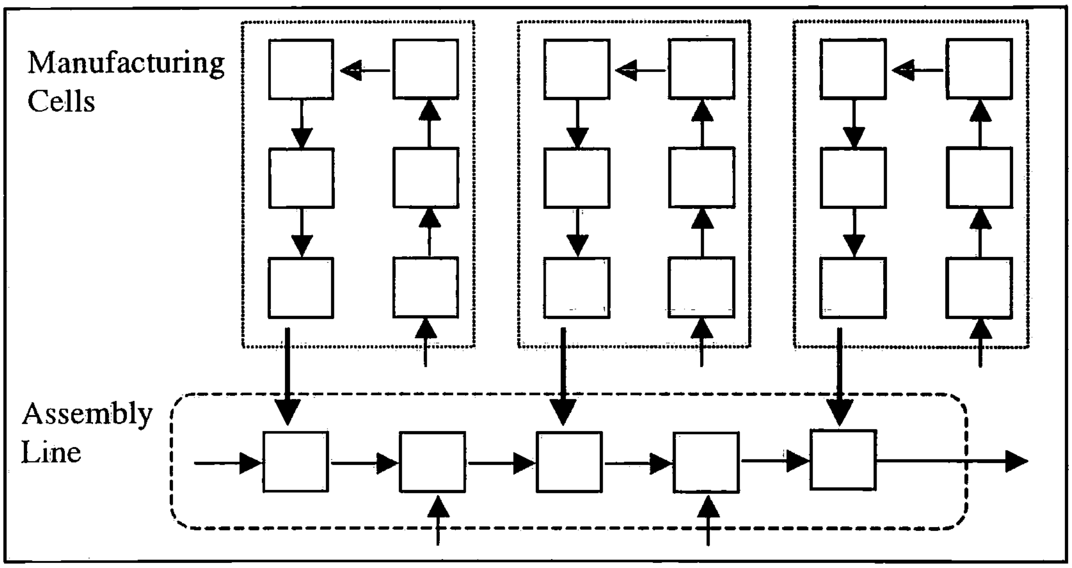

Figure 2.3 Cells-based layout in a JIT Manufacturing System.

Reduction of inventory and work-in-progress can be accomplished by withdrawing some of the Kanbans. Other benefits include reduction of production lead time, reduction of the work force, reduction of setup times, reduction of plat floor needed, reduction of indirect costs and improvement of quality.

2.2.3 Computer Integrated Manufacturing

CIM is a strategy for integrating the different manufacturing functions of an enterprise, using computer and information technology to improve the operations and communication between internal as well as external areas. Figure 2.4 shows the main areas encompassed by a CIM approach.

To achieve good results when implementing a CIM strategy, the areas shown in Figure 2.4 have to be effectively integrated with each other. The area of planning and control embraces computer-based MRP systems, inventory control, purchasing, capacity planning, financial management, marketing and sales. CAD systems allow an improved representation of the product (multidimensional views) and the conduction of sophisticated modelling tasks. CAM systems are closely related to CAD developments. The ultimate idea is to obtain the model generated by CAD systems and support the manufacturing of the product using automated shop-floor facilities such as robots, automated guided vehicles and networked CNC machines. The extended automation of planning and control activities allows the integration of these activities with the shop-floor processes, which are mainly represented by fully automated FMSs. Important shop-floor processes include automated material handling, real-time machine control, automated assembly and quality assessment and control.

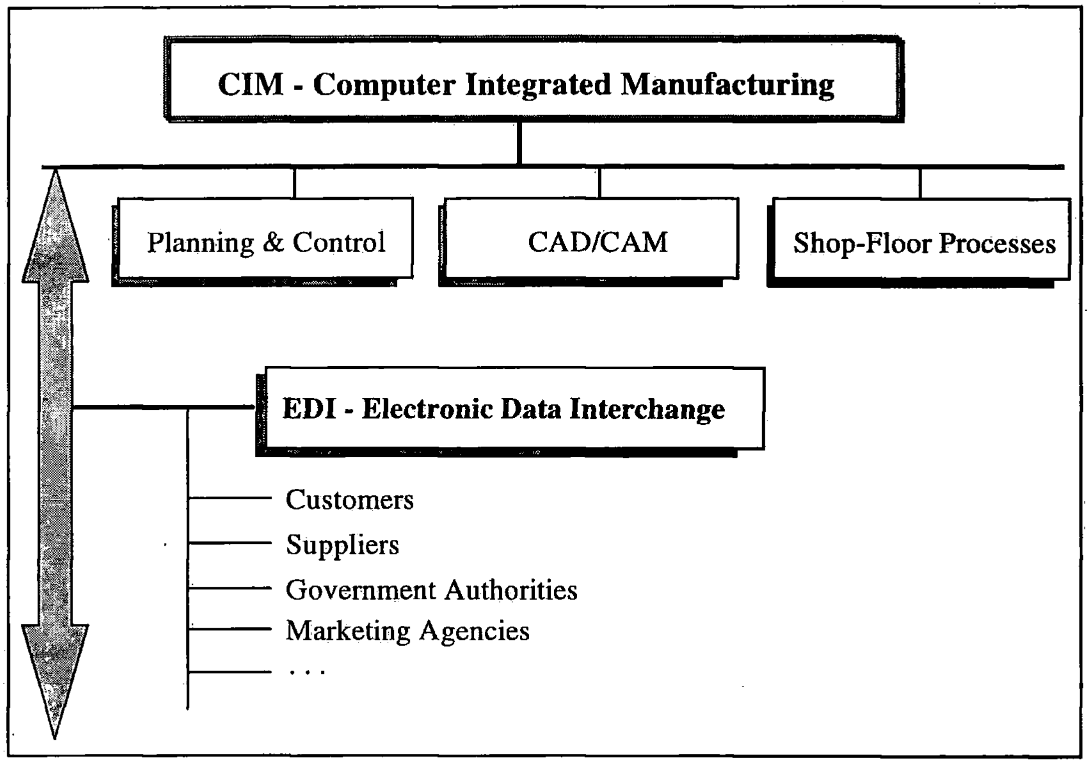

Figure 2.4 Main areas within the CIM strategy.

The CIM strategy inherits all the benefits of its constituent components such as reduction of lead times, costs and inventories, concurrent engineering, etc. Furthermore, it incorporates a networked computer environment (automated communication) to effectively channel the flow of information among all these components. According to Hannam (1997), CIM is often described as moving towards a paperless factory. In other words, internal and external communication should not be based on slips of paper but on electronic mail. Similarly, standards should not be held in standards books but in company databases; engineering product designs should not be held in large drawing-cabinets but within CAD systems as computer models, which can be accessed to obtain any form of engineering view or cross-section as and when needed. EDI (Electronic Data Interchange) is seen and is currently being implemented for integrating internal areas as well as external agents such as customers and vendors.

2.3 TOOLING INDUSTRY

Tooling is one of the most critical sectors of the manufacturing industry. It is based on metal cutting processes needed to machine a great diversity of products, utilised by other manufacturing sectors and final customers. Process planning functions and important tooling parameters are examined in the following sections.

2.3.1 Process Planning (PP)

The fabrication of a product usually involves three general stages: *Design, Process Planning* (PP) and *Production Planning and Control* (PPC). PP is a tremendously important phase within the total process of manufacturing a specific product. It is the link that permits the translation of product design specifications into the work instructions needed to obtain a finished product with the parameters of quality, economy and performance required. It is a complex phase, because to design plans for all processes requires a wide knowledge of the plant, operations and equipment. PP will have a significant impact in obtaining successful or undesirable results, during and after the production phase. Some definitions of PP are given below:

Society of Manufacturing Engineers: PP is the systematic determination of the methods by which a product is to be manufactured economically and competitively.

Dagli (1994): PP is the act of preparing detailed operation instructions to transform an engineering design to a final part. *It is the critical bridge between design and manufacture.*

There are many models that intend to define the activities and their correct sequence that must be included in PP. Depending on the application, PP may involve several or all of the activities listed as follows (Usher, 1995).

a) Interpretation of product design data.
b) Selection of machining processes.
c) Selection of cutting tools.
d) Selection of machine tools.
e) Determination of setup requirements.
f) Sequencing of operations.
g) Determination of production tolerances.
h) Determination of cutting conditions.
i) Determination of jigs and fixtures.
j) Calculation of process times.
k) Tool path planning & NC program generation.

Rapid response to market demands, especially in relation to customer satisfaction and costs reduction, is changing current practices in product design and planning functions. One of these changes is the reduction in the gap between design and manufacturing stages. Reduction of the manufacturing cycle time is becoming a primary goal in industrial activities. To meet these important demands, a Concurrent Engineering (CE) approach has been proposed. In CE, a strong emphasis is placed on the role of process planning in the design stage, to reduce lead times and costs. These two stages, product design and process planning, largely determine the minimum cost of the product. Of course, lead time and cost can also be increased at the production management stage. Therefore, process planning should also be matched with production planning (Hale and Weill, 1995). This last consideration is gaining rapid acceptance in the manufacturing community and, for example, the belief that PP does not take into account time and use of industrial facilities is being currently questioned. Because of the intensive integration of manufacturing technology and processes, it is now more difficult to determine the real frontier between two "different" manufacturing stages.

When computer facilities are introduced to improve the efficiency of the activities involved in PP we are in the presence of Computer-Aided Process Planning. CAPP is used in CIM environments to automate the linkage between the design and manufacturing phases of product development (Reimann and Sarkis, 1995).

Important concepts in the metal cutting industry, included as part of PP activities and from the point of view of machining processes, are presented in the following sub-sections.

2.3.2 Cutting Tool Selection

The task of cutting tool selection involves determining all the tools which can be used to machine the features of the part (a geometrical problem), and selecting the optimum set of tools from this list (a technological problem) (Van Houten, 1986). When evaluating potential tools, it is necessary to consider the geometry of adjacent features. This is important to avoid interference from other characteristics of the workpiece during the process of machining the section of interest. Intelligent process planning systems should perform tool selection by considering the features within the profiles defined during setup identification. Based on the characteristics within a profile, selection would be performed by first identifying all tools whose parameters match the requirements of the operation selected for each feature. This list could then be pruned on an analysis of interference between the tooling and the workpiece (Chen and Hinduja, 1988).

In some cases, the geometry constraints of the workpiece and optimisation of parameters such as maximisation of tool life, and minimum costs and manufacturing time cycle, determine the implementation of a *multiple tool selection* approach. Furthermore, when a tool is selected for a determined operation, this selection may be made more than once. Sometimes the machining conditions require the utilisation of the same tool for several operations. *Rationalisation* is another important parameter. It is an optimisation method that acts on a list of eligible tools, in order to apply a new reduction criterion for discarding redundant or unnecessary tools. Several factors can influence the implementation of tool rationalisation methods: the need for reducing tool inventories, the optimisation of the tool life or restrictions to place particular tools on the machine tool.

2.3.3 Cutting Conditions

The determination of cutting conditions for every machining process is an important function in the whole PP scheme. The information concerning cutting conditions that is generated through any method used for establishing these conditions, is known as *cutting data*. The data generated can include feeds, speeds, cut depths and so many cutting parameters as are required. These cutting parameters are the basic control variables for a machining process. F. Taylor conducted the earliest study on the economical selection of cutting parameters, in 1906. As a result of his effort and the later work of many others, machining data handbooks have been developed to recommend process parameters for efficient machining (Chang and Wysk, 1985).

Carpenter (1996) describes three user-defined criteria for cutting data optimisation, which are: maximum and minimum radial usage of the cutter, percentage of cutter cost to amortise across each operation and harshness of cutting data. Moreover, he suggests the following procedure for establishing cutting conditions:

- Select the workpiece material.
- Select the type of operation.
- Select the tool holder.
- Select the tool cutting material.
- Select other parameters such as coolant conditions, tooth coarseness and insert mounting mechanisms and the axial and radial depths of cut.
- Look up the recommended cutting velocity (*v*) and feed per tooth (*Sz*). Often the user must choose a value of *Sz* and the tables then provide a value of *v*.

Alamin (1996) designed a module called Technical Planning of the cutting Operation (TPO) implementing a similar sequence. This module selects tools and generates cutting conditions (turning operations) to perform the machining operation adequately. The main objective was the calculation of initial cutting data.

2.3.4 Tool Life

The most important parameter acting upon tool wear and therefore upon tool life is the cutting speed. However, very low speeds and feeds to give long tool life can be economically inefficient because of the low production rate (Boothroyd and Knight, 1989). A faster metal removal rate will result in both reduced tool life and reduced machining time. However, whenever a tool has been worn past some practical limits, it must be replaced. Therefore there is a trade-off between increased machining rate and machine idle time, which results in frequent tool changes. A tool's useful life is determined by one of two mechanisms: erosion (or progressive wear) and breakage (failures). Failures are usually quite unpredictable and a phenomenon that one tries to minimise. Hence, tool life is usually defined as the cut time a new tool undergoes before a certain flank wear is reached (Chang and Wysk, 1985).

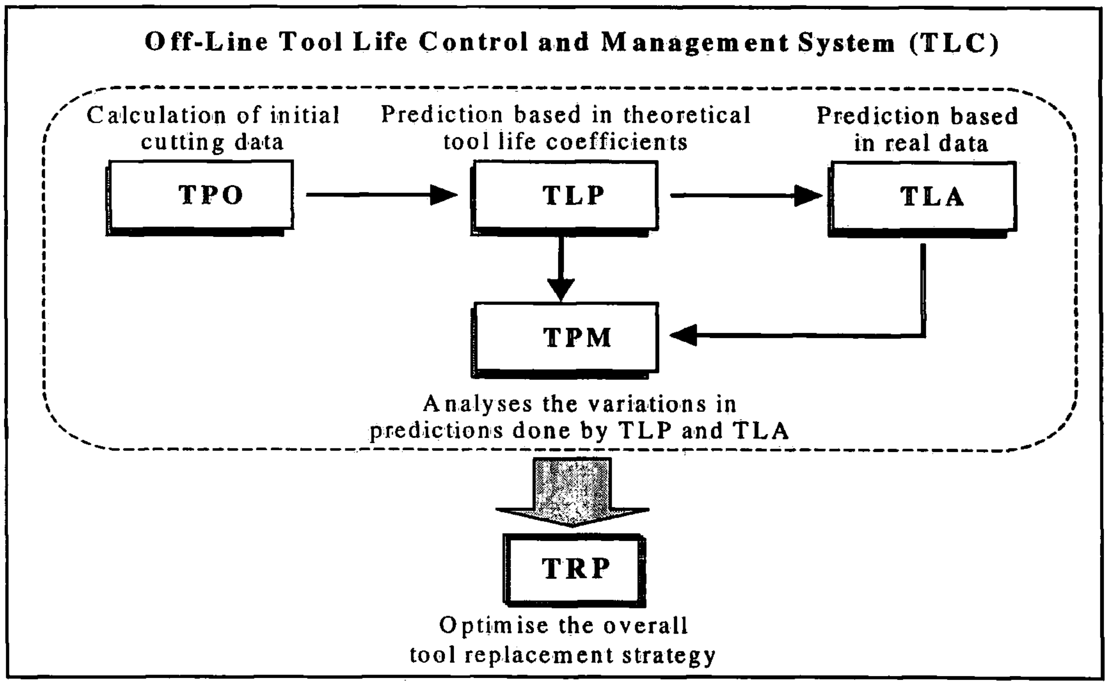

Figure 2.5 Main modules of TLC system.

An off-line Tool Life Control and management system (TLC) designed by Alamin (1996) is shown in Figure 2.5. As can be seen, TLC was conceived on the basis of a gradual integration of tool life considerations.

The system starts with the calculation of tool life based on optimisation of cutting data (theoretical coefficients). Then, using modified real tool life data, an analysis of variations between theoretical and real data follows. Finally, the optimisation of tool replacement strategies supported by wear balancing theory is performed.

2.4 GLOBAL MANUFACTURING SYSTEMS

Trends are focusing on global manufacturing and remote interconnected systems, in which design, manufacturing and final assembly may take place anywhere in the world (global factories). Equipment and computer technologies have experienced significant advances, but there remains the need to develop standardised interfaces and integrated solutions for distributed collaborative work and sharing information environments.

In global manufacturing scenarios, it is highly advantageous to have modular and easily portable systems, able to be installed across multiple and heterogeneous computer platforms. Likewise, computer software should be designed so that it can be easy to modify, extend and transfer. This would enable customisation for various clients, inter-organisational divisions and corporate branches.

Nowadays, the Internet has significantly enhanced the interaction between companies and their respective customers, suppliers and partners, acting as an important platform to deploy open and distributed manufacturing solutions (Park *et al.,* 1993). This exceptional growth has opened exciting opportunities to businesses by providing another way of reaching potential customers. Pant and Hsu (1996) state 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 1980s. It is becoming obvious that the Internet can be used as a computational platform, to integrate multidisciplinary work groups, taking decisions and developing applications in different and distant places. The next chapter will provide a deeper explanation of Internet-based distributed manufacturing approaches.

2.5 SUMMARY

Setting the scene for a chapter that reviews important concepts in manufacturing industry requires a variety of topics to be introduced. The selection of these topics has not been easy, given the breadth of the area and the continuous emergence of new concepts. This chapter has presented the importance and provided an overview of manufacturing systems. It was shown how the value qualities of a manufactured product are given by a wide range of criteria, embracing physical properties of the product as well as services inherent to the purchase. Main problems found in manufacturing are related to lack of employee involvement in design and planning and of management commitment, inadequate production planning, insufficient training in the emerging technologies and software requirements, and lack of company involvement with suppliers (one of the successful practices of Japanese industries). Two important production planning strategies, push and pull, represented by the techniques MRP and Kanban respectively, have also been analysed. The concept of CIM has been examined. CIM means an effective integration of the different manufacturing functions. It is not just a system, it is a complete strategy to provide effective and reliable information flows to internal as well as external areas of the company.

Also, important concepts in the area of metal cutting processes were discussed. It was shown how appropriate tool selection and determination of cutting conditions constitute two important functions influencing the whole process planning activity.

Finally, the increasing influence of networking environments has motivated the introduction of a section related to global manufacturing systems. A deeper explanation of these concepts, particularly under the optic of the Internet, is given in the next chapter.

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CHAPTER 3: INTERNET-BASED INFORMATION STRATEGIES IN DISTRIBUTED MANUFACTURING ENVIRONMENTS

3.1 INTRODUCTION

Due to the continuous evolution of global markets and the fast-growing development of communication technologies, manufacturing industry has experienced a considerable transformation. The changes have forced organisations to adopt agile strategies to improve their competitive position. Computer based methods to support design and planning, and production operations have been essential to improve established practices. These issues were discussed in the previous chapter. The tooling sector constitutes the area on which this research has been focused. Hence, an analysis of process planning tasks and metal cutting processes was also undertaken.

This chapter examines the role of Internet-based architectures and their impact on manufacturing. The first section analyses the motivation for implementing distributed systems in the manufacturing arena. This is followed by an investigation of Internet topics including three-dimensional developments and Intranet/Extranet technologies. Object-oriented models and technical considerations when working on distributed environments will also be discussed. A Web-based architecture for the exchange of information in corporate environments is then proposed. The final section presents a summary of important and recent Internet-based applications.

3.2 DISTRIBUTED MANUFACTURING - MOTIVATION

Efforts to gain a competitive advantage in current manufacturing scenarios characterised by open markets, reductions in trade barriers and global information networks, have led to the emergence of collaborative work schemes and information-sharing platforms in corporate environments.

The arrival of the Internet and its adoption as an international standard has been a decisive factor in implementing world-wide information exchange infrastructures, where experience, knowledge, technical support and remote collaborative work can now be considerably exploited.

The Internet is providing a global communication platform, where geographical distances, languages and time zones do not constitute critical factors in current commerce. Clearly, strategies for information retrieval, knowledge management and sharing remote resources are needed in such information environments.

Important benefits can be obtained when processes are undertaken using a distributed approach: a) efficient access to resources over a geographically dispersed area; b) cheaper information exchange processes; c) closer interaction between the clients and the company; d) major support to assimilate the company's growth; and e) improved distribution of software and hardware resources.

Because of the rapid advances in Information Technology (IT) new paradigms have been proposed to support distributed network environments. Among these are: *Virtual Enterprise* (Ettighoffer, 1992), *Networked Enterprise* (Poulain *et al.*, 1994), *Extended Enterprise* (Browne *et al.*, 1995). More recently, Vernadat (2000) provides a further review about *Networked Enterprise* and introduces *Enterprise Integration* architecture.

According to Vernadat, the Networked Enterprise, be it an extended enterprise or a virtual enterprise, is an emerging paradigm that results from the rapidly changing business environment forcing suppliers and manufacturers to work in a more tightly-coupled mode. Enterprise Integration (EI) consists of breaking down organisational barriers to improve synergy within the enterprise so that business goals are achieved in a more productive and efficient way.

Furthermore, Vernadat identifies some characteristics inherent to this kind of business environment:

- *Globalisation* - most companies must operate in world-wide markets.

- *Parallelisation*, or time-based competition, - simultaneous execution of co-operative tasks to reduce time-to-x (design, engineer, manufacture and delivery).
- *Agility* - the enterprise must be able to react quickly to respond to its changing environment.
- *Virtual enterprise* - an enterprise may use opportunistically activities and competencies from its own or outside its facilities to satisfy a temporary market.

Therefore, the main motivation for EI is to make possible true information and knowledge (not just data) exchange and sharing among heterogeneous, remotely located, systems within, and even outside, the enterprise in a vendor-independent information technology environment.

EI is a closely related paradigm to distributed manufacturing because it is concerned with:

- Support to teamwork or computer supported collaborative work (CSCW) for concurrent design and engineering activities.
- Increased flexibility through the company.
- Interoperability of IT solutions, systems and people to face environment variability in a cost-effective way.
- Computer architectures.
- Computer communication networks.
- Software engineering.
- Database technology.
- Multimedia and hypertext technologies.
- Distributed computing environments.
- Open systems architectures.

Rouibah *et al.* (2000) introduced the concept of *Dynamic Networks* oriented towards the design of complex products in distributed environments across company borders. This dynamic network is conceived to increase engineering transparency, reduce the time spent in PDM (Product Data Management), monitor processes and structure and control information exchange. From a perspective of distributed collaborative work, this dynamic network is defined according to the following characteristics:

- Composed of several enterprises in a distributed environment. Engineering partners must work together within a simultaneous engineering team, across company borders, in a climate of trust.
- Enterprises within the network collaborate to design a complex product that requires a high level of quality, and flexibility. The product complexity cannot easily be handled within only one enterprise. As the complexity is shared within a network, the design requires strict control. The network assumes the participation of partners at early design stages, to exchange ideas, stimulate learning, and support global innovation.

3.3 THE INTERNET AND THE WORLD WIDE WEB

According to Laudon and Laudon (1998), the Internet is a set of technologies, but it also represents a new mindset and a new culture in the information system world, as well as a new role for information technology in organisations. The Internet is the world's largest computer network. It is a global network of hundreds of thousands of other local, regional and national interconnected networks. Increasing numbers of individuals and organisations now access it through commercial Internet Service Providers (ISPs). An ISP is an organisation with a permanent connection to the Internet that sells temporary connections to subscribers.

The Internet opens new communications horizons. It now facilitates international connections that were never before possible, or relatively hard to achieve. Geography and time are no longer obstacles for individuals and business communities to undertake challenges, joint efforts and share remote services. One of the most significant contributions of the Internet is its global influence in multiple disciplines. It is impacting on areas as diverse as education, commerce, military, manufacturing, health, finances and entertainment.

In some areas, tools and implementations based on the Internet are already dramatically changing practice. In 1989, Tim Berners-Lee proposed the World Wide Web (WWW). This became the key application of the 1990s by transforming the Internet into a global, multimedia information service. It was the WWW, which attracted a much broader spectrum of users and led to the explosive growth of recent years. Web pages are the vehicle to deploy distributed systems using the Internet (Klein, 1997). These pages are written in a world-wide standard language known as Hyper Text Mark-up Language (HTML) and lie in a web server where they are accessed by the different users. HTML is based on tags to tell the browser what and how certain content is going to be displayed.

Revere (2000) affirms that one of the fundamental keys to the overall success of the WWW on the Internet is the way in which the gap between different computer architectures has been bridged. A browser may be used as 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. These new technologies provide interactive features to be portable across different platforms. 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. In the manufacturing sector for example, the emergence of CAD-enabled browsers with three-dimensional capabilities is currently expected to support collaborative work and distributed concurrent engineering approaches.

From the millions of people connected via the Internet, very few know how the Internet has evolved. In their book *"Netizens"*, Hauben and Hauben (1997) provide a good historical summary on the origins of the Internet. For a more extended information about the Internet, history and components, please refer to the APPENDIX A.

3.3.1 The Need for Three-dimensional Internet Developments

Web-oriented 3-D interfaces, Web-oriented 3-D languages and 3-D applications (like CAD-enabled browsers) are emerging to help organisations overcome some of the inherent problems with 2-D graphical interfaces. These new products will improve the management of the amount of information available and the well known 'information overloading' problem.

Only a few years after the creation of WWW, 3-D browsers are emerging, making possible a whole new range of applications. 3-D models of objects can be built into Web pages and viewed from all angles. Very complex models can be used, for example, to enhance on-line shopping catalogues, display engineering designs, model complex data sets, or model the layout of a new housing development. Perhaps the most exciting development is the ability to create shared three-dimensional worlds in which communities of people can meet. Users in a 3-D world are represented by avatars (3-D characters), which can move around in the world and interact with the other visitors. The developing capability of the Internet to support sound, and particularly spatially resolved sound within these 3-D worlds, will open up the potential for mass-market applications (Sim and Rudkin, 1998).

Virtual Reality Modelling Language (VRML) is the Internet-established standard for representing and exchanging three-dimensional objects and virtual worlds. VRML is widely being supported by current commercial browsers. For the future, a vast community of 3-D environments is envisaged, with rich social interaction and immersive sensory experiences (Crossley *et al.*, 1998). These 3-D environments, guided by the growing capabilities of the Internet, will impact on current manufacturing practices.

Regli (1997) affirms that as with other technological advances, maximising the economic impact of network-enabled CAD will require bringing new tools to market and seamlessly incorporating them into the workplace. Cultural and business-process issues will affect how strongly the network-enabled CAD paradigm takes hold. Effectively migrating designers and CAD users to the

Internet business model may prove as difficult as was the original migration to traditional CAD.

The performance of 3-D applications on Internet platforms, in terms of download time and speed of response or movement within worlds is dependent on the complexity of the models. A notable performance has not yet been achieved, but the imminent rise in PC performance and memory capacity, together with 3-D cards, will overcome performance issues.

3.3.2 Intranet

Intranet is an internal private network based on Internet and Web technology. One of the most popular uses for Intranets is to distribute corporate information. Through Intranets, companies can make a high variety of information available, such as electronic Web applications, to their employees and partners. This information includes customer profiles, product inventories, policy manuals, training materials, job postings and company telephone directories. Made available in this way, such information is always updated, minimising paper, printing and distribution costs.

The opportunities and key benefits of an Intranet include (Cochrane, 1998):

- Ease of communication.
- Cross-platform functionality.
- Consistent view of information.
- Ease of integration.
- Enabling technology (e.g. for videoconferencing and multimedia).
- Collaboration with partners and suppliers.
- Increased effectiveness of information.
- Relatively low cost of installation.

Intranet technology requires high security levels, particularly in relation to sensitive company information and attacks from external hackers. To avoid unauthorised accesses from outside, firewalls are implemented. This is a piece of dedicated hardware or software running on a router or dedicated host, which is situated between the internal trusted network and the wider world represented by the Internet. Figure 3.1 shows this concept.

Firewalls are installed either on a router or computer at the network interface and fall into two main types, namely packet screens or proxy servers. Packet screens examine each packet passing to and from the internal network. For example, to identify the source or destination IP address. Packets are either allowed through or discarded depending on a set of rules determined by the firewall security policy. Proxy servers work on a different principle and control the type of services which are allowed to be accessed via the firewall, for example, WWW or e-mail.

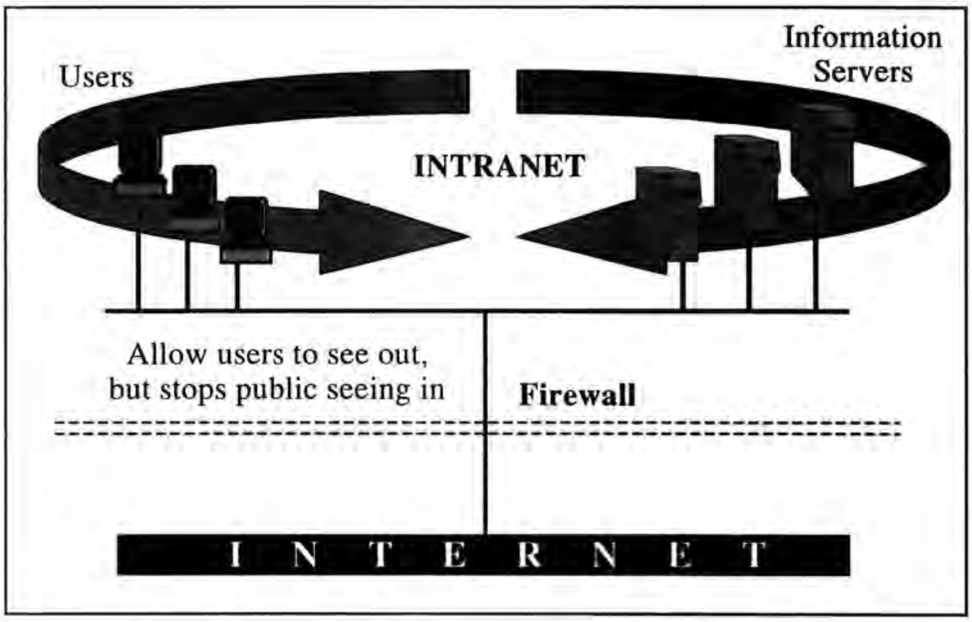

Figure 3.1 Firewall between an Intranet and the Internet.

Proxy servers can be highly secure and can also support strong user authentication. However, they are not very flexible and present proxies do not support new services such as video or multicast (Sim and Rudkin, 1998). Many variants of firewall implementations can be found in Hubbard and Sager (1998).

It is possible to allow limited outside access to internal Intranets. Private Intranets that are accessible to select outsiders are known as Extranets. These are especially useful for linking organisations with customers or business partners. Extranets allow companies to collaborate on joint projects and show specific information to specific clients about their portfolios.

In a sense the Intranet has moved on from being an internal-facing corporate Internet to an enterprise-wide network providing communications at all levels between distributed work groups operating in collaboration.

3.4 DISTRIBUTED OBJECT MODELS

Object Oriented Programming (OOP) is a technique used for organising computational programs under a particular structure. It was conceived to improve the tasks of analysis, design, development and maintenance of computerised applications, with regard to the traditional way of programming (sequential, procedural). OOP techniques were popularised and implemented by the programming language C++ and later other languages and software packages have adopted this methodology.

One of the most remarkable uses of OOP has been the development of languages and architectures for Internet-based distributed environments. The rest of this section will concentrate on three important object-oriented models widely implemented on distributed and Internet-based platforms.

3.4.1 Common Object Request Broker Architecture (CORBA)

The Object Management Group (OMG) is an international non-profit consortium of computer hardware and software vendors. This consortium has created an industrial standard architecture known as CORBA for building distributed and heterogeneous, object-oriented applications. CORBA has been created to define interfaces for interoperable software. When CORBA is used, communication between two computers is carried out by implementing an Object Request Broker (ORB). An object in a program running on a computer (the client) can use the ORB to access the public attributes of another object in some other program, perhaps on a different computer (the server) that is also using the ORB (Cornelius, 1998).

The only job of the ORB is to intercept a call and be responsible for *'finding'* an object that can implement the request, pass the parameters, invoke its method, and return the results. In the case of ORB *'finding'* simply means, having got the desired object reference from some other object, accessing it and discerning the method on that object that suits the parameters. The client does not have to be aware of where the object is located, its programming language, its operating system, or any other system aspects that are not part of an object's interface. A CORBA object has just one interface, which is not necessarily the case in other object models (Briscoe, 1998).

The OMG Interface Definition Language (IDL) is used to define interfaces in CORBA. An IDL interface file describes the data types and methods or operations that a server provides for an implementation of a given object. IDL is not a programming language; it only describes interfaces and it does not have implementation-related constructs. The OMG does specify mappings from IDL to various programming languages, including C, C++ and Smalltalk. (Ming *et al.*, 1998).

3.4.2 Component Object Model (COM)

COM is the foundation of Microsoft's object-oriented technology. In its common desktop variety it is also known as Object Linking and Embedding (OLE). A component in the COM is a binary entity that provides some service that may be used by application software. COM is primarily a specification for how objects and their clients interact through the standard of interfaces. It covers aspects such as interface negotiation, rules for memory allocation and error reporting. A particular design goal and strength of COM is the ability to manage versions of components. COM versions are manifested as multiple interfaces of one component, which have separate globally unique identifiers. Having found a component, a client can quickly establish whether it provides a compatible version of the service required. COM enables programming language independence, but unlike in CORBA, interface interaction is specified at a binary level, which reflects Microsoft's dominance of a single CPU architecture (Intel®)(Briscoe, 1998).

DCOM (Distributed COM) and ActiveX are two varieties of COM for the technologies that enable interoperability across networked Windows-based applications and the Internet.

3.4.3 Java

Java is a distributed object-oriented language providing cross-platform portability, suitable to support the development of Internet-based systems. The Java programs can be categorised into two groups, *Applications* and *Applets*, depending on their purposes. *Applications* are programs oriented to provide stand-alone solutions running in a local client-computer, as well as distributed solutions using a suitable API to establish communication and database access through the Internet. *Applets* are programs that can be downloaded from the WWW using a Java-enabled browser, and can be executed inside an HTML Web page. They are dynamic, interactive and can be used to create full multimedia applications involving text, audio, graphics and animations.

The design of *Applets* imposes the following restrictions:

- *Applets* cannot execute any other application on the user's system.
- They cannot have access to any storage on the client-computers; for example, they can not 'peek' at their files or delete the contents of their hard disks.
- *Applets* cannot make network connections to any machine other than the system containing the original Web page (the Web page that invoked the *applet*).

The most significant advantage of Java is that applications conceived in its programming environment can run in different platforms irrespective of where the application was developed (platform independent), always provided that these platforms have the Java virtual machine (Java Bytecode or Runtime Interpreter) installed. Figure 3.2 shows the differences between traditional compiled programs and Java-based approach.

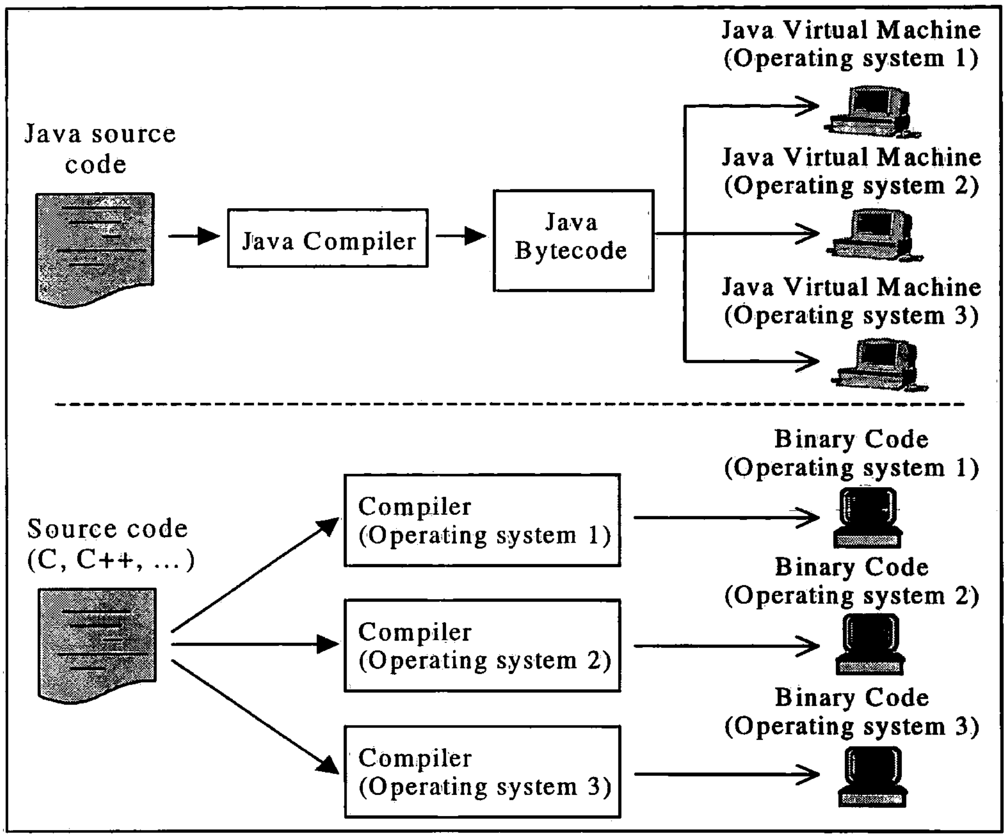

Figure 3.2 Traditional versus Java-based compiling approach.

The Java development environment has two parts, a Java compiler and a Java runtime interpreter. The Java compiler takes the Java source code instructions and, instead of generating machine codes (as most other languages) it generates *bytecodes*. Java bytecodes are a special set of machine instructions that are not specific to any one processor or operating system. For *Applets*, the bytecode interpreter is built into every Java-enabled browser. For Java *Applications*, it is necessary to have the interpreter installed in the respective system where the program will be running (Lemay and Perkins, 1997).

In future, because of the accelerated growing of Java-based applications, it is expected that the Java virtual machine will be built into every new operating system and Web browser.

Java will be a critical tool for distributed Internet programming. It enables the creation of novel platform-independent software tools, systems and agents. These capabilities are similar to those of CORBA and COM previously discussed, but not directly comparable. Java is a next-generation programming language, while CORBA and COM are general-purpose communications and interoperability infrastructures (Regli, 1997).

Having discussed three of the most influential distributed object models, the next section addresses important issues in relation to distributed and remote information exchange.

3.5 TECHNICAL ISSUES

Any service deployed on the Web can be classified in terms of the degree to which its user interface is specific to a particular domain. There are four levels of criteria (Tian *et al.*, 1997):

Level 1: Simple-publishing applications, including hand books and catalogues.

Level 2: Multimedia or heterogeneous publishing applications.

Level 3: Applications that treat documents as user interfaces.

Level 4: Applications in which the web acts as a software delivery vehicle.

This research is concerned with the deployment of distributed services in the 4th level. Therefore, because of the variety and heterogeneity of the issues involved, the following considerations are addressed.

A Standards

Manufacturing industry is based on an extensive use of automation and technologies and it has an active participation in the current globalisation processes. Furthermore, work groups are joining to facilitate the tasks of design, assembly and supervision from geographically alienated locations. Hence, there is an urgent need to create globally acceptable standards to support this dynamic and remote information exchange environment.

Standardisation is concerned with technical, commercial and political problems. World-wide acceptance, in this aspect, is slow and progress to date has not been as great as expected among international business community.

Extensive research has focused on standards for product models. Information protocols such as the Standard for the Exchange of Product (STEP) and CORBA are being developed so that geographically dispersed companies can collaborate on design and manufacturing. The STEP standard for product modelling is regarded as one of the most ambitious international standards initiatives ever conducted. Industry is strongly promoting this effort (Giachetti, 1998). Some other products are also gaining a considerable world-wide acceptance, but still they cannot be considered as world-wide industrial standards. The Java language, the products derived from the interoperability between CORBA and DCOM and SQL-based DBMSs are examples of these products.

B Security and Privacy

The widespread use of networks and the Internet has raised new ethical questions for information systems. Measures to keep the confidentiality of private information sources include the creation of security levels (hierarchical access), encrypted passwords and firewall programs (already explained in section 3.3).

According to Hubbard and Sager (1998) there are many potential security problems associated with connecting a business to the Internet. Some of these are: a) hackers attempting to gain unauthorised access to internal computing resources and also trying to prevent legitimate users, from using those resources; b) competitors attempting to impede or to spy on the business electronically; and c) a bad security breach on a machine holding customers' information leading to the possibility of expensive legal action against the business.

Electronic commerce is one of the most evident environments requiring high-level security mechanisms. The confidence in that environment, or the lack of it, will be a crucial factor in deciding its success or failure. Possibly the most important techniques available today to generate that confidence fall within the spheres of cryptography. Cryptography aims to achieve two essential, but independent, goals. The first of these is to ensure the confidentiality of data on an open network. The second is to ensure the authenticity of that data (Phoenix, 1998).

Development in technologies of encryption and authentication will be critical to the realisation of network computing in a variety of ways. Encryption will be necessary to support storage of personal data at remote sites, to authenticate software to be downloaded from or accessed by network servers and to support authentication of clients accessing Extranets of linked organisations (Revett *et al*, 1998).

C Bandwidth and Cache-Web

In WWW technology, the bandwidth is often a bottleneck. Cache-Web is the simplest cost-effective way to achieve a high-speed memory hierarchy. The idea is to improve the spatial and temporal locality of the information. In order to gain the best Internet performance, Cache-Web optimal replacement methods should be carefully and precisely adopted.

In general, a replacement policy specifies which information should be removed when new information is entered into an already full cache, and should be chosen so as to ensure that data likely to be referenced in the near future is retained in the cache. The replacement policy's goal is to make the best use of available Internet resources, including memory space and network bandwidth. Preliminary studies of this issue can be found in (Aguilar & Leiss, 2000), (Dilley & Arlitt, 1999) and (Krishnamurthy & Wills, 1999). Availability of high-bandwidth connections would give developers greater flexibility in applications design and would support the delivery of networked multimedia applications.

D Database Technology

The movement away from centralisation towards distribution of computing resources and the growth of computer networks has spawned a trend towards *distributed* and *replicated* databases. With a distributed database, a complete database or portions of it can be maintained in more than one location. With a replicated database, a central database can be duplicated at all other locations (Laudon and Laudon, 1998).

Another important aspect under intensive research is the storage of complex three-dimensional representations, audio, full-motion video, images and text, together in a single application. Object-oriented and hypermedia databases are emerging to support these capabilities.

In the arena of RDBMSs (Relational Database Management Systems), Java-based approaches currently allow the implementation of good solutions. For instance, JDBC (Java Database Connectivity) is a Java API[1] for executing SQL[2] statements. It consists of a set of classes and interfaces written in Java. JDBC provides a standard API for database developers and makes it possible to write database applications using a pure Java API.

Using JDBC it is possible to write a program to access different relational databases without having to re-write a different program for each one of them. One can write a single program using the JDBC API, and the program will be able to send SQL statements to the appropriate database.

JDBC extends what can be done in Java. For example, with Java and the JDBC API, it is possible to publish a web page containing an applet that uses information obtained from a remote database. Alternatively, an enterprise can use JDBC to connect all its employees (even if they are using a conglomeration of Windows, Macintosh, and Unix machines) to one or more internal databases via an Intranet (Hamilton *et al.*, 1997).

In 1990 the SQL Access Group defined the Call Level Interface (CLI) as a standard for accessing databases. To implement CLI, it is necessary a connector (commonly named driver). This driver translates a CLI call into the language used to access a particular database. For example, Open Database Connectivity (ODBC) is an API for Microsoft Windows that implements an extended version of CLI. There are different types of drivers to access databases using the Internet. Currently, there exist four of these (Hamilton *et al.*, 1997) shown in Table 3.1.

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[1] API: Application Programming Interface.

[2] SQL: Standard Query Language.

Table 3.1 Driver categories for database access using JDBC.

Driver Category	Pure Java	Needs to load code on user machine
1.- JDBC-ODBC Bridge.	No	Yes
2.- Native API as basis.	No	Yes
3.- JDBC-Net.	Yes	No
4.- Native protocol as basis.	Yes	No

1. - JDBC-ODBC Bridge driver: This provides JDBC access via an ODBC driver. The driver requires prior installation of client software on each user's computer.

2. - Native-API partly-Java driver: This kind of driver converts JDBC calls into calls on the client API for a range of DBMSs. As does category 1, this driver also requires software installation on user's computer.

3. - JDBC-Net pure Java driver: This driver translates JDBC calls into a DBMS-independent net protocol, which is then translated to a DBMS protocol by a server. The specific protocol used depends on the vendor. The driver does not need software installation on the user's machine.

4. - Native-protocol pure Java driver: This kind of driver converts JDBC calls directly into the network protocol used by DBMSs. This allows a direct call from the client machine to the DBMS server and is an excellent solution for Intranet access.

E Knowledge Capturing Systems

Thanks to recent advances in information and communication technology, the manufacturing community is moving from highly data-driven environments to a more co-operative information/knowledge-driven environment. The ability to manage knowledge as a result of analysing vast amounts of raw data is emerging as an important and fast-growing discipline named KD (Knowledge Discovery).

Two main factors lead the application of knowledge engineering approaches to data-rich scenarios. First, as a consequence of the multiple processes and operations that take place in the manufacturing industry, large amounts of raw data are continuously generated and stored for later, varied purposes. Secondly, decision-making processes are better supported through available knowledge than raw data.

3.6 NETWORKED INFORMATION MANAGEMENT

Nowadays, distributed manufacturing schemes are primarily based on networking computing. Network computing is a new approach to computing in which all information, data and software applications are stored remotely by servers in the network and downloaded on demand by users. Unlike mainframe computing the application is executed locally. Unlike PC computing, the application is stored in the network and not on the local machine. The main advantages of network computing are reduced version management, and rapid access to new application and services (Sim and Rudkin, 1998).

The increasing use of the Internet, particularly the WWW, represents the first steps on the most likely evolution path towards network computing. It has begun to show the enormous possibilities offered by widespread access to remote information sources and services.

A typical Web-based architecture to deploy multiple services to remote users is shown in Figure 3.3. The different applications are developed and published in a web-server, where remote users access these applications depending on their level of involvement on the type of service provided.

To provide a wider range of services and applications in distributed environments, a Web-based architecture for remote information exchange is currently being proposed (Velásquez *et al.*, 2000). Figure 3.4 shows this architecture. It is evident how the definition of connectivity functions, as well as database technology considerations, play a crucial role for performing manufacture support operations using the Internet.

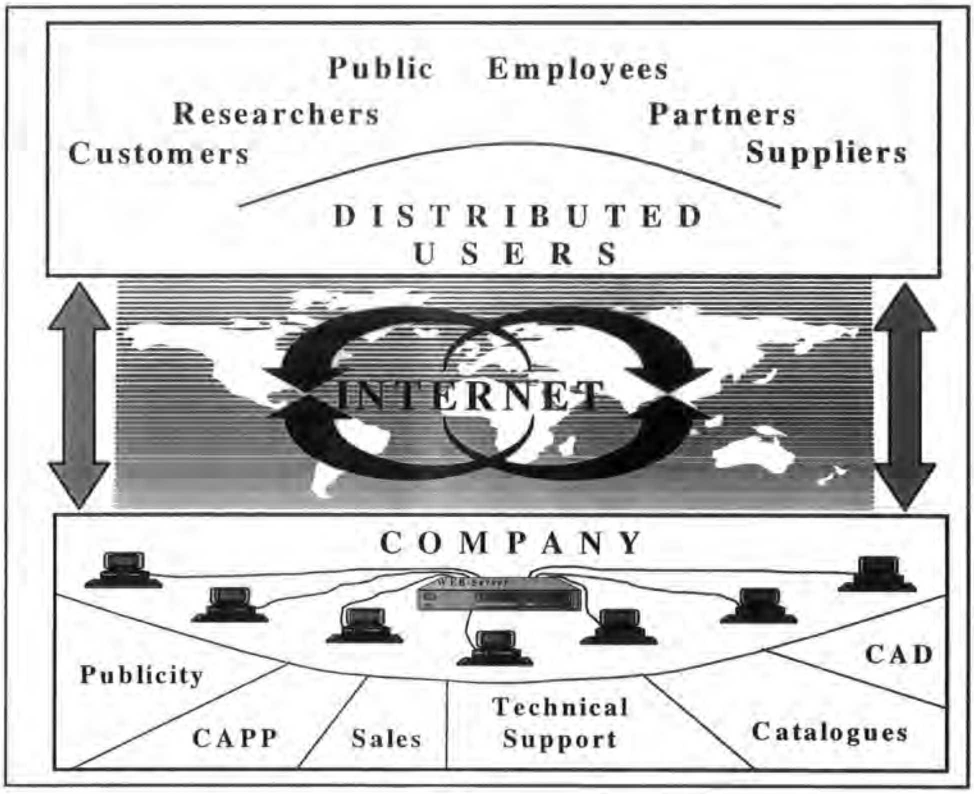

Figure 3.3 A simple Web-based distributed architecture.

The architecture relies on integration of corporate information, distributed on databases having the same internal structure but different data, along geographically dispersed branches. The convenience of sharing information of mutual interest to internal users (employees and partners) as well as external agents (suppliers and customers) working in a platform-independent architecture and controlling data security aspects, constitutes its main advantage. Also, it considers distributed access and centralised data management for those industries having a common platform or a low number of interconnected branches, providing a flexible work scheme.

The last approach (centralised data management) would eliminate the problems associated with fragmented databases requiring regular updating whilst also allowing distributed access for effective remote updating processes.

The connectivity aspect is covered by the utilisation of 100% pure Java-drivers, hence, the problem of asking the users to download and configure the driver is eliminated.

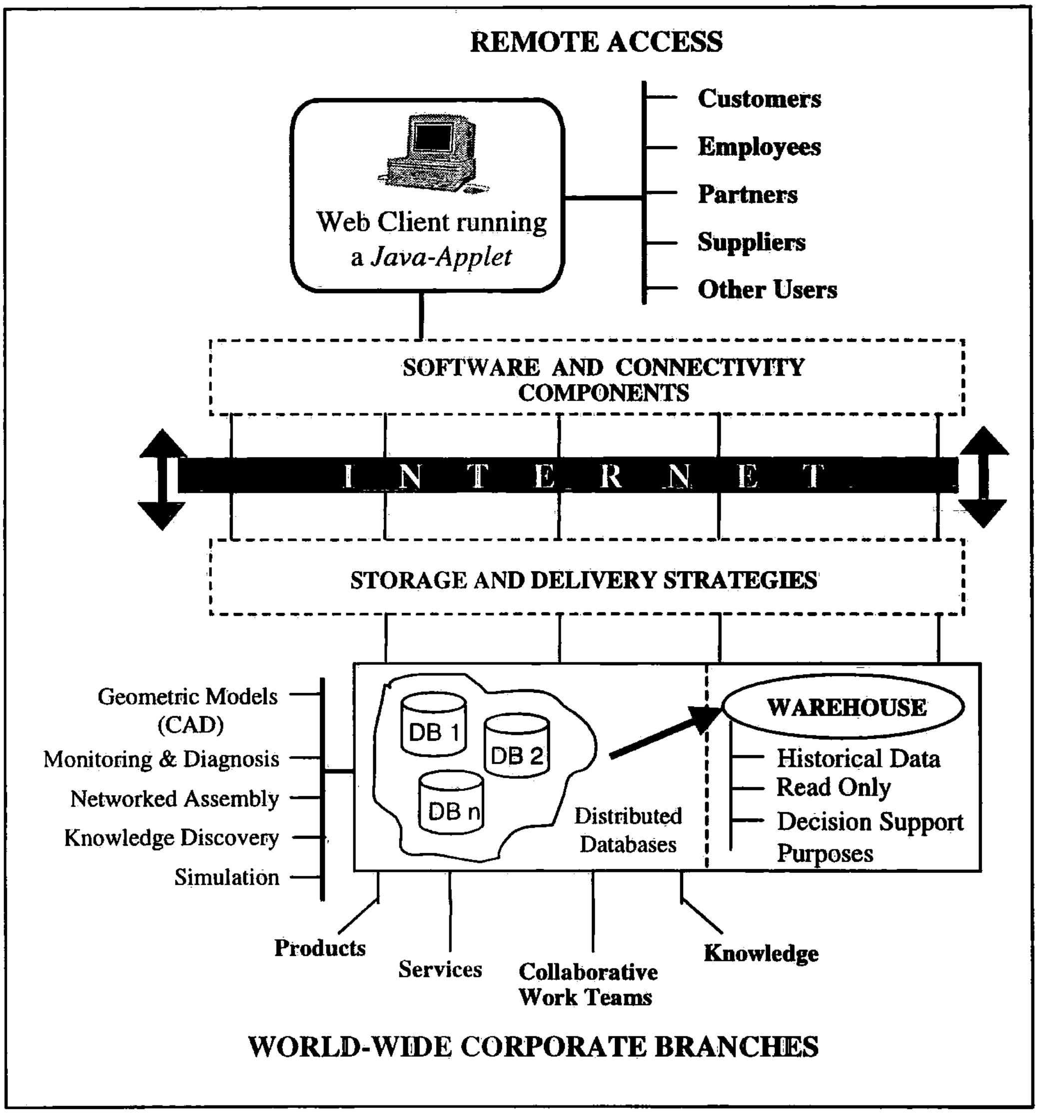

Figure 3.4 A multi-services Web-based distributed architecture.

All users have the option to establish a link to the required sites and databases of interest, accessing the data from remote locations using conventional browsers in the case of *Java-applets*, or otherwise executing *Java-applications*.

Although the data and Web services can co-exist in the same server machine, the best results are obtained when there are different servers working to deploy Web and database services separately. In this way, the data are stored in a database server and all the net services are the responsibility of an exclusive Web server, establishing a load balance between the data and Web access management.

The architecture proposed here considers a corporation having branches in widely dispersed places. In this context, as can be seen in Figure 3.4, three main functions have been defined, which are discussed as follows.

i) Free Information Sharing

This philosophy is ideal when companies wish to share information about products, services and operations with their customers or when employees of the same company in remote branch locations need to exchange information. It is an open solution, because there are no restrictions about the information that is going to be accessed.

Remote users can interact with the system entering input requirements and obtaining answers to their queries. The users only need any available commercial browser to download Java-applets. Also, all Java classes would be stored in the local user machines, to speed up the download operations.

The implementation of Internet-based strategies for delivering and exchanging information about product and services to widely distributed customers will overcome the well known problems in relation to the use of conventional representation (paper-based) and distribution (regular mail) mechanisms.

The financial implications are clearly favourable. For example, the savings in costs would be considerable, particularly when massive amounts of technical catalogues and information about products and services have to be sent to remote customers. Further benefits include instantaneous updates, better visualisation facilities (3-D and multimedia) and a higher participation of market.

ii) Knowledge Capturing Systems

Furthermore, within the business goals of the company, this architecture considers the implementation of knowledge capturing systems in an attempt to discover previously unseen relationships within the data, an expanding and relatively promising new area known as *Knowledge Discovery* (see chapter 5).

iii) Collaborative Work

Other benefits arise when this infrastructure is utilised for allowing distributed collaborative work, especially in concurrent engineering environments where CAD/CAM activities are carried out.

Geometric modelling, monitoring and diagnosis and networked assembly are some useful functions that would be implemented. In a product-manufacturing scenario, once the geometric model is designed, it will be sent to a geometric file translation server to perform file conversion. A collaborative module would then provide all participants with a virtual collaborative environment to view the converted VRML[3] created, and to perform communication via the Internet. Finally, after performing collaboration, the designer could send the new design part to a manufacturing module for process planning.

In this kind of collaborative work environment, the emergence of Internet-enabled CAD browsers is expected to improve the current capabilities of conventional browsers, particularly in relation to efficient 3-dimensional object manipulation and representation.

Table 3.2 Comparison of information management systems (Davies and Revett, 1998).

	Automatic query generation	Query enhancement	Use of user profile	Profile adaptation	Information extraction	Automatic information sharing	Automatic informaion categorisation	Proactive information management
Jasper			•	•	•	•		•
ProSearch		•	•	•				•
nDir			•				•	
RADAR	•			•				•
ProRate			•	•		•	•	•

[3] VRML, Virtual Reality Modelling Language, is the industrial standard of non-proprietary file format for displaying scenes consisting of three-dimensional objects on the World Wide Web (Ames, Nadeau & Moreland, 1997).

The market for networked information management is growing quickly, and the technology is very dynamic. Organisations are increasingly realising the importance of using knowledge and information residing in their networks for competitive advantage and they are developing their own systems. For example, Table 3.2 shows five information access systems developed at BTL (British Telecommunications Laboratories). A more extensive description of this systems can be found on Davies and Revett (1998).

3.6.1 Networked versus Centralised Systems

Networked systems are the core of distributed environments. Schroeder (1993) established an outstanding comparison between distributed versus centralised systems. Networked systems allow the sharing of information and resources over a wide geographic and organisational spread. These allow the use of small and cost-effective computers and can grow in small increments over a large range of sizes. Such systems allow a great deal of autonomy through separate component purchasing decisions, selection of multiple vendors, use of multiple software versions, and adoption of multiple management policies. Finally, they do not necessarily all crash at once. Therefore, in the areas of sharing, cost, growth, and autonomy, networked systems are better than traditional centralised systems.

In contrast, centralised systems in some aspects operate better than today's networked systems. All information and resources in a centralised system are equally accessible. Functions work the same way and objects are named the same way everywhere in a centralised system. It is easier to manage. Hence, despite the advantages of networked systems, centralised systems are often easier to use because they are more accessible, coherent and manageable.

However, for Internet-based applications, a centralised approach imposes some problems and becomes a bottleneck, particularly in relation to the heavy traffic of transactions generated when a unique centralised information repository is accessed. For instance, when communication with the central database cannot be established, the users are unable to take benefit of the data.

In the areas of security and availability, the comparison between networked and centralised systems produces no clear-cut advantage for either. A state-of-the-art distributed system will combine the accessibility, coherence and manageability of centralised systems with the sharing, growth, cost and autonomy advantages of networked systems.

3.6.2 The Role of Collaborative Virtual Environments (CVEs)

A Collaborative Virtual Environment (CVE) is a distributed, virtual reality that is designed to support collaborative activities. As such, CVEs provide a potentially infinite, graphically realised digital landscape within which multiple users can interact with each other and with simple or complex data representations. CVEs are increasingly being used to support collaborative work between geographically separated collaborators (Churchill and Snowdon, 1998).

In the context of product development "virtual organisation" is a strategic concept, which enables two or more organisations with complementary core competencies to jointly develop new products irrespective of departmental or organisational boundaries and geographical location (Wahab and Bendiab, 1997).

According to Hamel and Wainwright (1999), a virtual corporation is a temporary partnership of independent organisations and/or individual suppliers of specific goods and services, who are linked through modern telecommunication to exploit and profit from rapidly changing business opportunities. This corporation is called "virtual" because it is composed of partners of core competence and has neither a central office nor hierarchical or vertical integration.

Virtual Reality (VR) interaction techniques offer a significant step forward in man-machine communication, beyond graphical WIMP (Windows, Icons, Menus and Pointer) based interactive systems (Pimentel and Texeira, 1994). The implementation of highly immersive VR techniques in the manufacturing industry is still the subject of much research (Taylor, 1995). However, some concepts derived from VR technology have recently been applied to the industrial arena, supporting virtual manufacturing activities.

The advantages of using virtual reality for distributed environments and engineering applications are considerable. Geometrical models of the product component, for example, can be imported into a virtual environment and material and texture information added to enhance their visual presentation. Visualisation within a virtual environment is three-dimensional and the complexity of the geometrical objects can be handled efficiently to enable real-time interaction. Virtual prototyping, assembly and simulation are important applications for virtual reality (Sastry and Boyd, 1998).

3.7 DISTRIBUTED MANUFACTURING CONTRIBUTIONS

SIMNET is a project that aims to develop methods and systems that manage the links between product data and process data (workflow) within the philosophy of a dynamic network, as explained in section 3.2.

The dynamic network used as the test case is composed of several hundred engineers from Siemens SGP and six of its suppliers. These engineers exchange information in a collaborative and distributed networked environment, to design and develop "bogies" for passenger railcars. A *bogie* is a particular complex product. The Wheel-Set and Drive Units are manufactured by Siemens SGP at Graz. However, the *bogie* brake system components are designed at three different sites within the Knorr-Bremse group (Munich, Budapest and Mödling).

In the arena of concurrent engineering Chang *et al.* (1999) have developed a WWW-based collaborative system for integrated design and manufacturing. The proposed system is composed of three modules, collaboration, design and manufacturing. Their collaboration module is WWW-based platform independent and provides a virtual collaborative environment for a part designer to perform on-line communication with customers and manufacturers via the Internet. All participants in the collaborative environment can view and manipulate the solid model of the design part, as well as discuss their concerns on-line interactively.

In the area of Intelligent Manufacturing Systems (IMS), Ming *et al.* (1998) have presented a CORBA-based agent-driven methodology for representation, acquisition and processing of distributed manufacturing knowledge. Sirisawat and Duffill (1997) investigated how Intranet applications are becoming more attractive to manufacturers who need to use the Internet internally. An object-oriented framework for developing distributed manufacturing architectures was proposed by Kádár *et al.* (1998). In this work, distributed manufacturing architectures are examined from the point of view of *multi-agent* systems.

Although the term *agent* is used frequently, it is not easy to find a universal meaning, definition and structure, especially when used in different contexts. Ming *et al.* (1998) suggested that an *agent* is an entity that can perform some tasks and achieve the predetermined goal autonomously. According to this definition, human experts, intelligent CAD systems and intelligent machining cells are all agents of an Intelligent Manufacturing System (IMS).

Reviewing applications of multimedia technology in manufacturing, Gunasekaran and Love (1999) affirm that if multimedia is used effectively, it can support important emerging concepts as virtual enterprises and agile manufacturing. In this context, the World Wide Web has become an important recourse as an information multiplier resource.

Smith and Wright (1998) proposed to take advantage of WWW technologies to provide a design-to-fabrication system, through the development of a tool called *CyberCut.* This system consists of three major components: a) computer-aided design software written in Java and embedded in a Web page; b) a computer-aided process planning system with access to a knowledge base containing the available tools and fixtures; and c) an open-architecture machine tool controller that can receive high-level design and planning information and carry out sensor-based machining processes.

The scope of the above system was extended by Brown and Wright (1999), who developed *MAS* (Manufacturing Analysis Service), which is an Internet-based engineering reference tool. The service is intended to support four possible scenarios:

- To check suitability for manufacturing using the *CyberCut* system.
- To provide an educational resource on the most popular manufacturing processes.
- To inform the designer how to best alter a preliminary design to ensure manufacturing applicability of a predetermined process.
- To determine the most appropriate manufacturing process for any designed part.

MAS is essentially comprised of two major elements: a collection of Web sites containing in-depth descriptions of the most common manufacturing processes, and an interactive graphical user interface (GUI) to allow input of the details of the part design.

3.8 SUMMARY

The motivation for implementing Internet-based distributed manufacturing approaches was analysed in this chapter. Important benefits include an efficient access to resources over a geographically dispersed area and an improved distribution of software and hardware resources.

An overview of the main topics concerning the Internet and the WWW was also presented. Web-based distributed manufacturing is becoming a reality for many companies, especially networked corporations or enterprises involved in CAD/CAM activities and large supply-chains. Information integration from geographically dispersed locations is both an organisational problem as well as a technological problem. The organisational problem is a never-ending process, mainly because the enterprise is in a permanent process of change. The technological problem has been the focus of intensive research over the last decade, based mainly on distributed architectures, data exchange formats, object-oriented software, independent computer platforms, security and standardisation issues. In relation to the implementation of Web-based strategies to support information integration in corporate environments, this chapter has mainly concentrated on the investigation of technological issues rather than organisational problems.

As Internet-oriented 3-D technologies become more commonplace in organisations, new potential applications are certain to arise. Particularly, information representation, information sharing and virtual social interaction will increase rapidly. All these improvements will impact on the way in which remote work groups are collaboratively joining efforts to design, manufacture and validate new products.

Three distributed object models currently being widely used by the business community have been discussed. Also, important technical issues were analysed. It was found that a major obstacle to large-scale and efficient deployment of information using an Internet-based infrastructure, is the need for world-wide acceptance of crucial standards to emerge. Furthermore, security, knowledge discovery and database technology, were considered of major concern.

An Internet-based architecture for remote information exchange has been was proposed and discussed. Important considerations were addressed regarding networked information management environments. Particularly a comparison between distributed versus centralised systems and the fast-growing role of Collaborative Virtual Environments.

Finally, recent Internet-based distributed applications were reviewed. They have provided a wide panorama of the different ways in which distributed solutions would be implemented in the manufacturing industry. It has been noted how Web-based strategies play a predominant role in the development of current solutions.

In the next chapter, a Web-based distributed solution for the manufacturing tooling industry will be proposed.

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CHAPTER 4: A DISTRIBUTED ENVIRONMENT FOR TECHNICAL TOOLING SOLUTIONS

4.1 INTRODUCTION

The previous chapters in this thesis have introduced the conceptual basis for the implementation of distributed solutions in the manufacturing arena, specifically in tooling. Furthermore, an overview of manufacturing systems, process planning, metal cutting processes, distributed systems and their application in industry has been given. This chapter focuses on providing a distributed solution for manufacturing industry. To this end, an Internet-based system has been developed and its functionality is presented.

This chapter will investigate the needs of manufacturing industries in terms of tooling, technical support and logistics in process planning. It will also review available technical support from tooling manufacturers to help clients with process planning.

4.2 BACKGROUND TO TOOLING APPROACHES

Manufacturing industry is strongly supported by tooling operations, which are needed to machine the components used to make products. For this reason, the range of tooling available to industrial machinists is growing rapidly. The advance of technology and the increment of more demanding markets require more sophisticated processes and tools for machining tasks. Engineers therefore need more advanced systems in process planning to support the decisions that have to be made to achieve smooth operations in the production process. This section examines the needs of industry for decision support systems to provide tooling engineers with updated product information that can be used in the planning stages as well as dealing with problems encountered during production.

4.2.1 Needs from Manufacturing Industry on Tooling, Technical Support and Logistic sectors.

To assess the needs of the tooling sector, specifically in areas of tooling performance, technical support and logistical considerations, a survey of manufacturing companies has been undertaken (Revere, 2000).

This process was carried out through visits to companies in the Northeast region and a mail shot to the rest of the United Kingdom. The results were presented in terms of needs and priorities.

- *Results for Tooling performance requirements.*

⇒ In terms of material machinability, companies experience few problems when assessing the machinability of the materials they use.

⇒ Companies spent a short time selecting tooling and cutting data and encounter few problems when performing these activities.

⇒ The number of problems associated with the task of predicting tool life were high.

⇒ Companies attributed a high importance to material removal rate, set-up time reduction and tool variety reduction.

- *Results for technical support requirements.*

⇒ The frequency of technical queries from companies to tool manufacturers was quite high whilst the variability of these queries was relatively low. This indicates the industrial need for technical support from tooling manufacturers.

⇒ The time taken to receive technical support from tooling suppliers was regarded as important.

⇒ Employee experience is low when it comes to machining new materials.

⇒ Companies rely heavily on their own employees experience when dealing with tool selection, cutting data selection and tool life prediction activities.

⇒ In terms of the services provided by tooling companies (tool catalogues, technical guides, tooling engineers, telephone technical support and software systems), tooling engineers are regarded as being very important.

- *Results for logistics requirements.*

⇒ The cost of purchasing new tooling, the additional tooling inventory generated and the unclear benefits of adopting new tools were the most significant factors for the companies when a new product is introduced.

⇒ The cost of dealing with obsolescence is very high. It is expensive not only in terms of purchasing new tooling but also in evaluating the required cutting parameters needed to be able to adopt new tooling.

⇒ Companies found that it is difficult to justify changes from old tools to new ones when new tools are in general more expensive and improvement in performance is limited or not clear.

⇒ Companies indicated that they experienced 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.

From the results of this survey, it was ascertained that there is a need for better technical support to help the industrial manufacturer in process planning, especially when machining new materials. One of the most important results addressed by this survey was the necessity for implementing more accurate methods to demonstrate improvement of adopting new tools introduced to the market. These procedures must prove clearly the benefits that can be obtained in terms of costs, tool life or productivity when new products are used.

4.2.2 Technical Tooling Systems

In an effort to minimise company's problems associated with process planning activities, some technical tooling support systems [(Sandvik Coromant, 1997), (Iscar Tooling, 1997), (Velásquez *et al.*, 2000), (Seco Tools, 1998) and (Datos, 1998)] have been developed. These assist users of cutting tools in the tasks of tool component and cutting data selection.

In order to assess the applicability of these systems, a study of their functionality was undertaken. As a result, it was found that these systems are well developed and provide the user with a simple way of identifying a specific item of tooling. Furthermore, ample provision is made for the identification of physically compatible tooling, based upon considerations of the machine tool, the machining operation, the component geometry and material type.

At the opposite end of the spectrum, it was noted that the software only supplies information for the most common operations and workpiece materials. The methods used to calculate the machining parameters are highly simplified. The databases of tooling and the algorithms, the two most important components to calculate the cutting parameters, are very similar to those provided in catalogues. As a consequence, the answers supplied are very similar to those encountered in catalogues, which have been proved to be very conservative.

In an effort to compete in the market, tooling manufacturers maintain a constant process of research and development to provide their clients with better solutions for performing their processes. The original databases for tooling are constantly being updated with information about new products, optimised data for existing tools or elimination of obsolete ones. The providers of these systems do not give enough consideration to the updating of the databases in order to maintain current records. One disadvantage of these products is that both the data and the algorithms are revised yearly. The users of such software will only obtain the modified databases with the release of new versions of the program.

From all these considerations it can be deduced that some of the most important tooling software available to assist in the process-planning tasks do not satisfy companies current requirements.

4.2.3 JadeT: A Tooling Assistant Prototype System

The previous section has briefly discussed the strengths and weaknesses of existing technical support to companies in the arena of process planning. An alternative prototype project for tooling assistance is presented below.

Tool manufacturer engineers around the world constantly generate considerable amounts of tooling data for industrial machinists. These data are the result of tool trials carried out by tooling engineers in clients' companies. These tests incorporate:

- a request from industrial machinists to solve specific problems when using a tool;
- a performance study of new products of the tooling manufacturers; and
- a comparison of performance (in terms of cost and productivity) between the tool being used by the industry machinist and the tool proposed by the tooling engineer.

The aims are to:

- provide technical support to clients in solving problems presented by the use of specific tools;
- improve the operational methods by offering clients optimal tooling data according to their productivity goals;
- supply alternative tools to clients by promoting the products of the company and demonstrating better performance against traditionally used tools from competitors companies; and

- introduce new products to client companies by illustrating the profits that can be obtained with the use of these new tools. This also helps with the removal of obsolete tools from the market.

First, the tooling engineer defines the requirements of the trial and performs an initial test within the parameters being used by the machinist of the client company. Secondly, the engineer analyses the results and undertakes new tests with proposed alternatives. Finally, he/she makes a comparative study between the initial and the proposed tests in order to obtain cost, tool life and productivity values for the trials. These tests take place in client companies and the data are registered on specific forms designed by tool manufacturers.

Some operational and strategic problems can be identified when the tool trials data are generated.

- In many cases the results are registered manually on paper-based formats.

- The information generated in a particular test is not easily shared with others due to the difficulties of physically locating particular reports of interest.

- Information requests in relation to previous tests can not be addressed immediately, particularly between engineers located in geographically dispersed areas.

- It is not easy to obtain information about previous tests when the user is interested in only a few relevant parameters.

A system capable of storing the data generated from these tests could be seen to assist not only in the task of performing new tests but also help in process planning and research activities.

To prove the feasibility of this idea, an initial prototype was developed by Revere (2000). The two main issues to be addressed by this pilot project were first, the creation of a database for the tooling data and secondly, testing the remote communication between the system and the database through submission and data retrieval operations. This prototype was called JadeT (Java Assisted Development for Engineering – Tooling) and it was able to perform submission of the data in text fields as well as execute basic and advanced queries to the database. This system also enabled direct database access from remote locations using the Internet as a means of delivery of information.

Because of favourable results obtained from this first approach (in terms of submission and retrieval of the data using a stable communication between database and application) a formal and complete version of the system was developed. This was aimed of sales engineers and authorised people who perform the tool trials and use the data generated by the tests.

Before the system was developed, an exhaustive analysis of the prototype was carried out. The idea was to determine the weaknesses and strengths of the system. The results of this study suggested the consideration of the following issues.

- **A better structure of JadeT:** The structure of the database must be optimised. This will provide easier and better management, access and transformation of the data. It would be very useful to analyse the paper-based forms and balance the requirements of data for future applications with the available information in actual reports.

- **A good interface with the users of the system:** The new system will need a simple, more friendly interface, and one that looks like the original paper-based forms. These characteristics help the user submit and find information.

- **Validated data submission:** Another important issue is concerned with the validation of the data to be submitted. The new system will need to validate each field of reports to be input, not only with the correct formats but also with a consistent range of data. Furthermore, a list of choices should be incorporated to optimise time for data entering and minimise human errors during the submission of data. These features will minimise erroneous data during the submission of tool trial reports to the database.

- **Possibility of data updating:** The new system must allow not only the submission of data but also other functions like (modification), (view), (removal) and query of the information from and to the database. These functions will be very useful for quick and easy updating.

- **Optimisation of the submission and updating process of the data:** The new system will need a faster submission of reports in batches. This means providing the opportunity of avoiding resubmission of repeated data in new reports. Additionally, an option of field clearance could be offered in cases where reports are completely different.

- **Faster access to the database:** The procedures of submission, query and search of data must be substantially improved to provide faster and better communication and efficient data access.

- **Improved performance in the query utility module:** The query utilities methods should be improved to allow more accuracy when assigning confidence levels and during data searching for partial, relaxed and total solutions.

- **Users activities monitoring**: Due to the confidentiality of the trials performed by the sales engineers, a monitoring feature must be incorporated. This procedure will register queries and data update.

- **Database administrator system**: To allow an easy creation of user accounts, assignation of passwords, incorporation, removal and retrieval of sales engineers monitoring process in real time, an administrative support system should be also developed.

Furthermore, the creation of this new system would allow the globalisation and dissemination of highly technical information amongst tooling area researchers, engineers and manufacturers. Hence, after due considerations a new system called ***Tool Trial System (TTS)*** was developed (Velásquez and Velásquez, 2000).

4.3 A DISTRIBUTED ENVIRONMENT FOR TOOLING SOLUTIONS

This section will present an Internet-based system to support engineers in the tasks of technical support, process planning and promotion of new products. This system also will allow the creation of a tooling data bank to support further manufacturing solutions.

4.3.1 An Architecture using Internet Platform

The work of tooling engineers normally takes place in different and physically distant machining sites, which denies the convenience associated with centralised resources. With this in mind, the first goal was to make available distributed technical data for experienced engineers working nation wide. In this way, technical information captured by ***TTS*** would be made accessible from remote locations.

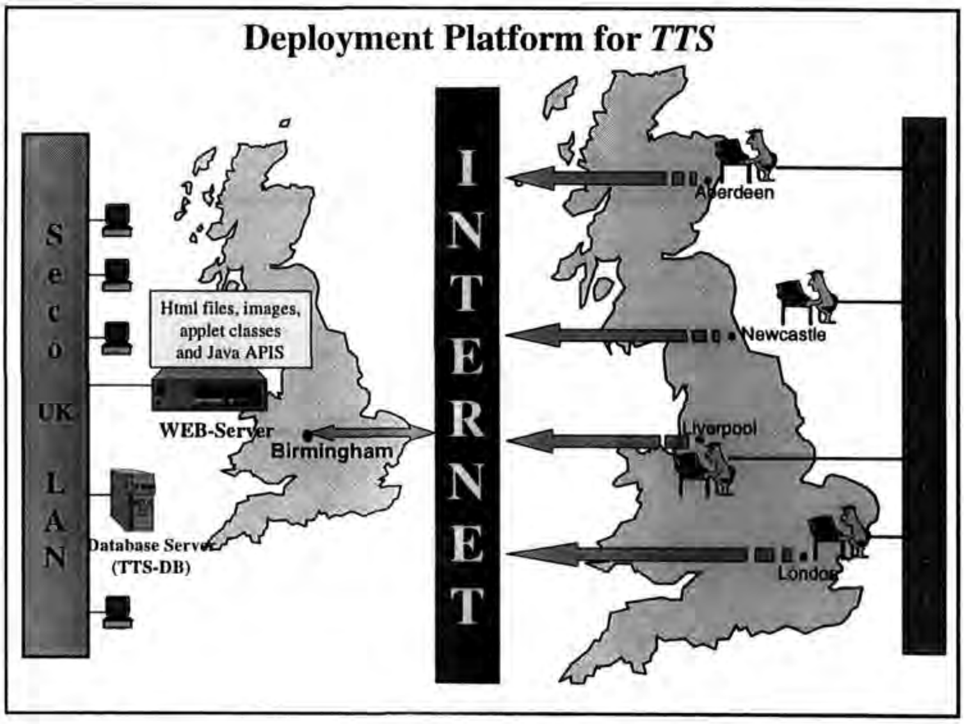


Figure 4.1 Internet Platform for ***TTS***.

In view of the fact that the initial prototype has proved to be highly feasible, it was decided to make use of this powerful resource for ***TTS***, implementing the expandable architecture proposed in chapter 3.

To illustrate the way in which the Internet will provide this support, Figure 4.1 outlines a scheme where the sales engineers connecting through the WWW and using their laptops, gain access to the system and the database. The applet, classes and files used by the system reside in a Web server in Birmingham. This server is connected through a Local Area Network (LAN) to the database server (where ***TTS*** database lies). The users run the system invoking an Uniform Resource Locator (URL) address which calls the main class of ***TTS***.

In UK, Seco sales engineers are distributed across nationwide areas. When a client requires technical assistance, the tooling engineer is contacted. The engineers go to the company and, using a mobile phone and a portable computer, connect to the Internet and access the applets located in a web-server of Seco offices in the UK. Due to the strict confidentiality of the data, the system will only allow access when an authorised login and password are entered. Every Seco engineer has an assigned login and password and their usage of the system is monitored (registered in the database). Once the engineer has identified the problem, it is analysed and the tool trial database is accessed through query facilities to search for previous trials with similar parameters. If the system cannot find information for the specified input, the sales engineer will initiate a series of tests to find the solution to the problem. These tests are submitted in real time to the database.

Another task of the sales engineers, is the implementation of demonstration tests for new tools. The objective of the test is to show the client the advantages of adopting the new tools. This study is based on cost and productivity results.

To test the functionality of this architecture, the ***TTS*** database was installed in two different places: the offices of Seco Tool UK in Birmingham and the offices of the Design and Manufacturing Research Group of the University of Durham. Then, the communication and performance of the system were tested. This was achieved by submitting real tests in the form of previous paper reports from distributed locations in UK. access

In order to speed up the downloading process of the system, the images and public Java classes were installed in the engineers laptop. This contributes to substantially reduce the downloading time of ***TTS*** by managing the data remotely while the images and programs can be accessed locally.

4.3.2 The Tool Trial System

The following sections will describe the development framework used for programming the modules of the system.

A Platform of Development

The selection of a good programming language is an important factor in developing a distributed system. Some considerations on why Java language was chosen, follow.

The Java Language.

As was mentioned in chapter 3, Java is an object oriented programming language developed by Sun Microsystems. Modelled on C++, the Java language was designed to be small, simple and portable across platforms and operating systems, both at the source and at the binary level. Its object oriented characteristic provides powerful class libraries that can be used to develop programs able to run across a heterogeneous network of machines. Some important features of this programming language are listed below.

Java supports dynamic class loading: It is easy to plug new modules into existing Java programs and integrate these automatically without exiting the system, recompiling, re-linking and re-executing the program.

Java is an Object Oriented Language: Everything in Java is an object (excluding primitive data). This allows the creation of flexible and modular programs.

Java presents some security levels: It guarantees the privacy of the information that is managed by a Java program.

Because of all these attributes, the Java language has become popular in the last five years. With the use of this language, any application may be run over any hardware or software resource without knowing its configuration or specifications and using any communication protocol.

Furthermore, many Java development platforms have been created to help the programming of systems. This is the case of PowerJ, a Java program builder.

The Java Program Builder

Powersoft PowerJ is a tool conceived for creating Java programs rapidly and easily. It allows speeding up the writing of sophisticated Java-Based code (Sybase 1997). This package offered a number of important advantages such as creation of GUI using drag and drop actions, generation of Java bytecode in a wide range of Java Language software manufacturers, full database connectivity APIs and complete DBMS (SQL-Anywhere) provided with PowerJ.

B Functionality of the System

One of the main issues considered during the creation of the system was its users. ***TTS*** was designed to be operated by the engineers of Seco UK with a high level of experience in tooling, but not necessarily experts in computing areas.

The system was therefore designed to be simple to operate, versatile in the number of functions offered and easy when retrieving information from the database. Because of the confidentiality of the information managed by the system, it was necessary to create a security module able to recognise user's authentication and authorisation functions. Based upon the easily expandable features of ***TTS*** and the multiple possible applications that would be developed using the tooling database, four security levels were defined: *open*, *medium*, *high level* and *super user*. After due consideration it was decided that the users' permission level of the system would be "*High level user*".

Figure 4.2 Presentation Screen for *Tool Trial System.*

Figure 4.2 shows the initial screen that appears when ***TTS*** is accessed. After the user verification is undertaken, a screen displaying the different functions of the system is shown.

Figure 4.3 Screens with functions and operations of ***TTS***.

As can be seen from Figure 4.3, ***TTS*** offers five functions for submitting, maintaining and retrieving the data. The system also includes two tooling operations. After the selection of the required function, the options for turning and milling operations are presented. When the operation is chosen, the corresponding screens appear. The functions managed by the system are explained in detail in the following sections.

Add Reports

This utility allows the incorporation of a new report of tool trials to the database. Using a friendly graphic interface, the system presents the first screen corresponding to the chosen operation. This screen will be used by the engineer to enter the general data about the trial (Figure 4.4(a) and Figure 4.5(a)).

Once the data are registered, the "Forward >>" option will lead to the presentation of the second screen which includes the test data (Figure 4.4(b) and Figure 4.5(b)).

The test data screen presents a very easy and versatile interface which allows, not only the addition of tests, but also the modification and removal of information that has been incorporated by mistake. Once the engineer has performed the initial test using the parameters of the client machinist, it is registered as an existing test. Then, the engineer performs the suggested test and obtains the results. The values of *Improvement in tool life, Tool cost savings, Productivity improvements and Cost reduction per component* are computed using equations provided by the industrial collaborator.

(a) First Screen for Turning Operation.

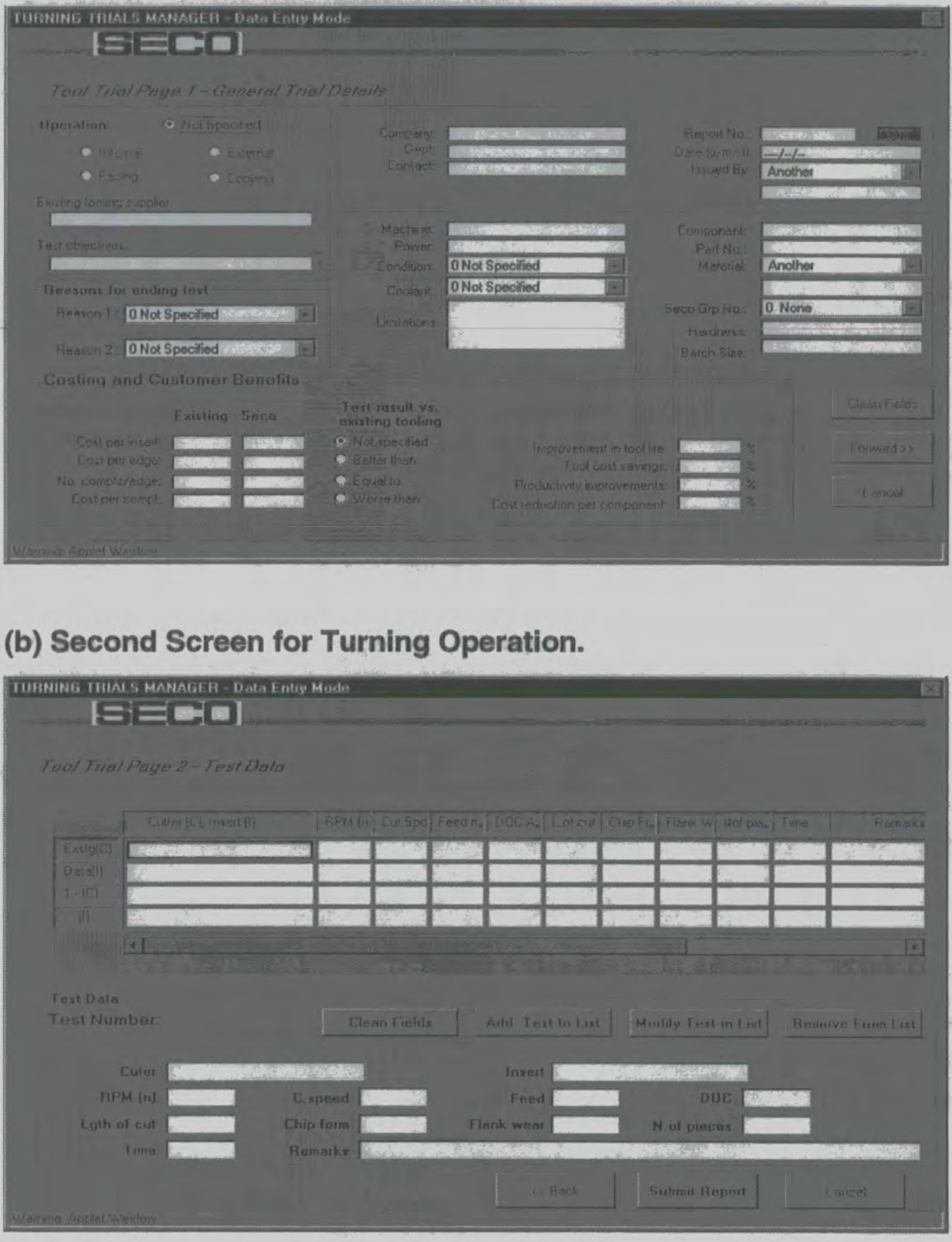
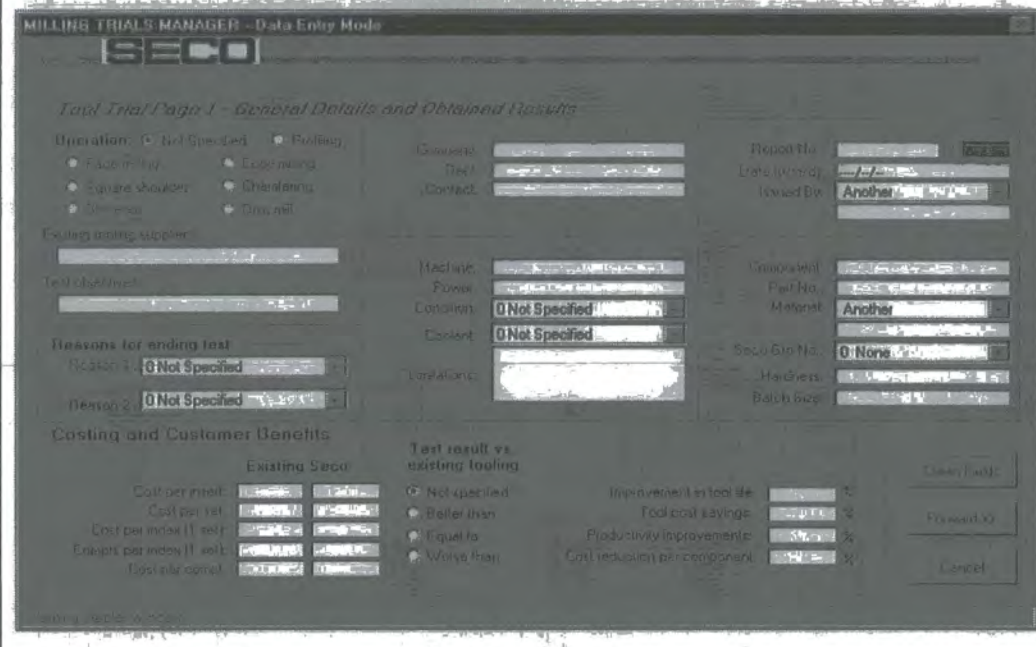


Figure 4.4 Screens For Turning Operation.

(a) First Screen for Milling Operation.



(b) Second Screen for Milling Operation.

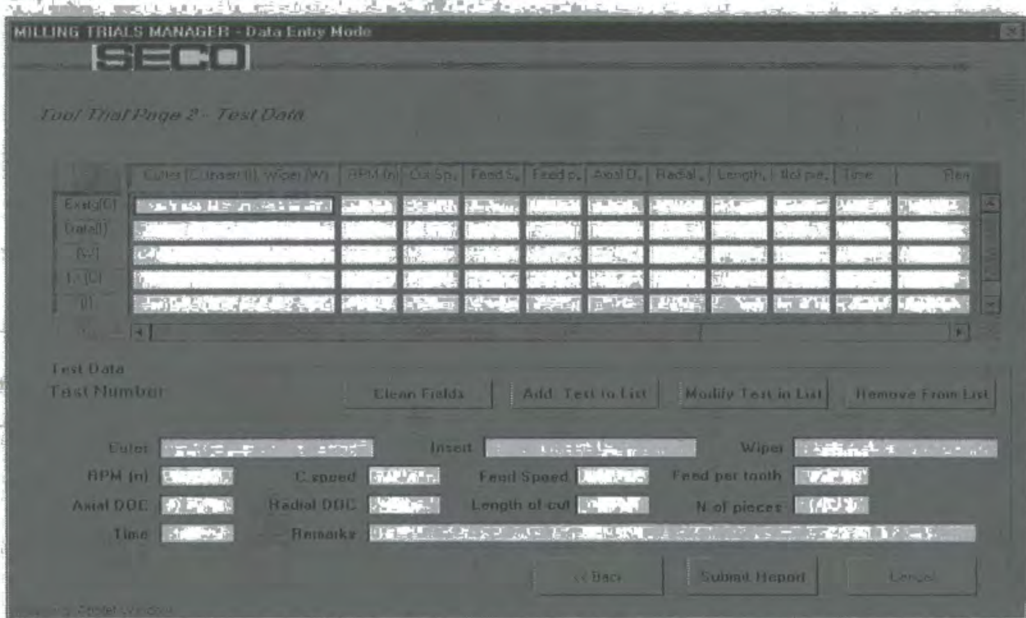


Figure 4.5 Screens For Milling Operation.

View Reports.

This function offers the possibility of viewing a report previously incorporated on the database. To achieve this, the general form is presented providing a list of all the reports in the database for the chosen operation. From Figure 4.6 it can be seen how ***TTS*** presents this range of reports for the turning operation.

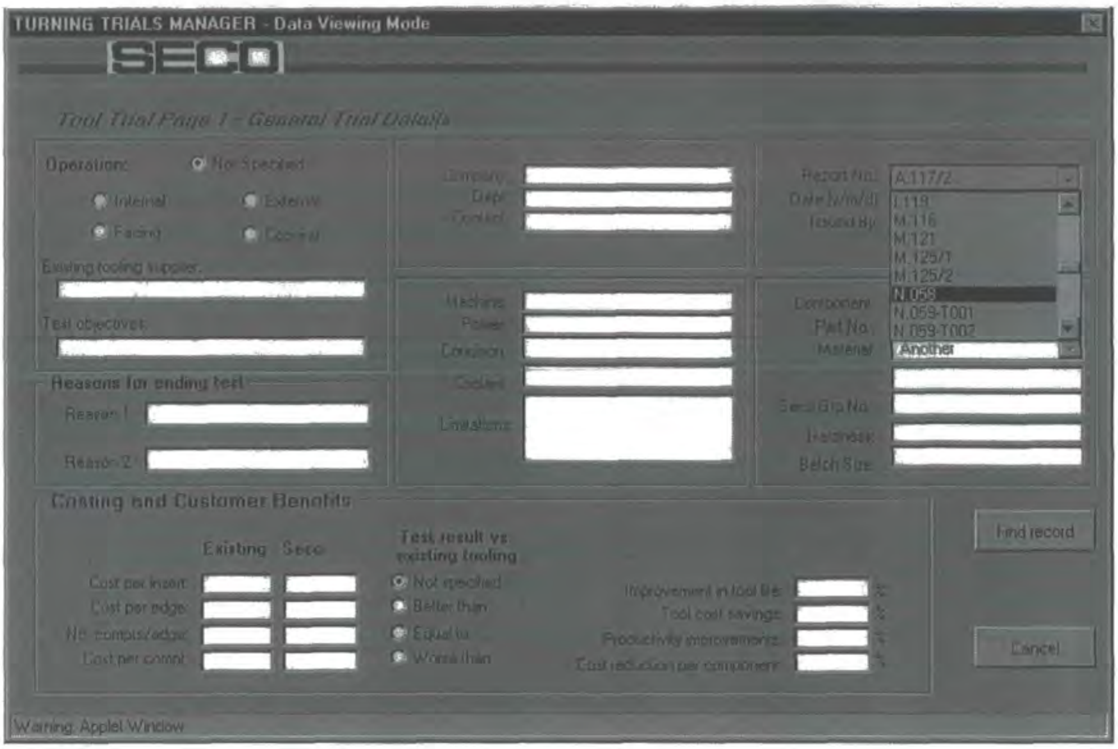


Figure 4.6 Viewing Mode of Turning Operation Reports.

Once the report has been chosen, a "Find record" operation is activated to retrieve the corresponding record from the database.

Edit Reports.

The Edit function also allows the retrieval of a record. This time, the user is able to make changes to the existing data and update the corresponding records. This feature of ***TTS*** helps reduce the time to correct previous errors.

Remove Reports

The Removal option allows users to delete existing reports from the database. The information is shown to the user and, before displaying a warning message, an option to delete the record permanently is presented. This feature is very useful when maintenance operations of the tooling database needs to be carried out.

Query information.

This option represents one of the most important features offered by the system. It provides two utilities, the Basic Query (BQ) and the Advanced Query (AQ). These support the users in obtaining specific information from previous tool trials. It is important to note that these methods were initially developed for the prototype version and have been reviewed and analysed to optimise their functionality.

The BQ module is a method that searches for relevant information based on specific knowledge parameters. The most important aim was to allow the request for reports having similar general features as those specified by the user. Four variables were taken into consideration to develop a query generator for retrieving these reports under the specified values: Seco Material Group, Material Description, Sales Engineer and Test Objectives. The appearance of the GUI for the basic query module is shown in Figure 4.7.

It can be seen that there are four possible options to execute the Query. The "Test Objective" is one of the most powerful parameters, since the reason for performing the tests is described in it. Then, with the use of some key words in the test objective field and the combination of other options, the appropriate range of previous tests is retrieved. Once the database is queried, the system provides the number of tests matching the request made by the user. The user can either elect to view the reports that matched the query or modify the values and submit it again to evaluate the number of matching reports with the new specifications.

If the user chooses to view the records, the forms containing the information of the first report will be shown. The user can navigate, forwards or backwards, through the group of reports resulting from the query.

The functionality offered by the basic query module is mostly related to the retrieval of reports with general characteristics. When the engineer faces technical problems related to specifications of tool trials, the methods implemented are not useful in providing an answer.

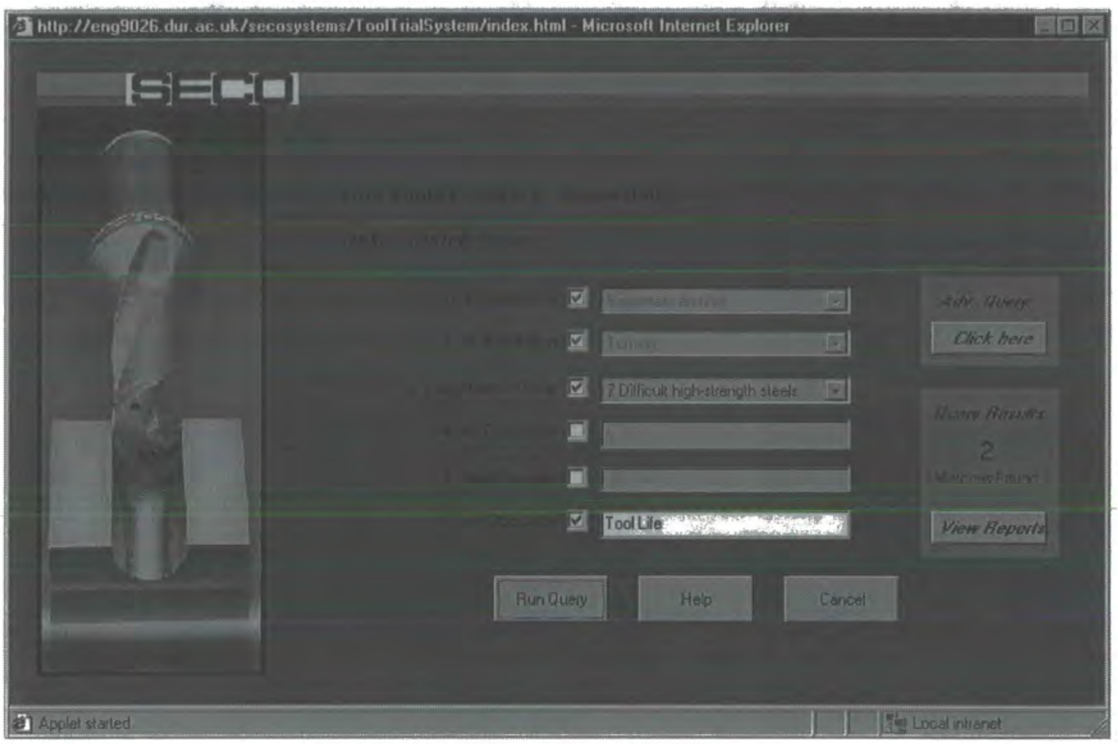


Figure 4.7 Basic Query Screen.

The AQ module was designed to solve technical problems related to the execution of cutting operations. One of the most important considerations, is the interface between the component being machined and the insert performing the cutting task. The selection of the query variables was based upon this technical consideration. Hence, it was decided to include the following parameters:

Material Group

Material Description.

Insert Type.

Insert Grade.

Chipbreaker (turning) / Designation (milling).

Insert Geometry.

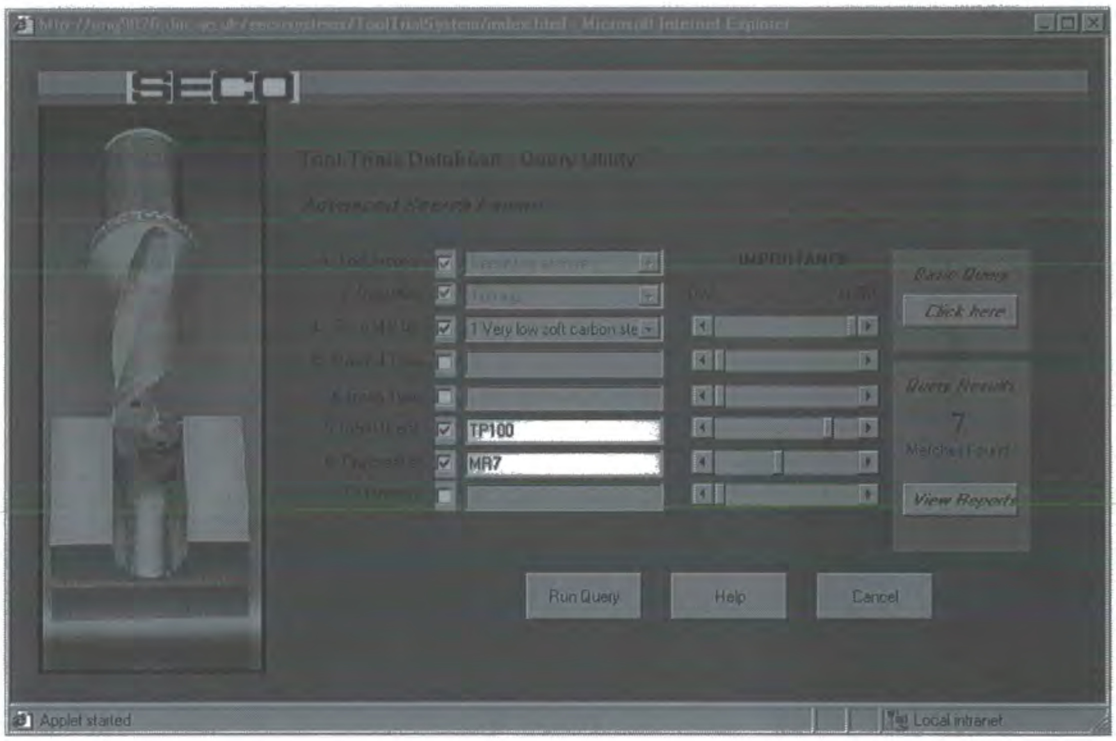


Figure 4.8 Advanced Query screen.

The AQ function provides more refined methods to allow the user not only the possibility to decide what parameter would be included in the query, but to attribute the relative importance of each query parameters by assigning weights. In this way, the engineer is able to obtain the reports that most closely match specific requirements. Figure 4.8 shows the GUI created for AQ module. It is apparent that seven reports were found with the specific input parameters.

Of course, it is always desirable to find full matches for each specific query submitted. Because of the availability of new materials, the development of new tools and the large number of possible combinations, this is not always possible. Additional methods to search for the closest solutions were therefore implemented. These methods evaluate partial matches and parameter relaxation of specified fields using a minimum confidence score allowed by the user. Figure 4.9 shows the different windows that are displayed when few or no full matches are found.

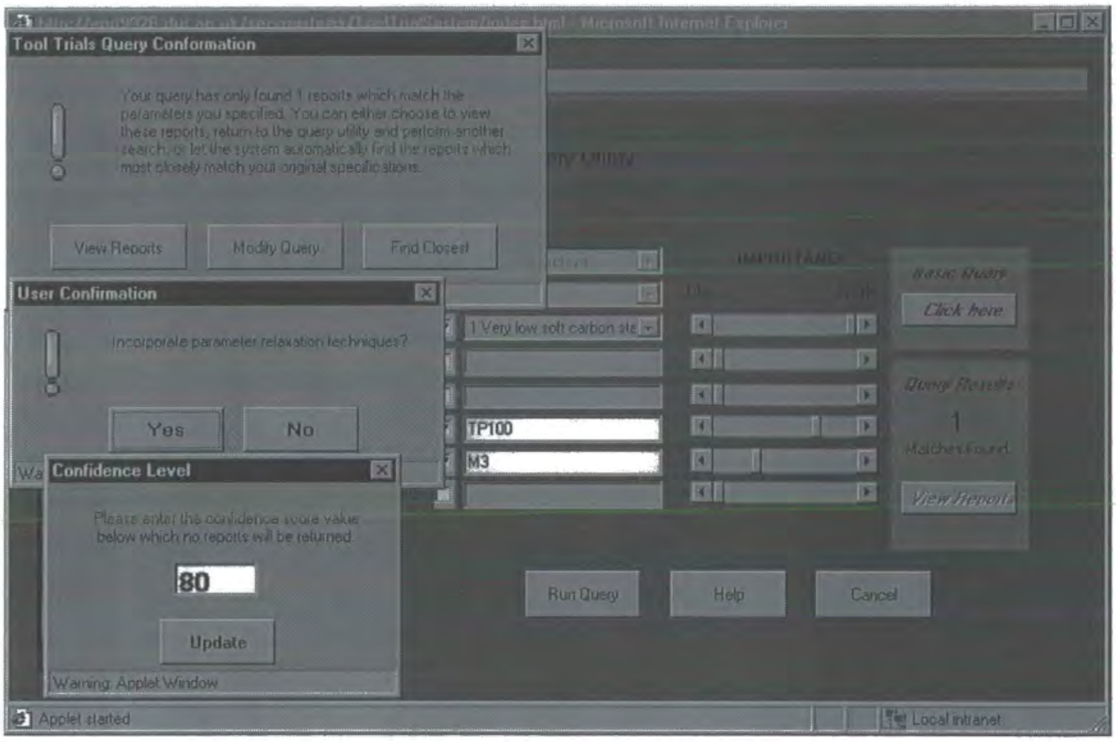


Figure 4.9 Windows shown to search for closest records.

In the case where less than five fully matched records are obtained, the system presents a window displaying this result and offering options to resubmit the query, view the matches found or find the closest records for the specified input. If the user chooses the option "Find Closest", the system interrogates the user about the application of parameter relaxation techniques. Finally, a minimum confidence score is required. This operates as a filter to reject those reports having a lower confidence level.

After the confidence score is updated, the process for searching the closest reports is initiated. Once the reports have been filtered, they are presented to the user in a summarised format.

Figure 4.10 Example of reports found using parameter relaxation.

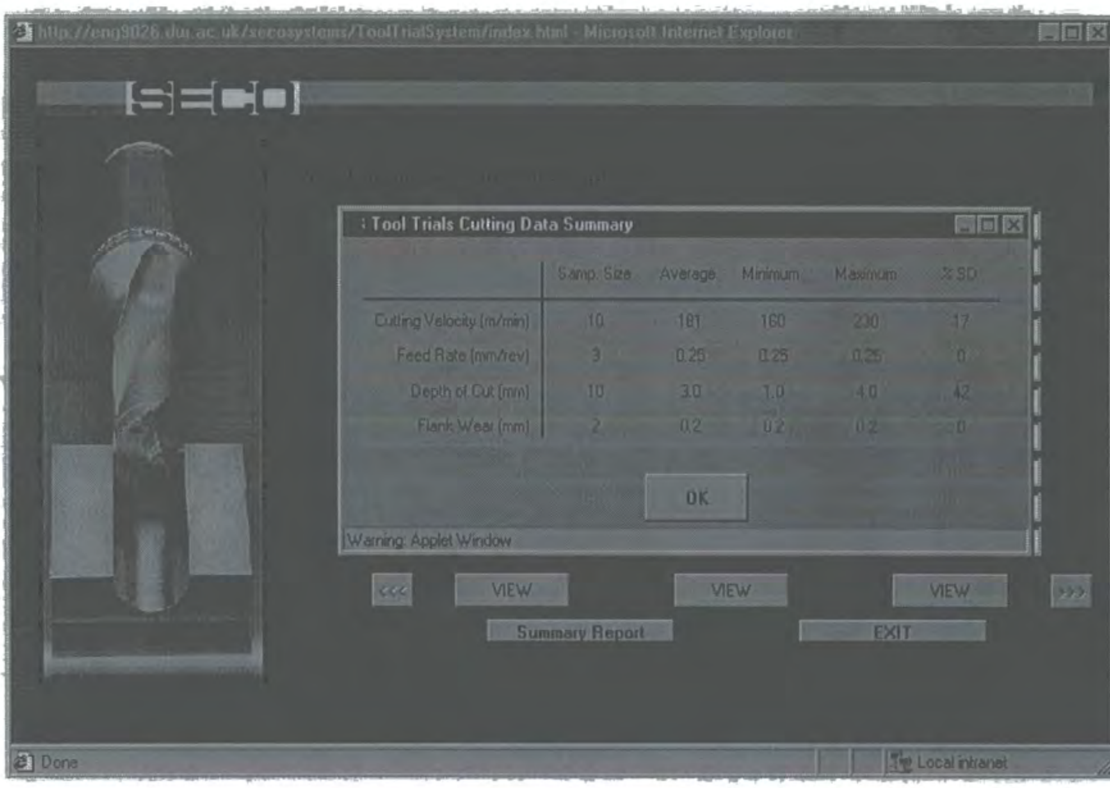


Figure 4.11 Summary Report Window.

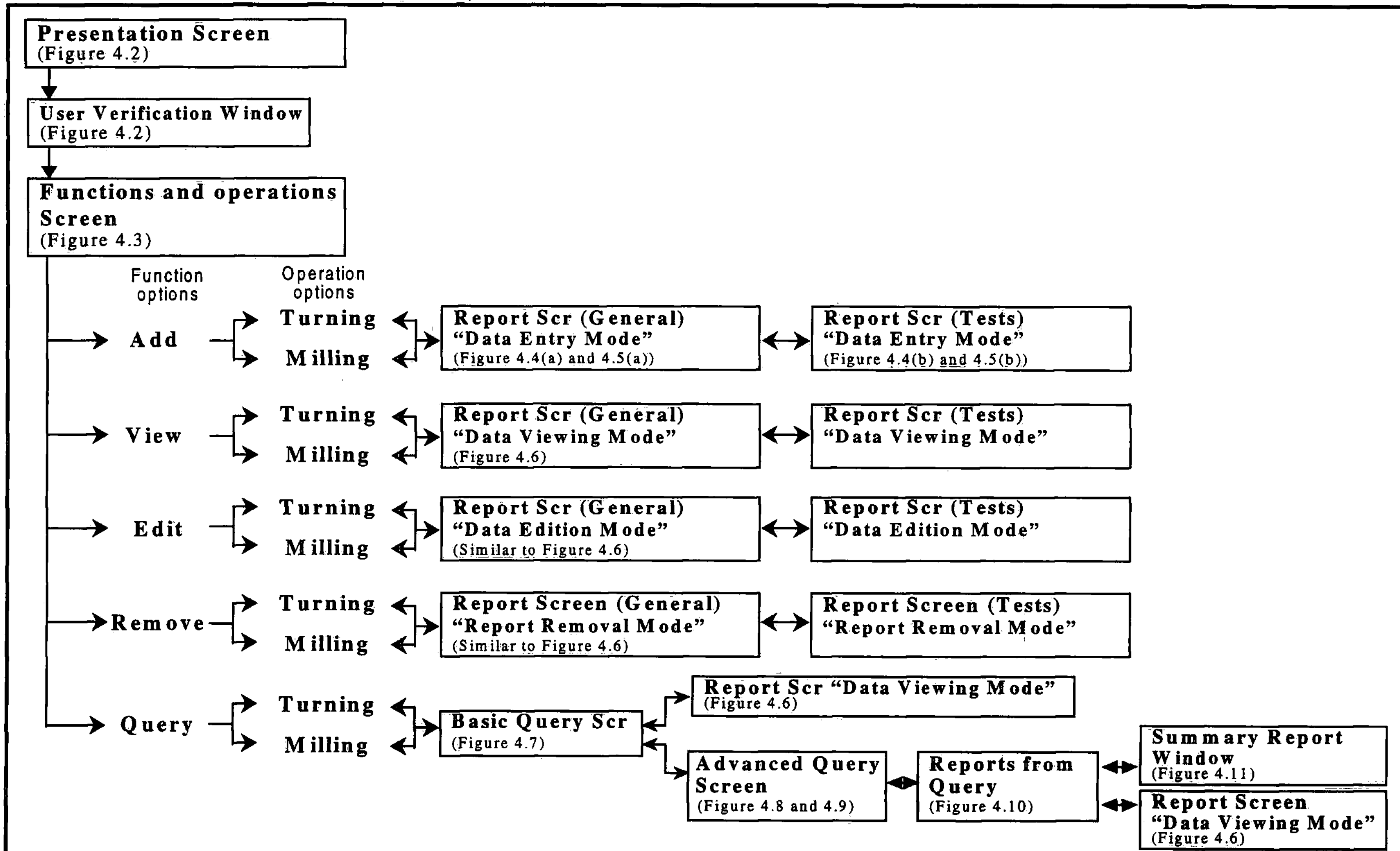


Figure 4.12 Structure of ***TTS***.

Figure 4.10 shows how the reports and respective confidence scores are presented. A similar screen is also displayed when the "View Reports" option is selected (Figure 4.8 and Figure 4.9). The user can either choose to view a specific report or select the "Summary Report" option.

The last of these alternatives displays some statistical values. The variables used for this summary are those defining the cutting parameters. Figure 4.11 shows the appearance of the "Summary Report" window.

Some of the GUIs shown in this section are examples of query processes applied to turning operation reports. It is important to emphasise that similar graphic interfaces have also been designed and implemented to allow the same functionality for the milling operation.

A complete structure of ***TTS*** is presented in Figure 4.12. This map of the system shows the different functions, operations, screens and windows offered by the system.

4.3.3 The Tool Trials Database

One of the most important features of a data bank is the organisation of the data. It provides a robust structure where management, access and transformation operations can be later efficiently applied. When the prototype was created, a database to support the submission and retrieval of the reports was also completed. The following sections will present the structure of the database to support the tooling, security, transaction monitoring and data validation modules. The DBMS and the driver to establish the connection between the system and database through the Internet will also be discussed.

A.- Structure of the Database

Because JadeT was a prototype, the initial database was based on the data contained on forms. This served as a temporary repository where the data would be stored.

Important considerations related to the data support for the development of the new system were taken into account. The paper forms were revised to extract and organise the maximum quantity of useful data for the system. It should be noted that although the data contained in the forms was very important for carrying out tool trials, the paper forms were created several years ago. They have not been reviewed to improve requirements of better-organised data to provide optimised results. Furthermore, in such a highly congested environment as the Internet, an optimum handling of the data represents a key advantage when dealing with widely dispersed information.

Significant thought had to be given to the optimisation of the tables that formed the initial database, their relational structure and the best organisation of the data to obtain the optimum performance.

In the light of the above considerations, it was decided to define a new structure for the tool trials database and reorganise the existing data within it. The first step consisted of evaluating the existing tooling and data support tables. The operations of turning and milling represent a very high percentage of the total of tooling trials. Thus, ***TTS*** was designed to cover only these two operations. It was decided that the inclusion of additional operations like threading and grooving would not justify the time and effort required to programme these modules.

With the help of Seco UK engineers, the existing paper forms and tool trial reports were analysed to determine the data requirements and hence meet the goals of the Tool Trial System. The result was the creation of ten tables. Four of these, two for each operation, would contain the general and test data for turning and milling. To assist the engineer in the classification of materials within the Seco material groups, the *Materials* and *Materials_group* tables were also created. The result was eight different standards of materials (BS, AISI, UNE_IHA, W-stoff, DIN, AFNOR, UNI and SS), and the materials group defined by Seco. Furthermore, the *Monitor* table to register the transactions of engineers was generated, as well as a table to maintain the information of the sales engineers of the company distributed nation-wide. To manage the system accessibility, the *Passwords* table was also built.

The next step consisted of defining primary keys, index and relational structure of the tables, Figure 4.12.

GeneralTurning, *GeneralMilling*, *TestDataTurning* and *TestDataMilling* tables incorporate the data from the tooling trials. The general tables contain information about each report and the test tables include the trials performed in the report.

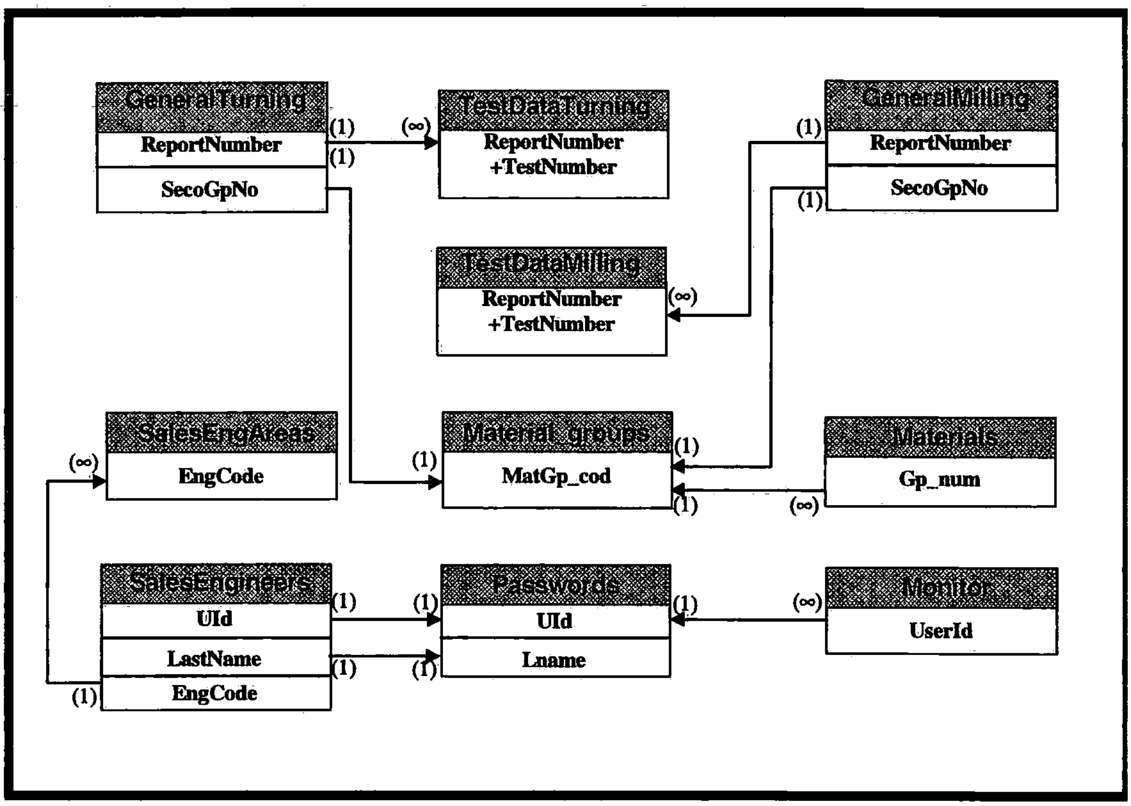


Figure 4.13 Relational structure of ***TTS*** database.

The *SalesEngineers* table includes the information of the Sales Engineers distributed nationwide, and the *SalesEngAreas* table comprises of the areas covered for each engineer. These two tables are linked through the engineer code.

The Passwords table includes the user's accounts. Because the main users of the system are the Sales Engineers, each of them has an access identity code and password. In this way, the password table is connected with the Sales Engineers table through the engineer ID and Last Name. Finally, all the operations carried out by the users of the system are registered in the *Monitor* table. *Passwords* and *Monitor* tables are related through the user ID.

B DBMS and Communication

The Structure Query Language is a powerful and popular tool that allows users to access data stored in Relational Database Management Systems (RDBMS). One of the most important features is that it is able to produce results sets from databases in a quick and efficient manner. Furthermore, it has the ability to submit, remove and even modify data from databases. Another important characteristic is that it is standardised and, because of this, a large number of DBMSs developers include exportation facilities from their databases to SQL format. This represents an excellent opportunity for extracting data from other database formats.

The DBMS chosen for the Tool Trial System was "SQL Anywhere". It is a full-featured transaction-processing SQL database management system that has excellent performance while requiring relatively few resources (memory space, disk space, and CPU speed). It is a fast and efficient system for many environments, from notebook computers to servers supporting large numbers of concurrent users. All these characteristics make this DBMS suitable for Web-based distributed applications.

One important characteristic when using the Internet is that the information might be distributed in different servers around the world and database operations need to be carried out to access the required information. The link between the software and the database is problematic when the connection has to be made through the WWW. The JDBC APIs facilitate the connection to SQL databases. The four existing categories of drivers were described earlier in section 3.5. The driver that uses ***TTS*** is 100% pure Java. It is classified under the category "1" and the databases are accessed through a gateway. Its name is *Jconnect* and it is a proprietary driver (Sybase Corporation). It provides a high performance to most types of relational databases. Moreover, it can be used by applets and works with both *Sun* and *Microsoft* Java virtual machines (the principal suppliers of Java versions). The most important feature when using this kind of driver is that the problem of asking the users to download and configure the drivers is eliminated. The clients need only to activate the Java Virtual Machine (VM) in their browsers to allow them to run Java programs.

C Data Population

Following the development of the system, it was necessary to evaluate its performance. In this sense, the populating of the database was carried out. This process addressed the following objectives:

⇒ testing the performance of the system in terms of submission and data validation;

⇒ evaluating the developed methods for data modification, data removal and system monitoring; and

⇒ generate a representative tooling database to test the technical support functions.

To accomplish this task, it was necessary to obtain examples of data from real tool trials. Seco UK agreed that a large sample of conducted tool trials in paper form would be provided for the database. Furthermore, information about sales engineers, areas of the UK they cover, User ID's and passwords were also provided by the company. The next step consisted of populating the *Materials* and *MaterialGroups* tables with information contained in catalogues.

Finally, 411 tool trials reports were submitted: 314 reports containing data of Turning operations (with 930 records between tests and general tables) and 97 reports of Milling (with a total of 318 records between general and tests).

4.3.4 A Database Manager System

To allow easy authorising of user accounts, incorporation, removal and consulting of sales engineers in real time and management of the trial monitoring feature, a support system was developed. This system was called

DBManager and offers three functions: Sales Engineers, User Accounts and Trials Monitor.

A Sales Engineers

This module permits the submission, viewing, removal and modification of Sale Engineers records. It facilitates the updating of both general information and user accounts of sales engineers.

B User Accounts

This module was created to provide other users (apart from the Sales Engineers) access to the tool trials system. This module enables the updating of user and password tables.

C Trials Monitor

This module is a maintenance utility. It was developed to search and remove records pertaining to the security monitoring function of the tool trials system. In other words, this option can filter the queries of user activities using search parameters such as date of processing, type of function performed (submission, edit, view, removal, query), type of operation (milling and turning) and user ID. The search result is shown and a removal option is presented to the user.

Due to the level of confidentiality the system administrator who has the highest level of permission in the password table is the only one who can access it. A complete group of screens contained in the ***DBManager*** system are presented in APPENDIX B.

4.5 SUMMARY

The first two sections of this chapter have sought to analyse the needs of industrialists in terms of tooling support, as well as the existing software provided by tooling manufacturers to help machinist in process planing tasks. Based upon this study the needs for new applications to provide better processes more and efficient methods to deal with tooling tasks emerged. An application called ***Tool Trial System*** was developed and has been described.

TTS builds the foundations for a bank of tooling data and offers aids to sales engineers from tooling companies in the difficult task of providing technical support to clients. This system uses the Internet as a vehicle to deploy data and applications to the engineers providing a distributed and collaborative information environment. ***TTS*** is capable of submitting, managing and retrieving data of tooling trials performed in the machining sites of manufacturing industries.

To administrate the systems users accounts, sales engineers accounts and tool trial monitoring process, a Database Manager System ***DBManager*** system was also developed. This supports the maintenance of user and sales engineer accounts not only for ***TTS*** but also for other systems with access restrictions that could make use of the tooling database.

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CHAPTER 5: FROM DATA-RICH SCENARIOS TO KNOWLEDGE MANAGEMENT

5.1 INTRODUCTION

The previous chapter has sought to examine the multiple aspects of implementing Internet-based solutions in the tooling sector. The functionality of ***TTS***, a *Tool Trials* ***System*** able to provide a Web-based platform to submit and retrieve highly specific tooling data, was also explained.

The preliminary sections of this Chapter will concentrate on the theoretical foundations of Knowledge Discovery and its current role in the tooling industry. Also, a formal methodology to assist in the development of KD-oriented systems is proposed, with the last section being dedicated to predicting the major trends in the future of KD technology.

5.2 THE KNOWLEDGE DISCOVERY APPROACH

Huge amounts of data are constantly being generated and stored by companies and organisations. This has been influenced by the progress of data-collection technology (Freitas and Lavington, 1998), such as the widespread use of bar-code scanners, sensors in scientific and industrial domains and the current facilities provided by information networked environments.

To take full advantage of these data as potential knowledge sources is not a trivial task, because in many cases the volumes are too large to manage. The data structures themselves are also complex and existing DBMSs are not currently oriented to identify hidden knowledge in the data sets.

In order to provide a suitable framework where interesting patterns and hidden useful knowledge can be revealed from raw data analysis, researchers have been exploring ideas and methodologies in fields such as machine learning, neural networks, statistical analysis, fuzzy sets, evolutionary computing and other artificial intelligence areas (Michalski *et al.*, 1998).

These efforts have led to the emergence of a new research area, often called Knowledge Discovery. This is also referred to as *Knowledge Discovery in Databases (KDD), Knowledge Mining from Databases (KMD), Knowledge Extraction, Data Analysis* or simply *Data Mining.* KD is a *process oriented to discover potentially useful knowledge, analysing a considerable amount of raw data.* KD-oriented systems are usually developed by complementing the application of algorithmic methods with an interactive participation of the end user, in order to reinforce the efficiency of the discovery process. KD provides invaluable opportunities to current organisations, allowing them to make better use of the massive volumes of operational and business data. The current commercially KD systems are not general-purpose, rather they are highly context-oriented. Financial analysis, communications, sales and marketing, manufacturing, social sciences, military, medical and consulting are some of the most important areas where KD technology has been applied. The subsequent sub-sections will contribute to provide a better understanding of this relatively young, expanding and promising research area.

5.2.1 Motivation for Applying KD Technology

The main motivation for implementing a KD-oriented system is making sense of large volumes of raw data, where "making sense" means the possibility of discovering previously unseen useful knowledge. Furthermore, there are a number of valuable contributions and reasons, which justify the development and deployment of KD.

a) In very large databases the number of possible relationships is enormous, thus prohibiting the selection for the correct ones. Also, the analysis of complex interactions between variables is not supported by current DBMSs and, in many cases, the system administrators do not know the relevance of the data. Therefore, intelligent search strategies and efficient algorithms are needed.

b) KD applications do not require special or dedicated hardware. They can be implemented in conventional workstations or PCs, providing a good performance.

c) KD applications can continue to scrutinise the data during nocturnal periods, holidays and any other business hours when the members of the organisation do not work.

d) 'Real' databases usually contain noisy data. The concept of "noisy" can be defined as the imprecise, contradictory, redundant or incomplete nature of the data. KD-oriented systems can provide appropriate mechanisms to handle these situations.

e) KD applications can be developed to incorporate domain expert knowledge, which is a valuable resource to guide and improve the discovery process (Djoko *et al.*, 1997).

f) Efforts to create a data set are often focused on issues such as storage efficiency. A plan for how the data will eventually be used and analysed is not taken into consideration when designing a database. This is one of the reasons why large amounts of data are not currently fully exploited as powerful and potentially useful knowledge sources. In contrast, a KD application incorporates this plan from its initial conception.

g) KD implementations contribute to a better understanding of the domain under study. The discovery of interesting patterns in the data can shed light on the adoption of better strategies, suggest exploration along new promising paths and change established practices.

h) Organisations do not necessarily need to provide online and interactive access to the data sources. In most cases, KD tasks are not undertaken in real time, so, static extractions of data will satisfy the requirements of most KD applications (W & B). However, the availability of data sources updated on a regular basis, would contribute to maximise the opportunity to find new interesting patterns and trends.

5.2.2 Issues and Challenges of KD

The previous section has described several advantages of applying KD technology. However, there are a number of issues that need to be addressed. This section presents some important considerations, mainly focused on the analyst or team in charge of developing a KD application.

a) Mining information from different and widely dispersed sources of data poses new challenges to KD technology. In this distributed information scenario, local and wide-area computer networks connect many sources of data, providing easier access to remote locations. In the same manner, the remarkable growth of the WWW has effectively created a global-market, overcoming the barriers of cultures and languages and where geographical distances are no longer a factor for consideration in commerce and sharing information (Wong *et al.*, 1998). Hence, the use of computer networks facilities, particularly the Internet, must be seriously considered.

b) In 5.2.1, the convenience of applying an efficient combination of existing technologies and methodologies was highlighted in order to maximise the efficacy of the discovery process. Hence, current developments in the area of KD technology must be able to provide flexible schemes at the moment of approaching a problem, allowing the incorporation of complementary and multidisciplinary solutions.

c) Even when KD has demonstrated its usefulness on multiple and different areas, the initial attempts to show the benefits of applying this technology in an organisation, may result in a strategically difficult task. There are usually established institutional policies and practices that should be conveniently identified. It will be necessary to show clearly how the implementation of the technology would have positive implications for ongoing operations to anticipate and overcome organisational inertia.

d) KD implementations should provide tangible results within the short-term. It is not a lifelong commitment (Westphal and Blaxton, 1998). If discernible results within a reasonable period of time cannot be obtained, it is time to go back to consider these plausible possibilities: a) The algorithms being implemented are too limited in the features they provide; b) The data are not being modelled in the most effective way; c) The scope of the analysis is too broad or too narrow; d) The whole analytical approach is inappropriate for the problem at hand; and e) Perhaps there are not interesting or revealing patterns in the data set.

e) Real-world databases are constantly updated. This dynamic nature of data demands the development of *incremental* KD solutions. Incremental means that the analysis of new records does not require the re-processing of previous analysed data. However, to create efficient incremental algorithms is not a trivial task, mainly because the outcome of any processing stage must be conveniently stored to establish new relationships, with results obtained through subsequent analyses.

f) KD techniques are oriented to analyse huge volumes of data. Hence, the use of heuristics or application of horizontal and vertical reduction methods should be used to support searching processes. Horizontal reduction can be accomplished, for example, separating continuous values of some attributes (Cios *et al.*, 1998). Vertical reduction, can be achieved, for example, by removing redundant data.

g) The existence of noisy data may require the application of particular techniques. In this sense, *fuzzy* and *rough* sets have proven to be useful for dealing with incomplete or imprecise data. Other methods for handling incomplete data have been developed within the field of machine learning, but their efficiency has been questioned (Uthurusamy, 1991).

h) The use of visualisation tools to gain better insight into the data, providing expressive ways and multidimensional schemes to show discovered patterns and trends of interest, plays an important role and should be considered.

i) The interfaces of KD-oriented systems should be developed assuming the user is unfamiliar with the technical issues. End users may not rely on the availability of an expert for explaining the meaning of some options or the adoption of particular methods. Hence, users must be carefully guided through the system by developing a friendly and efficient interface.

j) KD-oriented systems should take into account the fundamental role of external domain knowledge. The contribution of domain experts and end users familiarised with the context in which the KD application is implemented can be very useful. It will provide useful mechanisms to channel the discovery process, particularly when supervised learning strategies are considered.

k) Massive search operations, distributed data access and complexity of KD-oriented algorithms demand faster processing capabilities. A very challenging issue is to achieve efficient parallel data mining. The benefit achievable from parallelism can be significantly compromised with situations like transaction database partitioned across all the nodes and prohibitively large amount of inter-node data transmission required for reaching global decisions (Chen *et al.*, 1996).

5.3 KNOWLEDGE DISCOVERY IN THE TOOLING INDUSTRY

In spite of the tooling industry generating a considerable amount of data, formal KD-oriented systems have not yet been implemented in this area, to the author's best knowledge. KD technology has been applied in several areas, embracing military, medical, financial and social applications, but tooling remains a relatively unexplored sector.

The topics requiring more attention are those in relation to metal cutting, namely, *tool selection, tool life prediction, cutting data recommendation, machining operation selection and comparative analysis of cutting conditions.*

5.3.1 Applying Artificial Intelligence (AI) methods to the Tooling Industry

In order to provide a critical review of the type and range of solutions provided by current AI disciplines to the tooling sector, some applications are examined in the following sections.

A Machining Process – Fuzzy-Neural hybrid Model

This research, carried out by Zhou and Harrison (1997), describes a fuzzy neural hybrid model to compensate process errors in CNC machining by touch trigger probe systems.

Factors that influence the accuracy of the machining and In-Cycle Measuring (ICM) processes are varied. It is very difficult or impossible to identify and fix each error by ICM systems with tough trigger probes. Moreover, even when errors have been determined, their effects and relationships are complex, and there are no existing mathematical models to control or compensate the machining processes.

Two inputs, measured error and cutter wear are defined as fuzzy variables, being the fuzzy rules implemented by the hidden layer of the network. The proposed system reveals that it is feasible to achieve an improved machining performance by adapting the fuzzy membership functions and generating linguistic control rules.

B Machining Operation Planning – Expert System

A framework for machining operation planning systems has been proposed by Kojima *et al.* (1999), in which machining know-how, extracted and organised from electronic tool catalogues and machining instance databases available in the Internet environment, play a principal role.

In developing system organisation, WWW technology including XML markup language and Java programming environment, are utilised. A prototype system to advise the engineer of cutting conditions including trouble shooting for side end milling was developed to demonstrate the concept.

C Optimisation of Production Processes – Machine Learning and Search Techniques

A novel approach for generating multipurpose models of machining operations combining machine learning and search techniques, has been proposed by Monostori and Viharos (1995).

These models are intended to be applicable to different engineering and management assignments. Simulated annealing search is used for finding the unknown parameters of the model in given situations. It is expected that the developed block-oriented framework will be a valuable tool for modelling, monitoring and optimisation of manufacturing processes and process chains.

D On-line Tool Wear in a Turning Process – Neural Networks

Needs for Neural Networks (NN) in traditional machining processes are discussed by Wood *et al.*, 1997. Also, this work describes how a multi layer perceptron NN can be used to produce a correlation between vibration measurements gathered during a machining operation and the condition of the tool tip. This investigation showed the potential of NN in condition monitoring applications. However further machining tests are required to develop a more robust system where the nature of testing would be extended to assess the tool life of tungsten carbide tips. Other parameters such as tool tip force, power consumption or acoustic emission measurements could also be integrated into this basic system. The benefit of this multi-sensor approach would provide a more universal system, which could readily be used in a range of commercial processes to identify on-line tool wear at a moderate cost.

E Selection of Journal Bearings – Neural-Fuzzy Approach

In this investigation, conducted by Pan *et al.* (1997), an integrated neural-fuzzy system for the intelligence selection of journal bearings was developed. The designer's inputs, which may be certain or uncertain, are 'fuzzified'. The results are then used as the input to a Neural Network. The NN, which has generated its own rules from a range of training data, can select a suitable journal bearing.

Compared with other approaches such as expert systems, this intelligent system can overcome the inability to learn from operating experience and the difficulty in building inference sequence with particular reference to the multi-disciplinary requirements from an engineering application.

However, the system needs to be further developed to take account of a range of application factors. Further development is also required for the system to learn from new sample data and refine its fuzzification procedure and the NN, so that a better selection result can be provided for a specific engineering application.

5.3.2 Discussion

The formerly examined applications constitute good examples of AI-based implementations to provide solutions in this area. It was noted how disciplines such as Neural Networks and Fuzzy Sets play a predominant role in the development of several applications.

It should be noted that the primary reason for developing this work was not based on the implementation of a KD approach. Whilst the formerly examined applications constitute good examples of AI-based implementations in the tooling industry, a vast amount of raw data that is constantly generated in the machining sites of tooling companies is not considered for discovery knowledge purposes. There is a significant lack of KD implementations and tools applied to this sector, which could reveal the presence of potentially useful hidden knowledge and support decision-making processes.

In order to meet these needs, it was decided that a formal KD-oriented system would be developed. With this in mind, applications which implement KD technology on tool trials data, applying rough sets, fuzzy sets and clustering techniques (Velásquez *et al.*, 2000), have been developed and will be presented in subsequent Chapters.

5.4 A FORMAL METHODOLOGY TO BUILD KD-ORIENTED SYSTEMS

The purpose of this section is to provide a formal methodology to develop KD-oriented systems, based in a functional architecture implemented in this research.

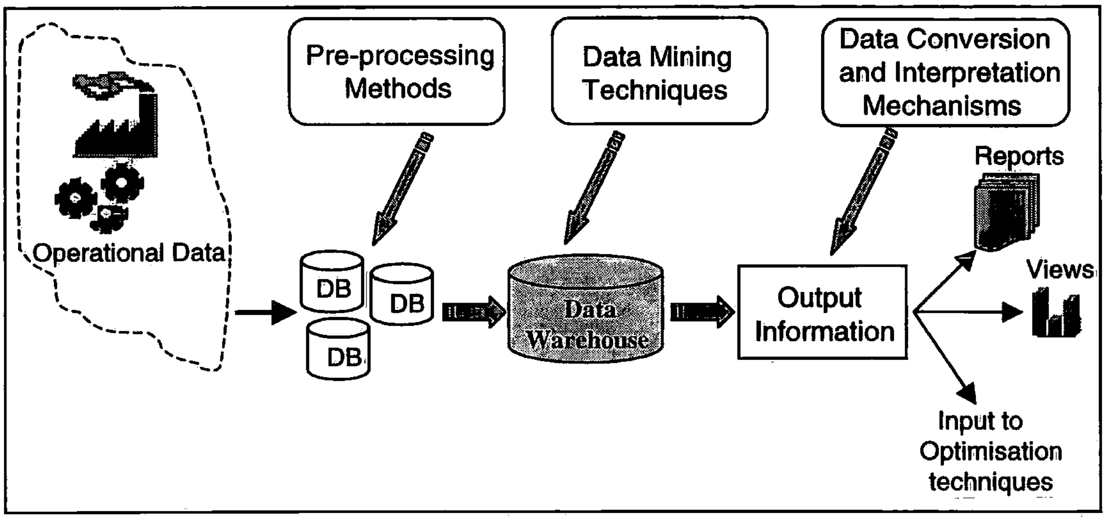

Figure 5.1 Functional architecture of a KD process.

Figure 5.1 displays the whole process, where four main stages, namely, *pre-processing*, *data warehousing*, *data mining* and *data interpretation mechanisms*, can be identified.

The above figure also shows how the data are analysed during the different KD stages. It is supposed that organisations generate data as a consequence of their business operations and these data are stored using some database facilities. At this point, the pre-processing methods will apply filtering techniques, providing "clean" data to be used in the subsequent creation of a robust Data Warehouse (DW). Application of Data Mining (DM) techniques then follows, to reveal potentially interesting patterns. Finally, post-processing methods allow a better use and interpretation of the knowledge discovered. A detailed discussion on each of the main steps of this process follows.

5.4.1 Pre-Processing Phase

In this first stage, the goal is to analyse the existing databases to apply filtering mechanisms and provide "clean" data for a later creation of an integrated, robust and efficient-access repository of data, called Data Warehouse. Three basic functions known as *Attribute Selection*, *Data Cleaning* and *Data Transformation* constitute the core of a pre-processing phase.

Attribute Selection concerns the decision of choosing those records and attributes, which correspond to the most significant variables of interest, according to the domain being studied.

The decision about what are the most representative variables is usually supported by the expert knowledge available in the context that is being analysed and guided by the organisation's goals.

Cleaning operations help to remove irrelevant and spurious data. Redundant or contradictory attribute values, tags, auxiliary characters and empty records constitute unwanted cases that should be discarded.

In a large database, many attributes may be used to characterise given entities. One important task is the selection of those variables closely related to the domain analysed. It is possible to apply different criteria for evaluating the relevance of an attribute for a given classification task. Some authors, such as Baim (1982) and Quinlan (1993) have addressed this problem.

The process of identifying conflicting relationships in the data can be adversely influenced by two main factors. First, when there are too many attributes to be analysed, and secondly, when there are a considerable number of qualitative and judgement values (low-medium, medium, medium-high, ...) associated with some attributes.

Finally, *Data Transformation* is mainly concerned with the application of data standardisation methods. Standardisation is applied when the values of the variables are expressed using too many different scales. Therefore, it will be useful to convert all these values into the same scale. This conversion process is often carried out dividing each value by an equalising factor. The mean, range and standard deviation are the most common equalising factors employed.

Weighting variables and discretisation, are two other operations often implemented to change the original appearance of data. In the process of weighting a particular variable, the investigator gives lesser or greater importance to this variable. This assumption is useful, for example, in cases where the criteria to select elements of distinct groups can be based on intuitive judgements. In these cases, the assignment of numerical weights constitutes viable alternative.

A variable with a range of continuous values (1, 2, ...10) can be discretised converting all the values into a single interval and generating a new and unique variable, grouping all the possible values into this interval (1-10). This is useful in scenarios where data reduction is recommendable.

5.4.2 Building a Data Warehouse

Many corporations are actively looking for new technologies that will assist them in becoming more profitable and competitive. Gaining competitive advantages requires that companies accelerate their decision making process. One key to this is having the right information, at the right time and easily accessible (Poe, 1996).

Currently, the data managed by companies are spread across multiple systems, platforms and locations, creating the need for its storage and future efficient retrieval. Building a Data Warehouse represents a challenge to integrate data from heterogeneous sources and use its storage facilities for Decision Support Systems (DSS).

In the context of KD, a DW constitutes a structured repository of raw and historical data. This repository is characterised by containing read-only data, that is, the data items are hardly ever modified. However, a DW must provide an adaptive and flexible source of information, which means that, when new data are added, the existing data and the technologies are not changed or disrupted. The design of a DW must incorporate a distributed and incremental structure.

5.4.3 Data Mining Techniques - the Engine of KD

Data mining methods can be considered the core stage during the development of KD-oriented systems and therefore, will be given considerable attention in this section.

Data mining is the process of extracting patterns from large sets of data. The field is still in its infancy, with ongoing research focused on better approaches to processing the data, more powerful techniques to extract information, and more intuitive ways of interpreting and reporting the findings (Wong *et al.*, 1998).

In this research, data mining methods have been applied in the tooling sector, specifically in the area of metal cutting operations. Figure 5.2 shows a general view of the whole process. A structured repository of tooling data is built from three different data sources, including existing databases containing information about tool trials performed in widely distributed locations, tooling technical catalogues and knowledge provided by domain-experts.

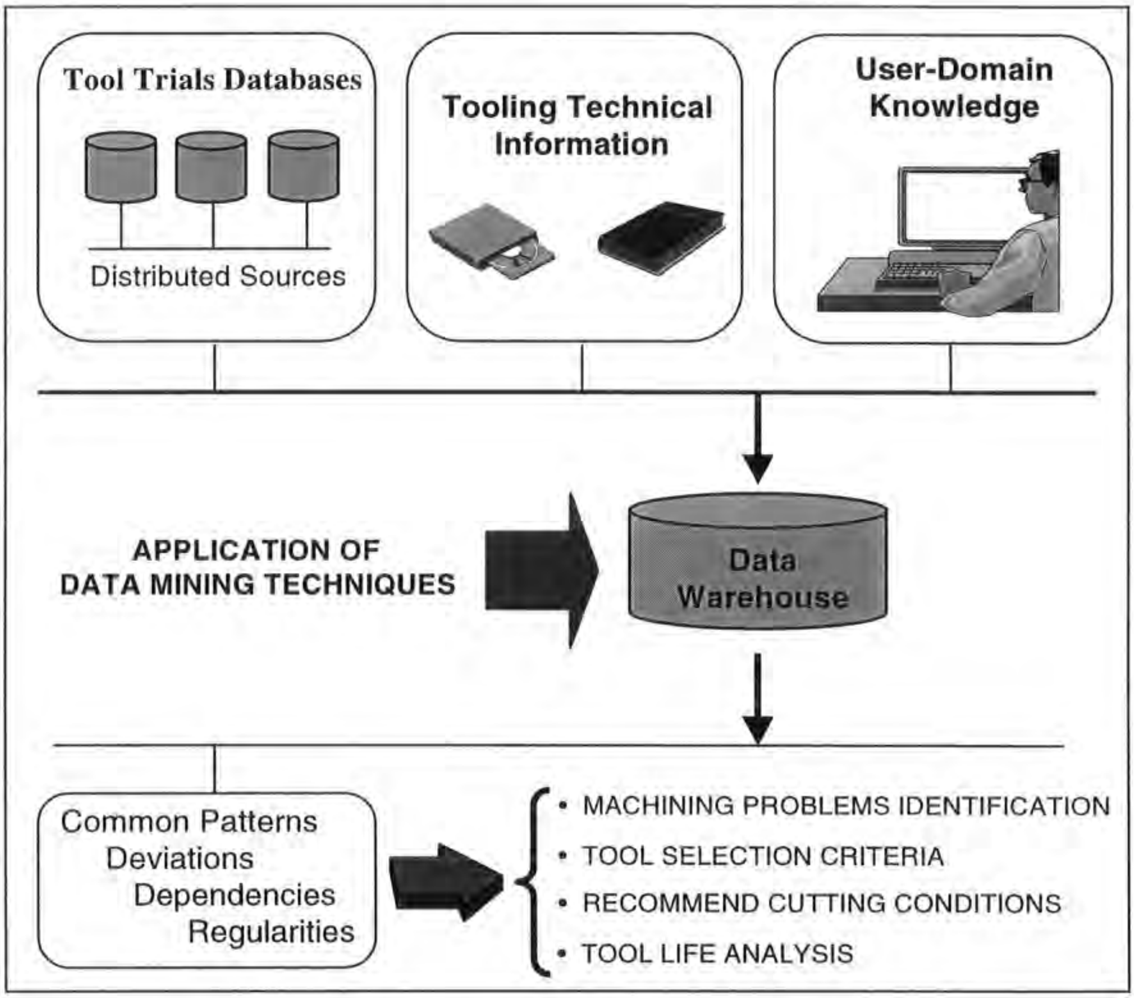

Figure 5.2 Data mining applied on the tooling sector.

Details about the implementation of selected data mining techniques to analyse tooling data, as well as the results obtained, are described in subsequent

Chapters.

There are some important techniques that have been applied for solving many practical problems in the process of KD, being *Decision Trees* one of the most widely used. A summary of this and other methods follows.

A Decision Trees

Tuples are database records or rows consisting of a set of predicting attributes, and a goal attribute. A decision tree is a technique usually supported by top-down algorithms, where at the initial stage of the analysis, all the tuples being considered are assigned to the root node of the tree. Then the algorithm selects a partitioning attribute and partitions the set of tuples in the root node according to the value of the selected attribute.

The goal of this process is to separate the classes, so that tuples of distinct classes tend to be assigned to different partitions. This process is recursively applied to the tuple subsets created by the partitions, producing smaller data subsets, until a stopping criterion is satisfied.

In general, a decision tree model has the following strengths and weaknesses (Aha, 1995):

Strengths:

Comprehensibility;
Fast classification; and
Mature technology.

Weaknesses:

Univariate trees are limited to axis-parallel partitions of the instance space. Multivariate trees are expensive to induce;
Missing values for attributes in the test set may affect the performance of the trees; and
The order of the attributes in the tree nodes can have an adverse effect on the performance.

Further to *Decision Trees*, Freitas and Lavington (1998), *Rule Induction* and *Instance-Based Learning* are two other important paradigms in the field of KD. Based in this classification, a summary of these techniques is presented.

B Rule Induction

In this case the KD algorithm induces a model, such as a rule set or a decision-tree, and uses the induced model to classify new records. These algorithms can be naturally cast as heuristic state-space search, which is based on the two key notions of "state" and "operator". A state is a description of a problem situation in a given instant, and an operator is a procedure that transforms a state into another. Solving a problem consists of finding a sequence of operators, which transform an initial stage into a goal stage.

In the context of *Rule Induction*, a state corresponds to a candidate rule and operators correspond to generalisation and/or specialised operations that transform a candidate rule into another. The choice of the operator to be applied to a given candidate rule, is determined by an heuristic function that evaluates the effectiveness of each operator with respect to the given candidate rule. Examples of specialisation and generalisation operations in the metal cutting area, are shown in Figure 5.3.

Original Rule: If (Operation = "External Turning")
Then (Insert Grade = "TP100"or "TP200")

Specialised Rule: If (Operation = "External Turning" and Material Group = "Cast Iron")
Then (Insert Grade = "TP100")

(a) Specialising a rule by adding a conjunction to its antecedent

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Original Rule: If (Operation = "Grooving" and Workpiece Material = "Soft and low carbon steels")
Then (Cutting speed = "200")

Generalised Rule: If (Operation = "Grooving" and Workpiece material = "steel")
Then (200 <= Cutting speed <= 220)

(b) Generalising a rule by relaxing a condition in its antecedent

Figure 5.3 Generalisation and specialisation examples.

Figure 5.3.(a) shows how adding a new condition (Material Group) to the

antecedent of the original rule, the criterion to obtain the resulting conclusion (Insert Grade = "TP100") is now more restricted.

In contrast, Figure 5.3.(b) shows how changing a particular kind of steel material subgroup (soft and low carbon steel) into a more generic group (steels), it is now possible to relax a condition in the antecedent of the original rule, so, the conclusion can now include a wider interval of values.

The current advances in the area of *Rule Induction* have been significantly inspired by two important families of systems, based on the *AQ* (Michalski, 1969) and *ID3* (Quinlan, 1983) algorithms. *Assistant* (Kononenko *et al.*, 1984) is another notable contribution, which is a descendant of Quinlan's *ID3* algorithm that incorporates a tree pruning mechanism for handling noisy data.

Finally, a classical example of rule induction systems is the *CN2* induction algorithm (Clark and Niblett, 1988). *CN2* combines the best features of the *ID3* and *AQ* algorithms, allowing the application of statistical methods similar to tree pruning in the generation of if-then rules. It is similar to *Assistant* in its efficiency and ability to handle noisy data, whereas it partially shares the representation language and flexible search strategy of the *AQ* family algorithms.

To use the induced rules to classify new examples, *CN2* applies an interpretation in which each rule is tested in order until one is found whose conditions are satisfied by the example being classified. The resulting class prediction of this rule is then assigned as the class of that example. Thus, the ordering of the rules is important. If no induced rules are satisfied, the final default rule assigns the most common class to the new example.

C Instance-Based Learning

Also known as the "Nearest Neighbour" in statistics, *Instance-Based Learning* (*IBL*) simply uses the stored data rather that an induced set of rules to classify new tuples (records or instances). The classification of a new tuple is based on the class of the "nearest" (most similar) stored tuple(s), according to a given distance metric, and its basic idea is illustrated in Figure 5.4.

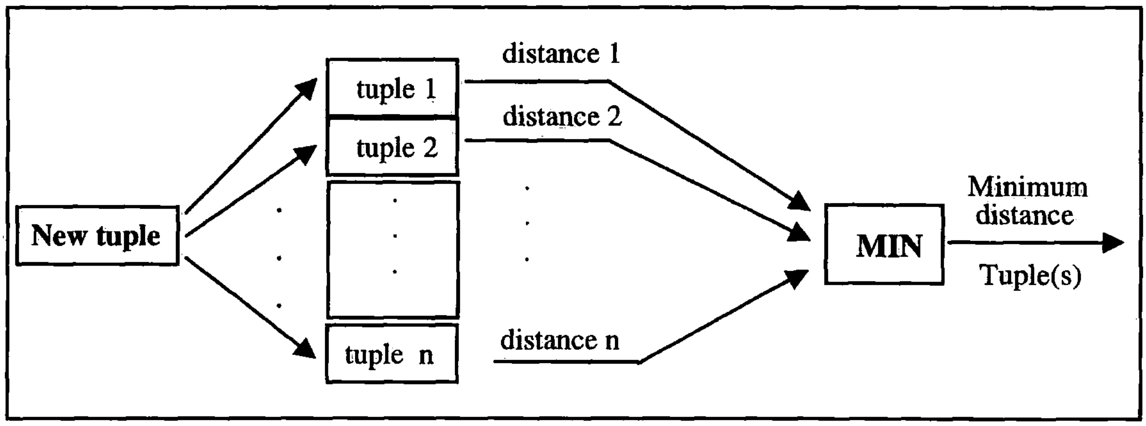

Figure 5.4 Classification of new records using Instance-Based Learning.

As can been in Figure 5.4, a new tuple (to be classified) is compared against all the tuples in the relation being mined, and a distance measure (the inverse of similarity) is computed between the new tuple and each stored tuple.

Depending on the *IBL* algorithm, the computation of tuple distances can take into account attribute weights or whole tuple weights. The computed distances are then passed to a MIN operator, which selects the stored tuple(s) with the minimum distance. The selected tuple(s) is(are) the output of the algorithm. In a classification task, the class of the selected tuple(s) would be used to predict the class of the new tuple.

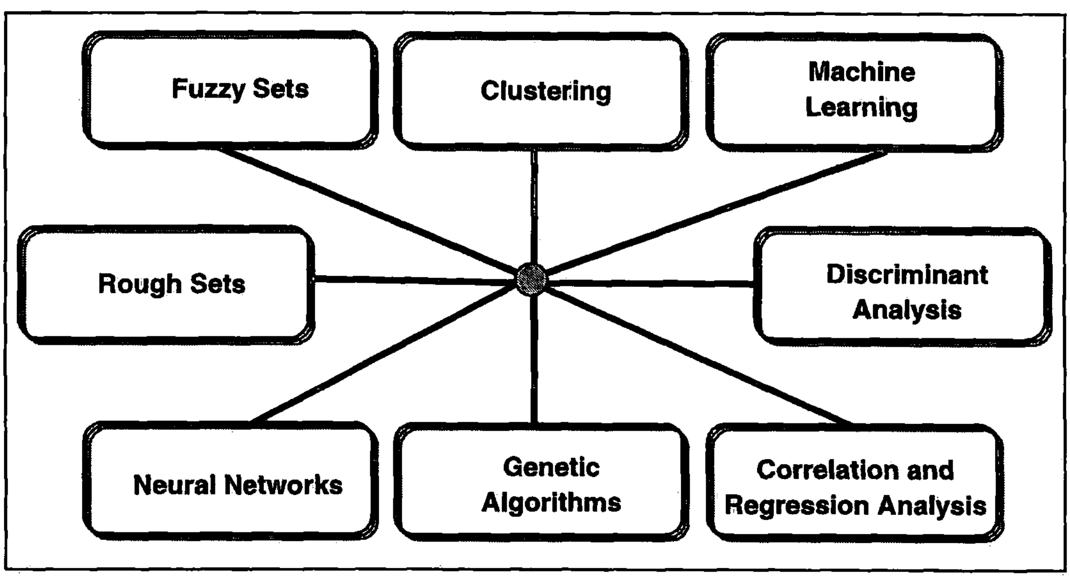

Figure 5.5 Important data mining techniques.

Further to the above described paradigms, the expanding field of KD technology has given rise to a considerable number of commercial data mining tools, which implement a variety of well established AI techniques. These form a homogeneous framework where multidisciplinary technologies can be integrated. Some of these techniques are displayed in Figure 5.5.

Each of the above data mining techniques can be viewed as a complete discipline in its own right, and their analysis is a matter beyond the scope of this thesis. However, subsequent chapters will extend the analysis of some of these techniques, particularly rough sets, clustering and fuzzy sets.

5.4.4 Data Interpretation Mechanisms

It is always important to bear in mind that the focus of the data mining process is to discover hidden patterns and trends. Once a particular trend has been identified, it may contain certain characteristics that prompt the data mining practitioner to move forward along a path of further discovery. However, once that particular pattern is identified, it can be described as a known quantity, and the task of the data mining application is finished.

From the above viewpoint, a post-processing task would be conducted in order to provide two important functions. First, the application of data interpretation techniques to show to the final users, clear and easy to understand results, and secondly, the application of data conversion mechanisms, to translate the discovered patterns into more refined processing tools. The pattern may be put to a multitude of uses including forming the content for a standard report, the input for a data visualisation tool, serving as the training input to a neural network, or being encoded as a rule in an expert system (Westphal and Blaxton, 1998).

In the preceding sections, fundamental issues and multiple factors involved in the implementation of KD-based systems have been examined, to provide the theoretical foundations for a later application of KD on the tooling sector. The final section will present certain trends that are expected to be a reality in a near future.

5.5 FUTURE TRENDS IN KNOWLEDGE DISCOVERY

The developments in the field of KD have been and will continue to be fast-paced and exciting. Within a few short years, approaches that we consider to be state-of-the-art today will seem simplistic when compared to those that are sure to develop. In this section, trends and the factors influencing these advances are anticipated.

A Increase of Web-based Applications

During the process of applying KD methods, it should be noted that whilst more data are available, there are more opportunities to disclose hidden high quality knowledge. Therefore, improving the access to complementary and widely dispersed information sources will contribute to providing a dominant position from which KD tools would be applied.

Obviously, this approach demonstrates its usefulness in distributed scenarios, rather than stand-alone work philosophies. An important factor, allowing a better access to geographically alienated information sources, is the fast growth of the World Wide Web technology.

The expanding powerful features of the Internet, such as the emergence of "Mobile Internet", oriented to access the Web through devices without physical connection capabilities (satellite-based networks), will allow more efficient access to remote data sources, improving in its turn, the conditions for an advantageous application of KD technology. In this way, the development of Web-based KD systems will rapidly increase.

B Major Participation in Decision-Making Processes

Traditional database management relies on end users to recognise problems/opportunities, select relevant data and write queries to supply answers. In contrast, KD tools automatically explore databases to transform raw data into information that can be processed into knowledge by end users.

It should be noted that answers provided by KD methods are generated by taking into consideration the organisation's goals, which helps to complement decision-making processes. These are usually "intellectual" and high level conceived tasks, reserved for the managers and planners. This strategic advantage will increase the relevance and applicability of KD as an important tool to support corporate decisions.

C *More Efficient Search, Processing and Interactive Capabilities*

Computing systems are becoming faster and more powerful. Only a few years ago, those tasks reserved for large and costly computers, are now becoming computationally achievable on smaller and cheaper workstations. As successful technologies are being implemented in the production of micro-processors and as the manufacturing processes become more refined, it is reasonable to expect a continuous growth in the power of computers for quite some time.

Furthermore, a large portion, if not all, of next-generation software will have some type of standard visual components, and graphic-programming environments will be in more general use. This will make it easier for non-technical people to become involved in the design, development and use of KD-oriented tools. Thus, KD tools will target a wider range of industry segments in a very timely manner and conduct analyses that were once beyond the reach of most analytical environments.

D *Virtual Reality-based KD Tools*

Until now, VR techniques have been mainly focused towards applications in relation to sensing and manipulating objects in virtual environments, with important implementations in the field of simulation. However, significant investment and effort are being dedicated to improve VR technology and, in the near future, using VR methods it could be possible to explore databases exploiting the benefits of manipulating records of data supported by virtual immersive environments.

E *Development of General Purposes KD Tools*

The existing KD-based commercial systems require adjustment according to the needs of client organisations, so, the current KDD-based commercial tools are highly context-dependent. Moreover, depending on the domain under study it is possible to have a diversity of formats, varying from text, sound, images, categorical and numerical data.

In such situations the current KD tools cannot be successfully applied considering multivariate data environments and well-differentiated contexts. Consequently, their development will be more oriented towards structures supporting multi-strategic approaches, rather than solutions concentrated on specialised domains.

F Major Integration of Disciplines

KD is definitely a multidisciplinary approach. It relies heavily on a number of existing techniques and algorithms. In order to face challenging problems in relation to noisy, very large and dynamic real-world databases, future KD tools will be developed not only integrating a major number of techniques but also promoting the increase of more complete hybrid solutions.

These KD tools should be integrated to exploit the benefits of applying complementary learning approaches and increasing the spectrum and quality of the findings.

G Major Integration of Functions

Over the past few years, several large information management systems have been developed to perform a wide range of KD activities. Even though many data warehousing and OLAP-related systems fall within this category, they tend to be very specialised, supporting limited analyses for a small range of data types.

As KD systems continue to evolve, they will become more sophisticated in their ability to support a wider array of data processing and analysis functions. Within this framework, the ideal situation is one in which the KD environment will contain all functions needed to support discovery across a range of data models and visualisation paradigms, while also supporting other analytical processes, such as data acquisition, report writing, replication, presentation of results and efficient maintenance of databases.

H Multiple Visualisation Architecture

Another future trend is the ability of certain systems to support multiple representations of the same data sets. The more complex the data sources, the more likely that different perspectives on the data will be required to fully characterise patterns and trends of interest.

Future KD tools will be developed taking into consideration the presentation of findings from different perspectives and multidimensional schemes, in order to provide more transparent and clear frames where end users can easily interpret the results.

I Major Integration of Discovered and Expert-Defined Knowledge

KD-oriented systems rely on a human-system interaction. It is difficult to envision a fully automated process of knowledge discovery as this requires that the system possesses all domain knowledge and is capable of recognising the intentions of the user (Cios *et al.*, 1998). Hence, the next generation of KD-oriented systems will have a major integration between the knowledge that the KD system is able to reveal, and the knowledge and participation of domain-experts, thus providing higher support to guide the discovery process.

J Major Implementation of Parallel Processing Algorithms and Techniques

The future will see an increase in the implementation of parallel processing techniques, as a consequence mainly of the need for speeding up the performance of data mining algorithms, analysing massive and widely dispersed databases and fulfilling the computational complexity of some searching methods.

Whilst this section has anticipated several positive KD trends, it is also the case that the future implementation of KD-oriented systems will not be an easy task. First, the area itself is quite new and not fully defined. Novel ideas need to emerge on how to approach the task of generating new knowledge that goes beyond the research of each contributing area. They need to be evaluated, and put in a meaningful context. Finally, as with any new research discipline, there is hype and perhaps some excessively high expectations (Cios et al., 1998).

5.6 SUMMARY

This chapter has shown how Knowledge Discovery has become a potentially useful discipline to analyse data-rich scenarios, revealing information that can contribute to a better understanding of the domain under study and support decision-making processes.

Data mining methods will later be implemented in the following chapters to analyse tool trials data. Due to this, the current role of KD technology in the tooling industry was analysed. Also, to provide a consistent framework to support the development of KD-oriented systems, a four-stage structured methodology was proposed. It was noticeable that data mining algorithms play a predominant role at the time of implementing the whole methodology.

KD is a relatively young discipline and it is likely that many new, more powerful methods will be developed in the future. Several trends that are expected to be relevant in the coming years, have been examined.

The next chapter will present the way in which cluster analysis and fuzzy sets techniques are combined, in order to apply efficient data classification methods to the tooling sector.

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CHAPTER 6: ASSESSING CUTTING PARAMETERS APPLYING A CLUSTERING-FUZZY APPROACH TO TOOLING DATA.

6.1 INTRODUCTION

A system called ***TTS*** to support tooling engineers in tasks of metal cutting was developed and explained in chapter four. Once in operation, the utilisation of ***TTS*** has generated a huge amount of tooling data. Due to the experimental nature of the trials carried out by tooling engineers, these data are a potential source of valuable knowledge. ***TTS*** also offers a technical support module that helps in finding previous tool trials, through the search of key attributes. Although this module is very useful, it embraces only a small area of many existing applications that could take advantage of the tooling database. Hence, it is necessary to create new mechanisms to explore the data and extract hidden knowledge and meaningful patterns.

The previous chapter has highlighted the importance of knowledge discovery in the analysis of large amounts of data. In addition to this, a four steps methodology for KD was described and the important role of DM methods in the extraction of knowledge was discussed.

In this chapter, a novel KD approach (***Cluster-F***) to assess cutting parameters for turning operations will be described. It is based upon the combination of two DM techniques: Cluster Analysis (CA) and Fuzzy Sets (FS). Clustering methods allow the classification of data generated by ***TTS***. FS concepts are incorporated to obtain proximity measures needed for the classification process. The main contribution of this approach is that it allows the generation of proximity values for categorical data using knowledge related to the domain analysed.

6.2 A CLUSTERING-FUZZY MODEL TO ASSESS CUTTING PARAMETERS FOR TURNING OPERATIONS

As was pointed out in chapter four, the existing technical support systems from tooling manufactures do not provide sufficient help for the needs of machinists regarding metal cutting activities. The databases only provide data to support the most common operations, materials and tools used in process planning activities. The development of ***TTS***, contributed to the coverage of some of these needs from clients. With the utilisation of ***TTS***, the considerable generation of tooling data opened the possibility of creating new programs, mining these data and assisting in tooling functions previously not exploited.

One important area in process planning is the definition of cutting parameters for the different tools, functions and operations in metal cutting tasks. It has a strong influence on the reduction in time and cost, improvement in productivity and tool life, simplification of process planning activities, and optimisation of the production processes. The main objective of ***TTS*** was focused on providing technical solutions to machinists. In this way, the data generated provide valuable information that can be used to recommend cutting parameters for user requirements. Some important advantages of this source of data are that *a)* the database is constantly growing with new tool trials incorporated every day. It supposes an updated information policy; *b)* the results of these tests are measured in terms of improvement of tool life, cost and productivity. It means that the data have been tested to provide good performance in the trials; and *c)* the database contains experimental data rather than catalogue-based data. It means that this type of data is more reliable for supporting tooling advice.

Taking all these points into consideration, it was decided to develop ***Cluster-F***[4], a KD application to provide solutions in the assessment of cutting parameters. The application area was oriented toward turning operations. The main contribution of the author to this system was to provide a novel mechanism to obtain similarity values for categorical values applying fuzzy set concepts.

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[4] Joint contribution (Velásquez, Luis)

The first step consisted of designing the system applying the methodology for KD proposed in the previous chapter. One important phase was the definition of the data mining technique to be used in the processing of the data. Some data mining methods are better applied on specific types of data. They can work well in some domains but fail in others. For instance, neural network technology seems to provide good results when it is applied to financial data. Fuzzy systems are preferred when dealing with control, supervision tasks and vague information. Genetic algorithms are better known as optimisation techniques used for re-processing and refining of results.

Clustering techniques have the advantage of being suitable for any kind of data. Their algorithms have been applied in a wide range of areas obtaining good results. Also, the methods used in cluster analysis do not need complicated rules that restrict the capacity to evolve with the growing of the database. In addition, vague and sometimes imprecise data were found in the tooling reports analysed. These characteristics encouraged the decision to apply a combination of cluster analysis and fuzzy concepts. To deal with incomplete and imprecise data, fuzzy sets were introduced. The next section will present the implemented methodology in this approach.

6.3 CLUSTERING METHODOLOGY

Data mining algorithms can be classified into three general areas: classificatory, association and sequencing (Carter and Hamilton, 1998). Classificatory methods distribute input data into disjointed groups. The technique commonly used to undertake this task is called Cluster Analysis.

The main objective of classificatory methods is to group a set of objects into clusters where similar elements are assigned to the same group, whereas dissimilar objects should belong to different clusters.

These techniques have been used in a wide range of disciplines [(Rosenberg *et al.*, 1996) and (Wang, 1997)]. Good results have been found in the application of cluster analysis in psychiatry to refine and redefine current diagnostic categories (Everitt, 1993). In medicine, cluster analysis has been used to classify diseases, diagnose patients depending on the symptoms and to define new diseases (Wastell and Gray, 1987).

6.3.1 Multivariate Data and Similarity-Distance Matrices.

One of the most critical tasks when applying cluster analysis techniques is the selection of the particular set of variables to be examined. This task depends on the purpose of the classification and the type of knowledge to be sought. Features are chosen according to their importance on the domain under study. They must present a high level of relevance in relation to the context that is being mined. When irrelevant attributes are considered, some objects that are different in some major ways may be classified as similar (Michalski and Stepp, 1983).

In metal cutting processes there are three variables regarded as very important for the specification of cutting parameters in turning operations. They are Workpiece Material, Grade and Nose Radius. The first is associated with the material of the piece that is going to be machined. Depending on the specification of this material, tools and cutting parameters are defined. The second variable is related to the material of the insert that should be used in the cutting process with certain workpiece materials. The Nose Radius influences the appearance of the workpiece. As a general rule, the larger the nose radius, the stronger the cutting edge, which also allows for higher feed rates. However, the disadvantage of larger nose radius is the increased risk of vibration (Seco Tools, 1997).

Three other less important variables to take into consideration are the cutting parameters themselves: cutting speed, feed rate and depth of cut.

Another important task when applying cluster analysis is the way the data are going to be prepared to perform the grouping of the objects. It is very common to find examples of classification using uni and bi-variate data. In these cases, not only the handling of the data is easier but the representation on one or two-dimensional graphs simplifies the visualisation of the classification. Many graphical techniques have been developed to evaluate and display these data.

Consequently the application of complicated methods to the data in order to obtain the clusters is not necessary.

Major problems arise when the number of variables to be evaluated increases. Graphical techniques are not easily applicable when more than three variables are being evaluated. In these cases, clustering algorithms could be applied to classify the data. These methods will be later reviewed.

The information is ordered in a two dimensional table representing the objects and the features (or variables) to be clustered. This table is known as the raw multivariate matrix. Some techniques make use of these raw data directly, while others pre-process the data to generate a new matrix with proximity levels between the elements. Thus, each pair of objects will have an associated numerical value which depicts the extent to which these two elements resemble one another (Gordon, 1981). In other words, this proximity matrix describes the relationship between the corresponding patterns in the data set.

A wide range of similarity and distance measures have been proposed. Each is applied depending on the type of data to be handled. Some of these proximity measures for quantitative and mixed types of data will be explained as follows.

A Proximity functions for quantitative data

Clustering methods have provided good performance in analysing numerical data. Proximity levels are calculated from the values of the different variables contained in the multivariate raw matrix. Distance equations are normally applied to the numerical data. Table 6.1 contains commonly utilised distance equations [(Gordon, 1981) and (Everitt, 1992)].

Table 6.1 Distance Equations for Quantitative data.

Euclidean distance:	$d_{ij} = \sqrt{\sum_{k=1}^{p} (x_{ik} - x_{jk})^2}$
Hamming or City block distance:	$d_{ij} = \sum_{k=1}^{p} \lvert x_{ik} - x_{jk} \rvert$

'Camberra' metric:	$d_{ij} = \sum_{k=1}^{p} \left(\mid x_{ik} - x_{jk} \mid / (x_{ik} + x_{jk}) \right)$
Angular Separation:	$d_{ij} = \dfrac{\sum_{k=1}^{p} x_{ik} * x_{jk}}{\sqrt{\sum_{k=1}^{p} x_{ik}^2 * \sum_{k=1}^{p} x_{jk}^2}}$
Correlation coefficient:	$d_{ij} = \dfrac{\sum_{k=1}^{p} (x_{ik} - \bar{x}_i) * (x_{jk} - \bar{x}_j)}{\sqrt{\sum_{k=1}^{p} (x_{ik} - \bar{x}_i)^2 * \sum_{k=1}^{p} (x_{jk} - \bar{x}_j)^2}}$
Genetic distance between populations A and B:	$d_{AB} = \sqrt{(1 - \cos\theta)}$, where $\cos\theta = \sum_{k} \sqrt{(p_{kA} * p_{kB})}$

B Proximity functions for mixed types of data

It is common in many cases to find that the variables chosen for the classification process are not measured in the same units or are not the same type of variables. Some can be numerical, some categorical while others possess interval values. In these cases, it is difficult to decide the type of equation to be used. It is clear, for example, that the categorical data are difficult to quantify when numerical distance equations are implemented.

The consideration of mixed types of variables has represented an obstacle in the application of clustering methodologies. To conduct classification in relation to mixed variables, many approaches have been applied.

One of these pretends to convert all the different types to one unique type of data. If one variable represents colour of the eyes, the numerical representation could be the codification of the colours depending on a certain similarity. For example, dark brown eyes are more similar to black than light blue eyes. Everything will depend on the importance these different levels are for the classification purpose. The problem confronted by this kind of approach is the discarding of potentially important information.

Another approach is to carry out separate analyses of the same set of objects for the different types of data, and then to try to synthesise the results of the different studies. This could lead to more problems if the separate results reflect different tendencies. This approach seems to be the least satisfactory, but represents an option when insuperable obstacles are present.

An alternative is the one that incorporates a general similarity coefficient with the combination of different types of variables. Gower (1971) suggested a formula for the evaluation of numerical and categorical data. It is defined

$$S_{ij} = \frac{\sum_{k=1}^{p}(w_{ijk} \times s_{ijk})}{\sum_{k=1}^{p} w_{ijk}} \quad (6.1)$$

In this equation, s_{ijk} is the similarity between the *i*th and *j*th elements as measured by the *k*th variable, and w_{ijk} is typically 1 or 0 depending on whether or not the comparison is valid for the *k*th variable. For example, a weight zero can be assigned when one or both values for the *k*th variable are unknown or the result of its match is negative. For categorical data, s_{ijk} takes a value of one when two individuals have the same value for the *k*th variable, and zero otherwise. For quantitative variables, the value of the similarity for the *k*th variable is given by

$$s_{ijk} = 1 - \left(|x_{ik} - x_{jk}| / R_k\right) \quad (6.2)$$

where x_{ik} and x_{jk} are the two values of the *k*th variable for the two objects evaluated and R_k is the range (either in the sample of objects to be clustered, or in some large population) of the variable *k*.

The two main variables that play an important role in the calculation of cutting parameters (*Workpiece Material* and *Grade*) were categorical. The methods mentioned above were evaluated in order to provide an answer for the calculation of the proximity values for these variables. Neither the codification of the possible values of the variables nor the simple comparisons of values to obtain *0* or *1*, were realistic options for these cases.

To deal with this situation, a model using fuzzy set concepts was implemented. It consisted in the creation of fuzzy sets for the comparison of categorical variables. This allows the quantification of the proximity between two elements through the membership levels. A brief review of fuzzy set concepts and the definition of the proposed fuzzy model is presented as follows.

A Fuzzy sets

Fuzzy logic is a means of dealing with imprecise terms. It is built around the concept of reasoning in degrees, rather than in absolute terms. We can sense when a room is warm or cold, but we cannot specify the exact temperature. The terms *warm* and *cold* are imprecise but adequate to specify rules that define control strategies.

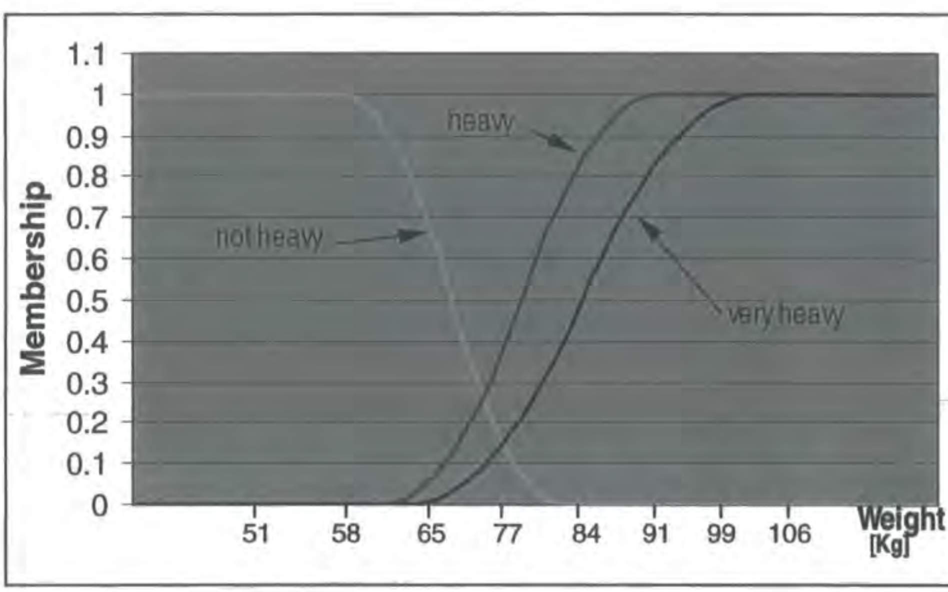

Figure 6.1 Fuzzy sets representation.

This is the essence of fuzzy logic. Variables are defined in terms of fuzzy sets. An ordinary set divides the universe into those items that are completely in the set and those items that are completely outside of the set (0 or 1). Fuzzy sets allow the possibility of degrees of membership. Any of the values between 0 and 1 (including them) may be assigned. Fuzzy membership functions are the way how the fuzzy system interfaces with the outside world (Welstead, 1994). The membership degree represents how close the feature value and the fuzzy concept are.

To illustrate the functionality of fuzzy sets let us suppose we are interested in defining when a person is very heavy, heavy or not heavy. For it, we need to determine one fuzzy set for each concept. Figure 6.1 shows the graph with these three fuzzy sets.

The membership functions for each concept would be:

$$\mu_A(x) = \begin{cases} 1 & \text{if } x < 58 \\ 1 - 2 * \left(\frac{x - 58}{81 - 58}\right)^2 & \text{if } x \in [58, 69.5] \\ 2 * \left(\frac{81 - x}{81 - 58}\right)^2 & \text{if } x \in [69.5, 81] \\ 0 & \text{if } x > 81 \end{cases}$$

A = Not Heavy

$$\mu_B(x) = \begin{cases} 0 & \text{if } x < 62 \\ 2 * \left(\frac{x - 62}{91 - 62}\right)^2 & \text{if } x \in [62, 76.5] \\ 1 - 2 * \left(\frac{91 - x}{91 - 62}\right)^2 & \text{if } x \in [76.5, 91] \\ 1 & \text{if } x > 91 \end{cases}$$

B = Heavy

$$\mu_C(x) = \begin{cases} 0 & \text{if } x < 65 \\ 2 * \left(\frac{x - 65}{101 - 65}\right)^2 & \text{if } x \in [65, 83] \\ 1 - 2 * \left(\frac{101 - x}{101 - 65}\right)^2 & \text{if } x \in [83, 101] \\ 1 & \text{if } x > 101 \end{cases}$$

C = Very Heavy

Then, if there is a person called Robert who weighs 71 Kgms., it is possible to obtain a linguistic description of the weight of this person using the fuzzy sets defined. It would be described with the following expression:

> Robert is *not heavy* with membership degree = *0.3780*, *heavy* with membership degree = *0.1926* and *very heavy* with membership degree = *0.0555.*

The proposed application for variables Workpiece Material and Grade is the creation of fuzzy sets that provide membership levels (or proximity) between the possible values using fuzzy concepts. This idea will be detailed in the next three sections.

B Workpiece Material Group

The analysis of materials was undertaken using two variables existing in the database: Seco workpiece material group and workpiece material. This section will cover the analysis of the first variable.

Table 6.2 Seco Material Groups.

Sup. Grp.	Mat. Grp.	Material Group Description
Steels	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. Hi-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.
Stainless	8	Easy-machining stainless steels. Free cutting stainless steels. Ca-treated stainless steels.
	9	Medium-difficult stainless steels.
	10	Stainless steels that are difficult to machine.
	11	Cast iron with high hardness.
Cast Irons	12	Cast iron with medium-high hardness.
	13	Low-alloy cast iron. Malleable cast iron.
	14	Medium-difficult cast iron. Medium-difficult malleable cast iron
	15	High-alloy cast iron which is difficult to machine. Difficult malleable cast iron.

The Seco Material Group (SMG) is the company classification for the most common used materials in metal cutting processes. Each group is a compilation of materials with similar features and properties based on their machinability. Table 6.2 shows these groups which are also classified into three super groups: Steels, Stainless Steels and Cast Iron.

Although numbers represent the material groups, the comparison to obtain proximity between two groups cannot be done using numerical methods. The material groups of each super-group, present some resemblance features that can be used to obtain similarity values. The machinability of materials can be assessed by analysing their mechanical properties (Yeo, 1995)].

To relax the material groups, Revere (2000) applied linear regression analysis. He used four important properties of the materials pertaining to these groups: *tensile strength, yield stress, impact strength* and *hardness.* He obtained the means values per group for each property. These values, shown in Table 6.3, were standardised, normalised and processed to obtain the linear regression equations.

Table 6.3 Properties values for Steel Material Groups.

Material Group	**Tensile Strength (MPa)**	**Yield Strength (MPa)**	**Izod Impact Strength (J)**	**Hardness (HB)**
1	452	280	23	142
2	519	325	22	162
3	631	349	30	183
4	646	403	31	209
5	732	428	30	237
6	898	496	35	242
7	928	545	38	272

These equations were used to calculate confidence levels of matches found for material groups. This method was a good first approach to deal with insufficient information in the Tool Trials Database, but it presented some inconsistencies:

- The result of comparing two identical material groups is a value below "100%".

- The comparison between two consecutive material groups (e.g. 1-2, 2-3, 3-4, 4-5, 5-6 or 6-7) always produces the same results.

The new approach is based on the mean values of the properties used by Revere, but it overcomes the above described inconsistencies. The objective of this method is to obtain one fuzzy set for each material group, which help to establish membership levels with others material groups. To illustrate how these FS were achieved, the complete procedure for the first super-group of materials will be explained.

The Steel super-group contains seven sub-groups. Using the values of the Table 6.3, a 7x7 matrix for each property was generated. These matrices are symmetric and contain the relative comparison between material groups.

The Equation 6.3 was used to obtain the final membership levels of material group *j* in relation with material group *i*.

$$\mu_{ij} = 2 - \frac{\sum_{k=1}^{p} (M_{kj}/M_{ki})}{p} \qquad j >= i \tag{6.3}$$

were:

μ_{ij} is the membership level of element j to the fuzzy set "*Group i*"

p represents the number of properties evaluated (p=4)

M_{ki}, M_{kj} are the values of property k for materials i and j

Using Equation 6.3 the values of the fuzzy sets were obtained.

$$\text{Groups } \{1, 2, 3, 4, 5, 6, 7\}$$

$$\mu_{MGrp.1}(x) = \{\mathbf{1.00}, 0.90, 0.69, 0.58, 0.47, 0.25, 0.11\}$$

$$\mu_{MGrp.2}(x) = \{0.90, \mathbf{1.00}, 0.80, 0.70, 0.61, 0.41, 0.28\}$$

$$\mu_{MGrp.3}(x) = \{0.69, 0.80, \mathbf{1.00}, 0.91, 0.83, 0.67, 0.55\}$$

$$\mu_{MGrp.4}(x) = \{0.58, 0.70, 0.91, \mathbf{1.00}, 0.93, 0.77, 0.67\}$$

$$\mu_{MGrp.5}(x) = \{0.47, 0.61, 0.83, 0.93, \mathbf{1.00}, 0.86, 0.76\}$$

$$\mu_{MGrp.6}(x) = \{0.25, 0.41, 0.67, 0.77, 0.86, \mathbf{1.00}, 0.91\}$$

$$\mu_{MGrp.7}(x) = \{0.11, 0.28, 0.55, 0.67, 0.76, 0.91, \mathbf{1.00}\}$$

These fuzzy sets are graphically displayed in Figure 6.2.

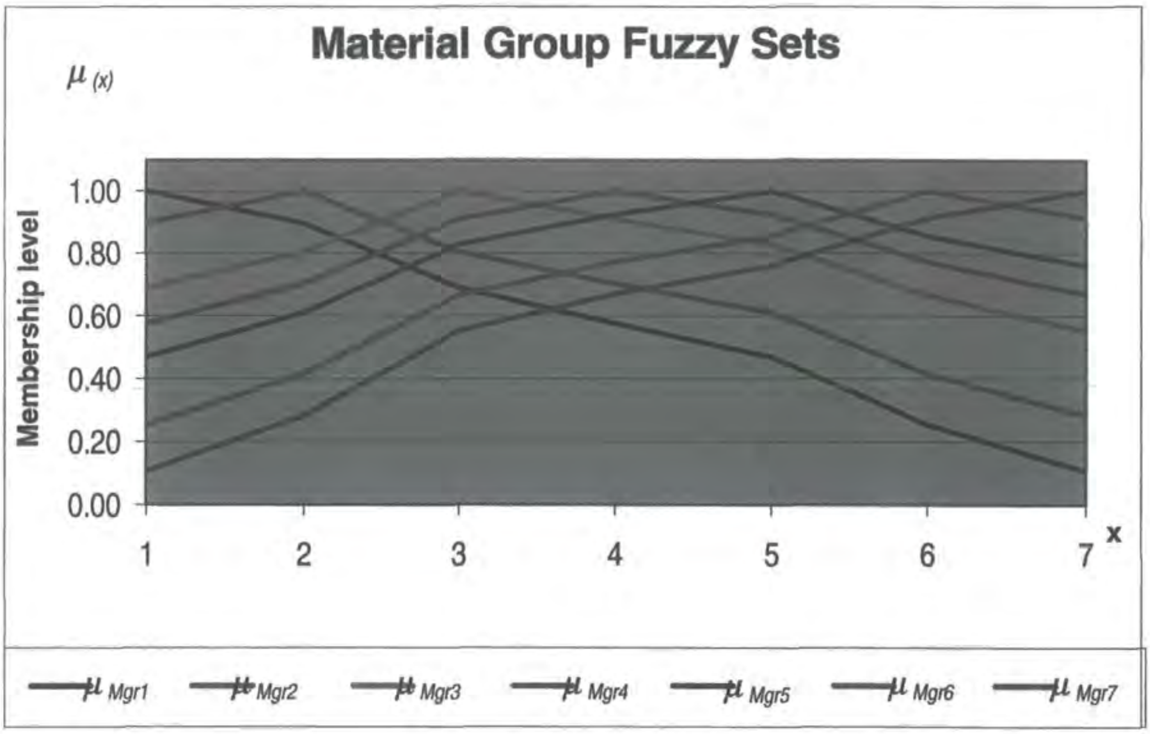

Figure 6.2 Fuzzy sets for Steel Super-group.

The aforementioned procedure was applied to Stainless Steels and Cast Iron super-groups. The final fuzzy sets obtained were:

Groups	{ 8, 9, 10, 11}	Groups	{ 12, 13, 14, 15}
$\mu_{MGrp.8}(x) =$	{**1.00**, 0.96, 0.52, 0.42}	$\mu_{MGrp.12}(x) =$	{**1.00**, 0.72, 0.39, 0.05}
$\mu_{MGrp.9}(x) =$	{0.96, **1.00**, 0.57, 0.48}	$\mu_{MGrp.13}(x) =$	{0.72, **1.00**, 0.74, 0.48}
$\mu_{MGrp.10}(x) =$	{0.52, 0.57, **1.00**, 0.93}	$\mu_{MGrp.14}(x) =$	{0.39, 0.74, **1.00**, 0.79}
$\mu_{MGrp.11}(x) =$	{0.42, 0.48, 0.93, **1.00**}	$\mu_{MGrp.15}(x) =$	{0.05, 0.48, 0.79, **1.00**}

Seco material group is an important variable in the ***TTS*** database. Tooling engineers are quite familiar with them, but, what happens when no classified materials are used by clients in their processes? One of the main problems found by tooling engineers is how to provide a technical advice when dealing with these not too common materials. The tooling database considers the incorporation of the variable *material* for these cases. Next, the proximity study for this variable will be explained.

C Workpiece Material no contained in the Seco Material Group

The analysis of the material was carried out when both material groups in the analysis were 0. A value of 0 for the material group variable means that the workpiece material used in the tests did not belong to any Seco Material Group. The procedure to obtain the proximity measure was undertaken by analysing the machinability percentages of each pair of materials.

In order to cover a major range of workpiece materials used in tooling tasks, Seco Tools has classified a set of alloys not included in the SMG. This classification is based on the percentage of machinability (Appendix D). Decreasing values indicate increasing machining difficulties.

In catalogues, the selection of important variables like grade, chipbreaker, depth of cut, feed rate and cutting speed are based in this machinability feature and the type of machining (finishing, medium or roughing). The percentage of machinability goes from 5%, very difficult to machine, to 60%, less difficult. These percentages are classified in three groups: 5-12%, 13-37% and 38-60%. It is logical to assume that two alloys having close machinability percentages are more similar than those with larger differences.

Table 6.4 Material proximity values based on machinability.

	Group 1		Group 2		Group 3	
Machinability (%)	38 - 60		13 - 37		5 - 12	
Difference (%) $[x_1 ; x_2]$	0	22	0	24	0	7
Range of proximity $[y_1 ; y_2]$	1.00	0.20	1.00	0.30	1.00	0.40
Linear Equation $x = \|\%m1 - \%m2\|$	$y = \frac{-40x + 1100}{1100}$		$y = \frac{-35x + 1200}{1200}$		$y = \frac{-60x + 700}{700}$	

One option to obtain the proximity value between two of these materials is analysing their machinability differences. No difference at all between machinability percentage of two materials produces a fuzzy membership of 1.

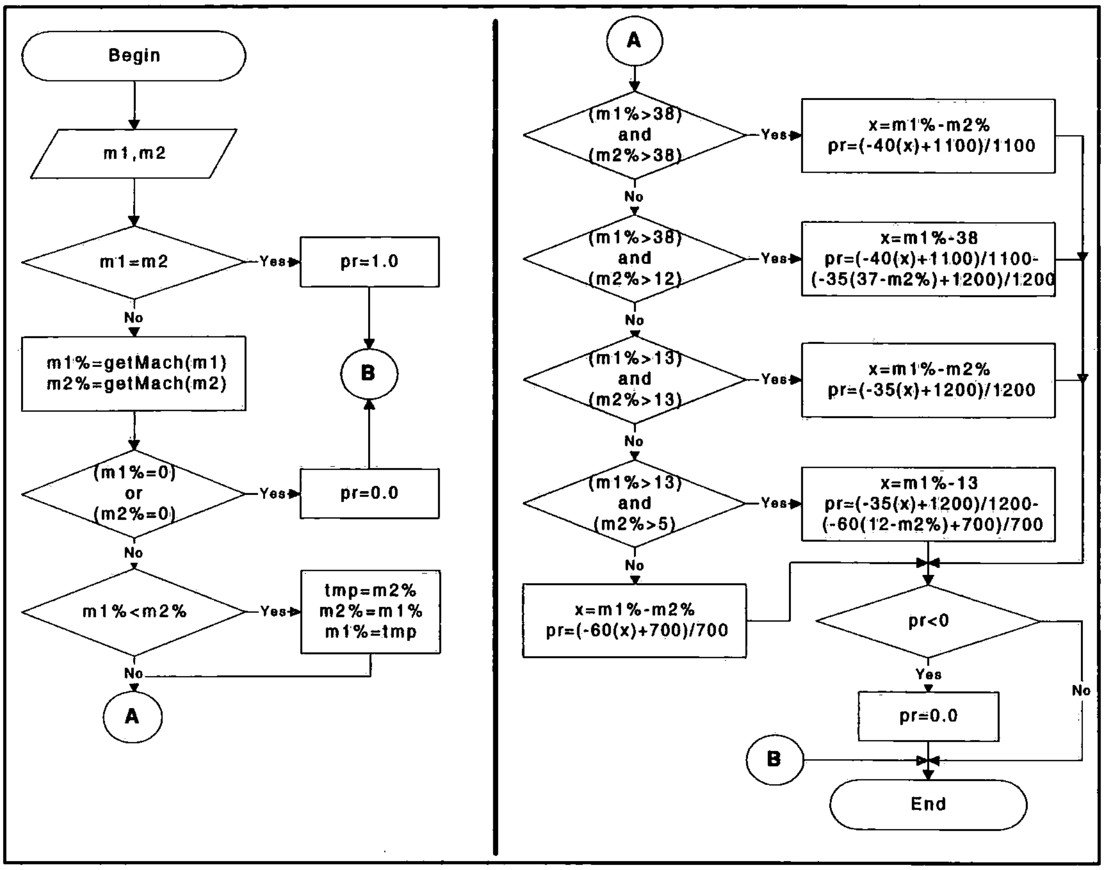

Figure 6.3 Procedure for materials analysis.

As the difference becomes bigger, the membership level decreases. To undertake this task, a linear equation for each group of machinability was calculated. Table 6.4 shows the percentage differences and corresponding membership range for each group. These proximity ranges where defined following discussions with Seco engineers.

Figure 6.3 shows the flowchart describing the procedure to obtain fuzzy membership values using the workpiece material variable. The inputs of this flowchart are the *m1* and *m2* representing the name of the materials to be compared. The output is the fuzzy membership value (*pr*) between *m1* and *m2*.

D Grade

Due to the high influence of grades in the assessment of cutting parameters, its analysis to determine proximity values represents an important task. Once again, the grade is a categorical variable and the study of their features and how they are chosen for metal cutting tasks, provide important information to develop a model to obtain similarity measures when they are compared.

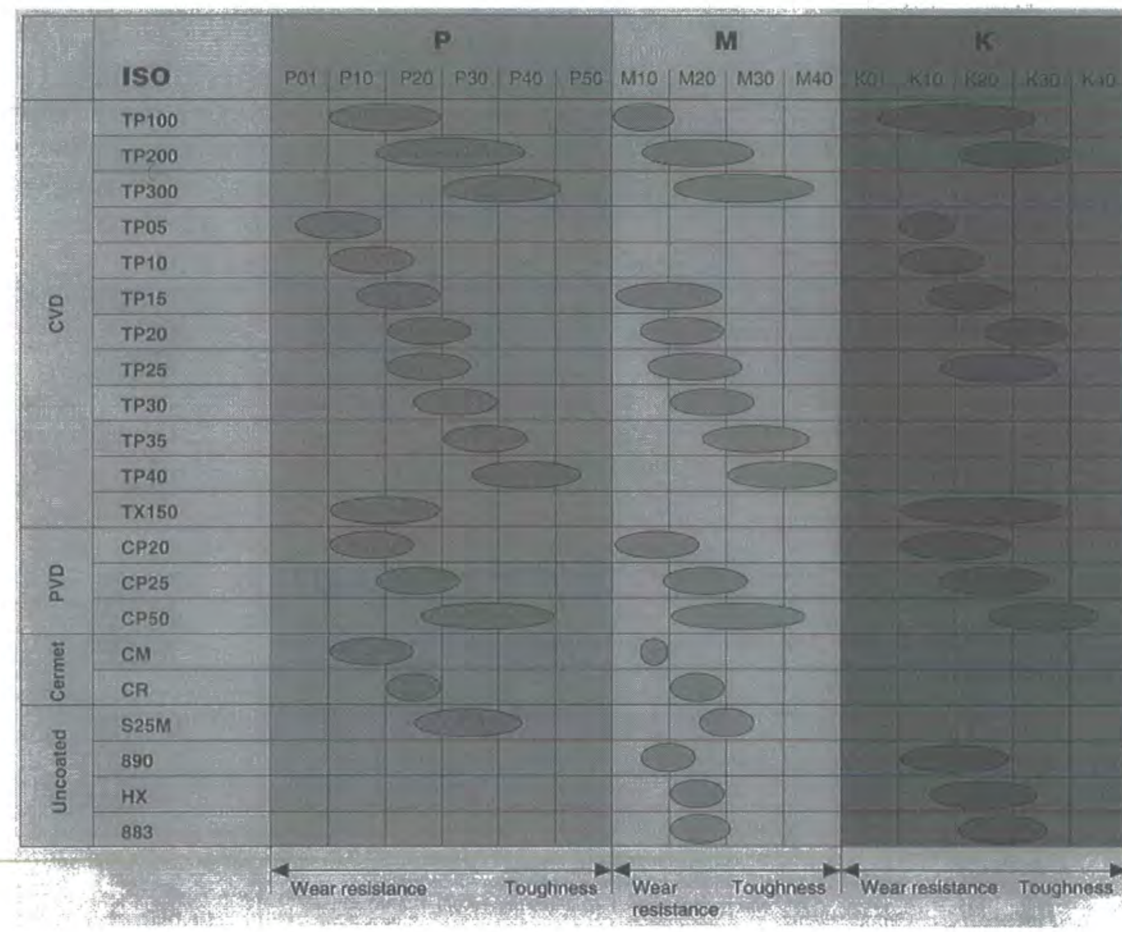

Figure 6.4 Grades capabilities to machine materials.

The inserts used for metal cutting are created from a material called cemented carbide. This material is a combination of two substances: tungsten and cobalt. The tungsten is very hard and responsible for the wear resistance of the insert. The cobalt is the binder and influences the toughness of the insert. Depending on the proportions of these substances the wear resistance and toughness of the inserts vary to make them more or less suitable to machine particular types of materials. The different combinations of tungsten and cobalt determine the grades. The higher the wear resistance of the grade, the lower its toughness. Grades with higher wear resistance have a longer useful life. In contrast, grades with higher toughness involve reduced risk of insert fracture. Seco company has determined the suitability of certain grades to machine particular materials by analysing the capability of grades to work with certain materials. Figure 6.4 illustrates this classification.

Table 6.5 Machinability range for grades.

	P		M		K	
GRADE	MIN	MAX	MIN	MAX	MIN	MAX
TP10	10	25	0	0	10	25
TP20	20	35	16	30	25	40
TP30	25	40	20	35	0	0
TP05	5	19	0	0	10	20
TP100	10	30	10	21	6	33
TP15	15	30	11	30	15	30
TP200	18	45	16	34	20	40
TP25	20	35	16	33	17	38
TP300	30	52	21	45	0	0
TP35	30	45	26	45	0	0
TP40	35	55	30	49	0	0
TX150	10	30	0	0	10	40
CP20	10	25	11	25	10	30
CP25	18	33	19	34	17	36
CP50	26	50	20	43	26	44
CM	10	25	15	20	0	0
CR	18	30	20	30	0	0
S25M	26	45	26	35	0	0
890	0	0	15	25	10	30
HX	0	0	20	30	15	33
883	0	0	20	31	20	36

These materials are classified according to the three material super-groups mentioned earlier but this time they are named with the ISO classification code

(PMK). The super groups are also subdivided depending on their machinability index and hardness.

The indexes are represented by a range of values that go from P01 to P60 for Steels, M10 to M50 for Stainless Steels and K01 to K50 for Cast Iron. The shaded ovals define the material index the insert is capable of machining. As can be noticed from Figure 6.4, some ovals have common areas. It means that two inserts with different grades are capable of machining the same material.

Revere (2000) applied a procedure to calculate confidence scores and relax the search of records that match user requirements by using overlapping of areas. In order to generate similarity measures between two grades an improved procedure using the basic concept utilised by Revere, was applied.

The proximity analysis seeks to obtain a value representing the percentage of shaded area between two grades. This area represents the fuzzy membership value between to grades. The membership value is defined by the capacity of these grades to machine certain materials. First, using the values on Figure 6.4, numerical representations of the shaded areas of machinability for grades and super-group material were defined. Table 6.5 shows this range of values. Three possible cases shown in Figure 6.5 were analysed.

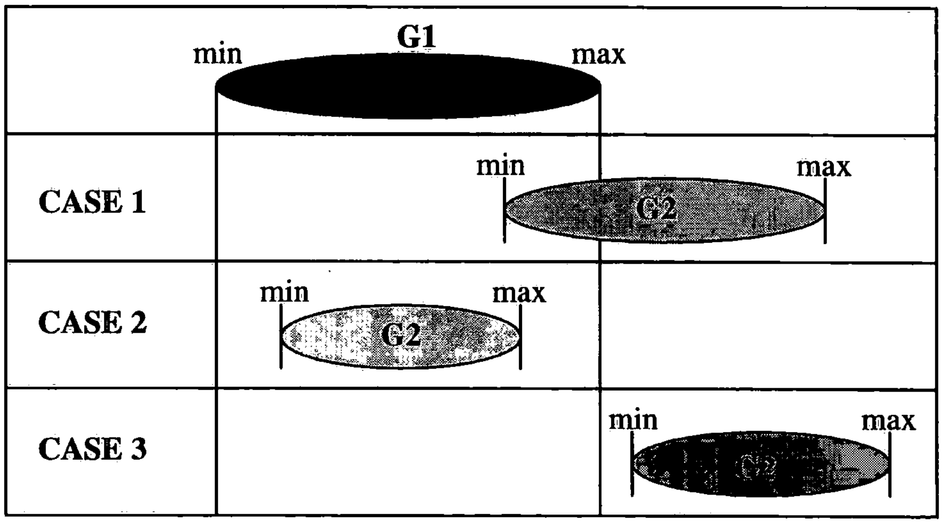

Figure 6.5 Overlapping cases of grades.

From considerations of the above figure it can be noted that there is no common area for CASE 3 and the proximity is 0. For CASES 1 and 2, two different equations were proposed:

$$pr = \left(\frac{G1.\max - G2.\min}{G1.\max - G1.\min} + \frac{G1.\max - G2.\min}{G2.\max - G2\min} \right) \Big/ 2 \qquad \text{CASE 1} \qquad (6.4)$$

$$\mathrm{pr} = \left(1 + \frac{\mathrm{G2.max - G2.min}}{\mathrm{G1.max - G1.min}} \right) \Big/ 2 \qquad \text{CASE 2} \qquad (6.5)$$

Figure 6.6 shows the flowchart describing the procedure to obtain membership values when two grades are compared. This procedure takes into consideration the workpiece material super-groups of each object and the corresponding grades. There are five functions used in the flowchart:

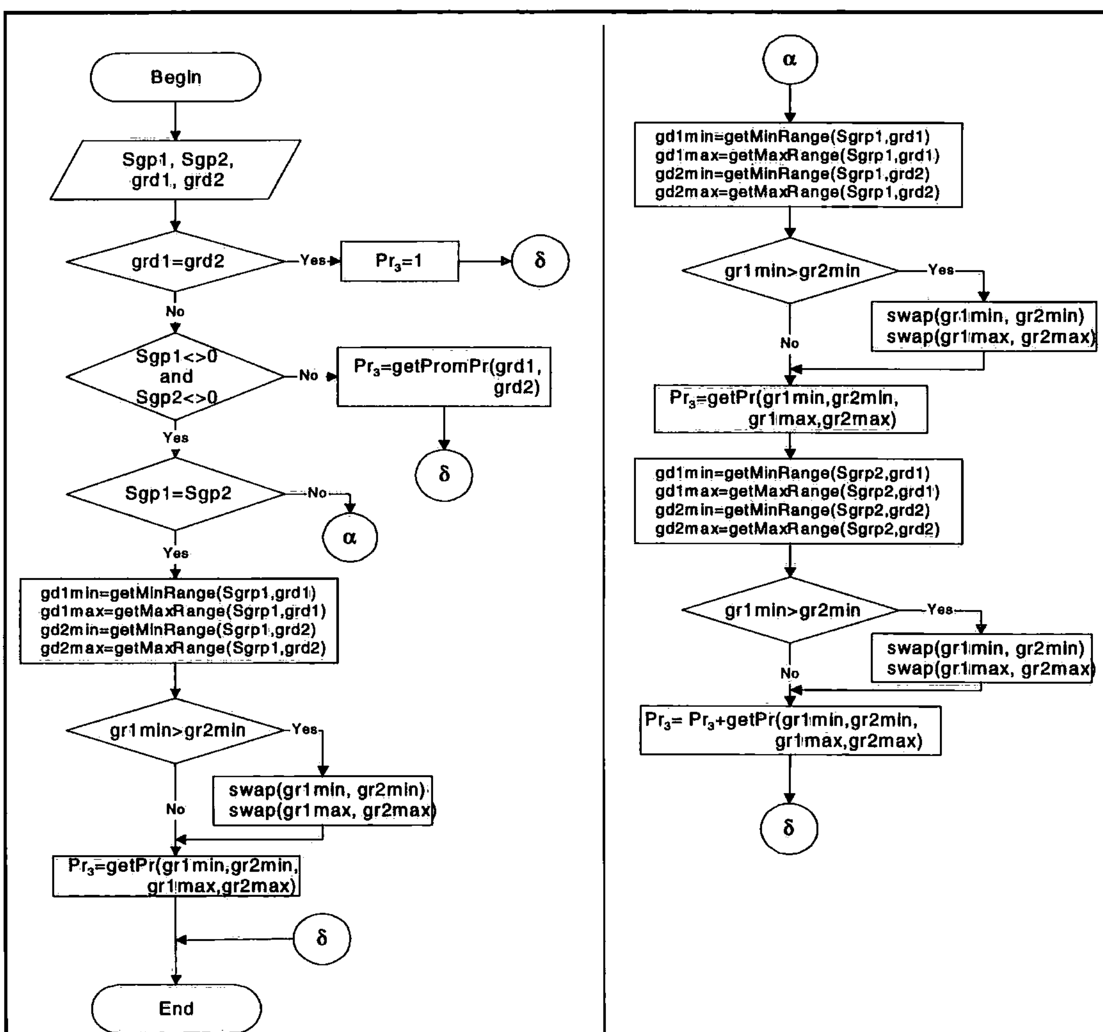

Figure 6.6 Procedure for grades analysis.

- *getMinRange(matSGrp, gr)*. This function returns the minimum value of the machinability range from Table 6.5 for the grade *gr* and the super-group *matSgrp*.
- *getMaxRange(matSGrp,gr)*. This returns the maximum value of the range.
- *swap(val1,val2)*. The function swaps the values between *val1* and *val2*.
- *getPr(g1min,g1max,g2min,g2max)*. This function evaluates the ranges of the two grades using Figure 6.5 and returns the proximity between them.
- *getPromPr(g1,g2)*: the function returns the mean of the proximities corresponding to the three material super-groups for grades *g1* and *g2*. This function is used when one or both workpiece material of the objects cannot be classified within the super-groups.

E Nose radius, cutting speed, feed rate and depth of cut.

In contrast to categorical variables, the numerical ones are easier to manage in terms of defining proximity values. This is the case of *nose radius, cutting speed, feed rate* and *depth of cut*. To maintain homogeneity between the proximity measures of each variable, the same range of values used for categorical variables (0-1) will be kept. Hence, the Gower similarity for numerical variables, described in Equation 6.2, will be applied. Using this proximity measure, the standardisation of the variables was unnecessary.

F Distance matrix.

Once all the variables were analysed, the similarity matrix was obtained by computing and averaging the different similarities. The equation applied to obtain the matrix was an extension of the Gower similarity measure, but more specific in terms of analysis of each variable. This formula is given by Equation 6.6.

$$S_{ij} = \frac{\sum_{v=1}^{4}(S_{ijv}) + \sum_{v=5}^{7}(W_v * S_{ijv})}{\sum_{v=5}^{7}(W_v) + 3} \qquad i \geq j \tag{6.6}$$

where:

v represents the seven variables (*workpiece material group, workpiece material, grade, nose radius, cutting speed, feed rate* and *depth of cut*).

S_{ij1} is computed using Equation 6.3.

S_{ij2} is computed using procedure described in Figure 6.3.

S_{ij3} is computed using procedure described in Figure 6.6.

S_{ij4-7} are computed using Equation 6.2.

W_{5-7} are 1 or 0 depending on user options to include cutting parameters (*cutting speed, feed rate* and *depth of cut*) in similarity matrix calculation.

Table 6.6 Raw matrix for similarity calculation.

Obj	Workpiece Material		Grade	Nose Radius (mm/10)	Cutting speed (m/min)	Feed Rate (mm/rev)	Depth of cut (mm)
	Seco gp.	Mat. Name					
1	2	Med.Carbon Steel	TP200	16	200	0.7	7
2	13	SG Iron Grade 420/12	TX150	12	150	0.4	3
3	0	Incoly 909	TP20	8	55	0.3	3
4	4	Steel Forging	TP25	12	250	1.5	2
5	0	Hastelloy C276	TP300	8	40	0.2	0.5

Table 6.6 presents a raw matrix with five objects and the corresponding variables for the analysis. These data will be processed to exemplify the calculation of the similarity matrix applying the described methodology.

Let us obtain similarity measure for objects 1 and 2. It is necessary to evaluate the partial similarities for each variable. First, the workpiece material. The two elements have material groups belonging to two different super-groups (Steel and Cast Iron). It means that there is not fuzzy membership level between groups 2 and 13. Then, the proximity value is 0 ($Pr_1 = 0$). The evaluation of material is carried out when the Seco Group for both objects are 0, so, this is not the case ($Pr_2 = 0$).

The comparison between grades is undertaken using the procedure on Figure 6.6. The range of machinability for each grade is obtained by searching the relation between workpiece material super-groups and grades on Table 6.5. The machinability ranges for grade TP200 are P[18-45] and K[20-40]. The corresponding ranges for grade TX150 are P[10-30] and K[10-40]. Using Equations (6.4) and (6.5) the proximity value is obtained.

$$Pr_3 = \left(\left(\frac{30-18}{30-10} + \frac{30-18}{40-10}\right)\Big/2 + \left(1 + \frac{40-20}{40-10}\right)\Big/2\right)\Big/2 = (0.5 + 0.83)/2 = 0.678$$

The proximity values for Nose Radius, Cutting Speed, Feed Rate and Depth of Cut are calculated using Equation 6.2. The compute values are:

$$Pr_4 = 1 - (|16 - 12|/(16 - 8)) = 1 - (4/8) = 0.5$$

$$Pr_5 = 1 - (|200 - 150|/(250 - 40)) = 1 - (50/210) = 0.762$$

$$Pr_6 = 1 - (|0.7 - 0.4|/(1.5 - 0.2)) = 1 - (0.3/1.3) = 0.769$$

$$Pr_7 = 1 - (|7 - 3|/(7.0 - 0.5)) = 1 - (4/6.5) = 0.385$$

Assuming the user has chosen to include cutting parameters in the similarity matrix calculation, the similarity value between objects 1 and 2 is obtained using Equation 6.6.

$$S_{12} = \frac{\sum_{v=1}^{4}(S_{12v}) + \sum_{v=5}^{7}(W_v * S_{12v})}{\sum_{v=5}^{7}(W_v) + 3} = \frac{Pr_1 + Pr_2 + Pr_3 + Pr_4 + 1 * Pr_5 + 1 * Pr_6 + 1 * Pr_7}{3 + 3}$$

$$S_{12} = \frac{0 + 0 + 0.678 + 0.50 + 1 * 0.762 + 1 * 0.769 + 1 * 0.385}{6} = 0.516$$

The obtained similarity matrix is given by:

$$
S = \begin{array}{c} \\ 1 \\ 2 \\ 3 \\ 4 \\ 5 \end{array}
\begin{array}{ccccc} 1 & 2 & 3 & 4 & 5 \end{array}
\begin{pmatrix}
1.000 & & & & \\
0.516 & 1.000 & & & \\
0.364 & 0.544 & 1.000 & & \\
0.559 & 0.475 & 0.397 & 1.000 & \\
0.211 & 0.381 & 0.778 & 0.261 & 1.000
\end{pmatrix}
$$

After the similarity matrix was obtained, the transformation of these values to distance measures was necessary to apply the classification methods. Distance (or dissimilarity) is the opposite of similarity. There are various formulas to perform this transformation. There is one expression that has proved to be useful in order to convert similarity to dissimilarity and vice versa (Gordon, 1981). It is given by Equation 6.7.

$$d_{ij} = \left[\left(1/s_{ij}\right) - 1\right] \qquad (6.7)$$

The dissimilarity matrix ***D*** is obtained applying the above equation to each value of the similarity matrix.

$$
D = \begin{array}{c} \\ 1 \\ 2 \\ 3 \\ 4 \\ 5 \end{array}
\begin{array}{ccccc} 1 & 2 & 3 & 4 & 5 \end{array}
\begin{pmatrix}
0.000 & & & & \\
0.848 & 0.000 & & & \\
1.745 & 0.840 & 0.000 & & \\
0.788 & 1.107 & 1.522 & 0.000 & \\
3.723 & 1.627 & 0.285 & 2.837 & 0.000
\end{pmatrix}
$$

6.3.2 Clustering methods

The methods used in cluster analysis have been commonly divided into two categories: hierarchical and partitioning or non-hierarchical.

A Partitioning Methods

The objective of this kind of algorithm is to maximise the homogeneity within each cluster while maximising heterogeneity between clusters (Arabie and

Hubert, 1996). These methods partition the original set of *n* objects into *m* clusters and find the optimal grouping of elements by moving them from one cluster to another. With each move of elements, values of intra and inter cluster homogeneity are calculated and compared with the previous values. If the new values reflect better classification of the objects, the algorithm proceeds to perform a new test. If the values do not improve the clustering of the data, the element is returned to its original cluster and a new movement of an element is carried out. The clustering process finishes when no better classification is found.

In the application of these methods, the user must specify the number of clusters for the partition of the data (*m*) and the initial centroid values for each of these clusters (Bagcsy and Ahuja, 1998). This fact supposes not only a previous understanding of the set of data by the researcher, but also the kind of knowledge the user is looking for. It is unsuitable when the user is not an expert in the area of study or when there is no pre-conception of the kind of knowledge to be discovered from the data.

The most commonly used partitioning methods are Error-square clustering. These are used to classify objects which can be represented as points in Euclidean space of some number of dimensions (Gordon, 1981). Each dimension of the point represents one feature of the object. The objective of these methods is to minimise the square error for the set of clusters.

Let $X_{ik}\,(i=1,..,n;k=1,..,t)$ denote the *k*th co-ordinate of the *i*th point, P_i. The aim is to partition the set of *n* points into m groups so as to minimise the total within-group sum of squares about the *m* centroids. For example, if the centroid of *r*th group, which contains the n_r points $\{P_{ri}(i=1,..,n_r)\}$, has co-ordinates $Z_{rk}=\frac{1}{n_r}\sum_{i=1}^{n_r}x_{rik}$ $(k=1,..,t)$ and if the within-group sum of squares of the *r*th group is $S_r=\sum_{i=1}^{n_r}\sum_{k=1}^{t}(x_{rik}-z_{rk})^2$ then the aim is to find a partition which minimises $S_{(g)}=\sum_{r=1}^{g}S_r$.

Due to extensive research in this area, equivalent forms of this sum of square criteria have been developed.

B Hierarchical Methods

Here, in contrast to the partitioning methods, the data set is not initially grouped into a particular number of classes. Instead, the classification consists of a series of partitions which may run from a single cluster containing all the individuals, to *n* clusters each containing a single individual. The objective of these methods is to find the most efficient step at each stage in the progressive division or synthesis of the data (Everitt, 1993).

The hierarchical methods are sub-divided into two categories: divisive and agglomerative. The first category starts off with one unique class containing all the elements. In successive stages an existing class is divided into two.

The agglomerative methods start with the number of clusters equal to the number of individuals and continuously reduce the number of clusters by merging. These algorithms are characterised by using a symmetric matrix containing similarity measures between the clusters. Differences between methods arise because of the different ways of defining the similarities between two groups of individuals. The agglomerative algorithms are the most common in clustering analysis. In this research, attention will be concentrated on this kind of method. Some of the most widely used methods used in practice are explained as follows [(Michalski et *al.*, 1998), (Gordon, 1987) and (Everitt, 1993)]. These methods were implemented in this approach.

i *Single linkage.*

This technique is also known as *nearest neighbour.* The distinguishing feature of this method is that the similarity distance between two groups is defined as that of the closest pair of individuals belonging to the two corresponding clusters. Figure 6.7 illustrates this method.

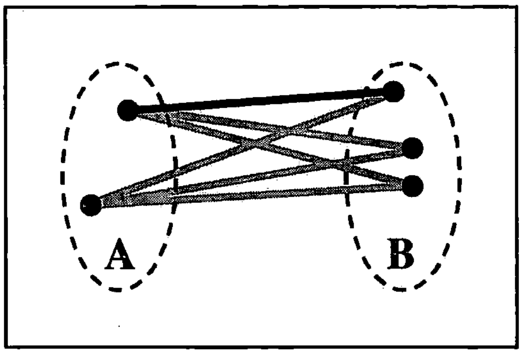

Figure 6.7 Single linkage distance.

The proximity between **A** and **B** is calculated based on the minimal distance between the elements belonging to these clusters.

$$\| A - B \| = \min_{\substack{x \in A \\ y \in B}} \| x - y \| \qquad (6.8)$$

Where $\|A - B\|$ is the distance between clusters **A** and **B**, and $\| x - y \|$ is the distance between object **x** belonging to the cluster **A** and object **y** belonging to the cluster **B**.

In order to illustrate numerically how the algorithm of this method works, let us take the distance matrix ***D*** computed before. Initially, each element is considered one cluster.

$$D = \begin{array}{c} \\ 1 \\ 2 \\ 3 \\ 4 \\ 5 \end{array} \begin{array}{c} \begin{array}{ccccc} 1 & 2 & 3 & 4 & 5 \end{array} \\ \begin{pmatrix} 0.00 & & & & \\ 0.85 & 0.00 & & & \\ 1.75 & 0.84 & 0.00 & & \\ 0.79 & 1.11 & 1.52 & 0.00 & \\ 3.72 & 1.63 & 0.29 & 2.84 & 0.00 \end{pmatrix} \end{array}$$

The smallest distance in the matrix is that for clusters 3 and 5. These two clusters are joined to form one cluster. The new distance matrix is given by

$$D=\begin{array}{c} \\ 1 \\ 2 \\ (35) \\ 4 \end{array}\begin{array}{c} \begin{array}{cccc} 1 & 2 & (35) & 4 \end{array} \\ \begin{pmatrix} 0.00 & & & \\ 0.85 & 0.00 & & \\ 1.75 & 0.84 & 0.00 & \\ 0.79 & 1.11 & 1.52 & 0.00 \end{pmatrix} \end{array}$$

$$d_{(35)1} = \min[d_{31}, d_{51}] = d_{31} = 1.75$$

$$d_{(35)2} = \min[d_{32}, d_{52}] = d_{32} = 0.84$$

$$d_{(35)4} = \min[d_{43}, d_{54}] = d_{43} = 1.52$$

Now, the smallest distance is between clusters 1 and 4. Then, clusters 1 and 4 are joined and the new ***D*** matrix is calculated.

$$D=\begin{array}{c} \\ (14) \\ 2 \\ (35) \end{array}\begin{array}{c} \begin{array}{ccc} (14) & 2 & (35) \end{array} \\ \begin{pmatrix} 0.00 & & \\ 0.85 & 0.00 & \\ 1.52 & 0.84 & 0.00 \end{pmatrix} \end{array}$$

$$d_{(14)2} = \min[d_{21}, d_{42}] = d_{21} = 0.85$$

$$d_{(14)(35)} = \min[d_{(35)1}, d_{4(35)}] = d_{4(35)} = 1.52$$

The third join occurs between clusters (23) and 4. The new D matrix is

$$D=\begin{array}{c} \\ (14) \\ (235) \end{array}\begin{array}{c} \begin{array}{cc} (14) & (235) \end{array} \\ \begin{pmatrix} 0.00 & \\ 0.85 & 0.00 \end{pmatrix} \end{array}$$

$$d_{(235)(14)} = \min[d_{2(14)}, d_{(35)(14)}] = d_{2(14)} = 0.85$$

ii <u>*Complete linkage*</u>

The complete linkage or furthest neighbour method is the opposite of simple linkage in the sense that the distance between groups is defined as that of the most distant pair of individuals between the two groups.

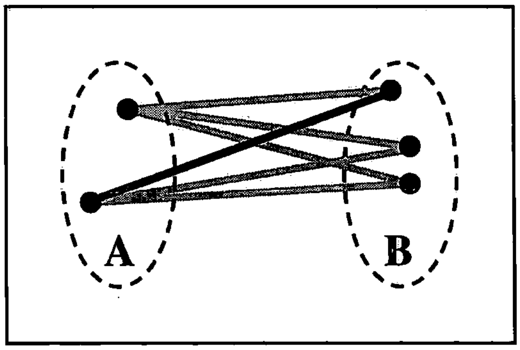

Figure 6.8 Complete linkage distance.

The illustration of this approach can be seen in Figure 6.8.

$$\| A - B \| = \max_{\substack{x \in A \\ y \in B}} \| x - y \| \tag{6.9}$$

In this case the distance considered is the maximum between the elements of the two clusters evaluated.

Starting off with the same distance matrix ***D***, the first joint of cluster is between groups 3 and 5. On this occasion, the new distances are calculated in a different way.

$$D = \begin{array}{c} \\ 1 \\ 2 \\ (35) \\ 4 \end{array} \begin{array}{c} \begin{array}{cccc} 1 & 2 & (35) & 4 \end{array} \\ \begin{pmatrix} 0.00 & & & \\ 0.85 & 0.00 & & \\ 3.72 & 1.63 & 0.00 & \\ 0.79 & 1.11 & 2.84 & 0.00 \end{pmatrix} \end{array}$$

$$d_{(35)1} = \max[d_{31}, d_{51}] = d_{51} = 3.72$$

$$d_{(35)2} = \max[d_{32}, d_{52}] = d_{52} = 1.63$$

$$d_{(35)4} = \max[d_{43}, d_{54}] = d_{54} = 2.84$$

Again, the next two clusters to be joined are 1 and 4. The new ***D*** matrix is:

$$D = \begin{array}{c} \\ (14) \\ 2 \\ (35) \end{array} \begin{array}{c} \begin{array}{ccc} (14) & 2 & (35) \end{array} \\ \begin{pmatrix} 0.00 & & \\ 1.11 & 0.00 & \\ 3.72 & 1.63 & 0.00 \end{pmatrix} \end{array}$$

$$d_{(14)2} = \max[d_{21}, d_{42}] = d_{42} = 1.11$$

$$d_{(14)(35)} = \max[d_{(35)1}, d_{4(35)}] = d_{(35)1} = 3.72$$

Finally, cluster (14) and 2 are joined to obtain:

$$D = \begin{array}{c} \\ (142) \\ (35) \end{array} \begin{array}{c} \begin{array}{cc} (142) & (35) \end{array} \\ \begin{pmatrix} 0.00 & \\ 3.72 & 0.00 \end{pmatrix} \end{array}$$

$$d_{(142)(35)} = \max[d_{(35)(14)}, d_{(35)2}] = d_{(35)(14)} = 3.72$$

iii *Group-average linkage*

This method combines two clusters based upon the averaged distances between the objects in the clusters. Figure 6.9 illustrates this method.

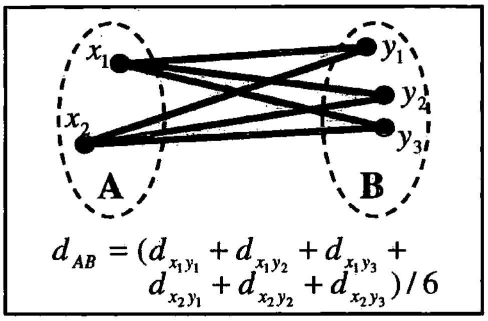

Figure 6.9 Group-average linkage distance.

The distance between the two clusters is calculated by adding all the distances between objects of the two clusters and dividing this value by the number of distances considered.

$$\| \mathrm{A} - \mathrm{B} \| = \frac{1}{card(A) * card(B)} \sum_{\substack{\mathbf{x} \in \mathrm{A} \\ \mathbf{y} \in \mathrm{B}}} \| \mathbf{x} - \mathbf{y} \| \tag{6.10}$$

Starting off from the matrix ***D***, the first fusion is once again between clusters 3 and 5. Using Equation 6.10 the new distances are calculated.

$$\boldsymbol{D} = \begin{array}{c} \\ 1 \\ 2 \\ (35) \\ 4 \end{array} \begin{array}{c} \begin{array}{cccc} 1 & 2 & (35) & 4 \end{array} \\ \begin{pmatrix} 0.00 & & & \\ 0.85 & 0.00 & & \\ 2.74 & 1.24 & 0.00 & \\ 0.79 & 1.11 & 2.18 & 0.00 \end{pmatrix} \end{array}$$

$$d_{(35)1} = \frac{(d_{31} + d_{51})}{2*1} = \frac{1.75 + 3.72}{2} = 2.74$$

$$d_{(35)2} = \frac{(d_{32} + d_{52})}{2*1} = \frac{0.84 + 1.63}{2} = 1.24$$

$$d_{(35)4} = \frac{(d_{43} + d_{54})}{2*1} = \frac{1.52 + 2.84}{2} = 2.18$$

The next two clusters to be joined are 1 and 4. The new ***D*** matrix is:

$$\boldsymbol{D} = \begin{array}{c} \\ (14) \\ 2 \\ (35) \end{array} \begin{array}{c} \begin{array}{ccc} (14) & 2 & (35) \end{array} \\ \begin{pmatrix} 0.00 & & \\ 0.98 & 0.00 & \\ 2.46 & 1.24 & 0.00 \end{pmatrix} \end{array}$$

$$d_{(14)2} = \frac{(d_{21} + d_{42})}{2*1} = \frac{0.85 + 1.11}{2} = 0.98$$

$$d_{(14)(35)} = \frac{(d_{31} + d_{51} + d_{43} + d_{54})}{2*2} = \frac{1.75 + 3.72 + 1.52 + 2.84}{4} = 2.46$$

Finally, cluster 2 and (14) are joined to obtain:

$$\mathbf{D}= \begin{array}{c} \\ (142) \\ (35) \end{array}\begin{array}{c} \begin{array}{cc} (142) & (35) \end{array} \\ \begin{pmatrix} 0.00 & \\ 3.72 & 0.00 \end{pmatrix} \end{array}$$

$$d_{(142)(35)} = \frac{(d_{31}+d_{51}+d_{43}+d_{54}+d_{32}+d_{53})}{3*2} = \frac{1.75+3.72+1.52+2.84+0.84+0.61}{6} = 1.88$$

iv <u>*Ward's clustering method*</u>

This method seeks to form the partitions $P_n, P_{n-1}, ..., P_1$ in a manner that minimises the loss associated with each grouping. The method was proposed by Ward (1963) who defined the information loss in terms of an error sum-of-squares criterion, ESS.

$$ESS = \sum_{i=1}^{n}(x_i - \bar{x})^2$$

When two groups are joined, the ESS of each cluster is evaluated. If the sum of all these ESS is less than the former value, the algorithm proceeds with a new merge of clusters. If it is not smaller, the clusters are not joined and a new fusion of groups is evaluated. The algorithm finishes when no better fusion is found. As can be seen, this method does not use the distance matrix in order to merge clusters.

Lance and Williams (1967) proposed a general formula which, starting with the distance matrix, calculates the distance between a cluster *k*, and a cluster (*ij*) formed by the fusion of clusters *i* and *j*. The formula is:

$$d_{ijk} = \alpha_i * d_{ki} + \alpha_j * d_{kj} + \beta * d_{ij} + \gamma|d_{ki} - d_{kj}|$$

Through an appropriate choice of the parameters $\alpha_i, \alpha_j, \beta$ and γ, the algorithms of some hierarchical techniques can be developed applying the Lance and Williams recurrence formula. Wishart (1969) demonstrated that Ward's method could be included with the following parameters:

$$\alpha_i = \frac{n_k + n_j}{n_k + n_i + n_j};\ \alpha_j = \frac{n_k + n_i}{n_k + n_i + n_j};\ \beta = \frac{-n_k}{n_k + n_i + n_j};\ \gamma = 0$$

Where n_k, n_i and n_j represent the cardinality values of clusters *k*, *i* and *j* respectively. This would allow the application of Ward's method using the distance matrix generated with the methodology formerly explained. The final equation for Ward's method is given by

$$d_{ijk} = \frac{n_k + n_j}{n_k + n_i + n_j} * d_{ki} + \frac{n_k + n_i}{n_k + n_i + n_j} * d_{kj} + \frac{-n_k}{n_k + n_i + n_j} * d_{ij} \qquad (6.11)$$

Starting off with the distance matrix ***D***, the first joint of clusters is between 3 and 5. Using Equation 6.11 to compute the new distances, the new matrix is obtained.

$$\boldsymbol{D} = \begin{array}{c} \\ 1 \\ 2 \\ (35) \\ 4 \end{array} \begin{array}{c} \begin{array}{cccc} 1 & 2 & (35) & 4 \end{array} \\ \begin{pmatrix} 0.00 & & & \\ 0.85 & 0.00 & & \\ 3.55 & 1.55 & 0.00 & \\ 0.79 & 1.11 & 2.80 & 0.00 \end{pmatrix} \end{array}$$

$$d_{(35)1} = \frac{(1+1)1.75}{1+1+1} + \frac{(1+1)3.72}{1+1+1} + \frac{(-1)0.29}{1+1+1} = 3.55$$

$$d_{(35)2} = \frac{(1+1)0.84}{1+1+1} + \frac{(1+1)1.63}{1+1+1} + \frac{(-1)0.29}{1+1+1} = 1.55$$

$$d_{(35)4} = \frac{(1+1)1.52}{1+1+1} + \frac{(1+1)2.84}{1+1+1} + \frac{(-1)0.29}{1+1+1} = 2.80$$

The next two clusters to be joined are 1 and 4. The new ***D*** matrix is:

$$\boldsymbol{D} = \begin{array}{c} \\ (14) \\ 2 \\ (35) \end{array} \begin{array}{c} \begin{array}{ccc} (14) & 2 & (35) \end{array} \\ \begin{pmatrix} 0.00 & & \\ 1.05 & 0.00 & \\ 4.37 & 1.55 & 0.00 \end{pmatrix} \end{array}$$

$$d_{(14)2} = \frac{(1+1)0.85}{1+1+1} + \frac{(1+1)1.11}{1+1+1} + \frac{(-1)0.79}{1+1+1} = 1.05$$

$$d_{(14)(35)} = \frac{(2+1)3.55}{2+1+1} + \frac{(2+1)2.80}{2+1+1} + \frac{(-2)0.79}{2+1+1} = 4.37$$

Finally, cluster 2 and (14) are joined to obtain:

$$\boldsymbol{D} = \begin{array}{c} \\ (142) \\ (35) \end{array} \begin{array}{c} \begin{array}{cc} (142) & (35) \end{array} \\ \begin{pmatrix} 0.00 & \\ 3.44 & 0.00 \end{pmatrix} \end{array}$$

$$d_{(142)(35)} = \frac{(2+1)4.37}{2+2+1} + \frac{(2+2)1.55}{2+2+1} + \frac{(-2)1.05}{2+2+1} = 3.44$$

6.4 CONTEXT ORIENTED ANALYSIS OF THE DATA

In cluster analysis there are two main models of learning: unsupervised and supervised. The unsupervised methods (or primarily clustering) use the simple data and the patterns in them to determine a structure within the family of such patterns. In the supervised model, the data is labelled and pre-processed with certain criteria in order to map the classification process and minimise the grouping error (Cios et. al, 1998). Most of the approaches using clustering methodologies are based on unsupervised learning [(Bajcsy and Ahuja, 1998) and (Geva, 1999)]. Others have found that the incorporation of some guidance when grouping of the data can improve, significantly, the classification process [(Carter and Hamilton, 1998) and (Djoko et. al, 1997)].

As was explained earlier in chapter four, it is not easy to provide solutions to user requirements in tooling applications when a wide range of possible combinations of variables is considered. Assessment of cutting parameters is no exception. In order to provide the option of guiding the classification of the data, a module that includes both models of learning was incorporated.

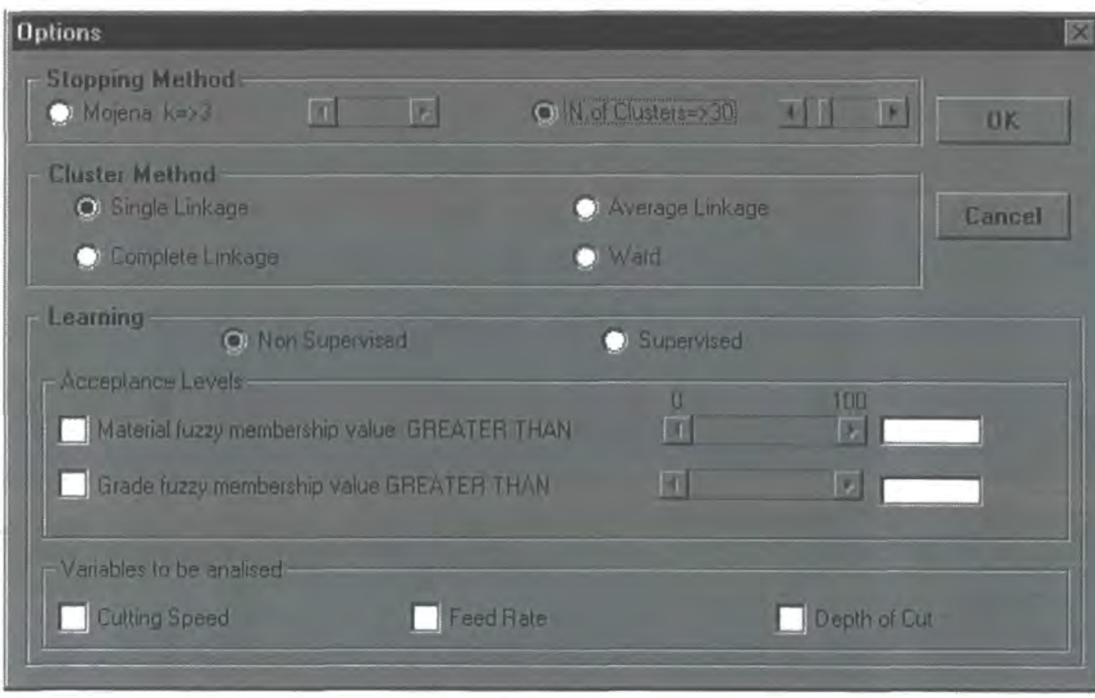

Figure 6.10 Options window for fuzzy clustering approach.

Figure 6.10 shows the option window where these alternatives of learning can be chosen. The default option is unsupervised learning. When supervised learning is included, the system provides alternatives to specify the minimum range of materials and grades membership. When two objects are compared the individual proximity value of material and grade are calculated. If these proximities are smaller than the ones specified by the user, they are converted to 0. The supervised learning mode also allows the user to incorporate cutting speed, feed rate and depth of cut variables in the computation of the distance matrix.

In order to classify the data, four agglomerative methods are presented to user as options of ***Cluster-F***. They are displayed in the options screen of the system (Figure 6.10). Other system alternatives that can be set by the user are related to the stopping method for the cluster process. In this case, two options are offered: fix previously the number of clusters or apply a method called Mojena. The last method calculates an average of the distances in order to define when to stop the classification using a constant *K*.

6.5 MEMBERSHIP DEGREES FOR CLOSEST SOLUTIONS.

Once the clusters have been obtained, it is necessary to evaluate each of these to determine similarities and user requirements. Figure 6.11 shows the possible variables the user can submit for guiding the search for the best cluster.

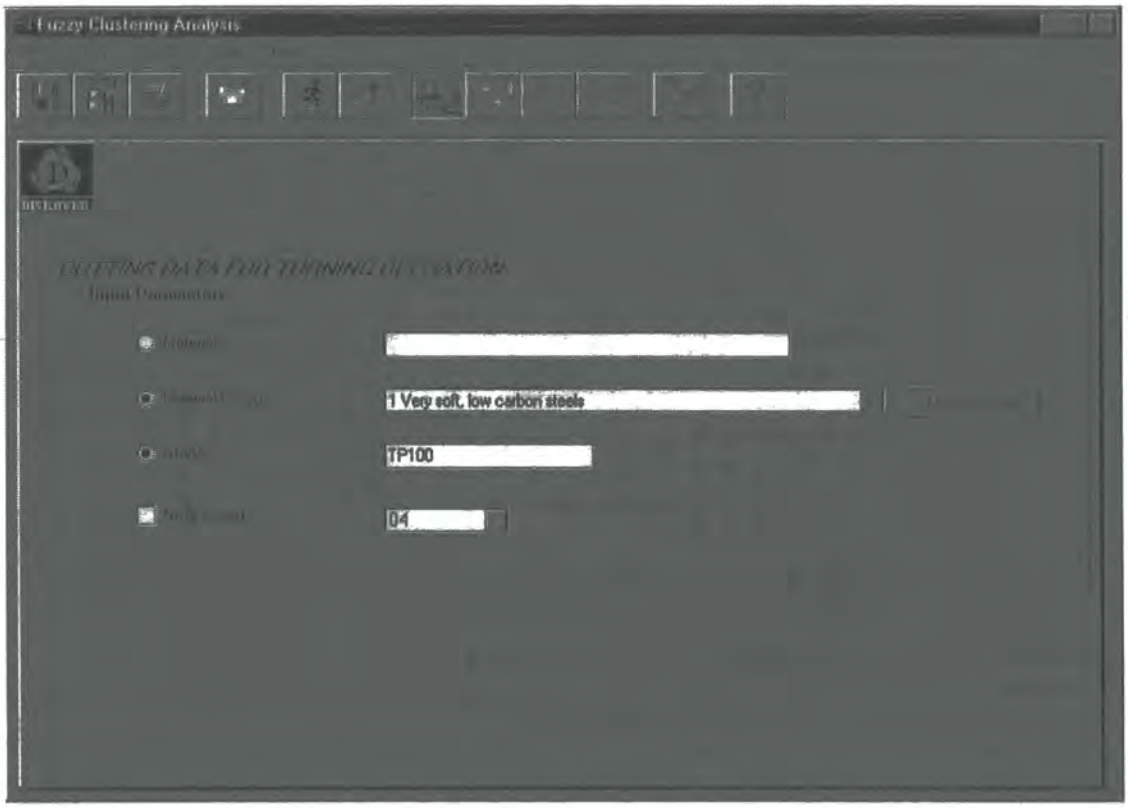

Figure 6.11 User input screen.

The variables are considered in the context of cutting parameter for turning operations. The user must introduce the grade of the tool that will take part in the metal cutting process. He/she also has to submit information about the workpiece material, either the material group or the material name. In addition, the user has the option of choosing the nose radius of the tool, but this value is not obligatory.

The expression to obtain the membership index per cluster is given by

$$MDU_k = \left(\sum_{i=1}^{t} \sum_{v=1}^{p} S_{kiv} \Big/ p \right) \Big/ t \qquad (6.12)$$

where

k represents the cluster analysed.

t is the number of elements grouped in the cluster k.

p is the number of variables considered by the user. This term can take the values of "*3*" if the user submits the *nose radius* and "*2*" if it is not incorporated.

S_{kiv} represents the similarity measure for the variable *v* between element *i* of cluster *k* and the value introduced by the user.

The optimum cluster fulfilling user requirements is the one with the highest membership degree (MDU_k) according to the values submitted by the user. This cluster is analysed to present the information, allowing the user to visualise and interact with the results.

6.6 SUMMARY

This chapter has described the implementation of ***Cluster-F***, a KD approach to discover useful relations from the data generated by ***TTS***. The idea was to exploit the data contained in the tooling database to take advantage of their potential to assist machinists, engineers and other users in the tooling arena.

The specific application area of this approach was the assessment of cutting parameters for turning operations.

The main objective of the system was based on providing users with a system capable of grouping the data into clusters by analysing the variables and finding common patterns. Then, specific user requirements could be compared to them to obtain the cluster with the closest features in relation to the user's input. The system also offers the alternative of incorporating the user's knowledge to guide the classification and refine the results by the utilisation of a supervised learning option.

The most important contribution of this system is the combination of fuzzy set notions and the cluster analysis technique in the grouping process. Due to the difficulty in managing proximities with categorical data, fuzzy set concepts were implemented to generate the sets that define these values. Later, these fuzzy sets were used to calculate the distance matrix for the classification process.

The next chapter will be concentrated on the development of a context-oriented rule generator applying a rough set methodology to analyse the tooling database.

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CHAPTER 7: A KNOWLEDGE APPROACH APPLIED TO THE TOOLING SECTOR

7.1 INTRODUCTION

In the previous chapters the fundamental issues of clustering and fuzzy sets were examined. It was shown how the combination of these two concepts constitutes a powerful technique for data classification purposes. The definition of fuzzy membership functions allowed the establishment of similarity relationships between categorical attributes. This resulted in significant improvements over traditional procedures, which do not consider, for example, that elements exhibiting imprecise characteristics may belong to a set on a gradual, rather than on an absolute basis.

This chapter presents a KD methodology that applies rough set concepts. The goal of this is to eliminate data redundancy, identify relevant attributes, detect data inconsistency, and generate knowledge rules with the analysis of relationships among attributes. This methodology was created to implement a KD system able to evaluate the variables contained in the tooling database. The aim is to discover cause-effect patterns in the data. This system is called ***R-sets*** and is an attribute-oriented application. The approach is presented in four stages: 1) input and data-warehouse conformation, 2) pre-processing, 3) mining of the data, and 4) post-processing. These four modules are fully explained and basic notions of rough set theory and examples of applications are presented.

7.2 A KD METHODOLOGY FOR DETECTING RELATIONSHIPS AMONG VARIABLES USING ROUGH SETS.

Chapter six described a KD approach using the combination of two datamining techniques to exploit tooling data generated by ***TTS***. This KD system has been developed to help Seco engineers in the specific area of cutting parameters for turning operations. The relationships between the variables included in the analysis have already been the subject of extensive research where their dependencies and correlation have been determined. These contributed to the development of ***Clust-F*** and the classification of the data. As well as the variables used for the ***Clust-F*** approach, the tooling database has other important variables that can also be analysed to refine existing links or discover new connections. Interesting relationships occurring in the database may assume the form of functional or partial functional dependencies. Their discovery, analysis and characterisation could be undertaken by applying rough set theory (Ziarko and Shan, 1995). In the light of this consideration, it was decided that an attribute-oriented knowledge inductor system able to generate decision rules would be developed. The general idea is to extract relevant knowledge contained in chosen features applying rough set theory.

The concept of Rough Sets (RS) is based on equivalence relations that partition a data set into equivalence classes. It was introduced by Zdzislaw Pawlak (1982) to provide a systematic framework for analysing incomplete and imprecise information. The idea of rough set theory overlaps, to a certain extent, with other mathematical tools dealing with vagueness and uncertainty, such as fuzzy sets and the Dempster-Shafer evidence theory. However, it can be viewed as an entity in its own right (Pawlak, 1996). RS and FS are both techniques that are neither competing nor identical. Instead, they complement each other naturally. FS theory focuses on the intensity of membership, whereas rough set theory is based on equivalent relationships or indiscernibility. RS theory uses lower and upper approximation sets as the main vehicles for problem solving (Khoo *et al.*, 1999). RS theory can represent degrees of consistency between condition and decision attributes.

An RS Information System (S) allows practical representation of the data that describe the objects under analysis. It is defined by four components

Information System $\rightarrow$ $S = < U, Q, V, f >$[5], where

[5] There is not an unique nomenclature adopted by the rough sets community. In this chapter, the nomenclature of Cios *et al.* (1998) is used.

a) Universe $\rightarrow U$ = a finite and non-empty set of N objects $\{x_1, x_2 .....x_N\}$

b) Attributes $\rightarrow Q$ = a finite and non-empty set of *n* attributes $\{q_1, q_2 ....q_n\}$.

c) Domain of the attributes $\rightarrow V = U_{q \in Q} Vq$, where Vq is a domain (value) of the attribute q.

d) Decision Function $\rightarrow f : U \times Q \rightarrow V$, such that $f(x,q) \in Vq$ for every $q \in Q$, $x \in U$.

To elaborate on the approach for the tooling data, a KD methodology has been developed. Its structure is shown in Figure 7.1. This methodology includes four steps: 1) input and data-warehouse, 2) data pre-processing, 3) data mining, and 4) post processing and output of results. Rough set theory is used to undertake the datamining task. Due to the attribute-oriented feature of this methodology, the first two stages play important roles in the component definition and representation of the information model.

The methodology was applied to develop the KD system for the tooling data to generate knowledge using *IF-THEN* format rules. This system is called ***R-sets***. Here, the universe *U* is represented by records containing the trials submitted by the sales engineers (*x*). The attributes are the different variables existing in the database (*q*) and the attribute domains are the possible values for those attributes. The decision function is the value presented by each object *x* of *U* for the attribute *q*.

In order to offer a more applicable KD system with a large range of attributes, it was decided to undertake an analysis of the database variables. This guides the selection of those attributes presenting high level of importance for the Seco Company and the tooling arena. The result of this selection was a set of fifteen variables to be used as the possible attributes. These were included in the development of an interface module where the user can interact with the system to define attributes of interest and their respective domains. The next sections will detail the four-step methodology implemented in the development of ***R-sets***.

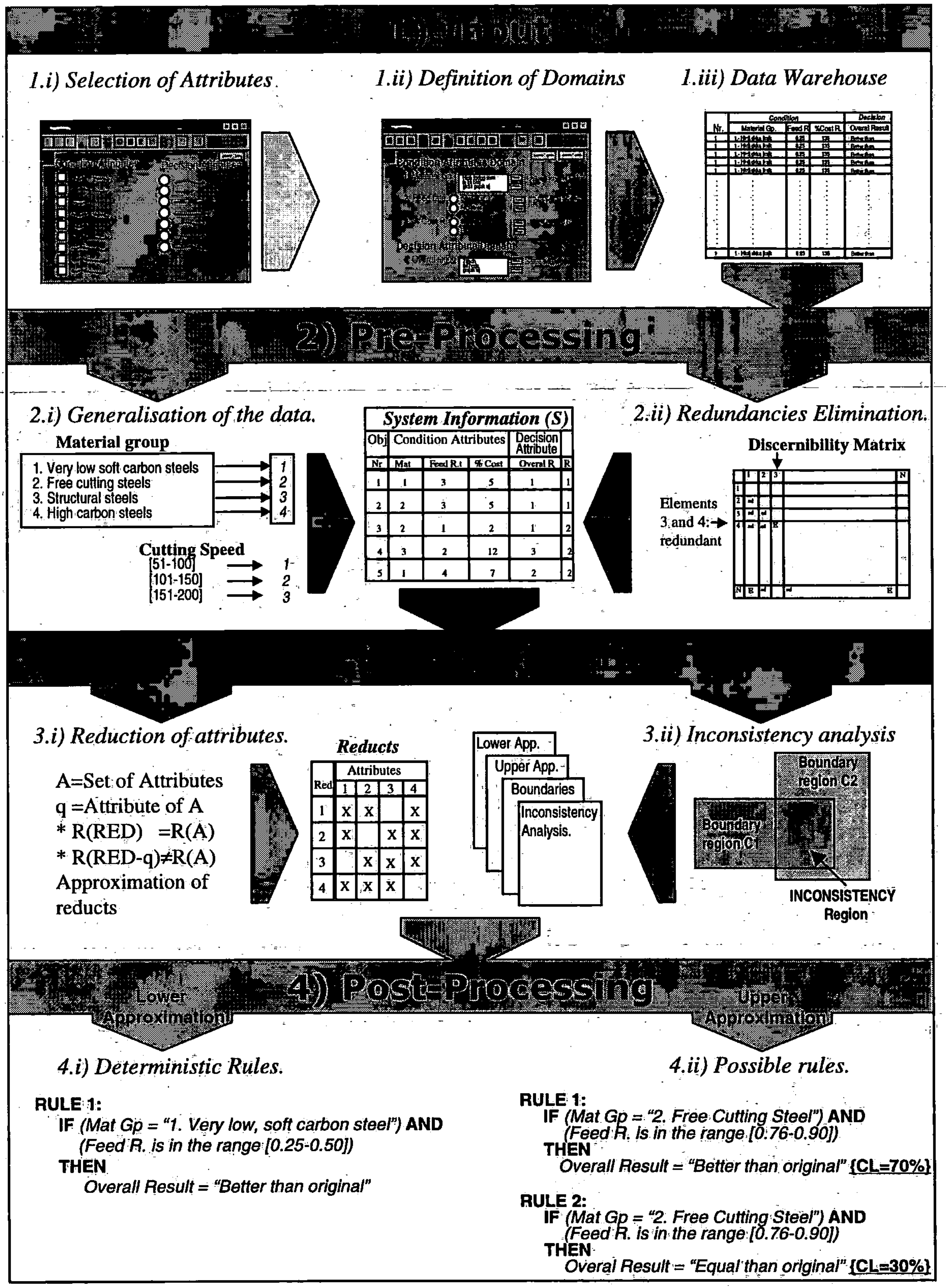

Figure 7.1 Methodology structure.

7.2.1 Input: Definition of Attributes and Domains

Due to the general character of ***R-sets*** in relation with the area of application, a user interface was developed to allow the operator to specify both attributes and domains for the data analysis.

i) Input of attributes

Figure 7.2 shows the first input display. It presents the possible attributes that can be chosen to evaluate their relationship.

Figure 7.2 Input Screen for Attributes Selection.

A rough set model has two kinds of attributes: *condition* and *decision*. The decision attribute is referred to as the target of the analysis. The condition attributes impose constrains that affect the final values of the decision variable. ***R-sets*** permits the input of one decision attribute and up to fifteen condition attributes. Each attribute corresponds to one variable of the database. Figure 7.2 shows a selected set of attributes. These will be used to exemplify the functionality of the system. The condition attributes are *Seco Material Group,* *Nose Radius, Cutting Speed, Depth of Cut and Feed Rate*, while the decision variable is the *Grade* of the insert.

ii) Definition of attribute domains

Once the attributes of interest have been chosen, these are evaluated to generate a dynamic screen with the domain options for each attribute. These domains are attribute-oriented and are automatically generated depending on the variable chosen. Figure 7.3 shows the screen to specify the domains for the set of attributes submitted in the first input screen. The attribute domain constrains the set of values that will be taken into consideration for the analysis. The domain for numerical variables is generated by ranges of values. The default choice shows only one range represented by the minimum and maximum values found in the database for the variable. The user has the option of submitting and fixing the desired ranges of values. The numerical attributes considered in the analysis are: *cutting speed, feed rate, depth of cut, length of cut, % of improvement in tool life, % of tool cost savings, % of productivity improvements and % of cost reduction per component.*

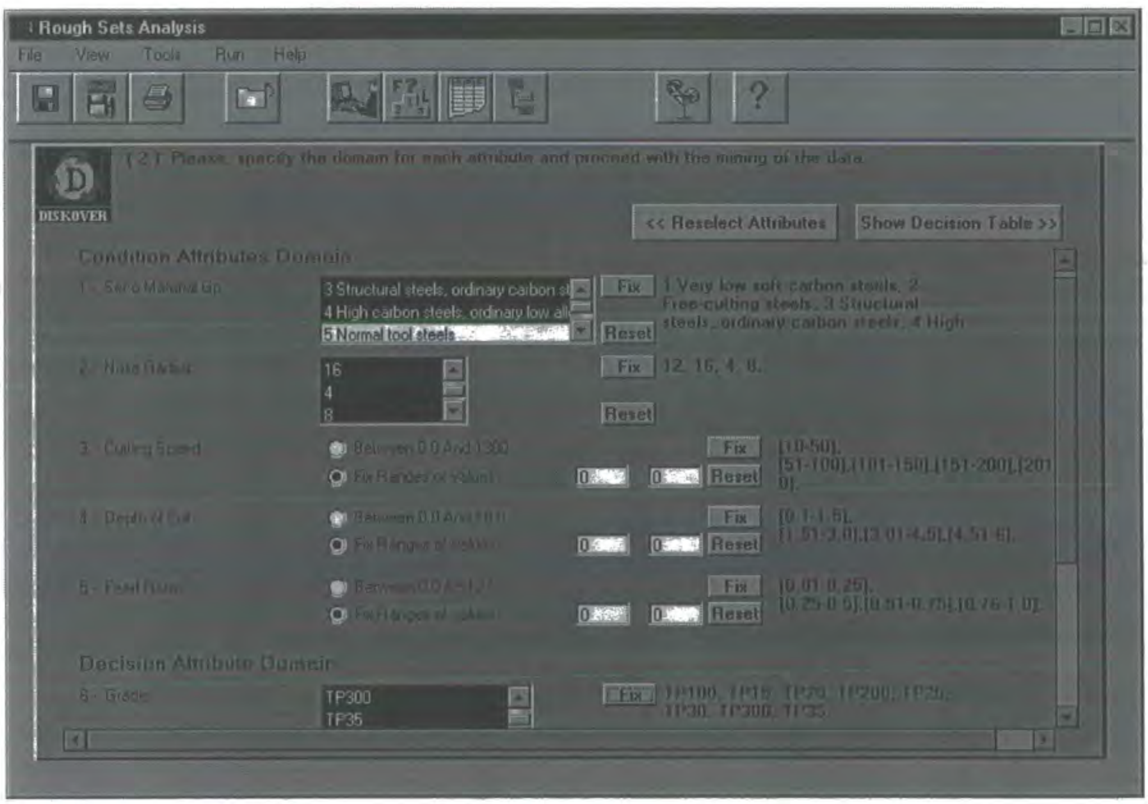

Figure 7.3 Input screen for attributes domain specification.

In the case of categorical variables, the application automatically generates a list with the total of values encountered in the database for the variable. The domain is defined by selecting and fixing the values of interest. In Figure 7.3, the corresponding domains for the chosen attributes are established. These are reviewed in Table 7.1.

iii) Conformation of the Data-warehouse

Once the attribute domains have been determined, the connection with the database is established and the records fulfilling the attributes and domain specifications are retrieved. This information constitutes the data-warehouse that will be manipulated in the KD process.

Table 7.1 Domain for chosen attributes.

Nr.att.	Attribute Name	Attribute Domain
1	Seco Material Group	*1. Very low soft carbon steels, 2. Free cutting steels, 3. Structural steels, 4. High carbon steels*
2	Nose Radius	*1.2, 1.6, 0.8, 0.4*
3	Cutting Speed	*[10-50], [51-100], [101-150], [151-200], [201-250]*
4	Depth of Cut	*[0.1 - 1.50], [1.51 – 3.00], [3.01 – 4.50], [4.51 – 6.0]*
5	Feed Rate	*[0.10 – 0.25], [0.26 – 0.50], [0.51- 0.75], [0.76 – 1.0]*
6	Grade	*TP15, TP20, TP25, TP30, TP35, TP100, TP200, TP300*

Table 7.2 presents a set of data with fifteen objects corresponding to part of the records found in the databases for specified attributes and domains. These data will be used to facilitate the exposition of modules and methods developed for the ***R-sets*** system. The next task consists of pre-processing the data. The following section describes how the data are prepared for the mining process.

Table 7.2 Obtained data set for sample specifications.

Nr.	Mat.Gp.	Nose R. (mm/10)	Cutt.Sp. (m/min)	D.O.C. (mm)	Feed R. (mm/rev)	Grade
	q_1	q_2	q_3	q_4	q_5	q_6
1	3	8	170 (4)	1.50 (1)	0.12 (1)	TP30
2	4	4	230 (5)	0.25 (1)	0.20 (1)	TP30
3	2	16	130 (3)	5.00 (4)	0.80 (4)	TP200
4	3	12	120 (3)	3.00 (2)	0.21 (1)	TP200
5	3	8	170 (4)	1.50 (1)	0.12 (1)	TP30
6	3	8	170 (4)	1.50 (1)	0.12 (1)	TP30
7	2	16	130 (3)	5.00 (4)	0.80 (4)	TP200
8	3	8	170 (4)	1.50 (1)	0.12 (1)	TP30
9	4	12	198 (4)	4.50 (3)	0.40 (2)	TP100
10	2	12	150 (3)	2.50 (2)	0.25 (1)	TP30
11	3	8	170 (4)	1.50 (1)	0.12 (1)	TP30
12	2	4	220 (5)	0.50 (1)	0.15 (1)	TP100
13	4	12	198 (4)	4.50 (3)	0.40 (2)	TP100
14	3	4	90 (2)	0.40 (1)	0.12 (1)	TP30
15	3	12	120 (3)	3.00 (2)	0.21 (1)	TP200

7.2.2 Pre-processing of the data

The pre-processing module performs two main functions: *i)* categorising the data into discrete ranges and *ii)* eliminating redundancies in the data set.

i) Categorisation of the data

The categorisation of the data (also called generalisation) is undertaken by substituting some values with more general classification. For instance, *cutting speed, feed rate* and *depth of cut* values can be replaced with an identifier of the range in which each value falls. These ranges are shown beside the corresponding values in Table 7.2.

ii) Redundancy elimination

The elimination of redundant information is undertaken by using the *Discernibility Matrix* among the objects of the universe U.

Skowron and Rauszer (1992) introduced the notion of *Discernibility Matrix* to provide an efficient way to represent which specific attributes are responsible for discerning each pair of objects in an information system S. The discernibility matrix helps the construction of efficient algorithms related to the generation of minimal subsets of attributes sufficient to describe all concepts in a given information system (Cios *et al.*, 1998). Félix and Ushio (1999) proposed a rough sets-based machine learning approach using a binary discernibility matrix. Their representation takes advantage of parallel processing to analyse groups of attributes at one time.

To obtain the discernibility matrix, it is first necessary to define *Indiscernibility*. This is one of the most important concepts in rough set theory. Let $A \subseteq Q$ be a subset of attributes and $x_i, x_j \in U$ are objects. Then, objects x_i and x_j are indiscernible by the set of attributes A in S, if $f(x_i,a) = f(x_j,a)$ for every $a \in A$.

The indiscernibility relation $IND(A)$ is defined

$$IND(A) = \{(x_i, x_j) \in U \times U : \text{for all } a \in A, f(x_i,a) = f(x_j,a)\}$$

In simple terms, objects x_i and x_j are called indiscernible with respect to A, if it is not possible to distinguish object x_i from x_j in terms of attributes from set A only. The indiscernibility relation $IND(A)$ splits the universe U into a family of equivalence classes (also called $A-elementary\ sets$) $\{X_1, X_2, ..., X_w\}$.

A discernibility matrix $M(Q)$ for an information system S with the set of attributes Q is a square $N \times N$ dimensional matrix, with rows and columns labelled by objects x_i $(i = 1, 2, ..., N)$. Each m_{ij} entry of the discernibility matrix is a subset of attributes, which discerns these objects. These m_{ij} entries are defined

$$m_{ij} = \begin{cases} 0 & x_i, x_j \in \textit{the same class of } IND(Q) \\ \{a \in Q : f(x_i,a) \neq f(x_j,a)\} & x_i, x_j \in \textit{different classes of } IND(Q) \end{cases}$$

Table 7.3 Discernibility Matrix.

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}
x_1	-														
x_2	$q_1q_2q_3$	-													
x_3	$q_1q_2q_3q_4q_5q_6$	$q_1q_2q_3q_4q_5q_6$	-												
x_4	$q_2q_3q_4q_6$	$q_1q_2q_3q_4q_6$	$q_1q_2q_4q_5$	-											
x_5	empty	$q_1q_2q_3$	$q_1q_2q_3q_4q_5q_6$	$q_2q_3q_4q_6$	-										
x_6	empty	$q_1q_2q_3$	$q_1q_2q_3q_4q_5q_6$	$q_2q_3q_4q_6$	empty	-									
x_7	$q_1q_2q_3q_4q_5q_6$	$q_1q_2q_3q_4q_5q_6$	empty	$q_1q_2q_4q_5$	$q_1q_2q_3q_4q_5q_6$	$q_1q_2q_3q_4q_5q_6$	-								
x_8	empty	$q_1q_2q_3$	$q_1q_2q_3q_4q_5q_6$	$q_2q_3q_4q_6$	empty	empty	$q_1q_2q_3q_4q_5q_6$	-							
x_9	$q_1q_2q_4q_5q_6$	$q_2q_3q_4q_5q_6$	$q_1q_2q_3q_4q_5q_6$	$q_1q_3q_4q_5q_6$	$q_1q_2q_4q_6$	$q_1q_2q_4q_5q_6$	$q_1q_2q_3q_4q_5q_6$	$q_1q_2q_4q_5q_6$	-						
x_{10}	$q_1q_2q_3q_4$	$q_1q_2q_3q_4$	$q_2q_4q_5q_6$	$q_1q_3q_4q_5q_6$	$q_1q_2q_3q_4$	$q_1q_2q_3q_4$	$q_2q_4q_5q_6$	$q_1q_2q_3q_4$	$q_1q_3q_4q_5q_6$	-					
x_{11}	empty	$q_1q_2q_3$	$q_1q_2q_3q_4q_5q_6$	$q_2q_3q_4q_6$	empty	empty	$q_1q_2q_3q_4q_5q_6$	empty	$q_1q_2q_4q_5q_6$	$q_1q_2q_3q_4$	-				
x_{12}	$q_1q_2q_3q_6$	q_1q_6	$q_2q_3q_4q_5q_6$	$q_1q_2q_3q_4q_6$	$q_1q_2q_3q_6$	$q_1q_2q_3q_6$	$q_2q_3q_4q_5q_6$	$q_1q_2q_3q_6$	$q_1q_2q_3q_4q_5$	$q_2q_3q_4q_6$	$q_1q_2q_3q_6$	-			
x_{13}	$q_1q_2q_4q_5q_6$	$q_2q_3q_4q_5q_6$	$q_1q_2q_3q_4q_5q_6$	$q_1q_3q_4q_5q_6$	$q_1q_3q_4q_5q_6$	$q_1q_2q_4q_5q_6$	$q_1q_2q_3q_4q_5q_6$	$q_1q_2q_4q_5q_6$	empty	$q_1q_3q_4q_5q_6$	$q_1q_2q_4q_5q_6$	$q_1q_2q_3q_4q_5$	-		
x_{14}	q_2q_3	q_1q_3	$q_1q_2q_3q_4q_5q_6$	$q_2q_3q_4q_6$	q_2q_3	q_2q_3	$q_1q_2q_3q_4q_5q_6$	q_2q_3	$q_1q_2q_3q_4q_5q_6$	$q_1q_2q_3q_4$	q_2q_3	$q_1q_3q_6$	$q_1q_2q_3q_4q_5q_6$	-	
x_{15}	$q_2q_3q_4q_6$	$q_1q_2q_3q_4q_6$	$q_1q_2q_4q_5$	empty	$q_2q_3q_4q_6$	$q_2q_3q_4q_6$	$q_1q_2q_4q_5$	$q_2q_3q_4q_6$	$q_1q_3q_4q_5q_6$	q_1q_6	$q_2q_3q_4q_6$	$q_1q_2q_3q_4q_6$	$q_1q_3q_4q_5q_6$	$q_2q_3q_4q_6$	-

Table 7.3 shows the discernibility matrix for the sample set of data. Two objects x_t and x_r of U are considered redundant when the entry m_{tr} is empty. This means that they are indiscernible. In this case, the procedure to eradicate redundancy is based on the elimination of one of the two objects presenting redundancy.

It can be noted from Table 7.3 that there are four objects (x_5, x_6, x_8 and x_{11}) which present redundancy with object x_1. Likewise objects x_3 with x_7, x_4 with

x_{15}, and x_9 with x_{13} also present redundancy. The new universe U should contain these elements only once.

Table 7.4 shows the set of data after generalisation and elimination of redundancies.

Table 7.4 Decision table.

Objects	**Condition Attributes**					**Decision Attribute**	Occurr
U	c					d	
Nro.	**Mat.Gp.**	**Nose R.** (mm/10)	**Cut.Sp.** (m/min)	**D.O.C.** (mm)	**Feed R.** (mm/rev)	**Grade**	
x_1	3	8	4	1	1	TP30 (4)	5
x_2	4	4	5	1	1	TP30 (4)	1
x_3	2	16	3	4	4	TP200 (7)	2
x_4	3	12	3	2	1	TP200 (7)	2
x_5	4	12	4	3	2	TP100 (6)	2
x_6	2	12	3	2	1	TP30 (4)	1
x_7	2	4	5	1	1	TP100 (6)	1
x_8	3	4	2	1	1	TP30 (4)	1

For the data set from the above table the information system with all its components is given by

a) Universe $\rightarrow U = \{x_1, x_2 .....x_N\}$

b) Attributes $\rightarrow Q = \{q_1, q_2, q_3, q_4, q_5, q_6\}$= {*Mat.Gp, Nose R., Cut.Sp., D.O.C., Feed R., Grade*}

c) Domain of the attributes $\rightarrow V = U_{q \in Q} Vq$

$$Vq_1 = \{2,\ 3,\ 4\}; \quad Vq_2 = \{4,\ 8,\ 12,\ 16\}; \quad Vq_3 = \{2,\ 3,\ 4,\ 5\};$$
$$Vq_4 = \{1,\ 2,\ 3,\ 4\}; \quad Vq_5 = \{1,\ 2,\ 4\};$$
$$Vq_6 = \{\text{TP30}, \text{TP100}, \text{TP200}, \text{TP300}\}$$

d) Decision Function $\rightarrow f : U \times Q \rightarrow V$;

$$\left\{ \begin{array}{l} f(x_1, q_1) = 3;\ f(x_1, q_2) = 8; f(x_1, q_3) = 4; f(x_1, q_4) = 1; \\ f(x_1, q_5) = 1; f(x_1, q_6) = \text{TP30}; f(x_2, q_1) = 4; f(x_2, q_2) = 4; \\ f(x_2, q_3) = 5; f(x_2, q_4) = 1; .... ; f(x_8, q_6) = \text{TP30}; \end{array} \right\}$$

7.2.3 Mining of the data

The RS philosophy is based on the idea of dealing with imprecise knowledge or concepts. These imprecise concepts can be defined approximately in the available knowledge by using two precise concepts: lower and upper approximation.

To mine the data, two important modules were developed. One uses Reducts to simplify the rule induction process by obtaining sets of relevant features from the original set of attributes chosen by the user. The second module identifies inconsistencies in the data and analyses these to generate the dependency of the condition attributes with the concepts. These two modules will be extensively described and exemplified and some rough set concepts will be also explained.

i) Reduction of the data

In an attribute-oriented system, it is difficult to determine which features are important or relevant for a specific learning task. All the attributes are believed to be useful and equally important, and they are initially treated in the same way. The fact is that some chosen attributes may be irrelevant or unimportant for a discovery routine.

One of the most useful, but also difficult, tasks in rough sets is the determination of relevant attributes according with the decision function without loss of potential knowledge. The goal is to obtain the minimal subset of important attributes that provide the same information to discern the concepts of the system. In these cases, the condition-decision relation is simplified and irrelevant attributes are removed to produce a set of more meaningful decision rules.

Thus, the reduction of the set of attributes represents a powerful tool to facilitate the knowledge discovery process, although the algorithms to undertake this task are very complex. Another problem encountered when finding reducts is the time these algorithms take to process extensive amount of tuplas. Taking these facts into consideration, a recursive algorithm was developed to obtain reducts from a set of chosen attributes. This was called *ATTReduct*. Before presenting the structure of this algorithm, some ideas of rough set theory will be reviewed.

A. Atoms and Concepts in rough set theory

Atoms and *Concepts* are two very important notions in rough sets. The set of all equivalence classes is denoted by A^*. The $Q-elementary\ sets$ (all attributes are considered, including the decision attribute d) are called *atoms* of an information system S. Likewise, subsets of objects in S, which are represented by the *decision-elementary sets* are called *Concepts.*

For example, in the information system depicted in Table 7.4, the $q_2-elementary\ sets$, *atoms* and *concepts* are expressed

$q_2-elementary\ sets$:

$X_1=\{x_1\},\ X_2=\{x_2,x_7,x_8\},\ X_3=\{x_3\},\ X_4=\{x_4,x_5,x_6\}.$

Atoms:

$A_1=\{x_1\},\ A_2=\{x_2\},\ A_3=\{x_3\},\ A_4=\{x_4\},\ A_5=\{x_5\},\ A_6=\{x_6\},\ A_7=\{x_7\},\ A_8=\{x_8\}.$

In this particular case, we can distinguish all the objects of U (all of them are discernible) in terms of attributes from set Q.

Concepts:

$C_1=\{x_1,x_2,x_6,x_8\}$ → Class 1 (d = TP30);

$C_2=\{x_3,x_4\}$ → Class 2 (d = TP200);

$C_3=\{x_5,x_7\}$ → Class 3 (d = TP100).

B. Reducts and Core

Reducts and *Core* are useful notions used in the RS community for reducing unnecessary information. Reducts allow the identification of redundant attributes, which is important to reduce information in a data set. The idea behind reducts is that superfluous attributes can be removed without loss of classification power by the reduced set of attributes (reducts).

According to Ziarko and Shan (1995), a reduct is a set of attributes $RED \subseteq A$ such that

a) $R(RED) = R(A)$, i.e., RED produces the same classification of objects as the whole attribute collection A.

b) For any $q \in RED$, $R(RED - \{q\}) \neq R(A)$, that is, reduct is minimal subset with respect to the attribute (q).

A reduct of set A, denoted by $RED(A)$, is defined

$$E = RED(A) \Leftrightarrow (E \subset A,\ IND(E) = IND(A),\ E \text{ is orthogonal}).$$

Being an attribute $q \in E$, if $IND(E) \neq IND(E - \{q\})$, for all attributes of E, then all these attributes q_i are indispensable and E is orthogonal.

A core is a common part of all reducts which allows the identification of the most significant attributes in the relationship. The core is constituted by those attributes that cannot be eliminated without affecting the ability to classify an object into a particular category. The intersection of all reducts of A is a core of A such that:

$$CORE(A) = \cap RED(A).$$

Applications involving calculation of *Reducts* and core can be found in the work of Shao (1996), Grzymala-Busse and Wang (1996) and Hu (1995). Most of the algorithms to reduce attributes start with the evaluation of one attribute. Progressively new attributes are then added. Instead of evaluating the combination of features from a single attribute, the proposed algorithm implements a top-down mode to evaluate them. *ATTReduct* initially receives the complete set of attributes Q. The process begins by extracting one of these, evaluates the indiscernibility of the new set of attributes. If this is indiscernible, the algorithm checks the orthogonality by recursively calling itself, sending the new set of attributes as parameter of the function. When the indiscernibility and orthogonality are checked, the algorithm stores the new set of attributes as a reduct and returns these values to the last call of the function. In cases where the new set of attributes is not indiscernible, the algorithm repeats the operation by extracting a different attribute until all of these are evaluated.

Algorithm 7.1 ***ATTReduct(****Sdata, N, M****).*** *Obtains the reducts for the set of attributes.*

INPUT: (i) An array *Sdata* of order *N*M* containing the identification of the attributes in the index 0 of the rows and the total of tuplas in index 1 to *N* (ii) An integer *N* -rows- representing the total of tuplas + 1 of *Sdata* (iii) An Integer *M* -columns- representing the total of attributes contained in *Sdata*.

OUTPUT: A vector *REDUCTS* containing the reducts found in *Sdata*.

Method:

Integer *Rsize* ⇐ 0, **boolean** *discern* ⇐ true,

string *s* ⇐ " ", **string[][]** *partialRed*

For *i* ⇐ 0 to *M* **Do** // Evaluates the combination of *M* attributes //

s ⇐ *s+Sdata[0][i]*

newSdata ⇐ *Sdata* - Column *i* // Generates a new array from *Sdata* but extracting attribute *i* //

If (*isIndisernible*(*newSdata*, *M*-1)) **Then** // Evaluates if the new array with the new set of attributes and data *newSdata* is indiscernible as *Sdata* is. It will evaluate the first characteristic of a reduct $R(RED) = R(A)$ //

partialRed[i] ⇐ *ATTReduct*(*newSdata*, *N*, *M*-1) // Evaluates the second characteristic of a reduct. For any $q \in RED,\ R(RED - \{q\}) \neq R(A)$. The set *newSdata* cannot contains more reducts. To evaluate this feature, the algorithm undertakes a recursive call (the algorithm calls itself) sending the new set of data *newSData*, *N* and *M*-1 as input values //

discern ⇐ false // If it is indisernible, is not discernible //

Rsize ⇐ *Rsize* + sizeOf(*partialRed[i]*)

EndIf

EndFor *i*

If (*discern*) **Then**

```
        REDU[0] ⇐ s // Assigns the string contained the input set of attributes as the
                       first reduct found //
    EndIf Else
        Integer k ⇐ 1
        For i ⇐ 0 to M Do // Organises all the reducts found in vector REDU //
            For j ⇐ 0 to sizeOf(partialRed[i]) Do
                If ((partialRed[i][j] ≠ null) And
                    (partialRed[i][j] Not In REDUCTS)) Then
                        REDUCTS[k] ⇐ partialRed[i][j]
                        k ⇐ k + 1
                EndIf
            EndFor j
        EndFor i
    EndElse
    Return REDUCTS
```

The first loop evaluates the set of attributes sent. For each value *i* in the loop the corresponding attribute and column of data are extracted from the array and stored in a new array. Thus, the new data set is evaluated. If it is indiscernible (which means there is no loss of information in comparison with the initial set of attributes), a new call to the algorithm *ATTReduct* with the new set of data is undertaken. This call is made to verify that there are no more sub-reducts of the already reduced set of attributes. If the returned vector *REDUCTS* contains only one element, this element corresponds to the complete set of attributes sent (the only reduct found is the set of attributes itself Q). This means that there are no reducts for the set of attributes Q. If the returned vector has more than one element, the reducts are those located from the position 1 of the vector *REDUCTS*.

Table 7.5 shows the initial input data to algorithm *ATTReduct* from the information contained in Table 7.4.

Table 7.5 Input Data to *ATTReduct*

Sdata (9x6)

Rows \ Columns	0	1	2	3	4	5
0	1	2	3	4	5	6
1	3	8	4	1	1	4
2	4	4	5	1	1	4
3	2	16	3	4	4	7
4	3	12	3	2	1	7
5	4	12	4	3	2	6
6	2	12	3	2	1	4
7	2	4	5	1	1	6
8	3	4	2	1	1	4
N = 9				*M = 6*		

For the entire set of attributes $A = Q$ = {*Mat.Gp., Nose R., Cut.Sp., D.O.C., Feed R, Grade*} identified as {1, 2, 3, 4, 5, 6} resulted reducts of A:

E_1 = {*Nose R., Cut.Sp., Grade*};

E_2 = {*Mat.Gp., Cut.Sp., Grade*};

E_3 = {*Mat.Gp., Cut.Sp., D.O.C*};

E_4 = { *Mat.Gp., Cut.Sp., Feed R.* };

E_5 = { *Cut.Sp., D.O.C., Grade*}.

E_6 = { *Cut.Sp., Feed R.,Grades*}.

E_7 = { *Mat.Gp., Nose R.*}.

The Core is given by $E_1 \cap E_2 \cap E_3 \cap E_4 \cap E_5 \cap E_6 \cap E_7 = \{\emptyset\}$

Why E_1 = {*Nose R., Cut.Sp., Grade*} is a reduct of A ?

a) By definition,

$$E_1 = RED(A) \Leftrightarrow (E_1 \subset A,\ IND(E_1) = IND(A))$$

$$A^* = \begin{Bmatrix} X_1 = \{x_1\},\ X_2 = \{x_2\},\ X_3 = \{x_3\},\ X_4 = \{x_4\}, \\ X_5 = \{x_5\},\ X_6 = \{x_6\},\ X_7 = \{x_7\},\ X_8 = \{x_8\} \end{Bmatrix};$$

$$E_1^* = \begin{Bmatrix} X_1 = \{x_1\},\ X_2 = \{x_2\},\ X_3 = \{x_3\},\ X_4 = \{x_4\}, \\ X_5 = \{x_5\},\ X_6 = \{x_6\},\ X_7 = \{x_7\},\ X_8 = \{x_8\} \end{Bmatrix};\ \text{so,}$$

$A^* = IND(A) = E_1^* = IND(E_1)$.

b) Verifying that E_1 is orthogonal

Being an attribute $q \in E_1$, if $IND(E_1) \neq IND(E_1 - \{q\})$, for all attributes of E_1, then all these attributes q_i are indispensable and E_1 is orthogonal.

$E_{11} = E_1 -$ {*NoseR.*} = { *Cut.Sp.*, *Grade* };

$$E_{11}^* = \begin{Bmatrix} X_1 = \{x_1\},\ X_2 = \{x_2\},\ X_3 = \{x_3, x_4\},\ X_4 = \{x_5\}, \\ X_5 = \{x_6\},\ X_6 = \{x_7\},\ X_7 = \{x_8\} \end{Bmatrix}$$

$E_1^* \neq E_{11}^*$

$E_{12} = E_1 -$ {*Cut.Sp.*} = { *NoseR.*, *Grade* };

$$E_{12}^* = \begin{Bmatrix} X_1 = \{x_1\},\ X_2 = \{x_2, x_8\},\ X_3 = \{x_3\},\ X_4 = \{x_4\}, \\ X_5 = \{x_5\},\ X_6 = \{x_6\},\ X_7 = \{x_7\} \end{Bmatrix}$$

$E_1^* \neq E_{12}^*$

$E_{13} = E_1 -$ {*Grade*} = { *NoseR.*, *Cut.Sp.* };

$$E_{13}^* = \begin{Bmatrix} X_1 = \{x_1\},\ X_2 = \{x_2, x_7\},\ X_3 = \{x_3\},\ X_4 = \{x_4, x_6\}, \\ X_5 = \{x_5\},\ X_6 = \{x_8\} \end{Bmatrix}$$

$E_1^* \neq E_{13}^*$

The reducts E_2, E_3, E_4, E_5, E_6 and E_7 can be verified in the same way.

The information originated from reducts is much more specific than those extracted from the entire set of attributes. Once the reducts are obtained, it is necessary to evaluate each one to obtain the approximation subsets which will lead to the generation of knowledge rules. These subsets are commonly called *lower* and *upper* approximations sets.

The lower approximation contains all objects in the universe of objects U that, based on the knowledge of a given set of attributes A, can be *certainly* classified as belonging to a concept C_i, such that

$$\underline{A}C_i = U\{x \in U/A : x \subset C_i\};$$

The upper approximation contains all objects that can be *possibly* classified as belonging to the concept C_i by the set of attributes A, such that

$$\overline{A}C_i = U\{x \in U/A : x \cap C_i = \varnothing\};$$

Therefore, a rough set is defined as an approximation of a set, defined as a pair of sets: the upper and lower approximation of a set.

The difference between the upper and the lower approximation constitutes a *Boundary* region (also called *Doubtful* area), which contains vague information regarding the concept analysed. The *Boundary* region is given by

$$BN_A(C_i) = \overline{A}C_i - \underline{A}C_i,$$

To illustrate the above ideas, an example that considers the attributes pertaining to the last reduct and the decision attribute is presented.

A = *{MatGp., NoseR}*, $X = \{x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8\}$.

For this particular set of attributes A, the following equivalence classes can be defined

$X_1 = \{x_1\}$, $X_2 = \{x_2\}$, $X_3 = \{x_3\}$, $X_4 = \{x_4\}$, $X_5 = \{x_5\}$, $X_6 = \{x_6\}$, $X_7 = \{x_7\}$, $X_8 = \{x_8\}$, so:

<u>Analysing Concept 1 (d= TP30)</u>

A-lower approximation for = $\underline{A}X = \{x_1, x_2, x_6, x_8\}$;

A-upper approximation = $\overline{A}X = [x_1]_A \cup [x_2]_A \cup [x_6]_A \cup [x_8]_A$

$= \{x_1, x_2, x_6, x_8\}$

A-boundary region = $BN_A(X) = \overline{A}X - \underline{A}X = \varnothing$

<u>Analysing Concept 2 (d= TP100)</u>

A-lower approximation for = $\underline{A}X = \{x_3, x_4\}$

A-upper approximation = $\overline{A}X = [x_3]_A \cup [x_4]_A = \{x_3, x_4\}$

A-boundary region = $BN_A(X) = \overline{A}X - \underline{A}X = \varnothing$

<u>Analysing Concept 3 (d = TP200)</u>

A-lower approximation for = $\underline{A}X = \{x_5, x_7\}$;

A-upper approximation = $\overline{A}X = [x_5]_A \cup [x_7]_A = \{x_5, x_7\}$

A-boundary region = $BN_A(X) = \overline{A}X - \underline{A}X = \varnothing$

The boundary region represents the set of objects that cannot be certainly classified as belonging to the concept by the set of attributes in study. It is evident that the boundary regions for the three concepts of the system are empty. This means that the classification generated from reducts originates more specific and accurate knowledge.

ii) Inconsistency Analysis

The inconsistency and vagueness of information about objects is one of the greatest obstacles to performing learning tasks (Khoo *et al.*, 1999). It is common to find that objects contained in databases have imprecise, incomplete or uncertain data, which makes their classification difficult. Rough set philosophy emphasises the discovery of patterns in the incomplete or vague data.

Along with the reduction of attributes, the analysis of inconsistent relations in the data set is also a significant tool in the process of datamining using rough set concepts. It permits the detection of contradictory data and the generation of mechanisms to manipulate and represent these in an understandable way.

The methodology results in a module to identify inconsistent relationships in the data. The algorithm uses the ideas of lower, upper approximation and boundary region to detect a set of objects that contradict the concepts.

Algorithm 7.2 ***INCONSISTMatrix(****Tdata, N, M)* *Obtains the inconsistent objects for each pair of concepts.*

INPUT: (i) An array *Sdata* of order *N*M* containing tuplas of data (ii) An integer *N* -rows- representing the total of tuplas of *Tdata* (iii) An Integer *M* -columns- representing the total of attributes contained in *Tdata.*

OUTPUT: A quadratic matrix *INCONSIST* containing the inconsistent objects for each pair of concepts.

Method:

```
Integer[] Concepts, Integer T ⇐ 0,
Integer[] UAppA, Integer[] LAppA,
Integer[] UAppB, Integer[] LAppB,
Integer[] BoundA, Integer[] BoundB,
Concepts ⇐ getConcepts(Tdata, N, M)
T ⇐ size(Concepts)
Integer INCONSIST[T][T]
For i ⇐ 0 to T-1 Do   // Evaluates the combination of T concepts //
   UAppA ⇐ getUpperApp(Tdata, N, M, Concepts[i])
   LAppA  ⇐ getLowerApp(Tdata, N, M, Concepts[i])
   BoundA ⇐ UAppA - LAppA
   For j ⇐ i+1 to T Do
      UAppB ⇐ getUpperApp(Tdata, N, M, Concepts[j])
      LAppB  ⇐ getLowerApp(Tdata, N, M, Concepts[j])
      BoundB ⇐ UAppB - LAppA
      INCONSIST[i][j] ⇐ BoundA ∩ BoundB
   EndFor
EndFor
Return INCONSIST
```

The following example demonstrates the procedure undertaken in the algorithm.

The possible concepts for the set of data from Table 7.4 are:

$C_1 = \{x_1, x_2, x_6, x_8\}$ → Class 1 (d = TP30);

$C_2 = \{x_3, x_4\}$ → Class 2 (d = TP200);

$C_3 = \{x_5, x_7\}$ → Class 3 (d = TP100).

According to the set of attributes A = *{Nose R., D.O.C., Feed R}* the following indiscernible relationships can be identified:

$X_1 = \{x_1\}$; $X_2 = \{x_2, x_7, x_8\}$; $X_3 = \{x_3\}$; $X_4 = \{x_4, x_6\}$; $X_5 = \{x_5\}$;

Using the notations previously described, the approximation can be obtained as follows.

Analysing Concept 1

A-lower approximation for = $\underline{A}X = \{x_1\}$;

A-upper approximation = $\overline{A}X = X_1 \cup X_2 \cup X_4 = \{x_1, x_2, x_4, x_6, x_7, x_8\}$

A-boundary region = $BN_A(X)C1 = \overline{A}X - \underline{A}X = \{x_2, x_4, x_6, x_7, x_8\}$

Analysing Concept 2

A-lower approximation for = $\underline{A}X = \{x_3\}$;

A-upper approximation = $\overline{A}X = X_3 \cup X_4 = \{x_3, x_4, x_6\}$

A-boundary region = $BN_A(X)C2 = \overline{A}X - \underline{A}X = \{x_4, x_6\}$

Analysing Concept 3

A-lower approximation for = $\underline{A}X = \{x_5\}$;

A-upper approximation = $\overline{A}X = X_2 \cup X_5 = \{x_2, x_5, x_7, x_8\}$

A-boundary region = $BN_A(X)C3 = \overline{A}X - \underline{A}X = \{x_2, x_7, x_8\}$

Inconsistency between C1 and C2 = $BN_A(X)C1 \cap BN_A(X)C2 = \{x_4, x_6\}$

Inconsistency between C1 and C3 = $BN_A(X)C1 \cap BN_A(X)C3 = \{x_2, x_7, x_8\}$

Inconsistency between C2 and C3 = $BN_A(X)C1 \cap BN_A(X)C3 = \varnothing$

Table 7.6 Array returned in *INCONSIST*

	C1 0	C2 1	C3 2
C1 0	-	$\{x_4, x_6\}$	$\{x_2, x_7, x_8\}$
C2 1		-	$\{\varnothing\}$
C3 2			-

Clearly, the boundary (doubtful) region for concepts *C1* and *C3* indicates that the results of elements 2, 7 and 8 are contradictory. This means that similar values for the set of attributes A define two different concepts. This also occurs with concepts *C1* and *C2*. The tuplas 4 and 6 contradict one another. In other words, they are indiscernible by the condition attributes A.

7.2.4 Post-processing of the data

Once the datamining process has been undertaken, the final step in the proposed KD methodology is the interpretation and representation of the results. The output generated by an RS application can be transformed to knowledge rules or decision trees. In the case of ***R-sets,*** the IF-THEN rules were the chosen representation for the results. With every dependency between condition attributes and decision attributes, a set of decision rules can be associated, specifying decisions that should be taken when certain conditions are satisfied (Pawlak, 1998), (Uthurusamy *et al.*, 1991). The knowledge represented in these rules is more direct and the user does not need too much interpretation of the output.

In the post-processing module of ***R-sets*** a rule inductor for deterministic and possible rules has been implemented. Sometimes, the information provided by an RS system could contain knowledge which is too general. Likewise, too specific knowledge could generate meaningless information, which is not very useful to the user. The post-processing module has therefore been provided with an interactive interface that permits the user to select the reducts of particular interest and generalise or particularise the represented knowledge.

i) Deterministic Rules Engine.

The deterministic rules, also called sure, certain or consistent rules, are those that completely define the decision term of the rule. This means that the conditions-decision relations are conclusive; the same values in the condition term (**IF** part of the rule) do not originate a different decision value. These rules are generated with the information obtained from lower approximation measures.

Table 7.7 Deterministic rules for A = *{MatGp., Nose R, Grade}*.

Concept 1 (d= TP30) $\underline{A}X = \{x_1, x_2, x_6, x_8\}$	Concept 2 (d= TP200): $\underline{A}X = \{x_3, x_4\}$	Concept 3 (d = TP100) : $\underline{A}X = \{x_5, x_7\}$
Rule 1: **IF** (MatGp. = "3 Structural Steels..." **and** Nose R.= 0.8) **or** (MatGp. = "4 High Carbon Steels..." **and** Nose R. = 0.4) **or** (MatGp. = "2 Free Cutting Steels..." **and** Nose R. = 1.2) **or** (MatGp.= "3 Structural Steels..." **and** Nose R.= 0.4) **THEN** Grade = TP30		
Rule 2: **IF** (MatGp. = "3 Structural Steels..." **and** Nose R.= 1.2) **or** (MatGp. = "2 Free Cutting Steels..." **and** Nose R. = 1.6) **THEN** Grade = TP200		
Rule 3: **IF** (MatGp. = "4 High Carbon Steels..." **and** Nose R.= 1.2) **or** (MatGp. = "2 Free Cutting Steels..." **and** Nose R. = 0.4) **THEN** Grade = TP100		

To exemplify the generation of deterministic rules let us take the lower approximation measures for the attributes A = *{ MatGp., Nose R, Grade }*. The rules for this set are presented in Table 7.7.

ii) Possible Rules Engine

In contrast with deterministic rules, the possible rules are those that define the decision term with a partial level of dependency. The relation condition-decision is not complete. These rules are also called non-deterministic, conflicting or uncertain. This type of rule can be derived from the boundary measures.

To provide the user with levels of certainty for the conflicting rules, it is necessary to determine the levels of dependency or quality of the classification between condition and decisions attributes. In order to obtain a measure to quantify the accuracy of the set of conditions of a tupla in relation to a specific concept, a condition certainty level equation has been proposed

$$\beta_A(x) = \frac{card([x]_{(A+d)})}{card([x]_A)} \times 100\% ; \tag{7.1}$$

where $0 < \beta_A(x) \leq 100$, $[x]_{(A+d)}$ is the equivalence class of the set of attributes $(A+d)$ to which the object x belongs and $[x]_A$ is the same equivalence class but for the set of attributes A.

The generator of possible rules has been provided with a procedure to obtain this measure. Instead of using the cardinality of the equivalence class without repetition, the module will take into consideration the number of times that the tuplas appeared in the original set of data (see Table 7.2). This will provide a more realistic measure based in the occurrences of the object in the database. This number of occurrences can be seen in the decision table of the system (Table 7.4).

To illustrate the generation of possible rules and their level of certainty, an analysis for the reduct E_1 will be described. In order to compute the approximation space for the generation of the rules, the set of attributes A must be only conformed by condition attributes. The decision variable d is one of the attributes contained into the reduct E_1. Then $A = E_1 - d$.

$E_1 = \{NoseR., CutSp., Grade\}$ and $A = \{NoseR., CutSp.\}$

The equivalence classes for A are

$$A^* = \begin{Bmatrix} X_1 = \{x_1\},\ X_2 = \{x_2, x_7\},\ X_3 = \{x_3\}, \\ X_4 = \{x_4, x_6\},\ X_5 = \{x_5\},\ X_6 = \{x_8\} \end{Bmatrix};$$

Now let us obtain the approximation space for each concept.

Analysing Concept 1 (d=TP30)

A-lower approximation for = $\underline{A}X = \{x_1, x_8\}$

A-upper approximation = $\overline{A}X = X_1 \cup X_2 \cup X_4 = \{x_1, x_2, x_4, x_6, x_7, x_8\}$

A-boundary region = $BN_A(X)C1 = \overline{A}X - \underline{A}X = \{x_2, x_4, x_6, x_7\}$

Analysing Concept 2

A-lower approximation for = $\underline{A}X = \{x_3\}$

A-upper approximation = $\overline{A}X = X_3 \cup X_4 = \{x_3, x_4, x_6\}$

A-boundary region = $BN_A(X)C3 = \overline{A}X - \underline{A}X = \{x_4, x_6\}$

Analysing Concept 3 (d=TP100)

A-lower approximation for = $\underline{A}X = \{x_5\}$

A-upper approximation = $\overline{A}X = X_2 \cup X_5 = \{x_2, x_5, x_7\}$

A-boundary region = $BN_A(X)C2 = \overline{A}X - \underline{A}X = \{x_2, x_7\}$

Table 7.8 shows the boundary region, generated rules in compressed and disjointed format and certainty levels for the analysed set of attributes.

Table 7.8 Possible rules generation.

Concept 1(*d= TP30*) $BN_A(X)C1 = \{x_2, x_4, x_6, x_7\}$	Concept 2(*d= TP200*): $BN_A(X)C2 = \{x_4, x_6\}$	Concept 3(*d = TP100*) : $BN_A(X)C3 = \{x_2, x_7\}$
Rules C1:	**IF** (Nose R.=0.4 **and** Cut.Sp. IN {151-200}, CL=50%) **or** (Nose R.=1.2 **and** Cut.Sp. IN {101-150}, CL=33.33%) **THEN** Grade = TP30	
	* **IF** (Nose R.=0.4 **and** Cut.Sp. IN {151-200}) **THEN** Grade = TP30 (CL=50%) * **IF** (Nose R.=1.2 **and** Cut.Sp. IN {101-150}) **THEN** Grade = TP30 (c=33%)	
Rules C2:	**IF** (Nose R.=1.2 **and** Cut.Sp. IN {101-150}, CL=66.67%) **THEN** Grade = TP200	

Rules C3:	**IF** (Nose R.=0.4 and Cut.Sp. IN {151-200}, CL= 50%) **THEN** Grade = TP100

To obtain certainty levels it is first necessary to obtain elementary classes for the set of attributes $(A+d)$.

$$(A+d) = \{\textit{Nose R., Cut.Sp., Grade}\}$$

$$(A+d)^* = \begin{Bmatrix} X_1 = \{x_1\},\ X_2 = \{x_2\},\ X_3 = \{x_3\},\ X_4 = \{x_4\}, \\ X_5 = \{x_5\},\ X_6 = \{x_6\},\ X_7 = \{x_7\},\ X_8 = \{x_8\} \end{Bmatrix}$$

Now, let us obtain certainty levels for the rules generated with objects x_2 and x_7.

$$\beta_A(x_2) = \frac{card([x_2]_{(A+d)})}{card([x_2]_A)} \times 100\% = \frac{1}{2} \times 100\% = 50\%$$

$$\beta_A(x_7) = \frac{card([x_7]_{(A+d)})}{card([x_7]_A)} \times 100\% = \frac{1}{2} \times 100\% = 50\%$$

Let us also obtain certainty levels for the rules generated with objects x_4 and x_6.

$$\beta_A(x_4) = \frac{card([x_4]_{(A+d)})}{card([x_4]_A)} \times 100\% = \frac{2}{3} \times 100\% = 66.67\%$$

$$\beta_A(x_6) = \frac{card([x_6]_{(A+d)})}{card([x_6]_A)} \times 100\% = \frac{1}{3} \times 100\% = 33.33\%$$

7.3 SUMMARY

In this chapter an important methodology to support the development of an attribute-oriented application using rough set theory has been proposed. This methodology was structured in four main stages: 1) input and data-warehouse, 2) pre-processing, 3) mining of the data, and 4) post-processing.

An important advantage of rough set theory is that it does not need any preliminary information about data, like probability in statistics, basic probability assignments in Dempster-Shafer theory and grade of membership or the value of possibility in fuzzy sets theory. Furthermore, in contrast to standard statistical methods, rough set theory finds a good applicability, even when the set of experimental data is relatively small.

This datamining technique is commonly used to remove superfluous data through measurement of dependencies between attributes. Sometimes, the complexity in the relationship of the attributes and the incremental size of the data makes the reduction of meaningless data more difficult. This idea was taken into consideration in the development and implementation of a recursive algorithm to obtain the reducts of the data set. This represented a substantial improvement in the quality of the final classification and representation of the results.

Another important feature of rough set is the possibility to deal with contradictory information through the definition of two keys sets, *lower* and *upper* approximations. This represented a foundation to develop a module able of detect inconsistencies in the data which were manipulated with certainty levels.

This methodology has been successfully applied to develop ***R-sets***, a system to extract information from tooling data generating knowledge rules. This will provide engineers and researchers around the world with a new mechanism to explore and take advantage of the data generated by ***TTS***.

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CHAPTER 8: TESTS AND RESULTS

8.1 INTRODUCTION

One important final step in this research is to test the proposed applications. This chapter presents the results of a set of experiments applied to ***TTS***, ***Cluster-F*** and ***R-sets***.

The first section examines the completeness of the tooling database and the effectiveness of attribute relaxation, importance levels and confidence scores, the features of ***TTS*** which are able to provide closest solutions to the submitted query. The completeness of the database is evaluated by implementing whole and partial integrity equations. To illustrate the effectiveness of the AQ module, the same set of cases is evaluated with and without attribute relaxation, different importance levels and varying confidence scores levels.

The second section evaluates the classification process of ***Cluster-F*** and demonstrates its functionality in obtaining cutting data from incomplete information. Also, some experiments with implementation of different clustering methods are carried out. This provides evidence of the classification processes implemented in the system. The last section examines the capacity of ***R-Sets*** to generate knowledge rules by *a)* filtering the data, *b)* eliminating redundancies, *c)* finding relevant attributes, *d)* evaluating inconsistencies in the data and, *e)* computing certainty levels for the generated rough sets.

8.2 TOOL TRIAL SYSTEM AND TOOLING DATABASE TEST

Following the development phase of ***TTS***, it was important to test the full functionality of the system. Some important aspects of the tests that were needed are:

- The robustness of the user-interface, particularly when the system has to support moderate or intense user interactions.

- The reliability of the answers given by the system. This analysis involves verifying the answers provided by the system against different knowledge sources, such as experts in the respective domain, technical catalogues and similar successful systems.

- The completeness of the database to satisfy user information requirements.

- The operational spectrum of the system. This involves introducing different input combinations to check the respective output values.

- That it uses data relaxation procedures to generate a scored result set when no exact matches are found. It will therefore be useful to determine the contribution of these relaxation methods to provide alternative and close answers when the specifications submitted by the user do not find any perfectly matching results.

- That it manages user Confidence Scores (CS), which allow more flexible criteria to relax the number of matching results

- That it manages Importance Levels (IL), which can be used to weaken or strengthen the importance of an individual parameter (for instance, Material Group, Insert Geometry, Grades and Chipbreaker) relative to another during the process of selecting suitable matches. It is important to analyse the variety of answers generated by the system when these IL are given a wide range of values.

- The database used for ***TTS*** currently contains 314 tool trial reports of Turning operations (930 records) and 97 reports of Milling operations (318 records). To determine whether the information stored in its tables satisfies the user requirements, a set of tests should be conducted.

These tests allow the evaluation of both the functionality of the Advanced Query Module and the integrity of the database. To perform this study, a set of tests has been undertaken, resulting in an extensive diagnosis of the system. The objectives of the tests have been grouped according to database and operational considerations. The first part of the tests considers the evaluation of the Integrity of the Tool Trials Database used by ***TTS*** to satisfy user requests under two modalities: whole integrity and partial integrity by key attributes; The second section analyses the effectiveness of the attribute importance levels and confidence scores. Three types of test were carried out:

- whole and partial integrity;
- effectiveness of confidence scores attribute; and
- effectiveness of Importance Levels attribute

There were four test phases: first, the design of the test runs for Milling and Turning operations that represents real life processes; the registration of the test runs into the system and organisation of the results; the generation of graphical representation of the information obtained from the tests; and the analysis and discussion of the results.

8.2.1 Integrity

'Integrity' is a term used to measure whether the database used by ***TTS***, satisfies user-requests. To develop this test, five options were considered.

Whole Integrity: This type of integrity considers only the full matches found when the four chosen parameters are evaluated. These attributes are Seco Material Group, Insert Grade, Chipbreaker/Designation and Type of Insert.

Partial Integrity relaxing Seco Material Group: This evaluates full matches found when the Seco Material Group is excluded from the test (any Seco Material Group) and the other three parameters are fixed with specific values.

Partial Integrity relaxing Insert Grade: Similar to the former Integrity evaluation, this considers the full matches found when the Insert Grade is relaxed (not included in the test).

Partial Integrity relaxing Chipbreaker/Designation: Once again, this takes into consideration full matches found when Chipbreaker or Designation is excluded from the test.

Partial Integrity relaxing Type of Insert: Finally, this test evaluates the integrity when the Type of Insert is relaxed.

The equations used to evaluate the different integrity values of the database were

$$WInt = \frac{FM}{n} * 100\% \quad (8.1)$$

$$PInt = WInt + \frac{(FMA - FM)}{(n - FM)} * 100\% \quad (8.2)$$

where,

$WInt$ = Whole Integrity;

$PInt$ = Partial Integrity considering any instances of individual key attributes;

FM = Full matches found for Whole Integrity;

FMA = Full Matches without the attribute(s) considered;

n = sample size;

To carry out the tests, the case studies were carefully designed (APPENDIX C: Tables C.1 and C.2). The result was 31 cases for Turning Operation and 20 for Milling. Each of these cases was run with the specified parameters for each test and the results were obtained (APPENDIX C: Tables C.3 and C.4). Importance Levels and Confidence Scores were not taken into consideration when evaluating Integrity. The next step consisted of applying the equations of integrity. For example, four full matches were found when all the parameters of the cases were considered. Then, the calculated Whole Integrity for the Turning Operation was 12.90%.

$$WInt_{Turning} = \frac{FM_{Turning}}{n_{Turning}} * 100\% = \frac{4}{31} * 100\% = 12.90\%$$

To calculate the Partial Integrity of the Seco Material Group for a Turning Operation

$$PInt(SMG)_{Turning} = WInt_{Turning} + \frac{(FMA(SMG)_{Turning} - FM_{Turning})}{(n_{Turning} - FM_{Turning})} * 100\% =$$

$$PInt(SMG)_{Turning} = 12.90 + \frac{(13-4)}{(31-4)} * 100\% = 46.23\%$$

Figure 8.1 shows the chart with the results of integrity for Turning Operations. These results indicate a low whole integrity for turning operations. This value demonstrates that it is not always easy to find full matching solutions for the thousands of possible combinations when performing queries using the variables offered by the module.

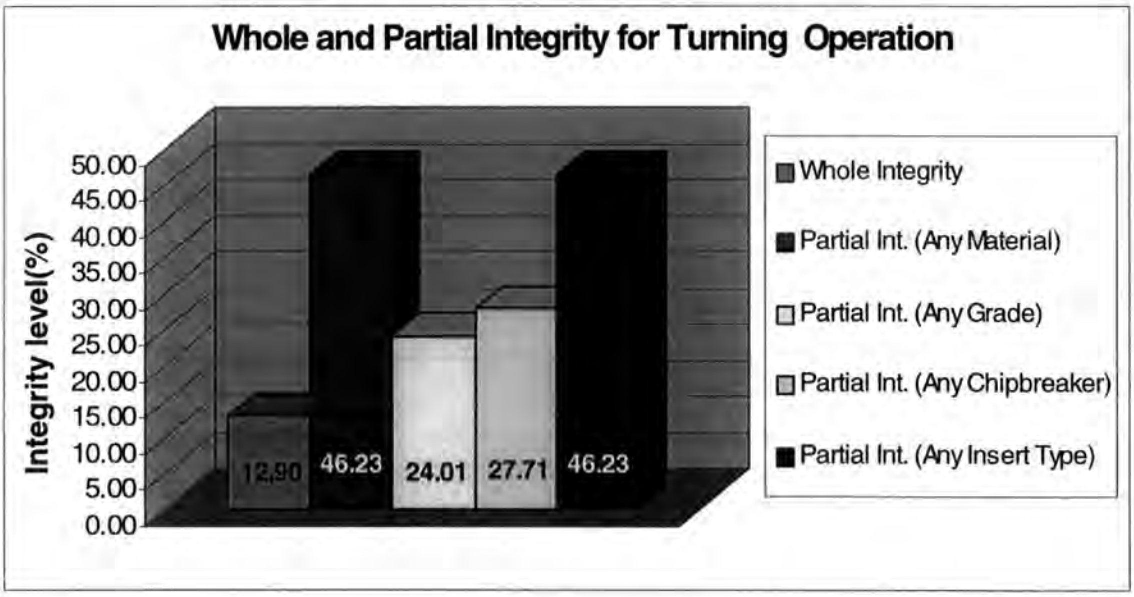

Figure 8.1 Database Integrity For Turning Operations.

It is also evident that there is a strong influence of Material Groups and Type of Insert parameters on the partial integrity results. This is understandable considering the spectrum of answers provided when 15 categories of material groups are relaxed into only one general category (any). Perhaps the decision to relax the material groups is not realistic in terms of user-requests.

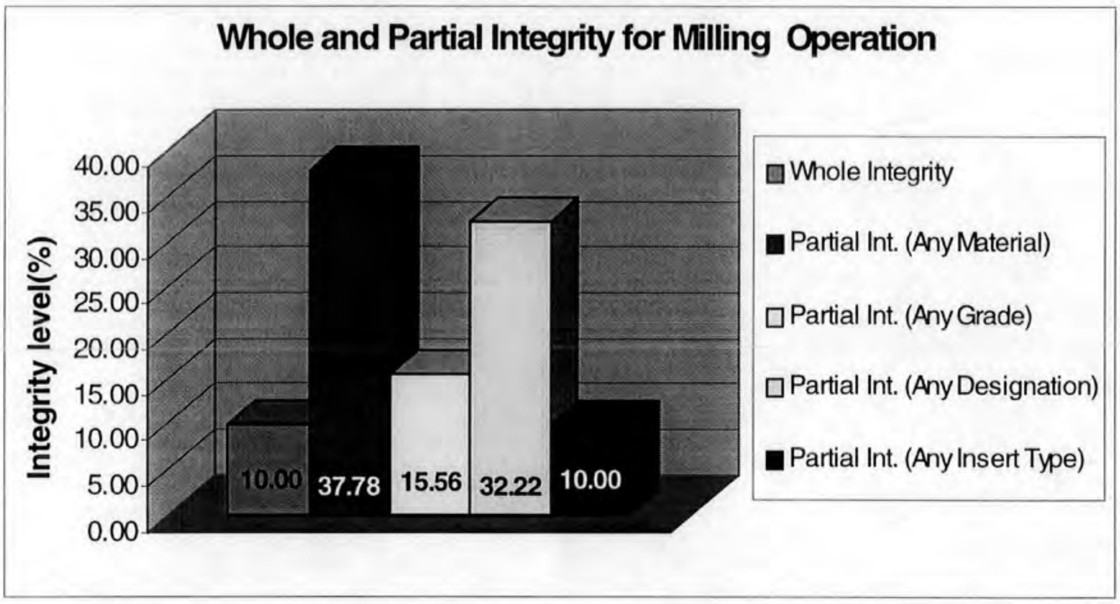

Figure 8.2 Database Integrity for Milling Operations.

However, it can be used in cases where no tests are found for specific combinations of parameters requested. In such cases, the engineers can obtain reports with part of the required information and use these to find possible solutions.

An illustration of the results obtained for Milling operations can be seen in Figure 8.2. The values of integrity shown in this figure were obtained using the same equations applied for turning operations. The result for whole integrity for milling operations reveals a value of 10%, which shows that the database in its current size (97 reports) is not able to provide many full matching results, based on the selected sample of 20 test cases.

In the case of Milling Operations, the strong parameters were the Material Group and the Insert Designation with 37.78% and 32.22%, respectively of partial integrity when these parameters are excluded from the variables in the case.

8.2.2 Effectiveness of Confidence Score

The 'Effectiveness' is a measure of the effectiveness of some key methods altering the number of valid answers. In this case, the analysis was carried out to test the effectiveness of Confidence Scores (CS) with and without applying relaxation methods.

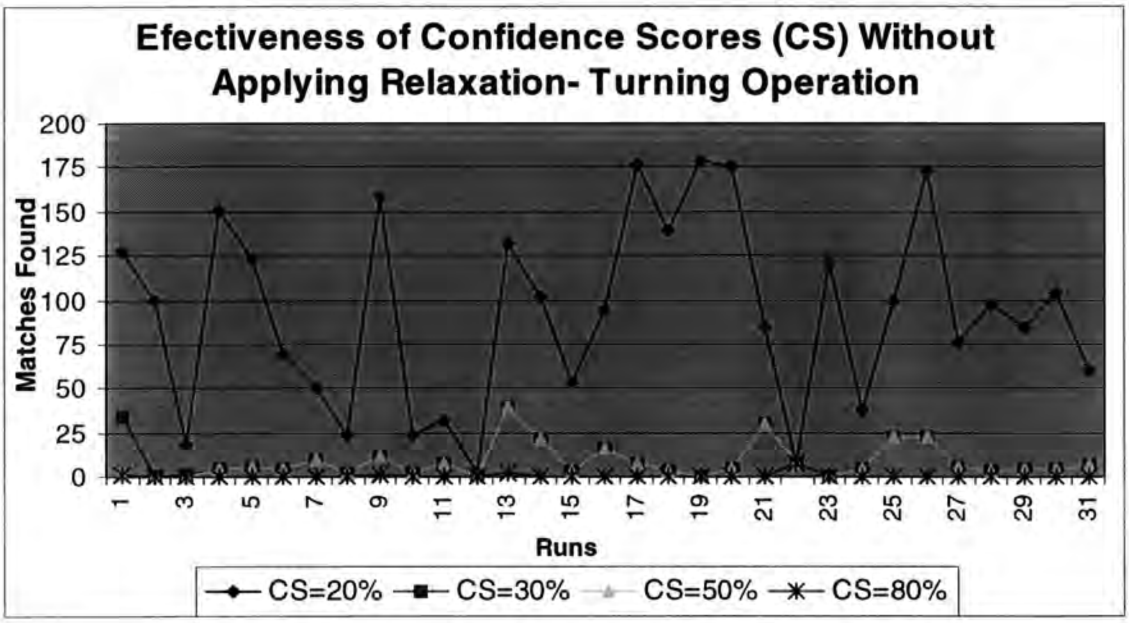

Figure 8.3 Confidence Score for Turning Operation without relaxation.

This was undertaken in two ways: running the system without applying relaxation techniques and fixing the Importance Levels (IL) in 50% of the key attributes; and using the same criteria but applying relaxation techniques. In both cases the functionality of Confidence Scores (CS) was tested for values of 20, 30, 50 and 80%. These measures involved the introduction of 416 test runs. The results for Turning and Milling cases are shown in APPENDIX C, tables C.5 and C.6.

Figure 8.3 shows the results for Turning operations without applying relaxation techniques, while the results obtained making use of the relaxation method is shown in Figure 8.4. It can be seen that the number of matches found is inversely proportional to the confidence score. When the confidence score is restricted to higher levels, the set of reports found decreases. This means that the system is adjusting the quality of the answer to the confidence level requested by the user.

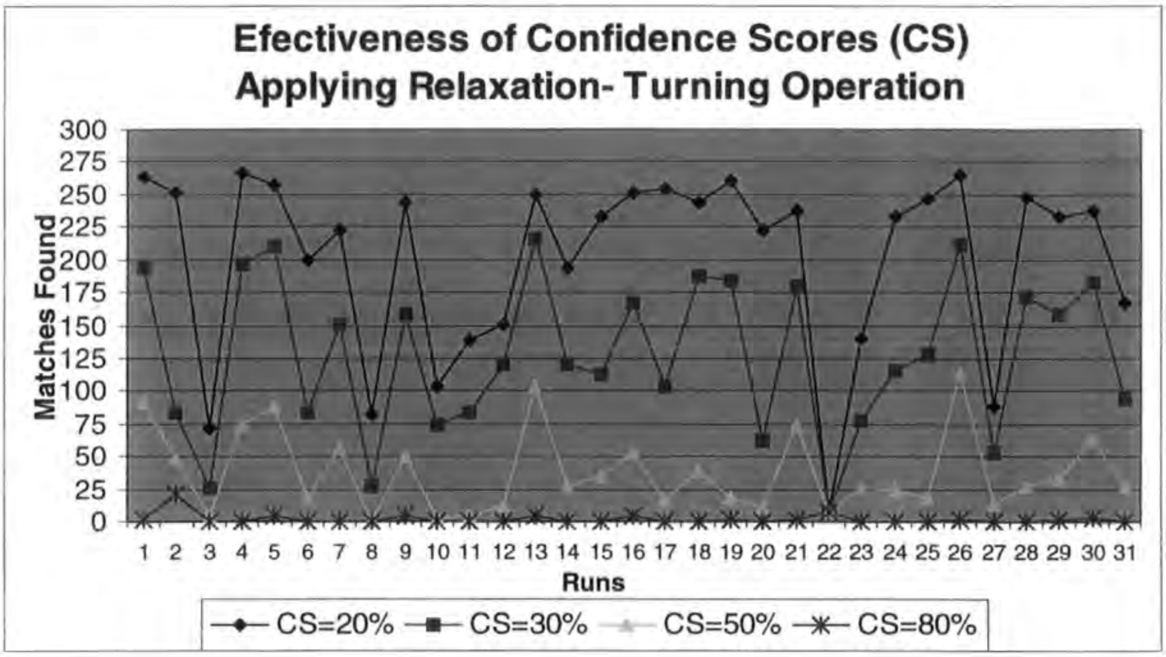

Figure 8.4 Matches found for Turning Operation using relaxation.

It is important to highlight "case 22" in both figures. The initial number of matches found for the parameters specified for this case was eight (8). The system does not provide the options for confidence score and relaxation when more than four matches are initially found. However case 22 was not evaluated applying these methods.

Another important result is the comparison between applying or not applying relaxation methods. A substantial increase in the matches is evident when relaxation techniques are applied. Furthermore, the number of matches with CS=30 and CS=50 without relaxation technique application is very similar. If four parameters are taken into account, each contributes 25% of the total confidence score of the report.

Any CS within the range of 0 and 25%, 26 and 50%, 51 and 75% or 76 and 100 will provide the same number of matches found for each group. However, the relaxation techniques perform comparisons between the user requirement and database values for each variable and calculate the confidence score. Figure 8.5 and Figure 8.6 show the results for milling operations.

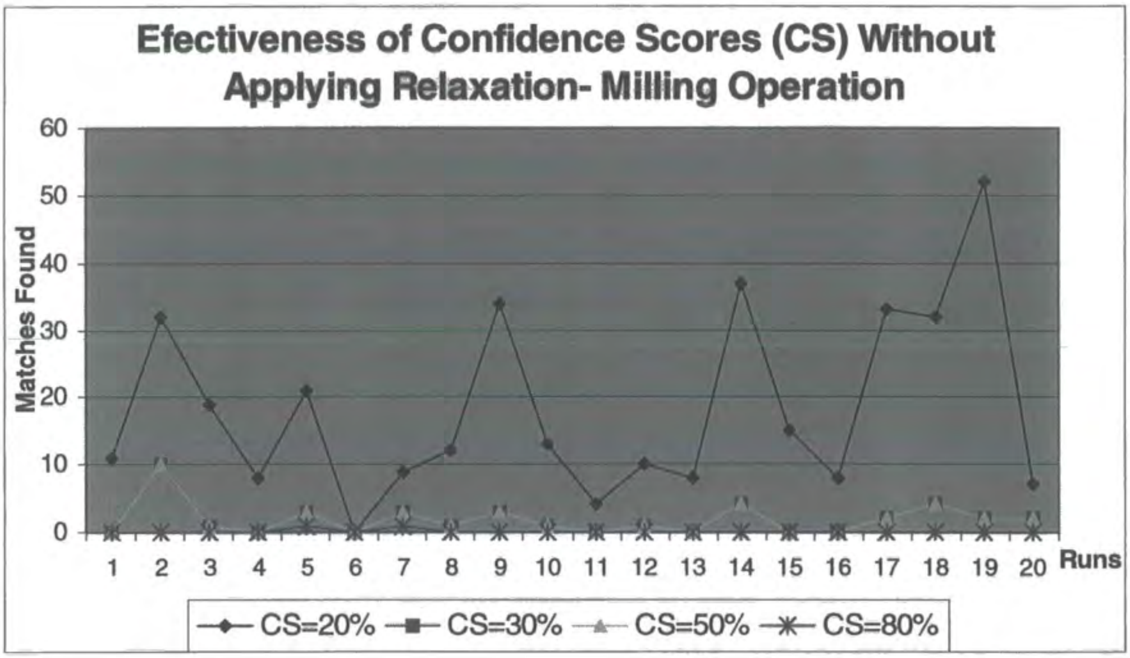

Figure 8.5 Matches found for Milling operation without relaxation methods.

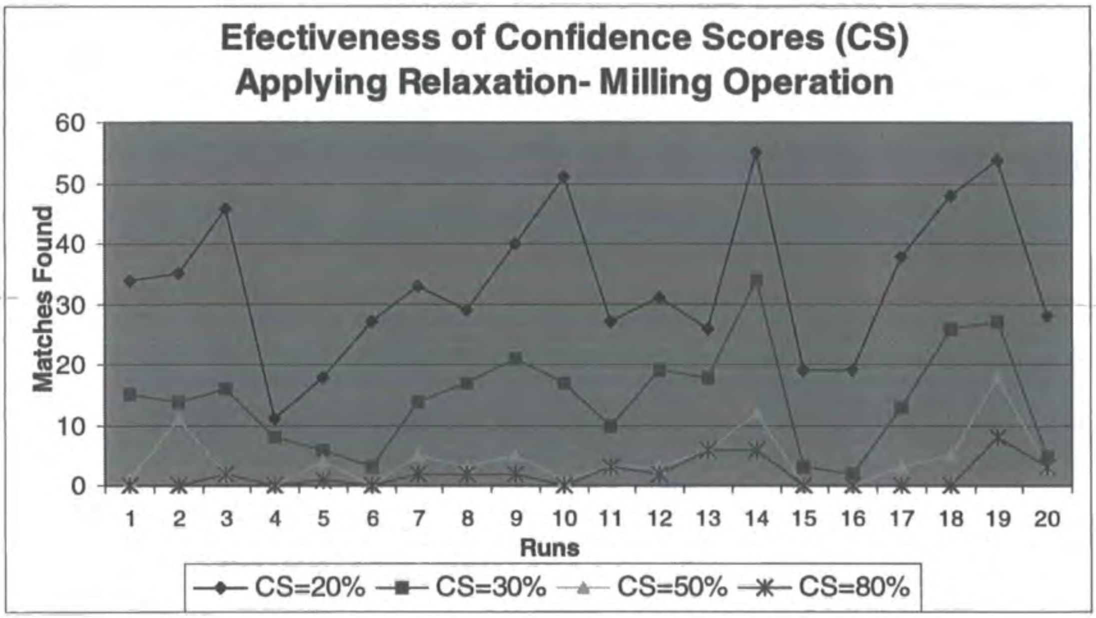

Figure 8.6 Matches found for Milling operation applying relaxation methods.

Once again, it is clear how flexible the system is in finding closed matches. The tendencies of matches found for the Turning operation are similar to those shown for Milling, except that smaller set of solutions is obtained for the later.

8.2.3 Effectiveness of Importance Levels

This test consisted of performing the runs for cases of nine trends of Importance Level combinations using the parameters of the cases. Figure 8.7 shows the configuration of these trends.

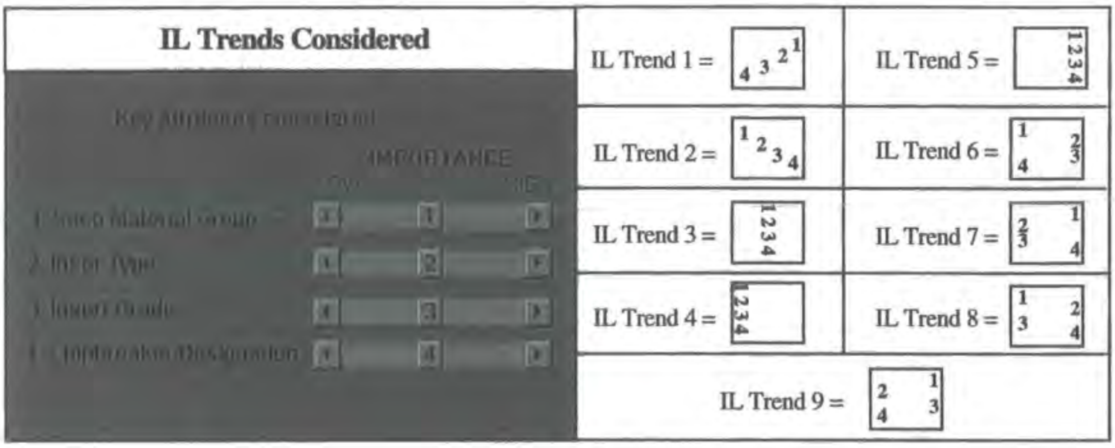

Figure 8.7 Importance Levels Trends.

To perform this test, each of the 51 cases (31 for Turning and 20 for Milling) ran each combination of IL using parameter relaxation and confidence score of 40 for Milling and 60 for Turning. The reason for using relaxation methods and CS values (40% and 60%) is that the test requires major flexibility to produce a large enough range of matches, to establish comparisons among the nine different combinations of IL considered. The results can be found in APPENDIX C, tables C.7 and C.8.

Figure 8.8 and Figure 8.9 show the averages of matches found for each trend. The figure below reveals that the *IL Trend 1* presents the largest average. The *IL Trends 3*, *4* and *5* have the same behaviour. This is due to all the attributes having the same importance level when they are evaluated. In addition, when IL Trend 2 is used, the system provides a smaller set of reports in comparison with the other trends. It is important to highlight that this trend assigns less importance to the Material Group, a key attribute with good capacities to be relaxed.

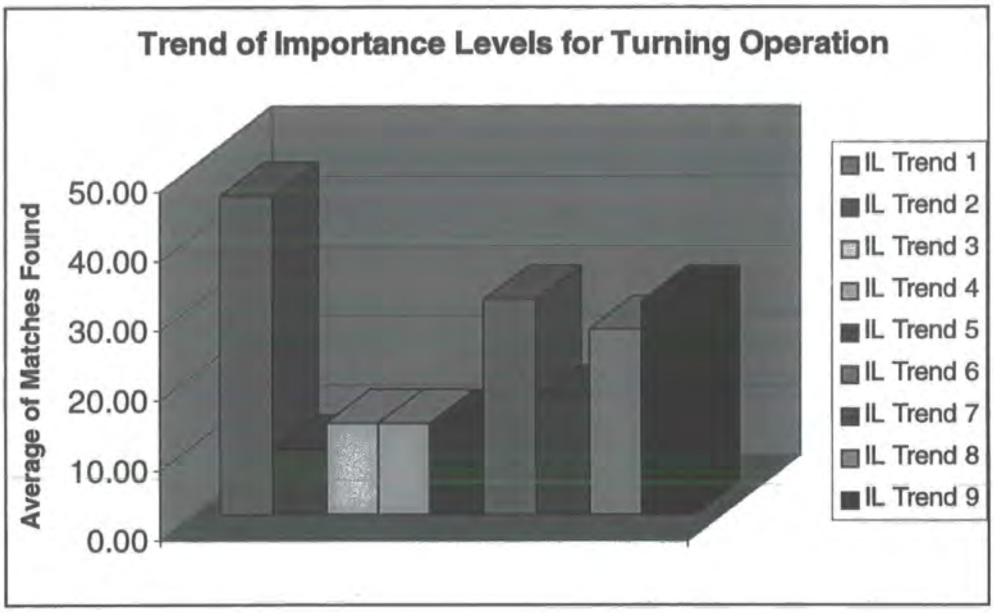

Figure 8.8 Average of Matches Found with IL Trends for Turning Operations.

In relation to the figure for Milling operations, the chart shows the lowest averages of matches found for IL Trends 2 and 8. These trends share a common pattern: the results have been obtained fixing *LOW* IL for the parameter Seco Material Group.

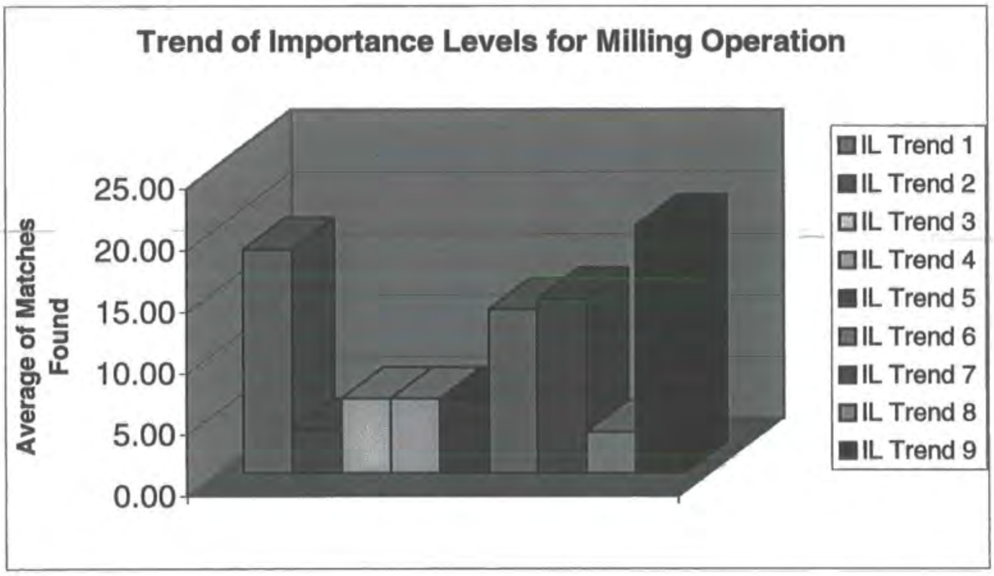

Figure 8.9 Average of Matches Found with IL Trends for Milling Operation.

In those cases where the IL for the parameter Seco Material Group was placed in *High* IL, the matches found were considerably higher than for other combinations, independent of the position of the rest of IL for other attributes considered.

The results indicate a stronger influence by the attribute Seco Material Group compared to the rest, which reinforces the same conclusion obtained for the integrity analysis

8.3 TEST AND RESULTS FOR *CLUST-F*

The main objective of the testing phase for ***Clust-F*** has focused on the functionality of the system. Two types of experiment were carried out. The first evaluates the capacity of the system to offer engineers with alternative cutting data for specific requirements. The second experiment analyses the results from applying different clustering method to the classification process.

8.3.1 Functionality to provide cutting parameters for turning operations

In order to demonstrate the ability of ***Cluster-F*** to provide tooling engineers with cutting parameters for turning operations, two tests were undertaken. The first was designed to obtain cutting data that cannot be found in manuals. The second test uses inputs parameters with values that cannot be found in the tooling database. The idea of the tables is to generate the closest cutting data from the system that can guide engineers in the planning of turning operations not previously performed.

Test #1:

The input parameters for this test are *Seco Material Group* = 3 and *Grade* = "TP30". The options for the classification process have been set as:

Clustering method = "Single Linkage"
Stopping method = "Number of clusters == 30"
Learning mode = "Non Supervised"

The cutting data provided by the company in manuals and software do not consider the grade TP30. As was pointed out in chapter four, technical support aids only utilise data for the most common grades and materials. Figure 8.10 illustrates the assessment of cutting data through a graphical interface. This provides the user with the possibility of choosing the combination of cutting parameters needed for the specified input.

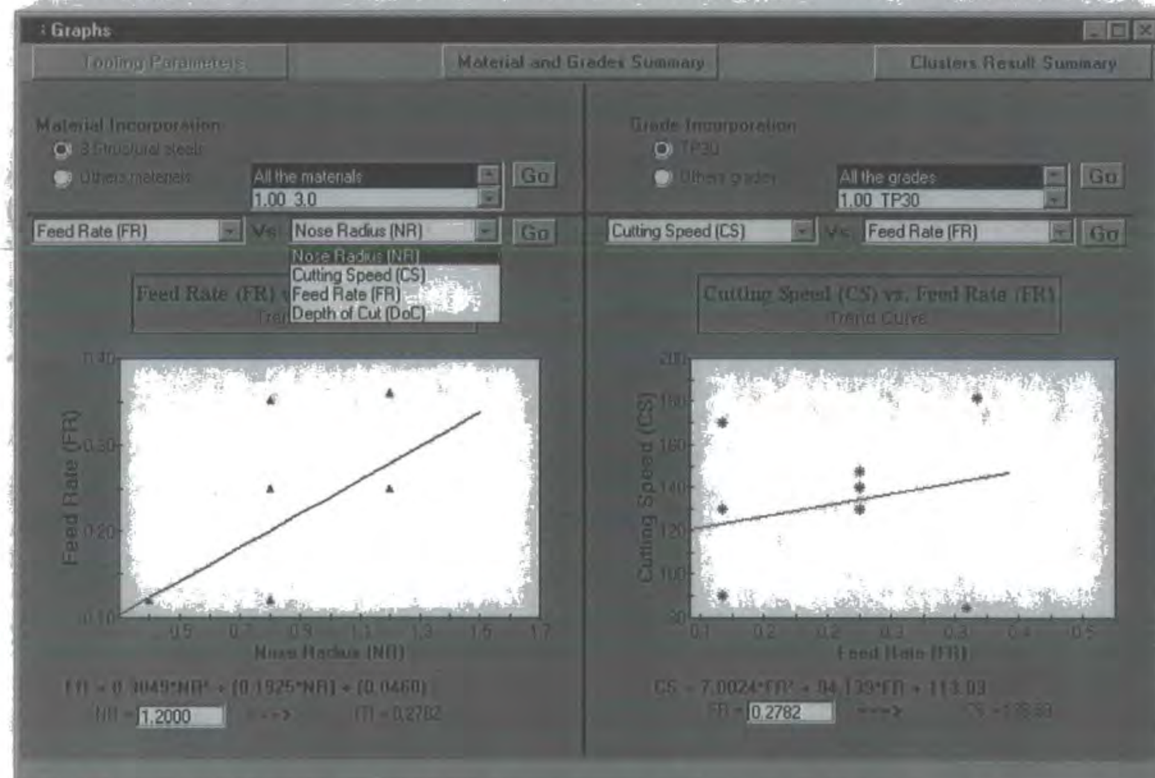

Figure 8.10 Cutting Data for Test #1.

The graph shows the points from data with the required input characteristics. The user can choose from four cutting variables to obtain the plotted points, the approximated line to these points and the second order equation generated by this line. This equation can be found below the graph. It can be used to obtain the required cutting data. The two graphs work in the same way. These can be combined to obtain the cutting parameters required by the user. In Figure 8.10, the left graph evaluates the relation between *feed rate* (dependent variable) and *nose radius* (independent variable). The user can obtain the estimated *feed rate* values depending on the *nose radius* of the inserts (bottom fields). The corresponding *feed rate* for a *nose radius* of 1.2 is 0.278.

Test #2:

The aim of this test is to demonstrate the functionality of ***Cluster-F*** to offer users cutting data guidance when no clusters with the combination of input variables are found. The options specifications for this test are the same as those used for Test #1. The *Seco Material Group* = 3 and the *Grade* = "CP50". Figure 8.11 shows the stratification and membership levels of the cluster with the closest solution to the input specifications for materials and grades.

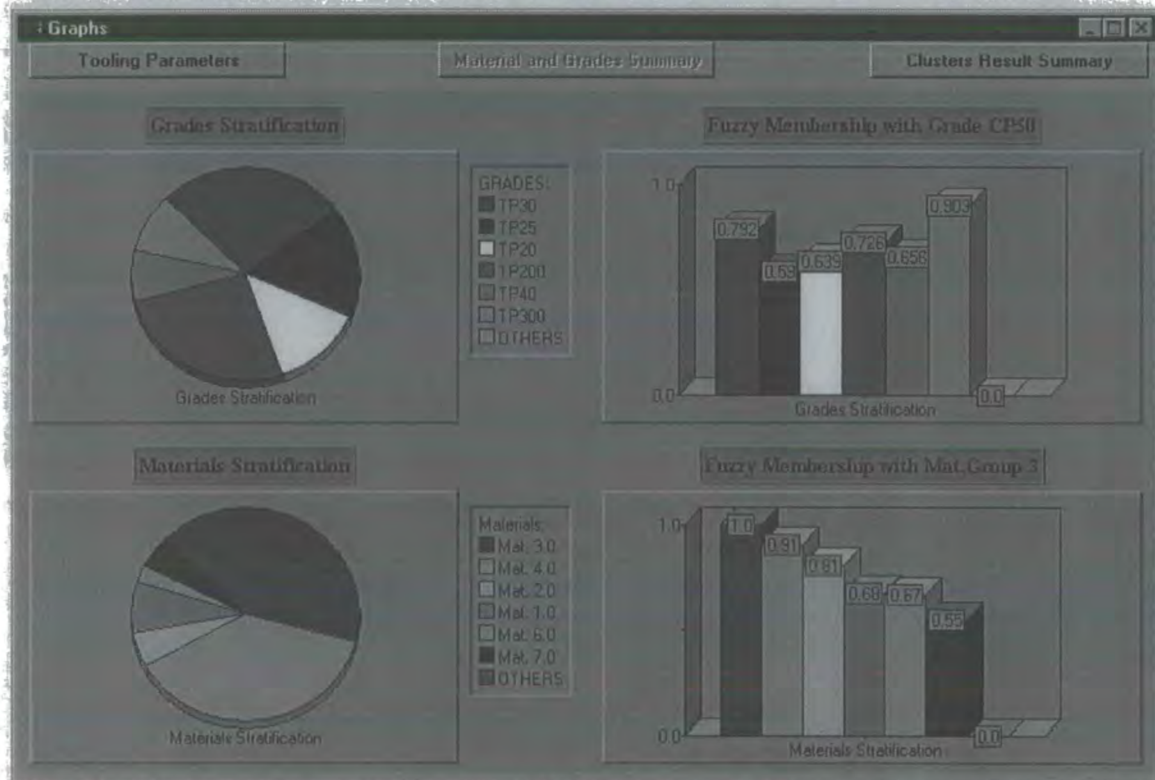

Figure 8.11 Cluster Summary for Materials and Grades in Test #2.

The right part of the figure presents the different grades and materials membership levels with input parameters. These membership levels provide important information about those grades and materials that are more similar to the data submitted by the user. The left charts show the distribution of the grades and materials in the cluster. This information can tell us about the quality of the results based in the quantity of objects that will be taken into consideration for the calculation of the cutting data.

It is evident from Figure 8.11 (top) that there are no elements in the cluster with the grade specified by the user (CP50). However, the system has grouped objects that present high levels of membership with the grade under analysis. The grade with the higher membership level (TP300) appears in only 7% of the objects grouped in the cluster, but the second grade with the highest membership level arises in almost 30% of the elements of the cluster. In the case of materials, about 45% of the objects present a *Seco Material Group* = "3".

Figure 8.12 shows the output screen for the test. In cases where the input parameters do not appear in the tooling data, the system provides a mechanism to obtain the cutting data from elements presenting high levels of similarity with user inputs.

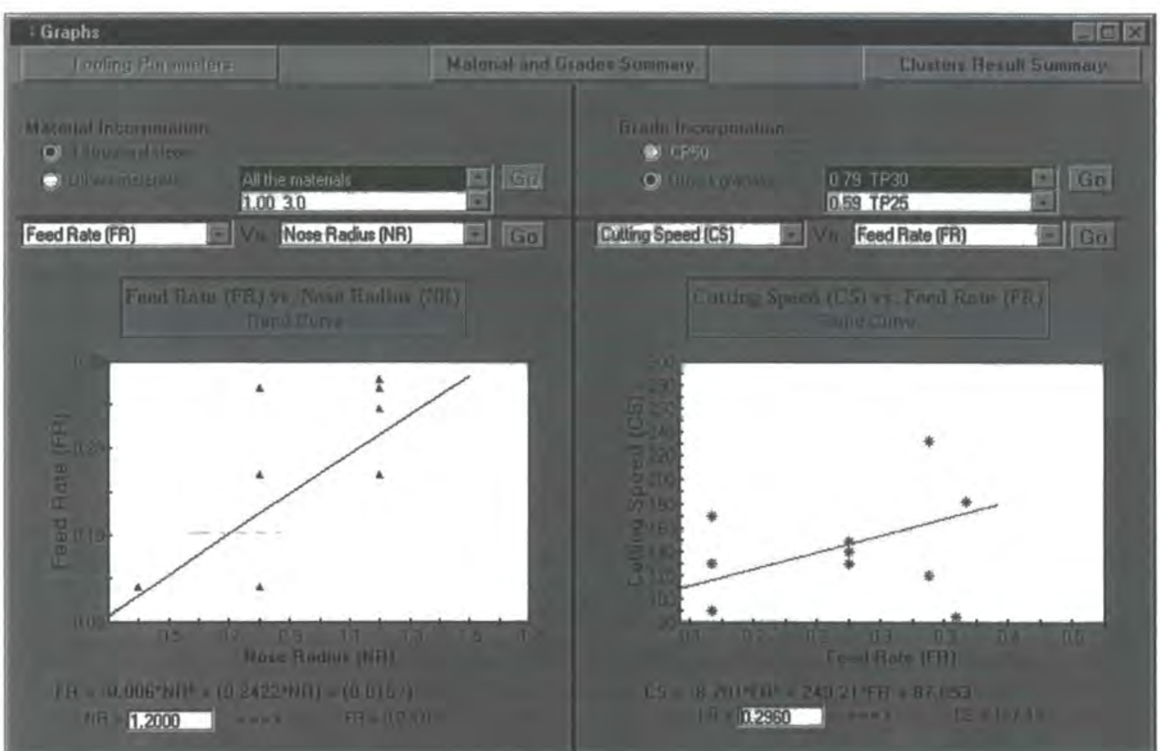

Figure 8.12 Output Screen for Test #2.

The best cluster found for input requirements has no elements with *grade* = CP50, but grades TP300 and TP30 show high levels of similarity to grade CP50 (0.903 and 0.792 respectively). These two grades were chosen from the list in Figure 8.12 to approximate the required information. The system builds the graphs taking into consideration the elements that fulfil the chosen options for materials and grades. The user can select the combination of variables to obtain the required cutting data. Although these parameters are not absolute values for the specified input grade, they can be used as approximate values of the required data for the metal cutting operation with the input specifications. It is important to highlight that the Seco manual states a proposed cutting speed of 150 m/min for *grade* = CP50 and *Seco Material Group*=3. This demonstrates that the approximation obtained from the clustering process (157 m/min) is very close to the manual value.

8.3.2 Classification process of *Cluster-F*

This test analyses the results provided by the system when different clustering methods are used.

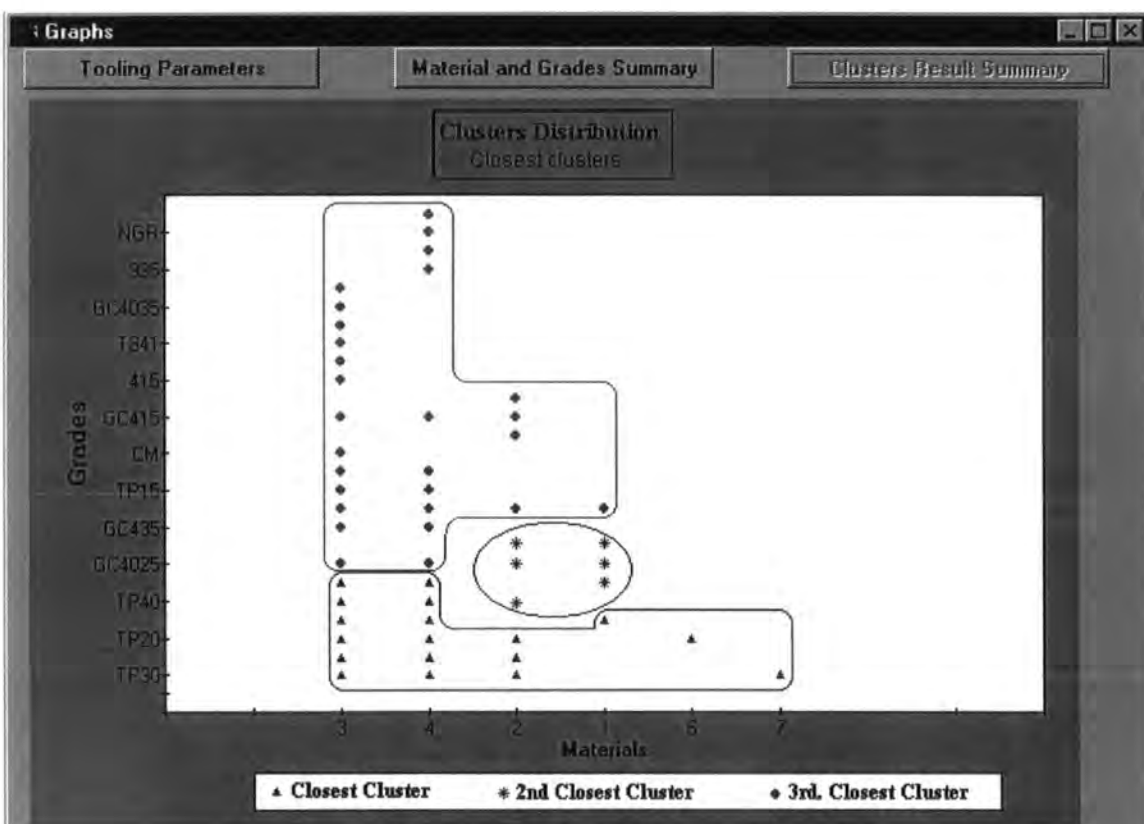

Figure 8.13 Distribution of Clusters using Single linkage Method.

In order to compare the single linkage method with the average method, the same run performed for Test #2 of the last section was conducted using, "average" as the clustering method. Figure 8.13 shows the classification chart for the results of Test #2 (Figure 8.11 and Figure 8.12) which uses the single linkage method. Figure 8.14 shows the distribution of the clusters using the average method.

The single linkage method merges two clusters with the smallest distance between two objects belonging to the clusters, one object from one cluster and the second object from the other cluster. The average method computes the distances between objects of two clusters and obtains the average of these distances. The clusters to be merged are those with the smaller average distance.

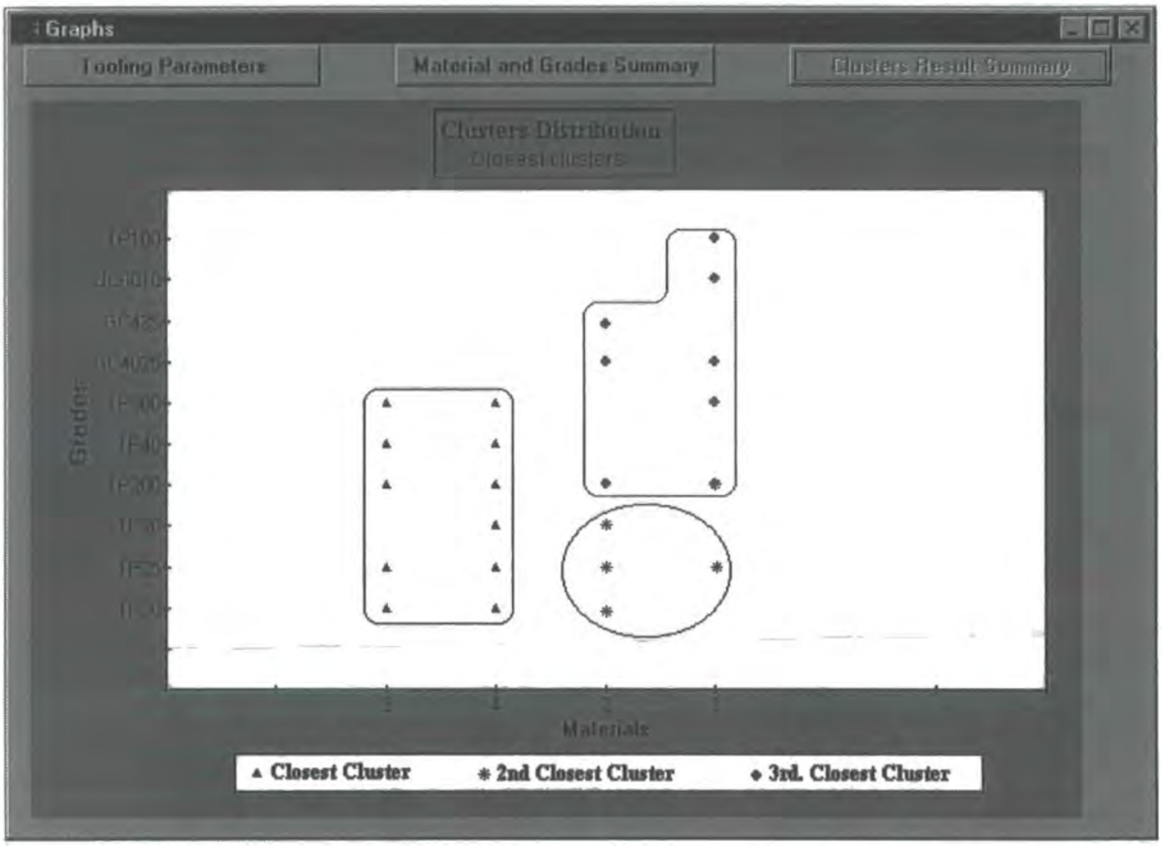

Figure 8.14 Distribution of Clusters using Average Method.

The cluster distribution chart shows the three closest clusters to the user specifications using *grades* and *materials* variables. The better cluster found for the assessment of cutting parameters is the one identified with triangles.

From Figure 8.13 and 8.14 it can be seen that the classification using the average method is more compact than that using the single linkage method. This may be due to the relaxed characteristic of this last method. Figure 8.15 illustrates the stratification of the data with the "average" classification. Comparing this with Figure 8.11, the differences in the classification for the material variable are evident. While the single linkage method links all the materials to any membership level, the average linkage method only includes those materials with high membership levels. This last method restricts the number of object classified in the cluster and makes the groups more concise.

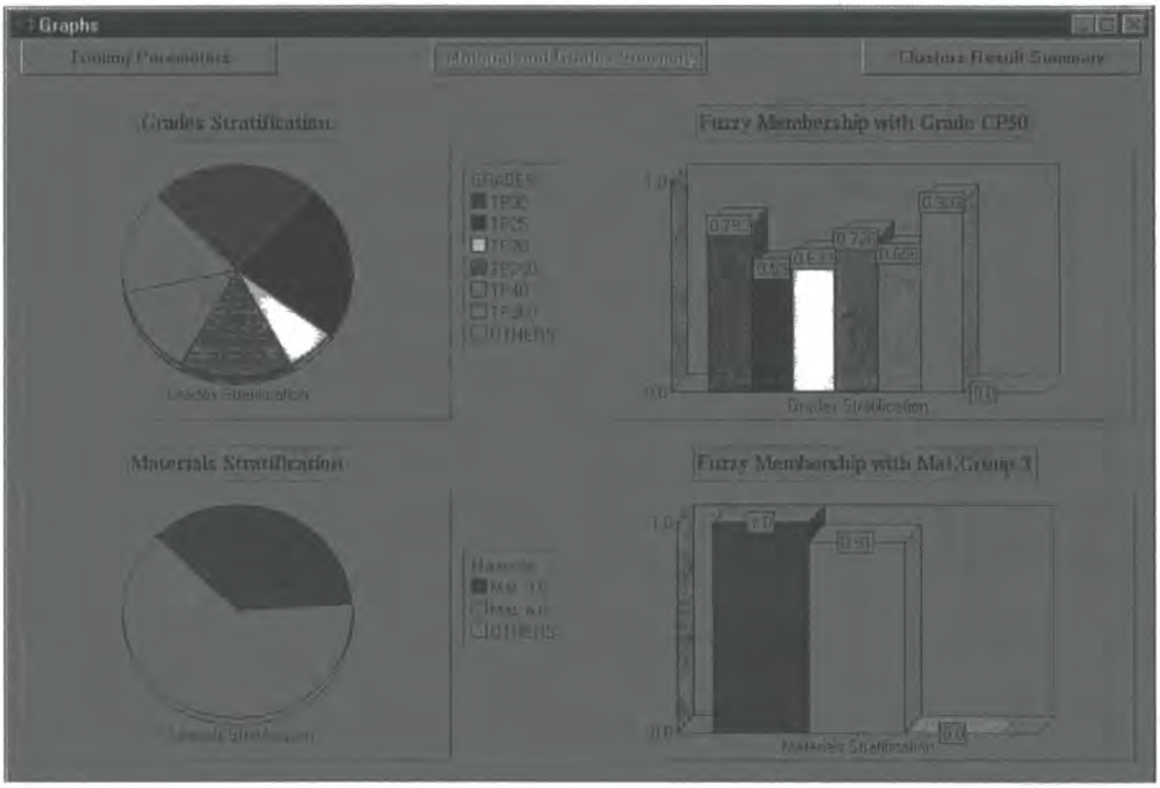

Figure 8.15 Cluster Summary for the Average Method.

Figure 8.16 shows the cutting data screen with the new results using the "average" method. The dots in this figure seem to be less dispersed that the points shown in Figure 8.16. As a consequence, the error in the approximation is smaller and the lines are more representative of cutting data for the tooling process.

Despite the results of this experiment, the single linkage method cannot be classified as a deficient algorithm. On the contrary, each method works well under specific environments. For instance, when the user specifies input parameters that are not present in the database, the single method will relax the linkage of objects and bigger groups will be formed. Then, the user will decide the characteristics that must be taken into consideration for the cutting data approximations.

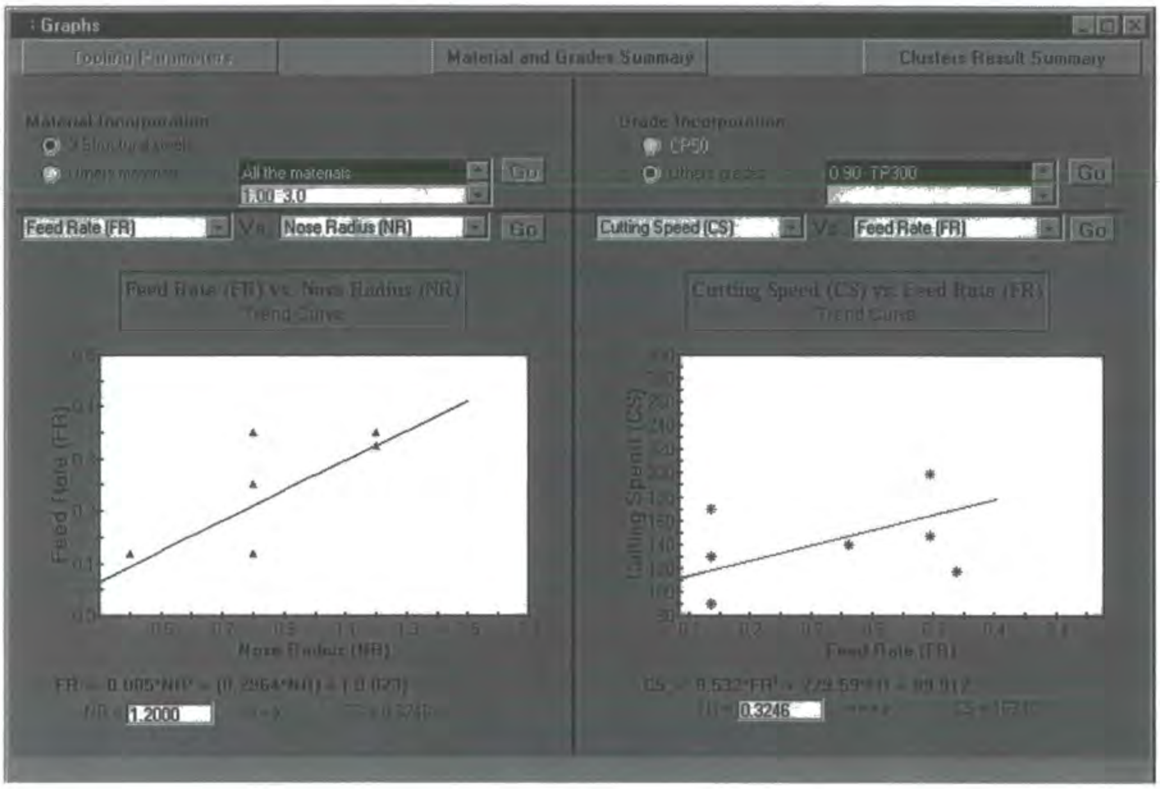

Figure 8.16 Cutting Data Results Using Average Method.

The complete linkage method works by taking into consideration the largest distance between objects of two clusters. Then, the clusters to be merged are those with the smaller of these measures. In comparison with single and average linkage, the complete linkage method is stricter. This is better used when there are plenty of objects that fulfil input specifications. The objects grouped using this method exhibit high levels of similarity and the computed approximate values are more realistic.

8.4 TEST AND RESULTS FOR *R-SETS*.

As was explained in chapter seven, ***R-sets*** is an attribute-oriented KD approach to eliminate data redundancy, identify relevant attributes, detect data inconsistency and generate knowledge rules applying rough sets concepts to the tooling database. To evaluate its functionality, a testing phase was undertaken. A two case study is presented in the following section.

8.4.1 Case Study 1

In the metal cutting process, the use of a coolant has been considered as desirable to preserve the condition and life of inserts. However, recent tests performed in the machining sites of the industrial collaborator have shown no damage or reduction in tool life when the coolant is not used.

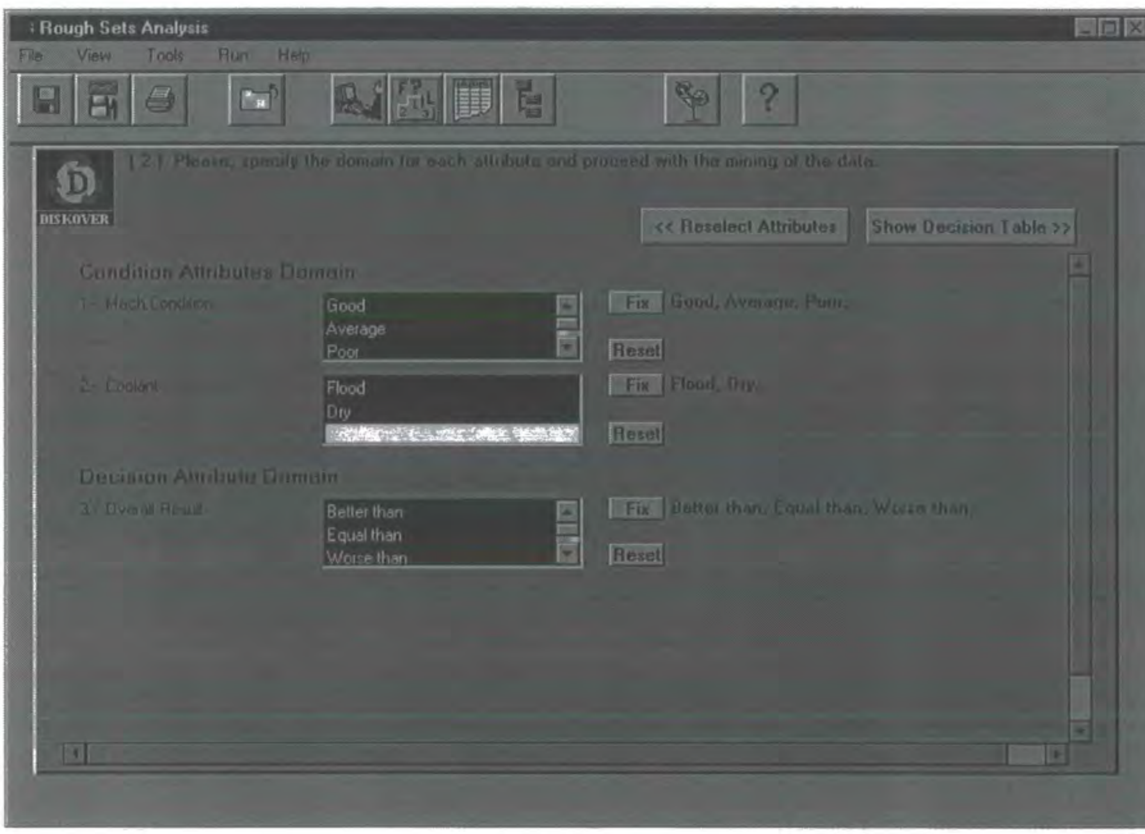

Figure 8.17 Domains Input: First case study.

According to tooling engineers the cutting process is much cleaner when no coolant is used, and the effect of the coolant on the life of the tool and the surface of the workpiece is not yet clear. In order to investigate this, the study-case presents the analysis of three attributes: *Machine condition, coolant* and *overall result.*

Figure 8.17 shows the input screen when the domain of the variables is specified. The system found 113 occurrences with the combination of attributes and domains specified. After the generalisation and redundancy elimination processes, the data were grouped in seven tuplas. In the datamining process, no reducts for the set of data were found. This can be due to the small set of selected attributes for the test. Figure 8.18 shows the output of the test. One "Certain" rule and six "Possible" rules were generated.

Figure 8.18 Generated rule for the first case study of ***R-sets***.

The certain rule states that the *overall result* is "Better" when no coolant is used in the test and the *machine condition* is "Average". In the same way, two possible rules suggest that when the *machine condition* is "Average" and *coolant* is used in the test (*coolant* = Flood), the *overall result* can be either "Better" with a Certainty Level (CL) of 70% or "Equal" with certainty level of 30%.

Similarly, with a good machine condition and the *coolant* = "Dry" the *overall result* is either "Better" with CL=96% or "Equal" with CL= 4%. Also, when the *machine condition* is "Good" and the *coolant* is "Flood", the *overall result* is either "Better" with CL=75% or "Equal" with CL= 25%.

The rules reveal very interesting information. No clear relationship between the use of coolant and the achievement of improved results in the test has been found. In contrast, the absence of coolant (*coolant* = “Dry”) implies the accomplishment of better findings (first certain rule, third and fourth possible rules). These results provide more evidence to tooling engineers about the influence of coolant on the performance of the tests.

8.4.1 Case Study 2

In this instance, we assume that the attributes to be analysed have no known relationship. The data to be retrieved are trials performed for turning operations.

Figure 8.19 Generated General Rules for Case Study 2.

The test is based on the evaluation of the influence of four variables on the insert grade. The chosen condition attributes are *machine condition*, *material group*, *coolant* and *nose radius.* Table 8.1 shows the defined domains for the specified attributes. ***R-sets*** found 11 tests with the specified information. These were grouped into six tuplas.

Table 8.1 Attribute Domains.

	Attribute		Domains
Cond. Att.	1	Machine condition	**1**.- Good, **2**.- Average, **3**.- Poor
	2	Material group	**9, 10, 11**
	3	Coolant	**1**.- Flood, **2**.- Dry
	4	Nose radius	**12, 16, 4, 8**
Dec.Att.	5	Grade	**1**.- TP100, **2**.- TP15, **3**.- TP20, **4**.- TP200

The output of the test is shown in Figure 8.19. The system initially shows the general rules in compressed format (grouping all the rules in one per each concept) and also offers the option of disjointed rules. Three certain general rules were found and no possible general rules were generated.

The available option for "Specific Rules" in Figure 8.19 indicates that the system was able to find reducts. The specific rules are those generated with a smaller set of attributes than the original set, without loss of infomation.

The system detected five different reducts. The specific rules output is shown in Figure 8.20, which displays a list with the reducts found by the system. Each reduct generates a set of *Certain* and *Possible* rules. The user must choose one of these reducts from the list and the system proceeds with the generation of the approximation space and the extraction of the rules from the sets.

The rules generated by the second reduct in the list are presented in Figure 8.20. These only contain two condition attributes: *Seco Material Group* and *coolant*. The first certain rule states that when the *coolant* is "Dry" and the *materials group* is "10" or "11", the *grade* used is "TP100". The other certain rule says that the *grade* used is "TP15" when *material group* is "9" and *coolant* = "Flood". The two possible rules state that the *grade* could be either "TP100" or "TP200" when the workpiece is *material group* = 10 and the *coolant* is "Flood".

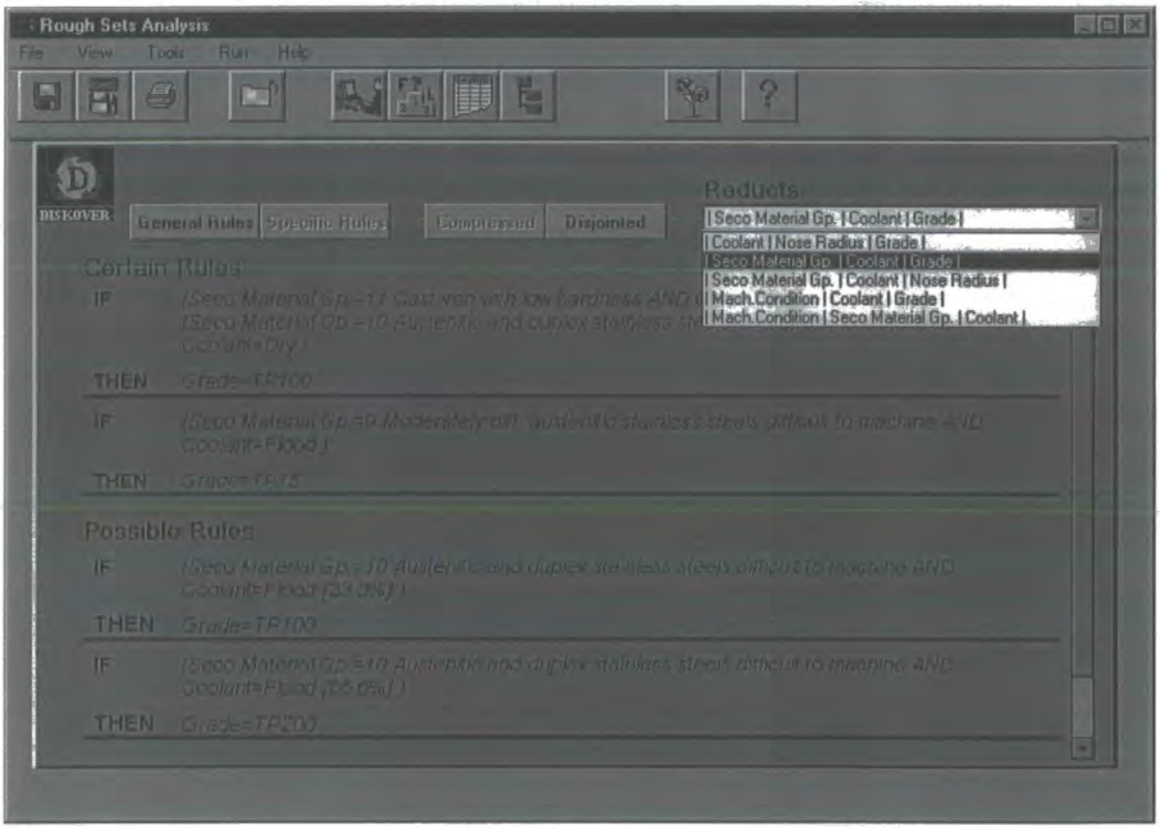

Figure 8.20 Specific Rules Output.

Comparing the output of these specific rules with the ones generated by the general data, it is clear that the general rules are more complex and contain additional attributes (*machine condition* and *nose radius*) that do not supply extra useful information. These facts, far from providing further knowledge for the user, make the understanding of the findings more difficult. The results from the reducts restrict the set of attributes that provide the closest relationship with the goal attribute, eliminating those attributes that do not have any impact on the decision variable.

8.5 SUMMARY

To evaluate the functionality of the advanced query utility of ***TTS*** a test phase was carried out. This revealed a good performance for the AQ module. In terms of completeness of the database, it was apparent there were difficulties in finding full matching solutions for the large amount of possible combinations when performing queries using the variables offered by the module. This fact strengthened the usefulness of the AQ module to provide users with closest solutions for specific requirements. Confidence score and relaxation methods have prove to be very beneficial when no full matches of tool trials could be found.

To test the capacity of ***Cluster-F*** to assess cutting parameters for turning operations, a number of experiments were conducted. The aims of these were to evaluate functionality and classification methods implemented in the system. For the functionality aspect, ***Cluster-F*** was able to provide approximate cutting data for specific user input. This system was useful in assisting users in the estimation of cutting parameters based in data that do not contain user specified values. The assessment of distances between objects by using fuzzy membership values has proved to be a good method to link similar objects in one cluster.

The test of ***R-sets*** focused on the evaluation of the system functionality. Two case studies were analysed. These showed interesting findings regarding the discovery of relationships among chosen attributes. The ability of the system to deal with inconsistent data and identify relevant attributes was seen. Such tests facilitate the representation of knowledge and make it more understandable to users of the system.

TTS, ***Cluster-F*** and ***R-sets*** have been developed to assist engineers in diverse tasks of the process planning activity. They have been elaborated as complementary modules to provide an integrated support in the solution of different problems.

CHAPTER 9: CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER WORK

9.1 CONCLUSIONS

In this thesis, special consideration has been paid to the proposal of distributed solutions to support collaborative work, corporate information sharing and information exchange in manufacturing industry. The suitability of implementing these solutions in corporate environments has been analysed and discussed. These strategies rely on an architecture where the Internet has been exploited as a vehicle to deploy information and make it globally available. This architecture is based on the integration of geographically distributed standardised databases to provide information to employees, suppliers, customers, collaborators and partners. To ensure a transparent delivery of applications and database access, the connectivity between users and systems has been embraced by using a pure Java-driver. The security aspects have been covered with the implementation of firewall programs and password encryption. The Java language provides a cross-platform portability which makes it suitable to support the development of Internet-based systems. This, in addition to the object-oriented philosophy and robustness of Java, has influenced the selection of this language to develop the applications. Four systems were developed.

TTS is a Web-based system to support engineers in the task of providing technical advice to clients. This system has been installed on laptops and is being currently used by sales engineers of the industrial collaborator across UK. The engineers run the system from remote machining sites and submit/retrieve/update the required tooling data located in databases at the company headquarters. This system has been shown to be an efficient mechanism to share information nationwide. It also has proved to be effective in providing methods to obtain valuable information and register new data by accessing the system from any part of the country. On the technical side, the implementation of data relaxation techniques, confidence score and importance levels of attributes have proved to be very helpful when no full matches of specific variables are found. These provide users with the closest solutions that may guide them to solve the problem under consideration.

DBManager is a web-based application developed to support aspects of maintenance of the databases and security of the systems. Due to the high level of confidentiality of the data, it was necessary to implement user security levels for system access and user monitoring functions to supervise the processing of the data. ***DBManager*** has shown to be functional and useful in controlling and ensuring privacy and confidentiality. This application has also been installed in the company and it is currently operative.

The last 10 years have seen the dawn of a new era where access to information is increasingly important. On the other hand, the increasing amount of data in organisations and around the world makes the assessment of useful information more difficult. Enterprises have realised that these sources of data are valuable repositories containing corporate knowledge. This has influenced the development of techniques to search for hidden knowledge, leading to the emergence of a new research area: Knowledge Discovery (KD).

Machining operations are still dependent on decisions made by skilled engineers. This can be due to tool obsolescence, lack of manuals covering utilisation of wide range of new tools and constant incorporation of new tools to the market. With the creation of the tooling database and the installation of ***TTS***, a wide range of opportunities became available. It was decided to develop two KD-based systems applying datamining techniques to discover useful patterns, deviations and regularities in the tooling database. These systems have been called ***Cluster-F*** and ***R-sets***.

Cluster-F has been developed to assist engineers and clients in the assessment of cutting parameters for the tooling process. It is a Java application running under an Internet-based platform. In this approach the Internet acts as a vehicle to transport the data between users and the database.

Cluster-F makes use of clustering and fuzzy sets techniques. Dealing with categorical variables has been a problem when classifying data. Hence, in the implemented approach, fuzzy sets are used to obtain proximity values for the categorical attributes. Then hierarchical clustering methods are applied to link the closest objects. This system has proved to be very efficient in classifying elements containing categorical data into similar groups to obtain the recommended cutting data. The greatest strength shown by this system is the assessment of cutting parameters when input specifications are not contained in the database. The average linkage clustering method has been proved to be the most efficient in the classification process. Even so, the single linkage method provides good results in cases where the input values present low levels of similarity with the data contained in the database.

A KD methodology applying rough set concepts was proposed. This covers aspects of data redundancy, identification of relevant attributes, detection of data inconsistency, and generation of knowledge rules. It was designed to support the development of the second KD system. ***R-sets*** has been developed to evaluate the variables contained in the tooling database. This system fulfils the need of Seco personal to analyse known and unknown relationships in the data generated after the execution of technical trials. The aim is to discover cause-effect patterns from fifteen selected attributes contained in the database.

R-sets was able to generate interesting rules by exposing the relationship among fixed attributes. It was shown how inconsistent data were processed and analysed to produce knowledge rules to guide the decision process using the computed certainty levels. It was also demonstrated how the implementation of reducts to identify relevant attributes produced knowledge rules much easier to understand and without unnecessary constrains that could contaminate the decision making process.

It is important to highlight that the developed applications, far from competing in terms of their performance, have been conceived as complementary modules to provide an integrated support in the solution of different problems.

Cluster-F and ***R-sets*** have been fully tested with tooling engineers in the development environment and their final presentation and delivery to the industrial environment will be undertaken shortly.

9.2 RECOMENDATIONS

There are two main areas that are deemed to be in need of further work. The first concerns the Internet while the second is related to industrial considerations.

Despite many advantages offered by the Web, developers still face significant problems in relation to database connectivity and remote access. Relational Database Management Systems have been adopted in the last decade, as standard database models. The current SQL-based databases do not support efficient management of queries in relation to multimedia data such as heavy images, animated objects and elements that can represent simulation of industrial processes. The object-oriented model appears to be the logical alternative to overcome the relational model limitations. Further work must be undertaken to create an object-oriented standardised language and address the problem of storing and retrieving multimedia data entities for object-oriented databases working on a WWW platform.

The system presented in Chapter 4 (***TTS***), offers good technical support to tooling engineers nation-wide. Although it has proved to be functionally useful, it is convenient to consider some possible developments:

- To create a mechanism to constantly evaluate data requirements and keep the database and system updated. This will avoid the obsolescence of the systems.
- To orient efforts to the standardisation and integration of ***TTS*** as a global system to be used by engineers of all Seco branches around the world.
- To improve the security mechanism to support the incorporation of new Seco branches as users of ***TTS***. This would include the implementation of a more sophisticated and controllable security module.

The database contains a large number of records with information that cannot be taken into consideration by ***TTS*** and ***Cluster-F***. The systems use comparison of attribute values to obtain similarity measures to provide closest solutions to stated problems. *Grades* and *Seco material groups* are two of these important variables. It is imperative to expand the current classifications of these attributes to incorporate new *grades* and *materials* to the existing lists.

An infrastructure for Information sharing/exchange has been implemented. This opens up the opportunity to increase the utilisation of the systems to offer clients more support for their tooling operations. Further, datamining techniques have been successfully implemented in many areas, such as financial, market, sales and production. It is important to extend the research horizons of new KD Internet-based approaches in the Seco company using existing historical databases with potentially useful knowledge. One interesting issue to address is the standardisation of the DBMS to be used by all the branches of the company. This will facilitate the development of flexible KD systems where the required database can be selected (regardless of the internal structure) to perform knowledge extraction process.

APPENDIX A: THE INTERNET.

A.1 BACKGROUND

From the millions of people connected via the Internet, very few know how the Internet has evolved. In their book *"Netizens"*, Hauben and Hauben (1997) provide a good historical summary on the origins of the Internet. Sim and Rudkin (1998) assert that the foundations of the Internet were established in the 1960s and 1970s, when computer scientists began looking at ways of directly connecting computers across networks. In the late 1960s ARPA (the US Advanced Research Projects Agency) funded the development of ARPANET, a network to support their researchers in various universities and research institutes. Further foundation stones were the development, in the 1970s, of the transmission control protocol (TCP) and the internetworking protocol (IP), which are still the basis for networking across the Internet.

Over the next decade the ARPANET grew as an increasing number of North American universities and research bodies joined. In 1973 the first European organisations were connected. By the early 1980s the development of Unix was leading to further rapid growth in networked computing, particularly in universities. A second network, MILNET, took over the military traffic, while European (EUNET) and Japanese Unix networks became established. In the UK, JANET (Joint Academic Network) was formed. Another significant development took place in 1986 when the US National Science Foundation established NSFNET to link five US university supercomputers. During the late 1980s, as regional networks in the US and networks in more and more countries were connected, what was by now called the Internet became truly global. It was no longer solely an academic network, Internet access was available from home. In 1990 the ARPANET was shut down and NSFNET took over the administration of the Internet. In 1991 the restriction on commercial use of the Internet was lifted and by 1994 several large commercial networks had grown within it.

A.2 WHO CONTROLS THE INTERNET ?

The Internet has no owner and does not exist as a dominant entity co-ordinating the establishment of international regulations. However, there are some groups and organisations that deliberate and recommend about the technical standards and policies.

The Internet is a co-operative effort among all the diverse networks that make up the larger network. Founded in the early 1980s, the Internet Architecture Board (IAB) oversees the architecture and receives reports from the Internet Engineering Task Force (IETF), which has rapidly become a major international standards-making body. The Internet Research Task Force (IRTF) develops and maintains networking and internetworking information science experiments. The IAB is a collection of concerned, knowledgeable people (Lynch and Rose, 1993). In 1992, the IAB, IETF and the IRTF joined into a voluntary membership organisation known as the Internet Society (http://www.isoc.org/).

The development of the WWW led to the formation of the World Wide Web Consortium (W3C), which was founded in 1994 to develop common standards for the evolution of the Web. W3C (http://www.w3.org) is integrated by the Massachusetts Institute of Technology (MIT) in the U.S., the Institut National de Recherche en Informatique et en Automatique (INRIA) in Europe, and the Keio University Shonan Fujisawa Campus in Asia.

A.3 BASIC COMPONENTS AND TOOLS

Despite the considerable amount and diversity of elements that are part of the Internet infrastructure, it functionality relies mainly on basic tools and components. The most important are summarised as follows. A more detailed description can be found in Lynch and Rose (1993) and Krol (1994).

a) Transmission Control Protocol/Internet Protocol (TCP/IP)

Every host computer on the Internet has a unique address called Internet Protocol. IP is a network protocol for routeing units of data, called packets, across the networks from one host computer to another. Figure A.1 illustrates the interconnection of hosts, routers and networks.

To support the functions of error checking, error correction or recovery, transport protocols are used together with IP. TCP is one of the two main transport protocols designed to handle network failures. Lost or corrupted packets and packets arriving out of order are related to TCP.

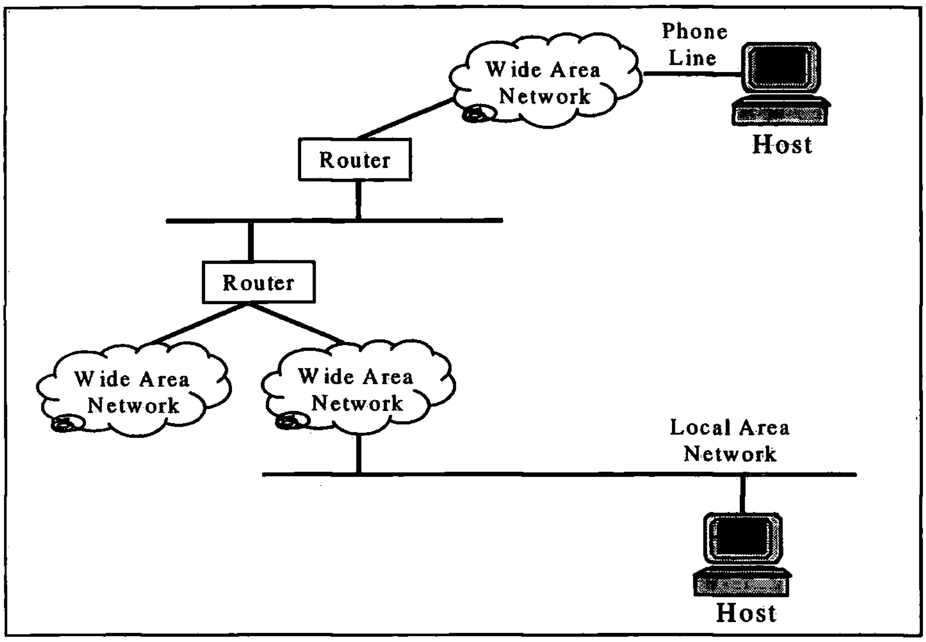

Figure A.1 Hosts, routers and networks (Sim and Rudkin, 1998).

User Datagram Protocol (UDP) is the other main transport protocol. In contrast to TCP, UDP is intended for sending messages without guarantee of arrival and without notifying the sender of successful or failed delivery.

b) Ports

Host computers may be engaged in many data transfer operations with other hosts, and a considerable number of different applications may be involved. Port numbers are then used to identify for which application and for which transfer operation a packet is intended.

c) Telnet

Telnet is the most elemental of all Internet functions. It is network tool that allows a user to log on to one server remotely. It works by carrying ASCII text typed by the user to the remote server and returning the output from the application on the remote server to the user.

d) File Transfer Protocol (FTP)

FTP is an Internet service for transferring and retrieving files to and from a remote computer Using FTP it is possible to gain access to any computer that is on the Internet and that allows FTP access. Once in the remote computer, the user can browse all directories that have been made open to FTP access, transfer and download operations.

e) Domain Name Service (DNS)

Every computer on the Internet has a name. The Domain Name is the unique identifier of a collection of computers connected to the Internet. The DNS name space allows the familiar period (.) as a separator concatenating the hierarchy of names. Figure A.2 displays a basic DNS structure.

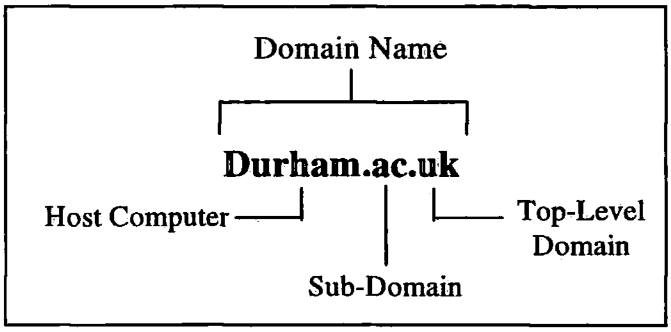

Figure A.2 Simple DNS representation.

f) E-mail

E-mail is one of the most popular tools of the Internet. This is because of two main reasons, the comparatively high cost of conventional mail services and its instantaneous nature. E-mail is sent from a local computer to the addressee using a Simple Mail Transfer Protocol (SMTP). Also, there are other protocols for checking and retrieving mail from a mailbox, such as POP3 and IMAP4.

Two main parts separated by the symbol @ compose an e-mail address. The portion of the address to the left of @ is the personal identifier selected by the individual recipient. To the right of the @ symbol is the domain name previously described.

g) Usenet Newsgroups

Usenet Newsgroups are discussion groups in which people share information and ideas on a defined topic through electronic bulletin boards. Anyone can reply to the message and the resulting sequences of messages arising from an initial posting are grouped into a discussion thread. Discussion groups can be restricted to specific individuals, but most are kept open.

h) World Wide Web

The WWW is a set of applications for storing, retrieving, formatting, and displaying information in a networked environment using graphical user interfaces and dynamic links to other documents. The predominant role of the WWW as the main tool of the Internet was highlighted at the main part of this section.

Any Web page is identified by a Uniform Resource Locator address. URL addresses are composed of the following components:

<protocol>://<hostname>:<port><directory><filename>.

The protocol, usually HTTP, is the access method used to transfer pages on the Web. The remaining parts help to identify the Web server storing the Web pages and the location of the files. The content presented at a WWW client may simply be stored files or may be generated dynamically through the execution of a program on the server. The standard means of communication between the Web server and other programs is the Common Gateway Interface (CGI). A typical usage of CGIs is the translation of an HTPP request into a query of a database on the server, e.g. to perform a search on the information stored (Sim and Rudkin, 1998).

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Hauben M. and Hauben R. *'Netizens'*, IEEE Computer Society Press, 1997.

Lynch D. and Rose M. *'Internet System Handbook'*, Addison-Wesley Publishing Company, Inc., 1993.

Sim S. and Rudkin S. *'The Internet – Past, Present and Future'*, in *The Internet and Beyond*, edited by Sim S. and Davies J., First Edition, British Telecommunications Research Laboratories, Chapman & Hall, 1998.

APPENDIX B: DBMANAGER SCREENS

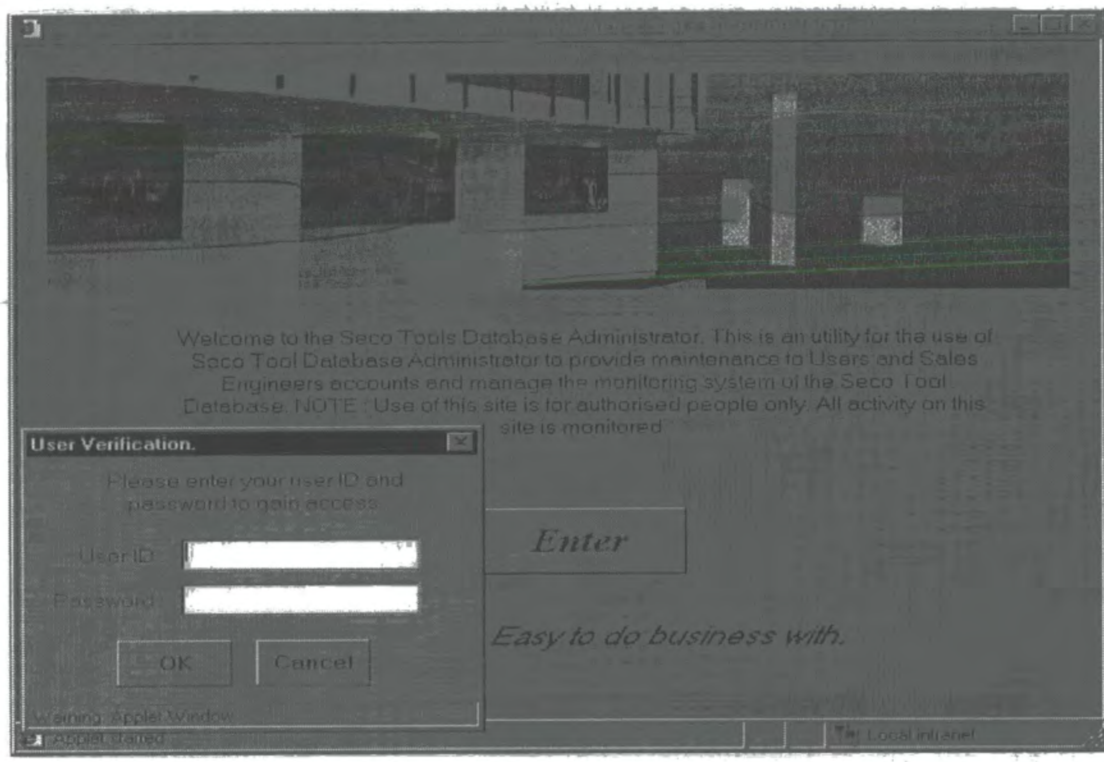

Figure B.1 Presentation screen for DBManager.

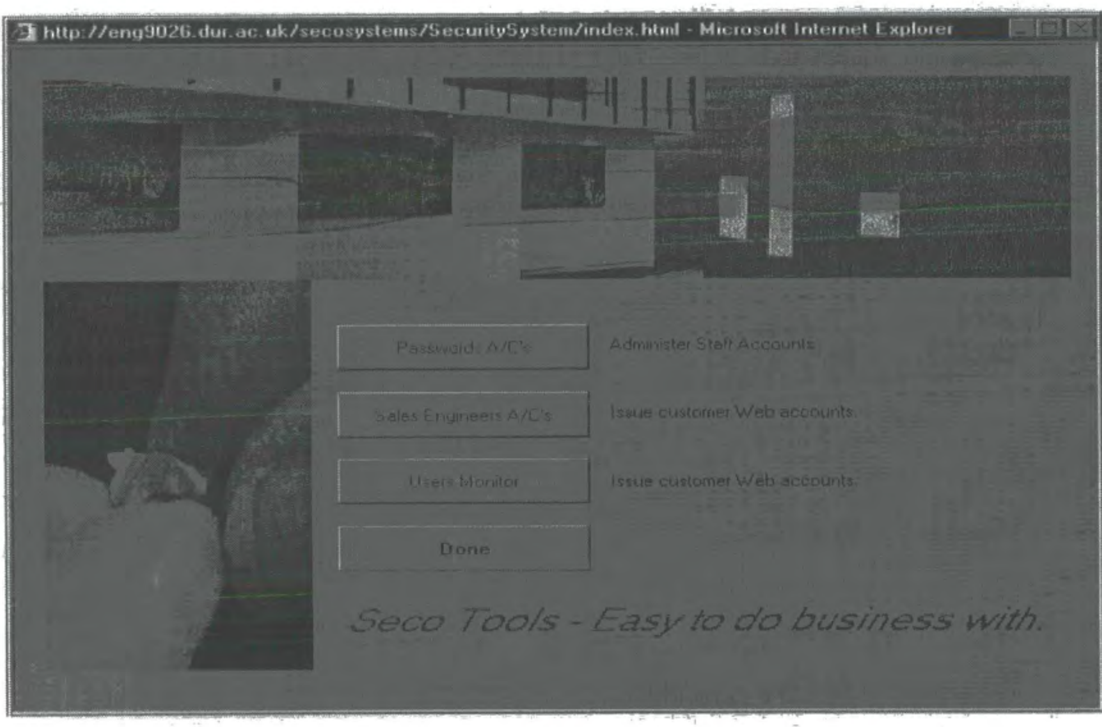

Figure B.2 Screen with functions of the DBManager System.

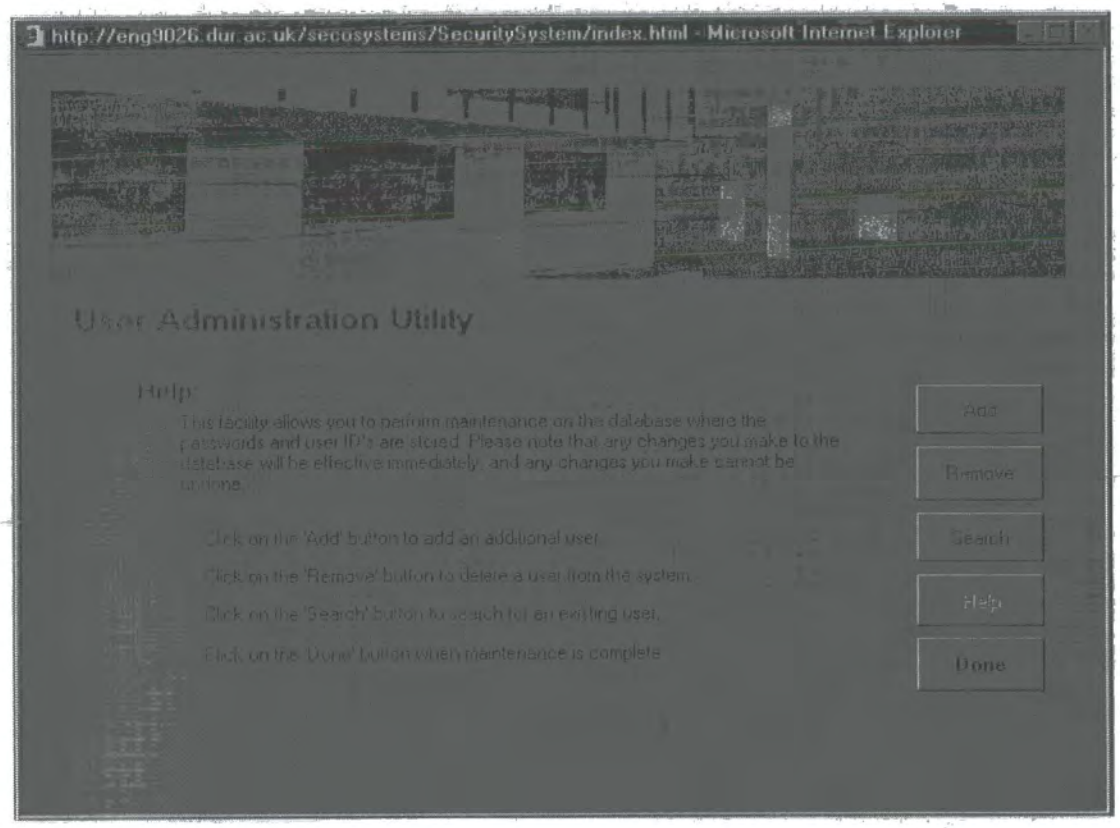

Figure B.3 Initial screen of the User Administration module.

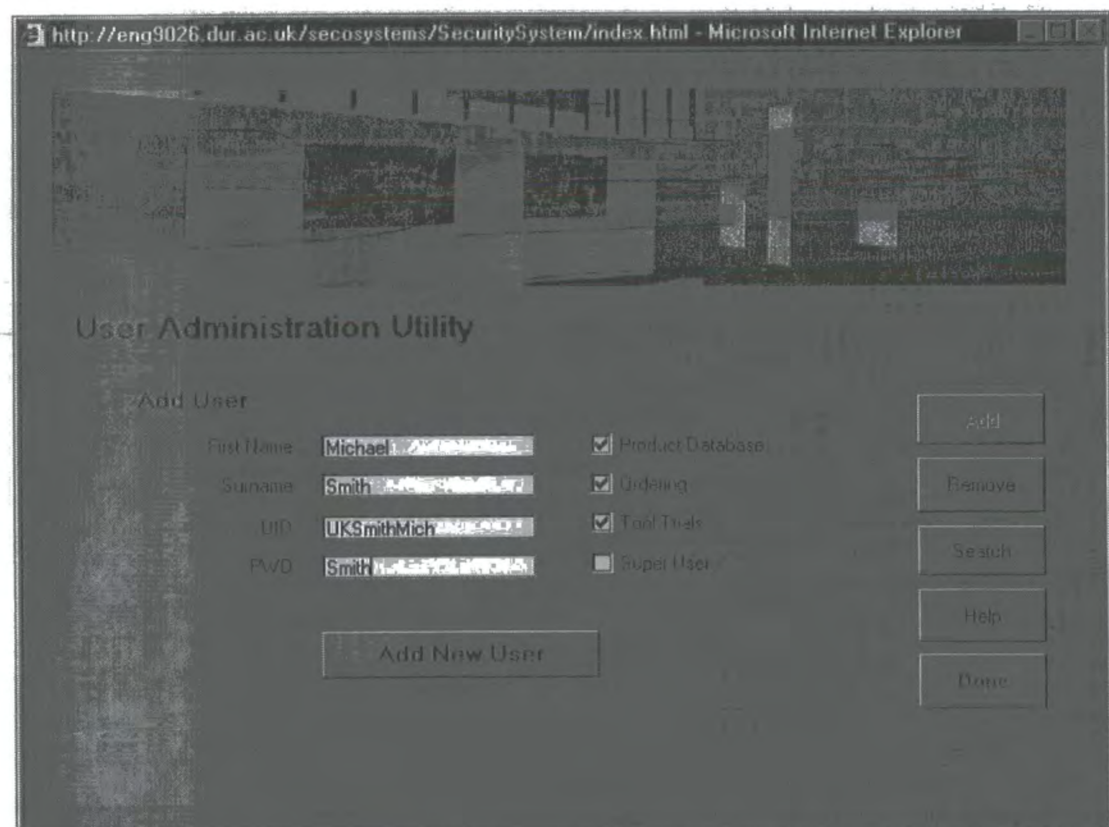

Figure B.4 Screen to Add new users of the systems.

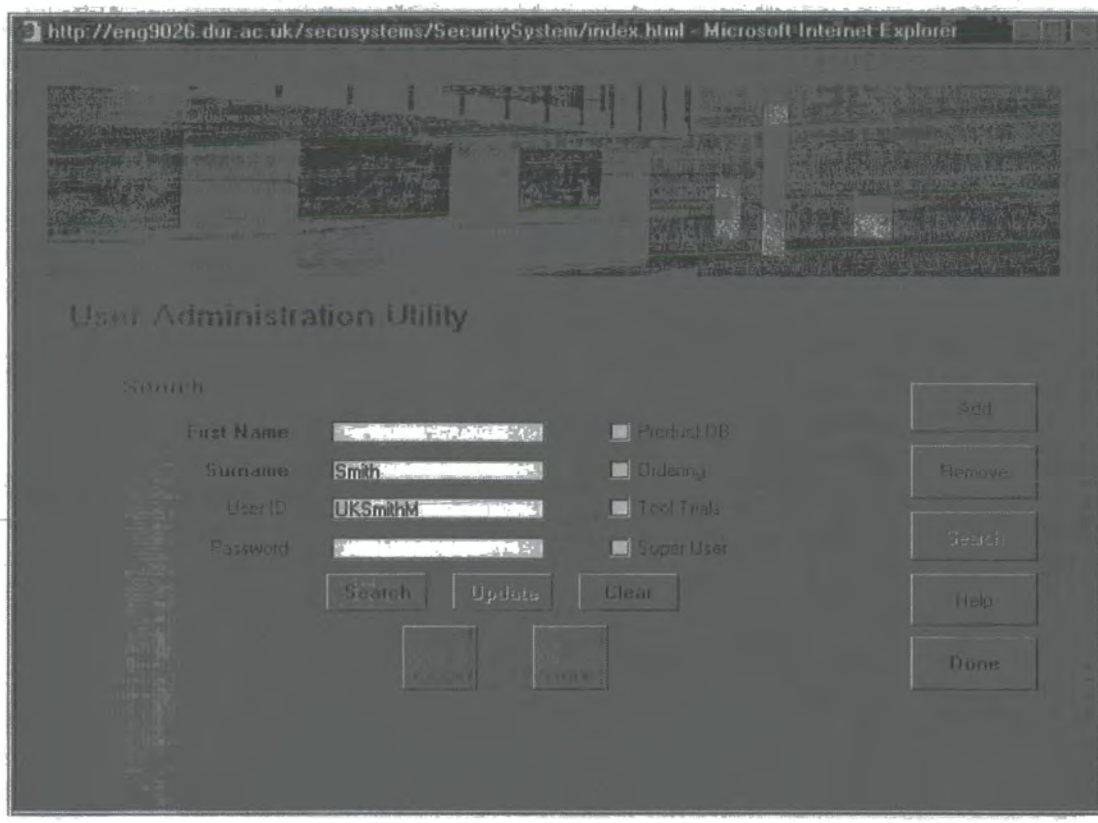

Figure B.5 Screen for Searching and Updating of users of the System.

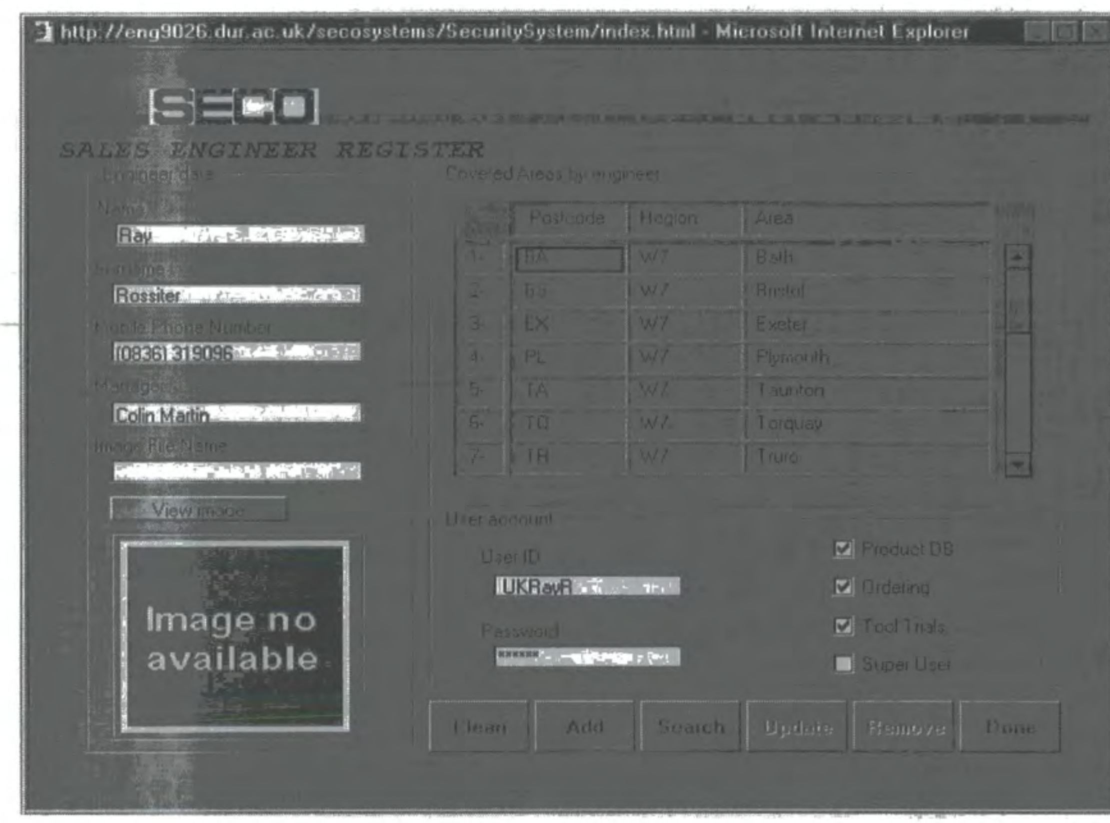

Figure B.6 Screen with the Sales Engineers utility.

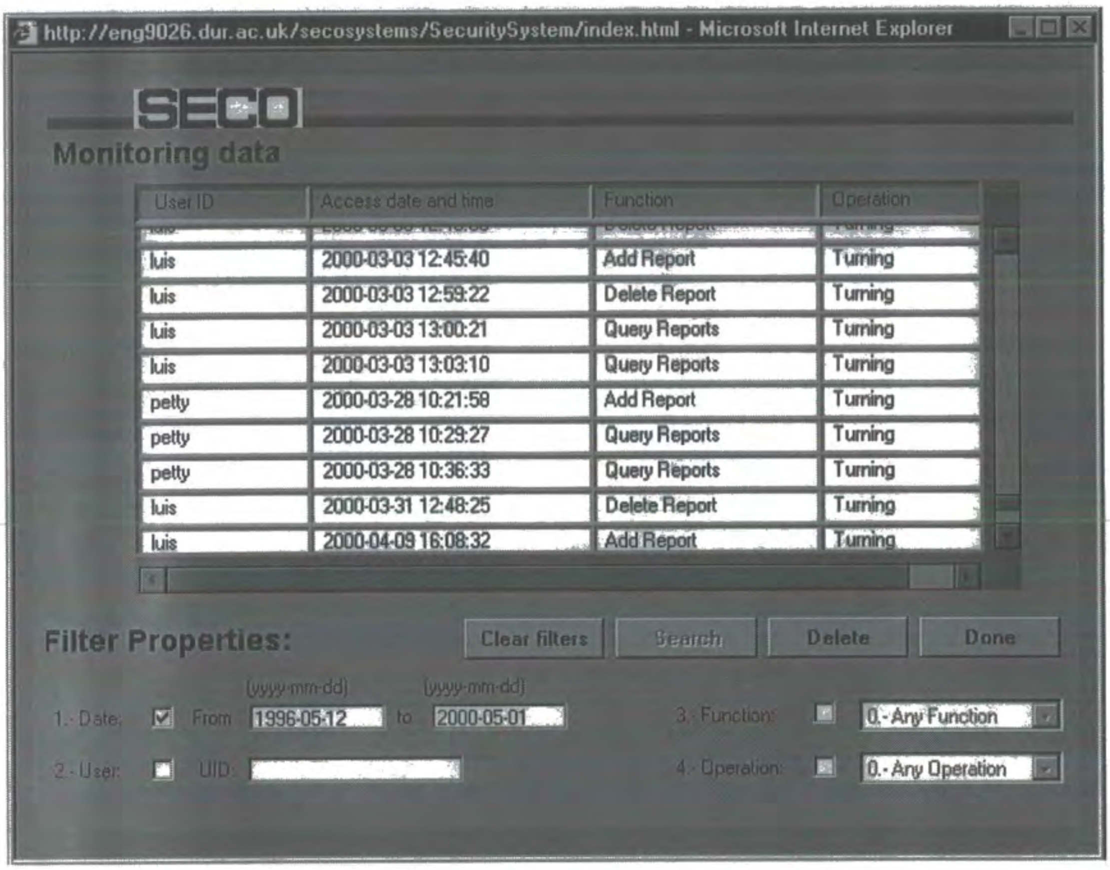

Figure B.7 Screen for the Monitoring Data utility.

APPENDIX C: TTS TEST TABLES

Table C.1 Test Specification for Turning Operation.

Test #	Seco Material Grp.	Grade	Chipbreaker	Insert Type
1	1	TP100	M3	WNMG
2	8	TP300	M3	WNMG
3	14	TP05	M4	CNMA
4	6	TP100	M3	SNMG
5	2	TP200	M5	SNMG
6	12	TP100	MF2	WNMA
7	3	TP200	R4	DNMM
8	12	TP05	M4	CCMT
9	10	TP40	MF3	CNMG
10	9	TP15	F1	VBMT
11	1	TP300	F1	VBMT
12	5	TP15	MF2	WNMG
13	3	TP200	M5	TPMR
14	4	TP25	M3	TPMR
15	10	CP50	MF1	WNMG
16	9	TP300	M3	WNMG
17	13	TP10	MF2	CNMG
18	7	TP20	M5	TNMG
19	15	TP100	M3	CNMG
20	12	TP10	M4	CNMG
21	3	TP100	MF2	DNMG
22	1	TP200	MR7	SNMG
23	8	TP40	M3	TPMR
24	6	890	MF1	SNMG
25	11	TX150	M5	SNMN
26	4	TP200	M3	CNMG
27	13	TX10	M5	TPUN
28	14	TX150	M5	SNMG
29	7	TP100	MF2	DNMG
30	2	TP200	M5	DNMM
31	10	TP35	MR7	CCMT

Table C.2 Test Specification for Milling Operation.

Test #	Seco Material Group	Grade	Designation	Insert Type
1	5	T20M	M06	OFER
2	1	T25M	ME06	XOMX
3	14	T20M	M11	SEKR
4	13	T15M	M08	OFEX
5	7	T25I	76	XCKX
6	3	F25M	ME06	XOMX
7	4	S10M	D15	APFT
8	9	T20M	D15	APFT
9	2	T25M	MD15	ACET
10	11	T20M	M08	SPKN
11	1	S25M	ME10	XCKX
12	6	T20M	M11	XCMX
13	10	F30M	ME12	APKX
14	4	T25M	ME12	APKX
15	15	T25M	MD06	CCMX
16	9	T15M	ME06	XOMX
17	12	T25M	75	SPMX
18	5	T25M	75	SPMX
19	8	T25M	M14	SEKN
20	2	F40M	ME10	OFER

Table C.3 Matches Found for Integrity Test - Turning Operation.

Test #	# Matches Found				
	Whole Integrity	Partial Int. (Any Mat.)	Partial Int. (Any Grade)	Partial Int. (Any Chipb.)	Partial Int. (Any Ins.T.)
1	1	11	1	1	1
2	0	6	0	0	0
3	0	0	0	0	1
4	0	1	0	0	0
5	0	1	0	0	1
6	0	0	0	0	0
7	0	0	0	0	0
8	0	0	0	0	1
9	1	1	1	4	1
10	0	0	0	0	1
11	0	0	0	0	0
12	0	0	0	0	0
13	2	6	2	5	4
14	0	0	0	0	0
15	0	0	0	0	3
16	0	6	1	0	3
17	0	1	0	1	0
18	0	0	0	0	0
19	0	5	0	0	0
20	0	0	1	1	0
21	0	1	2	1	0
22	8	8	8	8	16
23	0	0	0	0	0
24	0	0	0	0	0
25	0	0	0	0	0
26	0	5	0	0	6
27	0	0	0	1	0
28	0	0	0	0	0
29	0	1	0	0	0
30	0	0	0	0	1
31	0	0	0	0	1
Integrity	12.90	46.23	24.01	27.71	46.23

Table C.4 Matches Found for Integrity Test - Milling Operation.

Test #	# Matches Found				
	Whole Integrity	Partial Int. (Any Mat.)	Partial Int. (Any Grade)	Partial Int. (Any Desig.)	Partial Int. (Any Ins.T.)
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	0	0	0
4	0	1	0	0	0
5	1	1	1	1	1
6	0	0	0	0	0
7	1	1	1	1	1
8	0	1	0	1	0
9	0	1	0	0	0
10	0	0	0	1	0
11	0	0	0	0	0
12	0	0	0	0	0
13	0	1	0	0	0
14	0	0	0	1	0
15	0	0	0	0	0
16	0	0	0	0	0
17	0	0	0	0	0
18	0	0	1	0	0
19	0	3	0	1	0
20	0	0	0	0	0
Integrity	10.00	37.78	15.56	32.22	10.00

Table C.5 Matches Found Testing Effectiveness of Confidence Score (CS) - Turning Operation.

Test #	Without Relaxation (CS)				With Relaxation (CS)			
	20%	30%	50%	80%	20%	30%	50%	80%
1	127	34	1	1	263	193	91	2
2	99	0	0	0	252	23	48	22
3	18	1	0	0	72	26	5	0
4	151	4	4	0	266	196	74	0
5	123	5	5	0	257	210	88	5
6	70	4	4	0	199	83	18	0
7	50	10	10	0	222	151	57	0
8	24	2	2	0	82	28	0	0
9	158	12	12	1	244	159	50	4
10	24	2	2	0	104	74	3	0
11	32	7	7	0	138	83	4	0
12	2	0	0	0	151	120	12	0
13	132	40	40	2	249	216	103	5
14	102	21	21	0	194	120	28	0
15	54	3	3	0	233	113	35	0
16	94	16	16	0	252	167	53	4
17	177	8	8	0	255	103	17	0
18	139	3	3	0	244	188	40	0
19	179	0	0	0	261	184	19	1
20	175	4	4	0	223	63	11	0
21	85	30	30	0	237	180	75	2
22	8*	8*	8*	8*	8*	8*	8*	8*
23	121	0	0	0	140	77	26	0
24	37	4	4	0	233	115	25	0
25	99	22	22	0	246	128	18	0
26	173	22	22	0	265	211	114	1
27	76	5	5	0	89	53	14	0
28	97	3	3	0	248	172	27	0
29	85	4	4	0	233	159	33	1
30	104	4	4	0	238	183	64	3
31	60	6	6	0	168	94	27	0

Table C.6 Matches Found Testing Effectiveness of Confidence Score (CS) - Turning Operation

Test #	Without Relaxation (CS)				With Relaxation (CS)			
	20%	30%	50%	80%	20%	30%	50%	80%
1	11	0	0	0	34	15	1	0
2	32	10	10	0	35	14	11	0
3	19	1	1	0	46	16	2	2
4	8	0	0	0	11	8	0	0
5	21	3	3	1	18	6	4	1
6	0	0	0	0	27	3	0	0
7	9	3	3	1	33	14	5	2
8	12	1	1	0	29	17	3	2
9	34	3	3	0	40	21	5	2
10	13	1	1	0	51	17	1	0
11	4	0	0	0	27	10	3	3
12	10	1	1	0	31	19	3	2
13	8	0	0	0	26	18	6	6
14	37	4	4	0	55	34	12	6
15	15	0	0	0	19	3	0	0
16	8	0	0	0	19	2	0	0
17	33	2	2	0	38	13	3	0
18	32	4	4	0	48	26	5	0
19	52	2	2	0	54	27	18	8
20	7	2	2	0	28	5	3	3

Table C.7 Matches Found testing Effectiveness of Importance Levels (IL) - Turning Operation.

Test #	IL Trends- # Matches Found								
	A	B	C	D	E	F	G	H	I
1	99	18	38	38	38	63	42	62	60
2	63	14	19	19	19	33	33	60	25
3	9	3	2	2	2	11	4	10	5
4	81	16	28	28	28	60	29	57	51
5	104	27	50	50	50	87	45	71	69
6	18	7	2	2	2	15	3	4	20
7	100	3	11	11	11	12	10	8	72
8	5	0	0	0	0	6	0	0	12
9	63	15	22	22	22	55	24	69	63
10	9	2	0	0	0	1	1	0	0
11	8	0	0	0	0	4	5	0	22
12	91	8	22	22	22	56	8	21	49
13	39	10	15	15	15	4	32	5	70
14	21	7	5	5	5	1	47	3	34
15	63	0	6	6	6	25	3	1	31
16	64	14	21	21	21	34	27	61	44
17	17	5	4	4	4	33	3	12	9
18	36	19	15	15	15	39	11	60	12
19	9	11	5	5	5	68	1	71	3
20	20	0	0	0	0	33	0	0	12
21	104	10	31	31	31	64	28	18	61
22	8	8	8	8	8	8	8	8	8
23	23	6	12	12	12	3	24	4	31
24	42	0	0	0	0	1	0	1	0
25	38	14	1	1	1	11	1	13	6
26	108	20	55	55	55	105	53	77	62
27	2	0	0	0	0	0	5	0	0
28	12	19	9	9	9	38	7	83	11
29	38	10	8	8	8	60	2	18	14
30	96	18	17	17	17	20	37	20	68
31	26	5	4	4	4	5	21	5	29

Table C.8 Matches Found testing Effectiveness of Importance Levels (IL) - Milling Operation.

Test #	IL Trends- # Matches Found								
	A	B	C	D	E	F	G	H	I
1	21	1	5	5	5	8	15	0	23
2	20	2	4	4	4	13	9	0	28
3	10	3	4	4	4	31	5	6	6
4	8	0	4	4	4	4	4	0	9
5	8	3	4	4	4	3	7	3	7
6	14	0	0	0	0	0	20	0	20
7	25	2	5	5	5	7	18	2	23
8	20	2	8	8	8	10	20	2	21
9	24	4	9	9	9	17	20	3	31
10	11	0	3	3	3	35	9	3	13
11	24	3	4	4	4	5	11	3	18
12	22	7	7	7	7	5	15	3	24
13	23	6	8	8	8	6	23	8	22
14	38	18	21	21	21	26	27	10	37
15	0	1	0	0	0	12	0	0	10
16	18	0	0	0	0	1	18	0	19
17	12	0	3	3	3	16	5	1	17
18	21	1	10	10	10	17	15	1	30
19	23	15	20	20	20	47	22	19	26
20	22	3	3	3	3	3	20	3	18

APPENDIX D: SUPERALLOYS MACHINABILITY

Machinability – Superalloys SECO

Nickel-base alloys	Machinability* (%)
Astroloy (all forms)	14
Hastelloy B-2	20
Hastelloy C (sheet)	25
Hastelloy C (cast)	20
Hastelloy C-22	20
Hastelloy C-276	18
Hastelloy C-4	18
Hastelloy G	18
Hastelloy G-3	18
Hastelloy N (bar, forgings, rings)	20
Hastelloy N (cast)	18
Hastelloy S (all forms)	25
Hastelloy W	18
Hastelloy X (all forms)	18
IN 100	6
Inconel 600 (all forms)	20
Inconel 601	20
Inconel 601 (all forms)	20
Inconel 625 (cast)	24
Inconel 625 (bar, forgings, rings)	16
Inconel 625 (tube)	18
Inconel 706	20
Inconel 706 (bar, forgings, rings)	16–20
Inconel 713	14–18
Inconel 713 LC	16
Inconel 718 (cast)	16
Inconel 718 (bar, forgings, rings)	14
Inconel 718 (tube)	16
Inconel 901	14–18
Inconel X750 (solution hardened)	20
Inconel X750 (precipitation hardened)	14
Mar-M-200	8
Mar-M-247 (all forms)	10
Modified IN 100	8
Modified Inconel 792 (all forms)	12
Modified Inconel 792	12
Nickel 201	60
Nimonic 101	10
Nimonic 105	18
Nimonic 115	14
Nimonic 263	16
Nimonic 80A	18
Nimonic 81	16
Nimonic 86	20
Nimonic 90	10
Nimonic 901	18
Nimonic 91	10
Rene 95	6
TD Nickel	14
Udimet 500	12
Udimet 700 (all forms)	12
Waspaloy (cast)	16
Waspaloy (bar, forgings)	14

Titanium alloys	Machinability* (%)
Ti (rent) – (tube)	80
Ti (rent) – (sheet, bar, forgings, rings)	45
Ti 17	18
Ti 2Cu	30
Ti 3Al-2.5V (bar, forgings)	25
Ti 3Al-2.5V (annealed tube)	60
Ti 4Al-4Mo-2Sn-Si	30
Ti 5Al-2.5 Sn (annealed)	35
Ti 5Al-2.5 Sn (ELI)	40
Ti 5Al-2.5 Sn	35
Ti 5Al-2.5 Fe	30
Ti 6-2-4-2 (precipitation hardened)	25
Ti 6-2-4-2 (annealed)	30
Ti 6-2-4-6 (precipitation hardened)	25
Ti 6-2-4-6 (annealed)	35
Ti 6Al-4V (annealed bar and forgings, rings)	30–35
Ti 6Al-4V (annealed and cast)	35
Ti 6Al-4V (precipitation hardened forgings, rings)	30
Ti 6Al-4V (annealed tube)	30
Ti 6Al-4V (extruded)	35
Ti 6Al-4V (ELI)	40
Ti 6Al-5Zr-0.5Mo-Si	20
Ti 6Al-6V-2Sn	30
Ti 8-1-1 (all forms)	30
Ti Ni-Mo	40

Cobalt alloys	Machinability* (%)
Haynes 25	12
Air Resist 13	4
H531	6
Haynes 25	18
Haynes 188 (bar, forgings, rings)	12
Haynes 188 (tube)	14
MP35N	16
MP 159	16
Stellite 31	16
Stellite 21	18
Stellite 30	16
Stellite 31 (all forms)	16
W152	18
WI 52	14
Mar-M-302	16
Mar-M-509	12

*The machinability is specified in percent. Decreasing values indicate increasing machining difficulty.

Ferrous alloys	Machinability* (%)
A286 (sheet)	20
A286 (solution annealed)	18
A286 (precipitation hardened)	16
AM350 (cast)	18
AM350 (heat treated)	25
AM355	16
Custom 455	20
Discaloy	20
IN 800	16
IN 801	20
Incoloy 909	16
Lapelloy	25
M308	20
N 155 (bar, forgings, rings)	20
N 155	16

Precipitation hardened stainless steels	Machinability* (%)
15-5PH	16
17-4PH (precipitation hardened)	16
17-4PH (solution annealed)	30
17-7PH (solution annealed)	25
PH15-7Mo (precipitation hardened)	16
PH15-7Mo (solution annealed)	40

APPENDIX E: PUBLICATIONS

[1] *'Cluster Analysis Applied to Manufacturing Tooling Data',* (With L. Velásquez and P. Maropoulos). Proceedings of the Second International Symposium on Engineering of Intelligent Systems, EIS'2000, University of Paisley, Scotland, UK, June/2000.

[2] *'Web-Based Strategies to Support Collaborative Work in the Manufacturing Industry',* (With L. Velásquez). Proceedings of the Second International Conference on Management and Control of Production and Logistics, Grenoble, France, July/2000.

[3] *'An Internet-Based Tool Selection System for Turning Operations',* (With L. Velásquez and P. Maropoulos). Proceedings of the 16th International Conference on Computer Aided Production Engineering, CAPE 2000, Edinburgh University, Scotland, UK, August/2000.

[4] *'An Internet-Based Solution for the Technical Support of Tooling Operations,* (With L. Velásquez). Proceedings of the ASME 20th Computers and Information in Engineering (CIE) International Conference, Baltimore, USA, September/2000.

[5] *'Web-based Strategies to Support Remote Information Exchange in Corporate Environments'* (With L. Velásquez, J. Aguilar and C. Navarro). Submitted to *Automatica,* a Journal of the *IFAC,* June/2000.

[6] *'Applying Data Mining on Tooling Data Using Rough Sets Concepts on an Internet Platform'* (With L. Velásquez and J. Aguilar). Submitted to the Journal of Artificial Intelligence Review, September/2000.

[7] *'A General Ant Colony Model for Combinatorial Optimization Problems'* (With J. Aguilar and L. Velásquez). Submitted to Applied Intelligence Journal, Kluwer Academic, October/2000.